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Marine plastic debris and microplastics: global lessons and research to inspire action and guide policy change

Note by the secretariat

The annex to the present note sets out a report entitled *Marine Plastic Debris and Microplastics: Global Lessons and Research to Inspire Action and Guide Policy Change* for the information of participants in the first meeting of the ad hoc open-ended expert group on marine litter and microplastics, which was established pursuant to United Nations Environment Assembly resolution 3/7 (UNEP/EA.3/Res.7).

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Annex

MARINE PLASTIC DEBRIS & MICROPLASTICS

GLOBAL LESSONS AND RESEARCH TO INSPIRE ACTION AND GUIDE POLICY CHANGE

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Acknowledgements:

Members of the Advisory Group (Government and Major Groups and Stakeholder nominated experts): Chris Wilcox (CSIRO), Elchin Mammadov (Ministry of Ecology and Natural Resources, Azerbadjan), Flavia Pereira (Ministry of Environment, Brazil), Jacinthe Séguin (Environment and Climate Change Canada), Hao Chen (Institute of Water Environment, Chinese Research Academy of Environmental Sciences, China), Gustavo Alfonso Lacera (Ministry of Environment and Sustainable Development, Colombia), Paivi Munne (Finnish Environment Institute, Finland), Marion Gust (Ministry of Ecology, Sustainable Development and Energy, France), Marine Arabidze (National Environmental Agency, Georgia), Cindy Badore (Environmental Protection Agency), Agus Sudaryanto (Technology Center for Marine Survey, Indonesia), Porfirio Alvarez-Torres (International Affairs Coordination Unit - Ministry of Environment and Natural Resources, Mexico), Felicia Mogo (Nigeria Maritime Management and Safety Agency, Nigeria), Geir Wing Gabrielsen (Norwegian Polar Institute, Norway), Sonia Beatriz Aranibar Tapia (Ministry of Environment, General Directorate of Environmental Quality, Peru), Maricris T Laciste (Department of Environment and Natural Resources, Philippines), Jude Bijoux (Seychelles Fishery Authority, Seychelles), Sankoh Salieu (Natural Resources Management Specialist, Sierra Leone), Jesús Gago Piñeiro (Spanish Institute of Oceanography, Spain), Pradeep Kumara (Marine Environment Protection Authority, Sri Lanka), Susanne Tumlin (Rya Wastewater Treatment Plant, Gryaab AB, Sweden), Judith Wehrli (Institute of European and International Economic Law, Switzerland), Ililssaria Mangalili (Division of Environment, Vice President's Office, Tanzania), Nawarat Krairapanond (Natural Resources & Environmental Management coordination Division, Thailand), Meryem Arslan (Ministry of Environment and Urbanization, Turkey), Jenna Jambeck (University of Georgia, U.S.A), Michail Papadoyannakis (Marine Environment Unit, EC), Anthony Akpan (Gender and Water Alliance, Nigeria), Veronique Garny (CEFIC), Semia Gharbi (Association Abel Granier, Tunisia).

Peer reviewers: Emily Grilly (CCAMLR), Julian Augusto Reyna Moreno (CPPS), Tarub Bahri (FAO), Muhammad Ilyas (Marine Environment and Fisheries, Indonesia), Joan Fabres (Grid Arendal), Monika Stankiewicz, Marta Ruiz (HELCOM), Patrick Ten Brink (IEEP), Sara Regina Purca Cuicapusa (Instituto del Mar del Perú - IMARPE), Stefan Micallef, Edward Kleverlaan, Fredrik Haag (IMO), Gaetano Leone, Tatjana Hema (MAP), Kevin Victor Thomas (Norwegian Institute for Water Research), Alexander Tkalin (NOWPAP), Darius Campbell (OSPAR), Anne-Marie Hanson (Gender and Water Alliance), Keith Christman (American Chemistry Council), Sarah Da Silva (Environment and Climate Change Canada), Rolph Payet (Basel, Rotterdam and Stockholm Conventions) Sarah Smith, (International Whaling Commission), Heidrun Frisch (Convention on the Conservation of Migratory Species), Gabriele Goettsche-Wanli, Alice Hicuburundi, Charlotte Salpin, Michele Ameri, Shawn Stanley, Valentina Germani, Yoshinobu Takei, Lorna Joseph-Pal (United Nations Convention on the Law of the Sea), Heidi Savelli, Kaisa Uusimaa, Petter Malvik, Elisa Tonda, Helena Rey, Surendra Shresta, Shunichi Honda, Mushtaq Memon, Agnes Rube, Jing Zhang, Paulina Guerrero (UNEP).

Contributors: Members of the GESAMP Working Group 40: Linda Amaral-Zettler, Anthony Andrady, Sarah Dudas, Joan Fabres, Francois Galgani, Denise Hardesty, Valeria Hidalgo-Ruz, Sunny Hong, Peter Kershaw. Laurent Lebreton, Ramani Narayan, Sabine Pahl, James Potemra, Chelsea Rochman, Sheck A. Sherif, Joni Seager, Won Joon Shim, Paula Sobral, Shige Takada, Patrick ten Brink, Martin Thiel, Richard Thompson, Alexander Turra, Lisbeth Van Cauwenberghe, Erik van Sebille, Dick Vethaak, Kayleigh Wyles, Erik Zettler and Patrizia Ziveri; Tarub Bahri, Uwe Barg, Francis Chopin, Petri Suuronen and Jogeir Toppe of FAO;Giulia Gitti, Marianne Kettunen, Konar Mutafoglu, Daniela Russi, Jean-Pierre Schweitzer, Patrick ten Brink, Emma Watkins and Sirini Withana of IEEP; Sean Baker of ACC and employees of Tetra Tech; Britta Denise Hardesty and Chris Wilcox of CSIRO.

Main Author: Dr Peter J Kershaw (Independent Consultant),

Design: Viola Kup **Cover Design:** Virginia Njoroge

MARINE PLASTIC DEBRIS & MICROPLASTICS

GLOBAL LESSONS AND RESEARCH TO INSPIRE ACTION AND GUIDE POLICY CHANGE

UNEP

GLOSSARY

ORGANISATIONS AND OTHER TERMS

ALDFG	Abandoned Lost or otherwise Discarded Fishing Gear
BAT	Best Available Technique/Technology
BEP	Best Environmental Practice
BoBLME	Bay of Bengal Large Marine Ecosystem
CBD	Convention of Biological Diversity
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources
CMS	Convention on the Conservation of Migratory Species of Wild Animals
CSIRO	Commonwealth Science and Industrial Research Organisation
DFG	Discarded Fishing Gear
FAO	Food and Agriculture Organisation of the United Nations
GEF	Global Environment Facility
GESAMP	Joint Group of Experts on Scientific Aspects of Marine Environmental Pro-tection
GGGI	Global Ghost Gear Initiative
GISIS	Global Integrated Shipping Information System
GPA	Global Programme of Action for the Protection of the Environment from Land-based Activities
GPML	Global Partnership on Marine Litter
GPWM	Global Partnership on Waste Management
HELCOM	Baltic Marine Environment Protection Commission - Helsinki Commission
ICC	International Coastal Clean-up
IEEP	Institute for European Environmental Policy
IOC	Intergovernmental Oceanographic Commission of UNESCO
IMO	International Maritime Organisation
IUCN	International Union for Conservation of Nature
IUU	Illegal, Unreported and Unregulated fishing
IWC	International Whaling Commission
LC/LP	London Convention and Protocol
LME	Large Marine Ecosystem
MARPOL	International Convention for the Prevention of Pollution from Ships
MAP	Mediterranean Action Plan
MSFD	Marine Strategy Framework Directive
NOAA	National Oceanic and Atmospheric Administration
NOWPAP	Northwest Pacific Action Plan
OECD	Organisation for Economic Cooperation and Development
OSPAR	Convention for the Protection of the Marine Environment in the North-East Atlantic
PCCP	Personal Care and Cosmetics Products
RSCAP	Regional Seas Conventions and Action Plans
SIDS	Small Island Developing States
SPREP	Secretariat of the Pacific Regional Environment Programme
UNEP	United Nations Environment Programme
UNDP	United Nations Development Programme
UNGA	United Nations General Assembly
WACAF	West and Central Africa Region (Abidjan Convention)
WAP	World Animal Protection
WCR	Wider Caribbean Region
WWF	World Wildlife Fund

COMMON POLYMERS

ABS	Acrylonitrile butadiene styrene
AC	Acrylic
EP	Epoxy resin (thermoset)
PA	Polyamide 4, 6, 11, 66
PCL	Polycaprolactone
PE	Polyethylene
PE-LD	Polyethylene low density
PE-LLD	Polyethylene linear low density
PE-HD	Polyethylene high density
PET	Polyethylene terephthalate
PGA	Poly(glycolic acid)
PLA	Poly(lactide)
PP	Polypropylene
PS	Polystyrene
EPS (PSE)	Expanded polystyrene
PU (PUR)	Polyurethane
PVA	Polyvinyl alcohol
PVC	Polyvinyl chloride
PU (PUR)	Polyurethane
SBR	Styrene-butadiene rubber
TPU	Thermoplastic polyurethane

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FOREWORD

The global production of plastics in 2014 was 311 million tonnes. It has been estimated that in 2010 alone, between 4.8-12.7 million metric tons of plastic found their way into our oceans. Plastic debris and microplastics is transported by ocean currents across borders. It is found everywhere, even on the remotest shores of uninhabited islands, in the Arctic ice, the deep ocean and in a broad array of marine organisms. Whether due to poor waste and wastewater management, accidental losses that could have been prevented, or illegal dumping, the "leakage" of this debris into our oceans has serious environmental, social and economic consequences. It harms wildlife, safety of sea transport, fisheries, tourism, recreation, it threatens marine ecosystems and morally should be considered a common concern of mankind.

Microplastic particles are found in a large variety of marine organisms, including species we consume as seafood. The sparse knowledge on levels and effects does not indicate a health risk to humans now, but the uncertainty is high. The smallest plastic particles – the nanoplastics, are of even larger concern. They are so small that some can enter organs and body fluids of organisms, and due to their high surface/volume ratio they can carry larger amounts of environmental toxicants. Plastic debris breaks down very slowly in the marine environment, especially under cold and dark conditions. Levels of nanoplastics in the oceans, and how much of the plastic which is ultimately fully degraded, is not known.

While our knowledge of the impact of plastics in our oceans is incomplete, what we already know shows we should not wait before taking action.

This report presents both short- and long-term approaches to the problem of marine plastic debris and microplastics. It provides an overview of the latest science and experiences, identifies priority areas of action, and points out areas requiring more research. Improved waste management is urgently needed to reduce the flow of plastic into our oceans. We need to spread knowledge on why and how, and change social attitudes.

We need to get smarter about plastic, adopting a more circular economic model. We need to drastically reduce our use of single-use plastic items, and phase out microbeads in cosmetics and other products where it can be substituted with non-harmful alternatives. Unfortunately, the need for clean-up actions will still be there, and even increase in many areas. Clean-up of vulnerable areas needs to be prioritized.

Marine litter is a transboundary concern, requiring collaborative action — not simply from governments, but from industry and consumers as well. Regional cooperation and action plans, and cooperation through the Global Partnership on Marine Litter, is recommended to prevent further pollution at all levels. Strengthened International cooperation and local action are both necessary to follow up on the 2030 Agenda for Sustainable Development, including reaching the Sustainable Development Goal on Oceans.

This report is accompanied by a stand-alone set of policy recommendations. They are intended to guide decision makers to take action that can be adapted to different local, national, regional and global contexts. In the 60 years since its large-scale introduction, plastic has become a natural and necessary part of our daily life. However, its negative consequences when ending up in the environment can no longer be ignored.

It is our hope that this report and the recommendations will inspire and catalyze immediate action at all levels – it is only through joint efforts that we can have an impact and improve the state of our oceans for future generations. We need stronger international commitment to combat the plastic pollution of our oceans. The time to act is now. We have no time to lose.

Achim Steiner

Vidar Helgesen

Achim Steiner

United Nations Under-Secretary-General and UNEP Executive Director

Vidar Helgesen

Minister of Climate and the Environment, Government of Norway

POLICY-RELEVANT RECOMMENDATIONS

In the light of the evidence and findings contained in the study entitled "Marine plastic debris and microplastics: global lessons and research to inspire action and guide policy change", and in order to address problems related to marine litter in the most efficient and effective way, it is recommended that States:

(a) **Take cognizance of the study and its main findings, including that:**

(i) The accumulation of plastic litter in the ocean is a common concern for humankind owing to its far-reaching environmental, social and economic impacts;
(ii) While prevention is key, improving waste collection and management is the most urgent short-term solution to reducing plastic inputs, especially in developing economies;
(iii) Long-term solutions include improved governance at all levels as well as behavioural and system changes, such as a more circular economy and more sustainable production and consumption patterns;
(iv) Stormwater overflows and runoffs as well as inadequate waste water treatment contribute substantially to marine plastic and microplastic pollution, and their improvement will have additional far-reaching socioeconomic benefits;
(v) Stakeholder engagement, including the private sector, as well as legislation, the use of market-based instruments, best environmental practices and best available techniques, play a key role in marine plastic pollution mitigation;

(b) **Strengthen the implementation and enforcement of existing international and regional frameworks,** encourage States that have not yet ratified such frameworks to do so and promote compliance with frameworks and instruments, including stringent environmental assessment practices according to national and regional circumstances;

(c) **Review existing regulatory frameworks,** institutional arrangements and other instruments related to marine litter and their enforcement to identify synergies and gaps as well as potential solutions to address gaps globally and regionally;

(d) **Strengthen and increase cooperation at all levels,** including international multi-stakeholder initiatives such as the Global Partnership on Marine Litter;

(e) **Invite international bodies** to address and take into account as emerging issues of concern those aspects of the marine litter issues identified in the report, including microplastics and nanoplastics, that are of particular relevance to them. For example:

(i) The Basel, Rotterdam and Stockholm conventions in relation to the sound management of chemicals and wastes;
(ii) Appropriate bodies, such as the Strategic Approach to International Chemicals Management and the Organization for Economic Cooperation and Development, to consider macroplastics, microplastics and nanoplastics;
(iii) World Trade Organization in relation to trade and environment;
(iv) Institutional financing bodies (e.g., Global Environment Facility, World Bank);
(v) Non-traditional groups such as trade organizations;
(vi) Organizations already addressing marine litter such as UNEP, IMO and FAO;

(f) **Quantify the relative contributions** of all critical land-based and sea-based sources and investigate pathways of marine litter, including macrolitter and microlitter;

(g) **Prioritize actions for marine litter mitigation,** including through the identification of hotspots and the examination of future scenarios, by the use of best available technologies (e.g., models and simulations);

(h) **Develop cost-effective monitoring** and assessment strategies with regard to marine litter at all levels, taking into account existing programmes, especially at the regional level. In the development of such strategies, States:

(i) Promote harmonization and standardization of methods (e.g., protocols, sampling) for marine litter, including for assessment and monitoring of marine litter contamination;
(ii) Establish monitoring programmes for marine litter with a view to establishing baselines, e.g., for quantities of litter along coastlines, in water columns, on the ocean floor, in the upper ocean and in biota;
(iii) Report on actions they have taken in order to prevent, reduce and control marine littering, and evaluate the results thereof;
(iv) Strengthen international cooperation for data and information exchange, including capacity-building for States that need it;
(v) Improve identification, allocation and analysis of material flow cost accounting;
(vi) Develop key performance indicators to track and monitor the success of monitoring and assessment;
(vii) Share information (e.g., through a global or regional platform) on marine litter on a regular basis;

(i) **Promote synergies** with implementation and monitoring of the Sustainable Development Goals and related processes;

(j) **Promote willing** and informed stakeholder participation in marine litter prevention and reduction strategies and policies, including by:

(i) Mapping out relevant stakeholders prior to interventions in order to ensure their inclusion;
(ii) Providing and protecting a right to access to relevant information on marine plastics, including microplastics and nanoplastics;
(iii) Enabling the needs and considerations of vulnerable groups to be taken into account;
(iv) Recognizing gender aspects in the generation and prevention of marine litter;

(k) **Assess socioeconomic and environmental costs** associated with marine litter impacts (costs of inaction) and enhance cost-effective and cost-benefit analysis of mitigation and clean-up measures (costs of action); and facilitate financing, public-private partnerships, capacity-building and technology transfer;

(l) **Develop global and regional marine litter indicators** to guide the prioritization of targeted interventions;

(m) **Using the precautionary principle** and taking into account that there is unequivocal and quantified evidence of the degree of impact of marine plastic debris, reduce marine litter sources through measures such as market-based instruments and regulatory frameworks, including through:

(i) A drastic reduction or ban of single-use plastic products;
(ii) The promotion of measures to reduce plastic material use and of other incentives for behavioural change towards more sustainable production and consumption patterns;
(iii) The promotion of eco-friendly and recyclable materials in industrial production;
(iv) A phase-out of non-recoverable plastic materials that potentially accumulate in marine environments (e.g., microplastics in personal care products);
(v) The promotion of extended producer responsibility programmes and life cycle assessments;
(vi) The promotion of technological innovation to address sources;
(vii) The promotion of the "6Rs" framework: redesign-reduce-remove-reuse-recycle-recover;

(n) **Consider the economic,** social and environmental costs of marine litter in investments and the development of waste management policies and practices, and encourage:

(i) **Improved waste delivery,** including to port reception facilities, collection, sorting and recycling;
(ii) **Improved effectiveness of waste** and wastewater infrastructure;
(iii) **Proper management and control** of dumpsites, especially when situated close to coasts;
(iv) **The promotion of integrated** waste management;
(v) **The re-evaluation of plastic waste** as a resource;
(vi) **Appropriate recycling activities** to improve recovery, in addition to providing economic opportunities and supporting alternative livelihoods;

(o) **Support efforts to promote a life cycle** approach to plastic products, including the consideration of the degradation of different polymers and the rate of fragmentation (in the marine environment) by:

- (i) Internalizing the environmental and social costs of products (cost internalization);
- (ii) Enhancing the process of closing the loop in product and process development and manufacturing as well as in life cycle chains of plastic products;
- (iii) Improving the lifespan of products;
- (iv) Promoting green public and private procurement;
- (v) Considering green engineering principles and frameworks, eco-design and eco-labelling, among others;
- (vi) Strengthening the ability of private actors, including small and medium-sized enterprises, to shift to greener activities;

(p) **Be aware that,** until there is an internationally agreed definition of biodegradability (in the marine environment), the adoption of plastic products labelled as "biodegradable" will not bring about a significant decrease either in the quantity of plastic entering the ocean or the risk of physical and chemical impacts on the marine environment;

(q) **Promote cost-effective activities** and instruments as well as cooperation at all levels with regard to risk-based and environmentally sound clean-up activities for marine litter in rivers and coastal and marine areas, according to national circumstances; and facilitate financing, public-private partnerships, and capacity-building and, in that regard, develop and utilize international criteria for collective removal actions, clean-up and restoration including with regard to quantities, population, sensitivity of ecosystem, feasibility;

(r) **Strengthen education** and awareness measures on marine litter by:

- (i) Introducing elements into educational curricula at all educational levels;
- (ii) Providing educational and outreach materials targeted to specific interest groups and range of ages to promote behavioural change.


Photo: © Akhtar Soomro / Reuters

EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

Plastic debris, or litter, in the ocean is now ubiquitous. Society's adoption of plastics as a substitute for traditional materials has expanded almost exponentially since the 1950s, when large-scale plastic production began. Durability is a common feature of most plastics, and it is this property, combined with an unwillingness or inability to manage end-of-life plastic effectively that has resulted in marine plastics and microplastics becoming a global problem. As for many pollutants, plastic waste is a trans-boundary, complex, social, economic and environmental problem with few easy solutions. Warnings of what was happening were reported in the scientific literature in the early 1970s, with little reaction from much of the scientific community. It is only in the past decade that the scale and importance of the problem has received due attention. This report was prepared at the request of the first United Nations Environment Assembly, which took place 23-27 June 2014, hosted by UNEP in Nairobi, Kenya (Resolution 16/1). It is intended to summarise the state of our knowledge on sources, fate and effects of marine plastics and microplastics, and describe approaches and potential solutions to address this multifaceted conundrum. Plastic litter in the ocean can be considered a 'common concern of humankind'.

The report is divided into four main sections: Background, Evidence Base, Taking Action, and Conclusions and Key Research Needs. The Background section describes the rationale for the report, noting that marine plastic litter is a global concern, and summarises the UNEA process. This is placed within the context of existing governance frameworks, at international and regional scales, and linked to the UN Sustainable Development Goals under Agenda 2030.

The Evidence Base section provides the basis for the later discussion of potential reduction measures. It is divided into four chapters: Plastics, Sources, Distribution and fate, and Impacts. Plastics production increased rapidly from the 1950s, with global production reaching about 311 million tonnes in 2014. Plastics have been used increasingly in place of more traditional materials in many sectors, including construction, transportation, household goods and packaging. They have also been used for many novel applications including medical. There are many different varieties of polymer produced but in volume terms the market is dominated by a handful of main types: polyethylene (PE, high and low density), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS, including expanded EPS) and polyurethane (PUR). Most plastics are synthesised from fossil fuels, but biomass can also be used. Packaging accounts for about one third of production, and much of this is designed for single-use. Plastics intended for more durable applications may be manufactured with additive chemicals to improve the material properties. These include plasticisers to soften the product, colouring agents, UV-resistance and flame-retardation, an important property for applications in transportation and electronics. Some of these chemicals have harmful properties when released into the environment.

Microplastics are routinely defined as small particles or fragments of plastic measuring less than 5 mm in diameter. Some microplastics are purposefully manufactured for industrial and domestic purposes ('primary' microplastics). These include 'microbeads' used in cosmetic and personal healthcare products, such as toothpaste. 'Secondary' microplastics are created by the weathering and fragmentation of larger plastic objects. Weathering and fragmentation is enhanced by exposure to UV irradiation. The process becomes extremely slow once this is removed, as in much of the ocean. Plastics marked as 'biodegradable' do not degrade rapidly in the ocean.

Sources of plastics and microplastics to the ocean are many and varied, but the actual quantities involved remain largely unknown. Reliable quantitative comparisons between the input loads of macro and microplastics, their sources, originating sectors and users are not possible at present, and this represents a significant knowledge gap. Estimates of some sources, such as municipal solid waste, have been made. These are useful to focus attention but the numbers should be treated with some caution due to the large uncertainties involved. Some of the most important land-based sources of larger plastic objects (macroplastics) include: construction, household goods, packaging, coastal tourism, and food and drink packaging. How much of this material enters the ocean will be dependent largely on the extent and effectiveness of wastewater and solid waste collection and management. Land-based sources of microplastics include: cosmetics and personal care products, textiles and clothing (synthetic fibres), terrestrial transport (dust from tyres), and plastic producers and fabricators (plastic resin pellets used in plastics manufacture). A variable proportion of microplastics will pass through wastewater treatment plants, depending on the sophistication of the equipment and procedures adopted, and regional differences are likely to be very significant. Sea-based sources appear to be dominated by the fisheries and shipping sectors.

The quantities and types (size, shape, density, chemical composition) of material, together with the entry points to the ocean, will determine to a great extent the subsequent distribution and impact. Land-based inputs may be direct from shorelines or via rivers and wastewater pipelines. Inputs at sea may be from normal operations, accidental losses or deliberate discarding. There are likely to be significant regional differences in inputs to the ocean from land- and sea-based sources. Inadequate solid waste collection and management is considered to result in substantial leakages of plastics to the ocean. Rivers appear to act as conduits for significant but largely unquantified amounts of macro and microplastics, especially where catchments serve urbanised or industrial centres. Losses from commercial shipping correlate with busy shipping routes. Abandoned, lost or otherwise discarded fishing gear (ALDFG) gear tends to be concentrated in fishing grounds, but it can be transported considerable distances if floatation devices remain intact. Locally, aquaculture structures can produce significant quantities of plastic debris if damaged by storms.

Marine plastics are distributed throughout the ocean, from the Arctic to the Antarctic. This is due to the durability of plastics, the global nature of potential sources and the ease to which surface currents will carry floating plastics. The surface circulation is well known and is amenable to modelling. There are several persistent features such as the five sub-tropical gyres in the Indian Ocean, North and South Atlantic, and North and South Pacific. These are areas with relatively high concentrations of floating microplastics. However, higher abundances of plastics (especially macroplastics) are also found in coastal waters, particularly in regions with: high coastal populations with inadequate waste collection and management; intensive fisheries; and, high levels of coastal tourism. Larger floating objects are also driven by winds, accumulating on mid-ocean islands and on shores distant from the source. Many types of plastic are denser than seawater so will sink once any initial buoyancy is removed. For example, empty drinks bottles made with the plastic PET are very common litter items on shorelines, but their ultimate fate is often the ocean sea floor. Most fishing gear will sink if the floatation buoys are removed. For this reason, much of the plastic debris in the ocean is out of sight, and will remain so for the foreseeable future. It is also the reason why no reliable estimate of the total quantity of plastic in the ocean has been made.

Marine plastics can have significant ecological impacts. The impacts of macroplastics on biota are best known. Images of a dolphin or seal entangled in fishing gear, or the stomach of a young dead albatross full of plastic objects are arresting and can be distressing for the observer. However, some of the species affected are rare or endangered (IUCN red list) so there is concern also from a conservation perspective. Macro-debris can also cause damage to sensitive and at-risk habitats such as cold and warm water coral reefs. Microplastics have been found in many fish and shellfish species, and some cetaceans, but the impact is much more difficult to quantify and remains a knowledge gap. All sizes of plastic can provide an additional habitat for sessile organisms. This can have important implications, for example, in the success of jellyfish to extend their range. The rafting of species to a different region provides an additional mechanism for the introduction of non-indigenous species, most clearly demonstrated on the coast of North America as a consequence of the Japanese tsunami in 2011.

Marine plastics can have direct social and economic impacts. Floating debris represents a navigation hazard and has been implicated in many accidents, some of which have resulted in fatalities. From the available limited evidence, it is concluded that microplastics in seafood do not currently represent a human health risk, although many uncertainties remain. However, there is great uncertainty about the possible effects of nano-sized plastic particles, which are capable of crossing cell walls. Economic losses include the cost of non-action (loss of income) and the cost of action (e.g. beach clean-ups). Marine plastic debris may cause a reduction in income as a result of reduced fishing days or reduced tourist numbers, if people are discouraged from visiting by the presence of litter. 'Ghost' fishing by derelict fishing gear results in significant losses of potential food for human consumption. The extent of the social and economic impact, and the options for remedying losses, are dependent on the social and economic context. This includes better understanding perceptions and attitudes and the economic circumstance as to why littering takes place.

Improving wastewater and solid waste collection and management presents the most urgent short-term solution to reducing plastic inputs, especially in developing economies. This will also have other societal benefits in terms of human health, environmental degradation and economic development. Other priority areas include improving wastewater treatment and reducing ALDFG. However, a more sustainable solution in the longer term will be moving towards a more circular economy, in which waste is designed out of the production and use cycle, and society adopts more sustainable consumption patterns. There is sufficient evidence that marine plastics and microplastics are having an unacceptable impact to invoke the Precautionary Approach. This means that society should not wait until there is unequivocal and quantified evidence of the degree of impact before acting to reduce plastic inputs to the ocean. But this needs to be accompanied by an adaptive management approach. This should allow for sufficient flexibility to be built into governance frameworks, or technical measures, to permit for adjustment as more knowledge becomes available. In this way perverse incentives and unforeseen negative consequences can be removed as soon as they are recognised.

Improved governance is of overarching importance, which includes looking at the effectiveness of existing measures and the extent to which they are succeeding in bringing about the intended solutions. Stakeholder engagement is key to designing and agreeing more sustainable production patterns, and in bringing about and implementing effective litter reduction and removal measures. This needs to take account of all representatives of each community, with due account given to gender and other demographic factors, and build effective partnerships, including between the public and private sectors. The private sector has an important role in fulfilling the expectation of extended producer responsibility (EPR) and including the environmental impact of waste plastics when carrying out Life-Cycle Analysis.

Examples of measures are presented to bring about marine litter reduction and removal. These include Best Environmental Practices (BEPs), Best Available Techniques/Technologies (BATs), Market-Based Instruments (MBIs), legislation or some other intervention. These illustrate measures which have been successful, and which may have the potential to be replicated elsewhere. It is recognised that for most interventions to be fully successful there needs to be willingness by society to agree to the implementation, which is why the areas of education and awareness raising are important.

Risk assessment is a key element in identifying appropriate intervention points and establishing which stakeholder groups need to be involved in helping to define the problem and potential solutions to ‘close the loop’ and prevent plastics escaping to the ocean. Criteria are presented to help select the most appropriate measures. Indicators of the state of the environment are needed to establish trends, set reduction targets and evaluate the effectiveness of any measures that are introduced. Harmonisation of monitoring and assessment approaches will help to select, implement and oversee measures for marine plastics reduction on regional scales.

There is a great need to improve the sharing of knowledge and expertise, to encourage a more multidisciplined approach, to develop public-private partnerships and empower citizen-led movements. The Global Partnerships on Marine Litter (GPML) and Waste Management (GPWM) should be utilised to this end, together with other local-, national- and regional-scale arrangements.

There are several areas of research that should be pursued to gain a better understanding of the relative importance of different sources, and the fate and effects of marine macro and microplastics. Filling these knowledge gaps will help direct most cost-effectively the efforts taken to reducing further inputs of plastic to the ocean and mitigate the impacts of plastic debris that is already there.

KEY MESSAGES

KEY MESSAGES

1

Plastic debris/litter and microplastics are ubiquitous in the ocean, occurring on remote shorelines, in coastal waters, the seabed of the deep ocean and floating on the sea surface; the quantity observed floating in the open ocean in mid-ocean gyres appears to represent a small fraction of the total input;

2

There is a moral argument that we should not allow the ocean to become further polluted with plastic waste, and that marine littering should be considered a 'common concern of humankind'.

3

There is a clear need to move towards a more circular economic model for the plastic production cycle, to minimise waste generation; this can be summarised as Reduce (raw material use) – Redesign (design products for re-use or recycling) – Remove (single-use plastics when practical) – Re-use (alternative uses or for refurbishment) – Recycle (to avoid plastics going to waste) – Recover (re-synthesise fuels, carefully controlled incineration for energy production);

4

A Precautionary Approach is justified – however the case for making an intervention should be informed by making a risk-based assessment, backed up by an adaptive management approach;

5

An improved governance framework is needed - the existing governance landscape provides a basis for an expanded governance framework, but needs to take account of the goals and targets of the Agenda 2030, and improved implementation of existing arrangements is essential;

6

Stakeholder engagement is essential – partnerships are particularly useful for communities or nations that may have common concerns but be geographically isolated, such as SIDS;

7

There are many land- and sea-based sources of plastic debris and microplastics, with significant regional differences in the relative importance of different sources and pathways to the ocean;

8

'Leakage' of plastics into the ocean can occur at all stages of the production-use-disposal cycle, especially due to inadequate wastewater and solid waste collection and management, but the amount of marine plastic is so far poorly quantified;

9

Marine plastics have a social, economic and ecological impact – marine litter has been shown to have significant ecological impacts, causing welfare and conservation concerns, especially for threatened or endangered species; social impacts can include injury and death; and economic losses in several sectors can be substantial;

10

From the available limited evidence, it is concluded that microplastics in seafood do not currently represent a human health risk, although many uncertainties remain;

11

Social attitudes are important – they have a significant effect on littering behaviour and the acceptance of reduction measures;

12

Reduction measures are essential to minimise leakage of plastic to the ocean – measures can be based on best practice, most appropriate technologies and techniques, education, awareness raising, voluntary agreements and legislation, but the choice must take into account the social and economic circumstances of the community or region, and should be guided by a risk-based approach;

13

Improving waste collection and management presents the most urgent solution to reducing plastic inputs, especially in developing economies. This will also have other societal benefits in terms of human health, environmental degradation and economic development

14

Recovery and restoration may be justified where there is clear, unacceptable damage or loss of an ecosystem service;

15

There is a need to strengthen and harmonise monitoring and assessment effects to meet global commitments under the UN SDG targets, and to target and gauge the effectiveness of reduction measures;

BACKGROUND

1. RATIONALE FOR THE REPORT

1.1

MARINE PLASTIC DEBRIS IS A GLOBAL ISSUE

Society has benefitted enormously from the development of plastics (see definitions in Chapter 4). They have become indispensable in our economic and social development, and have offered a great many benefits to humanity covering every sector from health and food preservation, through to transportation and enhancing the digital age. We have become very good at designing plastics for a host of applications, but this has been accompanied by a significant social, economic and ecological cost. One of the more familiar aspects of any visit to the coast is the sight of plastic debris[1] on the shoreline or floating in the sea. Plastics are now ubiquitous in the ocean, found in every ocean and on every shoreline from the Arctic through the tropics to the Antarctic. Both sea- and land-based activities are responsible for this continuing plastic pollution of the marine environment.

One of the best-known properties of plastic is its durability. This is also the reason why plastics persist in the ocean for many years after first being introduced. The large quantities of plastics now in the ocean are there as a result of our failure to deal with plastics in a more considered and sustainable manner. It is not inevitable that this pattern will continue, but it will require a great collective effort to improve our production and use of plastics, and to minimise the proportion of end-of-life plastic that enters the waste stream.

Fortunately, there are initiatives in most parts of the world that are starting to successfully reduce the inputs of plastic to the ocean, and to recover and restore sensitive habitats, where this is practicable. These provide good examples of what can be achieved. However, there are some underlying issues, including the social and economic circumstances of many communities, which must also be addressed for marine litter reduction to be tackled on a global scale (Chapter 8).

This report attempts to provide a background on marine plastic debris, including a definition of what it is, why it occurs, in what way it is a global problem, and what measures can be taken to reduce its impact.

1.2

UNITED NATIONS ENVIRONMENT ASSEMBLY (UNEA)

The inaugural session of the UNEA took place in Nairobi on 23-27 June 2014 as a consequence of agreements made at Rio+20 to strengthen the role of UNEP as the leading UN environmental and coordinating body. The meeting was attended by over 1000 delegates, representing 163 countries, NGOs, youth groups, UN staff, stakeholders and the media. One of the intentions was for the outcome of the UNEA to inform the development of the Sustainable Development Goals discussed by the UN General Assembly (UNGA) in September 2015 (Chapter 2.1)[2].

Marine plastic debris and microplastics was one of a number of issues highlighted by the UNEA as being of particular concern. Delegates from more than 160 countries adopted Resolution 1/6 on 'Marine plastic debris and microplastics' (Annex I). This report has been prepared in response to Resolution 1/6, specifically to a request at Paragraph 14 to the Executive Director:

'… building on existing work and taking into account the most up-to-date studies and data, focusing on:

1 The terminology used to describe discarded plastic objects, particles and fragments in the ocean has the potential to cause confusion amongst different stakeholders, and is a matter of debate. Other terms that are frequently used include marine plastic debris, marine litter, marine plastic litter and ocean trash. 'Litter' and 'debris' are also used to describe naturally-occurring material in the ocean, such as wood, pumice and floating vegetation.

2 Lee, G.E. 2014. UNEA 2014: Ground-Breaking Platform for Global Environmental Sustainability [Online]. Available at: http://climate-exchange.org/2014/07/02/unea-2014-ground-breaking-platform-for-global-environmental-sustainability/ [accessed 22 December 2015]

*a) **Identification of the key sources** of marine plastic debris and microplastics;*
*b) **Identification of possible measures** and best available techniques and environmental practices to prevent the accumulation and minimize the level of microplastics in the marine environment;*
*c) **Recommendations** for the most urgent actions;*
*d) **Specification of areas** especially in need of more research, including key impacts on the environment and on human health;*
*e) **Any other relevant priority areas** identified in the assessment of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection;'*

The intention was to provide a basis for designing possible actions and developing policy-relevant recommendations to inform discussions at UNEA-2 in May 2016. An Advisory Group was established with experts nominated by governments and major groups and stakeholders who served on it in their individual capacity and developed policy relevant recommendations.

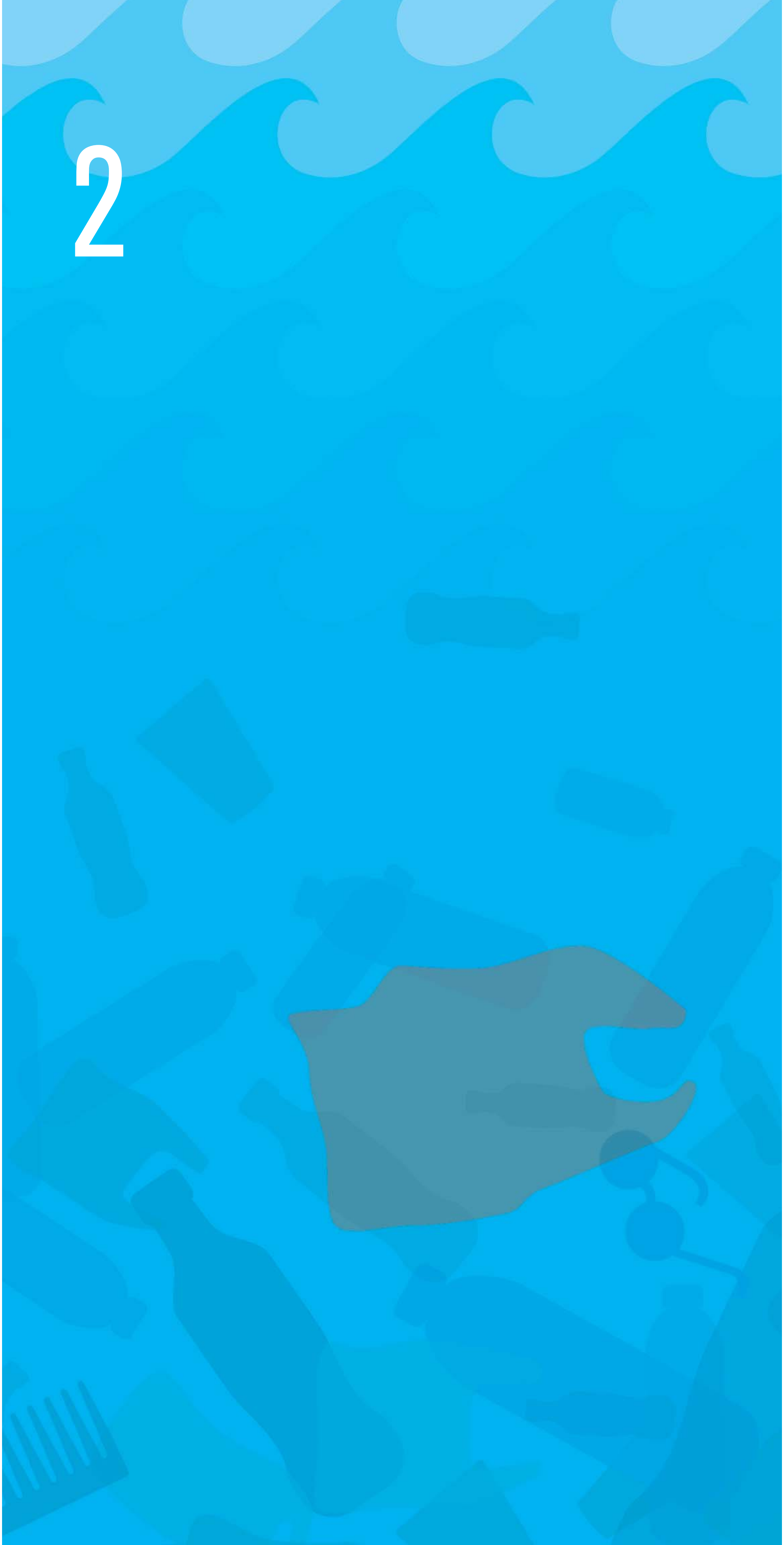
Paragraph 12 of Resolution 1/6 reads:

'[The United Nations Environment Assembly] … Welcomes the initiative by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection to produce an assessment report on microplastics, which is scheduled to be launched in November 2014'. This assessment, prepared by GESAMP Working Group 40 (Sources, fate and effects of microplastics in the marine environment – a global assessment), was published in April 2015 (GESAMP 2015). [3]

3 http://www.gesamp.org/publications/publicationdisplaypages/reports-and-studies-no.-90

Photo: © Siu Chiu / Reuters

2



2. GOVERNANCE FRAMEWORKS OF RELEVANCE TO MARINE PLASTIC DEBRIS

2.1

AGENDA 2030 AND THE UN SUSTAINABLE DEVELOPMENT GOALS

Any collective attempt to address the multi-facetted problem of marine plastic debris needs to take account of regional and international frameworks, intended to enhance marine environmental protection, that are either in place or currently under development (Bürgi 2015). These can be considered as part of the complex systems of governance that society uses to ensure the effective operations of institutions. In a narrow sense, governance can be defined as 'the exercise of authority, control, management and power of government' (World Bank 1991). However, public and private sector organisations, non-governmental organisations (NGOs, sometimes referred to as not-for-profit), charitable bodies and other less formal citizens' groups all depend on various internal systems of effective governance in order to achieve their objectives. With regard to organisations concerned with the production or use of plastics, governance includes producer responsibility for the sustainable use of resources, minimising material loss and energy usage, and effective design to reduce end-of-life waste generation (Chapter 11).

It is appropriate to consider the UN sustainable development agenda as providing an overarching framework to place other international, regional, national and local initiatives in context. Resolution 70/1, 'Transforming our World: the 2030 Agenda for Sustainable Development' was adopted by the UN General Assembly on 25 September 2015. The UNGA adopted an outcome document of the UN summit for the adoption of the post-2015 development agenda. It represents a plan of action which encompasses 17 Sustainable Development Goals (SDGs, Box 2.1) and 169 targets. Goals 11, 12 and 14 appear particularly relevant to the issue of marine plastics, although all 17 goals are in some way involved. The preamble of the resolution includes this statement:

'All countries and all stakeholders, acting in collaborative partnership, will implement this plan. We are resolved to free the human race from the tyranny of poverty and want and to heal and secure our planet. We are determined to take the bold and transformative steps which are urgently needed to shift the world on to a sustainable and resilient path. As we embark on this collective journey, we pledge that no one will be left behind.

… The Goals and targets will stimulate action over the next 15 years in areas of critical importance for humanity and the planet. '

Photo: © Cheryl Ravelo / Reuters

Box 2.1

SUSTAINABLE DEVELOPMENT GOALS
17 GOALS TO TRANSFORM OUR WORLD

1 NO POVERTY

2 ZERO HUNGER

3 GOOD HEALTH AND WELL-BEING

4 QUALITY EDUCATION

5 GENDER EQUALITY

6 CLEAN WATER AND SANITATION

Goal 6 – ensure availability and sustainable management of water and sanitation for all

7 AFFORDABLE AND CLEAN ENERGY

8 DECENT WORK AND ECONOMIC GROWTH

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

10 REDUCED INEQUALITIES

11 SUSTAINABLE CITIES AND COMMUNITIES

Goal 11 – make cities and human settlements inclusive, safe, resilient and sustainable

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Goal 12 – ensure sustainable consumption and production patterns

13 CLIMATE ACTION

14 LIFE BELOW WATER

Goal 14 – conserve and sustainably use the oceans, seas and marine resources for sustainable development

15 LIFE ON LAND

16 PEACE, JUSTICE AND STRONG INSTITUTIONS

17 PARTNERSHIPS FOR THE GOALS

Under each of these overarching goals are sets of more specific targets. Eleven targets under Goals 11, 12 and 14 are of relevance to reducing marine plastics with those of most relevance highlighted in bold in Box 2.2. A guide for stakeholders to become more aware and start to become involved in the SDG process has been published (SDSN 2015).

Box 2.2

SDG TARGETS RELATED TO MARINE LITTER:

6.3 By 2030, the proportion of untreated wastewater should be halved

11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

12.1 Implement the 10-year framework of programmes on sustainable consumption and production, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries
12.2 By 2030, achieve the sustainable management and efficient use of natural resources
12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products
14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution
14.2 By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, including by strengthening their resilience, and take action for their restoration in order to achieve healthy and productive oceans
14.7 By 2030, increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through sustainable management of fisheries, aquaculture and tourism
14.a Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries
14.c Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want

15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species

(UNSDG 2014)

2.2

INTERNATIONAL LEGAL FRAMEWORKS

The United Nations General Assembly and the United Nations Convention on the Law of the Sea (UNCLOS).

The United Nations Convention on the Law of the Sea (UNCLOS) provides the overarching framework, within which all the activities in the oceans and the seas must be carried out. It entered into force in November 1994 and has 167 parties, including the European Union. Many provisions of the Convention, including some relevant with regard to the issue under consideration (e.g. art. 192), reflect customary international law which, as such, is binding also on states that are not parties to the Convention. UNCLOS Part XII deals with 'Protection and preservation of the marine environment'[4] and requires states to take, individually or jointly as appropriate, all measures consistent with UNCLOS which are necessary to prevent, reduce and control pollution of the marine environment from any source, using for this purpose the best practicable means at their disposal and in accordance with their capabilities, and to endeavour to harmonize their policies in this connection. These measures have to include, inter alia, those designed to minimize to the fullest possible extent the release of toxic, harmful or noxious substances. Part XII includes detailed provisions on land-based sources of pollution, pollution from vessels, seabed activities, dumping, and pollution from or through the atmosphere.

UNCLOS Part XII Article 192 General Obligation:

'States have the obligation to protect and preserve the marine environment'

Article 194: ***'States shall take, individually or jointly as appropriate, all measures within this Convention that are necessary to prevent, reduce and control pollution of the marine environment from any source'***


Photo: © NOAA CREP

The UN General Assembly routinely has an agenda item on oceans and the law of the sea and on sustainable fisheries. The work of the General Assembly was informed, in particular, by the consideration of the topic 'marine debris' at the 6th meeting of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea in 2005, which resulted in the introduction of provisions relating to marine debris into the annual resolution on oceans and the law of the sea. At the 70th session in December 2015, resolution 70/235 was adopted which included the decision (paragraph 312) that the 17th meeting of the United Nations Informal Consultative Process on Oceans and the Law of the Sea would focus its discussions on the topic 'Marine debris, plastics and microplastics'. This is due to take place in June 2016.

A provision under UNCLOS of 10 December 1982 relates to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (United Nations Fish Stocks Agreement). This includes reference to reducing the impact of fishing gears, gear marking and the retrieval of ALDFG (Box 2.3). This is relevant to the discussion on the social, ecological and economic impact of ALDFG (Chapter 7).

4 http://www.un.org/depts/los/convention_agreements/convention_overview_convention.htm

Box 2.3

UNITED NATIONS FISH STOCKS AGREEMENT

The Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (United Nations Fish Stocks Agreement). The Agreement provides, inter alia, for the conservation and sustainable use of these stocks and mechanisms for international cooperation in this regard. In particular, it contains the obligation to:

'minimize pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species, both fish and non-fish species, (hereinafter referred to as non-target species) and impacts on associated or dependent species, in particular endangered species, through measures including, to the extent practicable, the development and use of selective, environmentally safe and cost-effective fishing gear and techniques' (article 5(f)).

It also lists amongst the duties of flag States the taking of measures including:

'requirements for marking of fishing vessels and fishing gear for identification in accordance with uniform and internationally recognizable vessel and gear marking systems, such as the Food and Agriculture Organization of *the United Nations Standard Specifications for the Marking and Identification of Fishing Vessels'* (article 18(3)(d)).

Furthermore, the Agreement assigns an important role to regional fisheries management organizations and arrangements (RFMO/As) for the conservation and management of these fish stocks and sets out, inter alia, the functions of such RFMO/As.

The Review Conference on the United Nations Fish Stocks Agreement in 2006 recommended States individually and collectively through regional fisheries management organizations to, inter alia, "[e]nhance efforts to address and mitigate the incidence and impacts of all kinds of lost or abandoned gear (so-called ghost fishing), establish mechanisms for the regular retrieval of derelict gear and adopt mechanisms to monitor and reduce discards" (A/CONF.210/2006/15, Annex, para. 18(h)). In response, States and RFMO/As have taken action to address lost or abandoned fishing gear and discards (see, e.g., A/CONF.210/2010/1, paras. 124-129). The resumed Review Conference to be held from 23 to 27 May 2016 may further address this issue.

Litter prevention at sea

MARPOL Convention

MARPOL Annex V of the IMO MARPOL Convention provides regulations for the prevention of pollution by garbage from ships. This prohibits the discharge of garbage into the ocean from all vessels of whatever type, except as provided in specific regulations (Table 2.1).[5]

MARPOL Annex V:

prohibits the discharge of garbage from:
'all vessels of any type whatsoever operating in the marine environment, from merchant ships to fixed or floating platforms to non-commercial ships like pleasure craft and yachts'.

A revised version of Annex V entered into force on 1 January 2013 (Table 2.1), following a review by an intersessional correspondence group of the Marine Environment Protection Committee (MEPC). This took account of resolution 60/30 of the UN General Assembly which had invited IMO to conduct a review in consultation with relevant organisations and bodies, and to assess its effectiveness. The MEPC also adopted the 2012 Guidelines for the development of garbage management plans (resolution MEPC.220(63)).

Under the revised MARPOL Annex V, garbage includes: *'all kinds of food, domestic and operational waste, all plastics, cargo residues, incinerator ashes, cooking oil, fishing gear, and animal carcasses generated during the normal operation of the ship and liable to be disposed of continuously or periodically. Garbage does not include fresh fish and parts thereof generated as a result of fishing activities undertaken during the voyage, or as a result of aquaculture activities'.*

5 http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Garbage/Pages/Default.aspx

Table 2.1

Type of garbage	**Ships outside special areas**	**Ships inside special areas**	**Offshore platforms and all ships within 500m of such platforms**
Food waste comminuted or ground	**Discharge permitted** ≥ 3 nm from the nearest land and en route	**Discharge permitted** ≥ 12 nm from the nearest land and en route	**Discharge permitted** ≥ 12 nm from the nearest land
Food waste not comminuted or ground	**Discharge permitted** ≥ 12 nm from the nearest land and en route	**Discharge prohibited**	**Discharge prohibited**
Cargo residues* not contained in wash water	**Discharge permitted** ≥ 12 nm from the nearest land and en route	**Discharge prohibited**	**Discharge prohibited**
Cargo residues* contained in wash water		**Discharge only permitted in specific circumstances**** and ≥ 12 nm from the nearest land and en route	**Discharge prohibited**
Cleaning agents and additives contained in cargo hold wash water	**Discharge permitted**	**Discharge only permitted in specific circumstances**** and ≥ 12 nm from the nearest land and en route	**Discharge prohibited**
Cleaning agents and additives* contained in deck and external surfaces wash water		**Discharge permitted**	**Discharge prohibited**
Carcasses of animals carried on board as cargo and which died during the voyage	**Discharge permitted** As far away from the nearest land as possible and en route	**Discharge prohibited**	**Discharge prohibited**
All other garbage including plastics, domestic wastes, cooking oil, incinerator ashes, operational wastes and fishing gear	**Discharge prohibited**	**Discharge prohibited**	**Discharge prohibited**
Mixed garbage	When garbage is mixed with or contaminated by other substances prohibited from discharge or having different discharge requirements, the more stringent requirements shall apply		

Simplified overview of the discharge provisions of the revised MARPOL Annex V, which entered into force on 1 January 2013 (www.imo.org)

* These substances must not be harmful to the environment
** According to regulation 6.1.2 of MARPOL Annex V, the discharge shall only be allowed if: (a) both the port of departure and the next port of destination are within the special area (Box 2.4) and the ship will not transit outside the special area between these ports (regulation 6.1.2.2); and (b) if no adequate reception facilities are available at those ports (regulation 6.1.2.3).

Box 2.4

SPECIAL AREAS ESTABLISHED UNDER MARPOL ANNEX V

- **Mediterranean Sea area**
- **Baltic Sea area**
- **Black Sea area**
- **Red Sea area**
- **Gulfs area**
- **North Sea area**
- **Wider Caribbean area**
- **Antarctic area**

Annex V also obliges Governments to ensure: 'the provision of adequate reception facilities at ports and terminals for the reception of garbage without causing undue delay to ships, and according to the needs of the ships using them'. This is discussed further in Chapter 9.

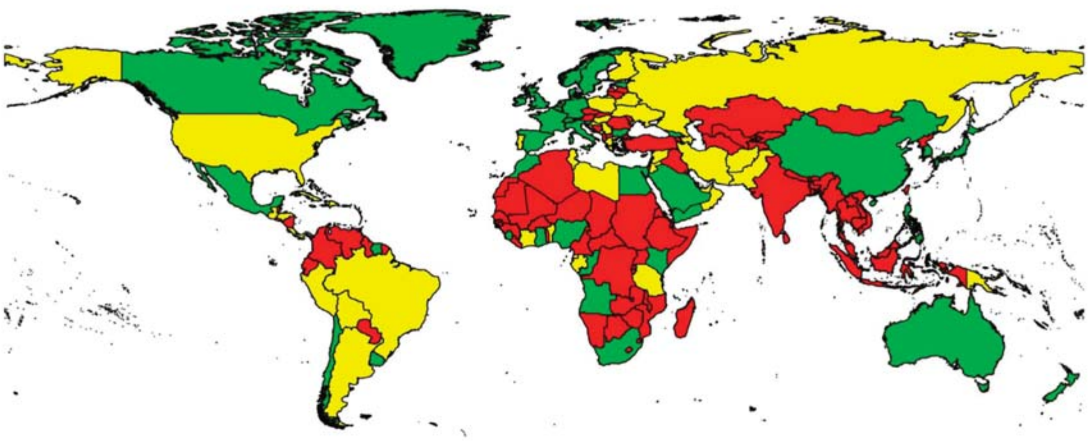
London Convention and Protocol

The 'Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972' (i.e. The London Convention, LC) came into force in 1975.[6] Its objective is to provide effective control of all sources of marine pollution and take all practical steps to prevent pollution by dumping of wastes or other matter at sea. Currently 87 States are Parties to the Convention. The London Protocol (LP) was agreed in 1996 to modernise, and eventually replace the Convention. It came into force in March 2006 and there are currently 46 Parties to the Protocol (Figure 2.1).

Under the Convention wastes are categorised according to a black- and grey-list approach. For black-list, dumping is prohibited, while for grey-list a waste, dumping is allowed provided a special permit is issued by a designated authority, and it has to take place under strict controls. All other non-list materials can be dumped provided a general permit is issued.

6 http://www.imo.org/en/OurWork/Environment/LCLP/Pages/default.aspx

Figure 2.1 **Parties to the London Convention and Protocol**



Map showing current LC/LP Parties (as of December 2015): green – Protocol Parties, yellow – Convention Parties, red – Non-Party States (www.imo.org).

Under the Protocol, a precautionary approach is adopted whereby all dumping is prohibited unless explicitly permitted (the 'reverse list' approach). The LC and LP prohibit disposal at sea of persistent plastic and other synthetic materials, for example netting and ropes (LC annex I, paragraph 2 and LP annex 1). The export of waste for dumping and incineration at sea are also prohibited. There is an obligation on States to ensure that waste disposal at sea is carried out in accordance with the LC/LP, equivalent regional agreements or UNCLOS (article 210).

One area of concern has been the possibly of plastics and microplastics becoming associated with the various waste streams under the LC/LP. Accordingly, the Secretariat of the LC/LP commissioned a 'Review of the current state of knowledge regarding marine litter in wastes dumped at sea under the London Convention and Protocol'. The work was undertaken within the framework of the UNEP-led Global Partnership on Marine Litter (GPML, Chapter 9), and is designed to stimulate further discussion about the nature and extent of marine litter in the waste streams under the LC/LP, in particular plastics and microplastics. Sewage sludge and dredged material were considered to be most likely to contain plastic litter (Chapter 5.8).

FAO instruments

The FAO Code of Conduct for Responsible Fisheries[7] contains a series of provisions and standards, some of which are relevant to marine litter. The Code is voluntary and global in scope, and is directed at both members and non-members of FAO, and at all levels of governance. Provisions concerning marine litter include the provision of port-reception facilities, storage of garbage on board and the reduction in abandoned, lost or otherwise discarded fishing gear (ALDFG) (Box 2.5).

Litter prevention from land-based sources – GPA

The Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) is the only global intergovernmental mechanism directly addressing the connectivity between

7 http://www.fao.org/fishery/code/en


Photo: © NOAA Marine Debris Program

Box 2.5

FAO CODE OF CONDUCT FOR RESPONSIBLE FISHERIES – ARTICLE 8

8.4 Fishing activities

8.4.6 States should cooperate to develop and apply technologies, materials and operational methods that minimize the loss of fishing gear and the ghost fishing effects of lost or abandoned fishing gear.

8.4.8 Research on the environmental and social impacts of fishing gear and, in particular, on the impact of such gear on biodiversity and coastal fishing communities should be promoted.

8.7 Protection of the aquatic environment

8.7.1 States should introduce and enforce laws and regulations based on the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78).

8.7.2 Owners, charterers and managers of fishing vessels should ensure that their vessels are fitted with appropriate equipment as required by MARPOL 73/78 and should consider fitting a shipboard compactor or incinerator to relevant classes of vessels in order to treat garbage and other shipboard wastes generated during the vessel's normal service.

8.7.3 Owners, charterers and managers of fishing vessels should minimize the taking aboard of potential garbage through proper provisioning practices.

8.7.4 The crew of fishing vessels should be conversant with proper shipboard procedures in order to ensure discharges do not exceed the levels set by MARPOL 73/78. Such procedures should, as a minimum, include the disposal of oily waste and the handling and storage of shipboard garbage.

8.9 Harbours and landing places for fishing vessels

8.9.1 States should take into account, inter alia, the following in the design and construction of harbours and landing places:

c. waste disposal systems should be introduced, including for the disposal of oil, oily water and fishing gear;

terrestrial, freshwater, coastal and marine ecosystems. It aims to be a source of conceptual and practical guidance to be drawn upon by national and/or regional authorities for devising and implementing sustained action to prevent, reduce, control and/or eliminate marine degradation from land-based activities. UNEP hosts the GPA and coordinates some activities in support of the programme. Intergovernmental Review Meetings are organized every five years to review the progress made by countries in the implementation of the GPA through their respective National Action Plans. Marine litter is wa priority source category under the GPA.

Conventions for the conservation and sustainable use of biodiversity

The UN Convention on Biological Diversity

The UN Convention on Biological Diversity came into force in December 1993. It is supported primarily by funding from member governments and operated by the Global Environment Facility (GEF). Articles 6 and 8 of the Convention are particularly relevant to the impact of marine plastic debris (Box 2.6). The Secretariat commissioned a major review of the impacts of marine litter on biodiversity, which was published in 2012 (SCBD 2012).

Box 2.6

UN CONVENTION ON BIOLOGICAL DIVERSITY

Article 6 General measures for conservation and sustainable use

Each Contracting Party shall, in accordance with its particular conditions and capabilities:

(a) Develop national strategies, plans or programmes for the conservation and sustainable use of biological diversity or adapt for this purpose existing strategies, plans or programmes which shall reflect, inter alia, the measures set out in this Convention relevant to the Contracting Party concerned; and
(b) Integrate, as far as possible and as appropriate, the conservation and sustainable use of biological diversity into relevant sectoral or cross-sectoral plans, programmes and policies.
Article 8 In-situ conservation
Each Contracting Party shall, as far as possible and as appropriate:
(a) Establish a system of protected areas or areas where special measures need to be taken to conserve biological diversity;
d) Promote the protection of ecosystems, natural habitats and the maintenance of viable populations of species in natural surroundings;
(e) Promote environmentally sound and sustainable development in areas adjacent to protected areas with a view to furthering protection of these areas;
(f) Rehabilitate and restore degraded ecosystems and promote the recovery of threatened species, inter alia, through the development and implementation of plans or other management strategies;

The Convention on the Conservation of Migratory Species of Wild Animals
The Convention on the Conservation of Migratory Species of Wild Animals (CMS or the Bonn Convention) was adopted in June 1979. It addresses the conservation of species or populations that cross national jurisdictional boundaries, as well as of their habitats.

In 2014, upon a request contained in resolution 10.4 on 'Marine Debris', CMS published three comprehensive reports, now available as UNEP/CMS/COP11/Inf.27 Report I: Migratory Species, Marine Debris and its Management, giving an overview of the issue and identifying knowledge gaps relevant to species conservation, UNEP/CMS/COP11/Inf.28 Report II: Marine Debris and Commercial Marine Vessel Best Practice, and UNEP/CMS/COP11/Inf.29 Report III: Marine Debris: Public Awareness and Education Campaigns.

Based on the recommendations in these reports, the CMS adopted resolution 11.30 in November 2014 on the 'Management of marine debris'[8] that referred to:

- i identifying knowledge gaps in the management of marine debris (paragraphs 5-13)
- ii commercial marine vessel Best Practice (paragraphs 14-17)
- iii public awareness and education campaigns (paragraphs 18-23)

This is very relevant to the identification and implementation of litter reduction measures discussed in Chapter 9.

8 http://www.cms.int/en/news/marine-debris-%E2%80%93-cms-and-ascobans-point-out-some-local-solutions-global-problem

The International Whaling Commission (IWC)

The IWC was set up in 1946 under the auspices of the International Convention for the Regulation of Whaling (ICRW). The Commission has a membership of 88 Contracting Governments. The ICRW contains an integral Schedule which sets out specific measures that the IWC has collectively decided are necessary in order to regulate whaling and other methods/mechanisms to conserve whale stocks. In addition, the IWC undertakes co-ordinates and funds conservation work on many species of cetacean. Through its Scientific Committee it undertakes extensive study and research on cetacean populations, develops and maintains scientific databases, and publishes its own peer-reviewed scientific journal, the Journal of Cetacean Research and Management.

The IWC began formally to consider marine debris in 2011 following its endorsement of the United Nations Environment Programme's Honolulu Commitment. Subsequent work has shown that marine debris, such as ALDFG and plastics, including microplastics, can be a conservation and welfare concern for cetaceans throughout the oceans. In addition to regular work by its Scientific Committee, the IWC has held two expert workshops on marine debris (IWC 2014 and IWC/65/CCRep04)[9], and three on large whale entanglement in all fishing gear, including ALDFG (IWC, 2012; IWC, 2013 and SC/66a/COMM2); established a global network for disentanglement of whales from gear, including a training and support programme for new teams around the world; and increased its efforts to strengthen international collaboration.

Regulation of harmful substances

Several International Conventions and Multilateral Environmental Agreements (MEAs) have been introduced to control the release of harmful substances into the environment. These are only relevant insofar as some plastics are produced containing compounds known to have toxic properties, and most plastics have a tendency to absorb organic pollutants and hence have the potential to impart a chemical impact if ingested or otherwise brought into close contact with marine organisms or people.

9 https://iwc.int/marine-debris

The Stockholm Convention on Persistent Organic Pollutants (POPs) was adopted in 2001 and came into force in May 2004[10]. It was established to protect human life and the environment from chemicals that persist in the environment, bioaccumulate in humans and wildlife, have harmful effects and have the potential for long-range environmental transport. Chemicals classified as POPs under the Convention have a number of undesirable effects, including disruption of the endocrine system, carcinogenicity and damage to the central and peripheral nervous system. POPs are widespread in the environment, but tend to be more concentrated in organic matter, for example in seabed sediments. Many are lipophilic, meaning they are readily absorbed by oils and fats, hence concentrations tend to be higher in oily fish than non-oily fish, in the same waters. For this reason, plastic tends to absorb organic contaminants, and POPs are routinely found in plastic particles. Some of the additive chemicals that were used several years ago to modify the properties of plastics, (e.g. to make the plastic resistant to fire, see Chapter 4.1), are now classified as POPs. This means that plastics have become carriers of POPs in the ocean. A system is in place to periodically review and add new chemicals to the Annexes of the Convention as appropriate. A global monitoring plan has been designed to provide comparable datasets on a regional and global basis. Clearly there is a potential synergy between POPs monitoring under the Stockholm Convention and monitoring the occurrence of plastic particles (Chapter 9). An annual meeting takes place to ensure cooperation and coordination between regional centres under the Basel and Stockholm Conventions[11].

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in March 1989 and came into force in 1992 (Box 2.7). One of the main drivers for doing so was the realisation in the 1970s and 1980s of the extent of the traffic in toxic wastes to Africa and other developing regions[12]. The trade was driven by a desire to reduce disposal costs, against a background of a lower level of environmental awareness and a lack of regulation and enforcement in countries in Eastern Europe and the

10 http://chm.pops.int/TheConvention/Overview/tabid/3351/Default.aspx

11 http://www.brsmeas.org/Default.aspx?tabid=4624

12 http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx

developing world. The Basel Convention is of relevance, as much of the waste trade involves plastics, and some of these contain relatively high levels of additive chemicals which are in Annex I or II of the Convention. These have known toxicological effects, with serious human health implications. This is discussed later in the report (Chapters 5.6 and 7.3). The Convention also requires Parties to: 'ensure that the generation of hazardous wastes and other wastes are minimised.' The Rotterdam Convention covers the Prior Informed Consent Procedure for Certain Hazardous Chemicals and Pesticides in International Trade[13], and forms another important restraint on the unregulated trade in waste. Again, plastics may be included if they contain substances listed within the Convention Annexes.

Other international agreements

Where measures are introduced (e.g. labelling, market-based instruments – see Chapter 11) they have to be consistent with existing legal arrangements, including World Trade Organisation law.

SIDS Accelerated Modalities of Action Pathway (SAMOA Pathway)

Small Island Developing States (SIDS) experience particular pressures and vulnerabilities, including the generation and management of waste and the presence of marine plastic debris, often originating from distant waters. The third conference on SIDS was held in Samoa in September 2014. The theme was "The sustainable development of small island developing States through genuine and durable partnerships". Nearly 300 partnerships were agreed. The SIDS Accelerated Modalities of Action Pathway (SAMOA Pathway) was adopted to address priority areas for SIDS[14]. This provides a key avenue for multi-stakeholder engagement when considering marine litter reduction measures (Chapter 11). There are three groupings of SIDS: the Caribbean Community, the Pacific Islands Forum and AIMS (Africa, Indian Ocean, Mediterranean and South China Sea).

Box 2.7

BASEL CONVENTION ON THE CONTROL OF TRANSBOUNDARY MOVEMENTS OF HAZARDOUS WASTES AND THEIR DISPOSAL

Principal aims:

i. the reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal;

ii. the restriction of transboundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management; and

iii. a regulatory system applying to cases where transboundary movements are permissible

13 http://www.pic.int/TheConvention/Overview/TextoftheConvention/tabid/1048/language/en-US/Default.aspx

14 http://www.sids2014.org/

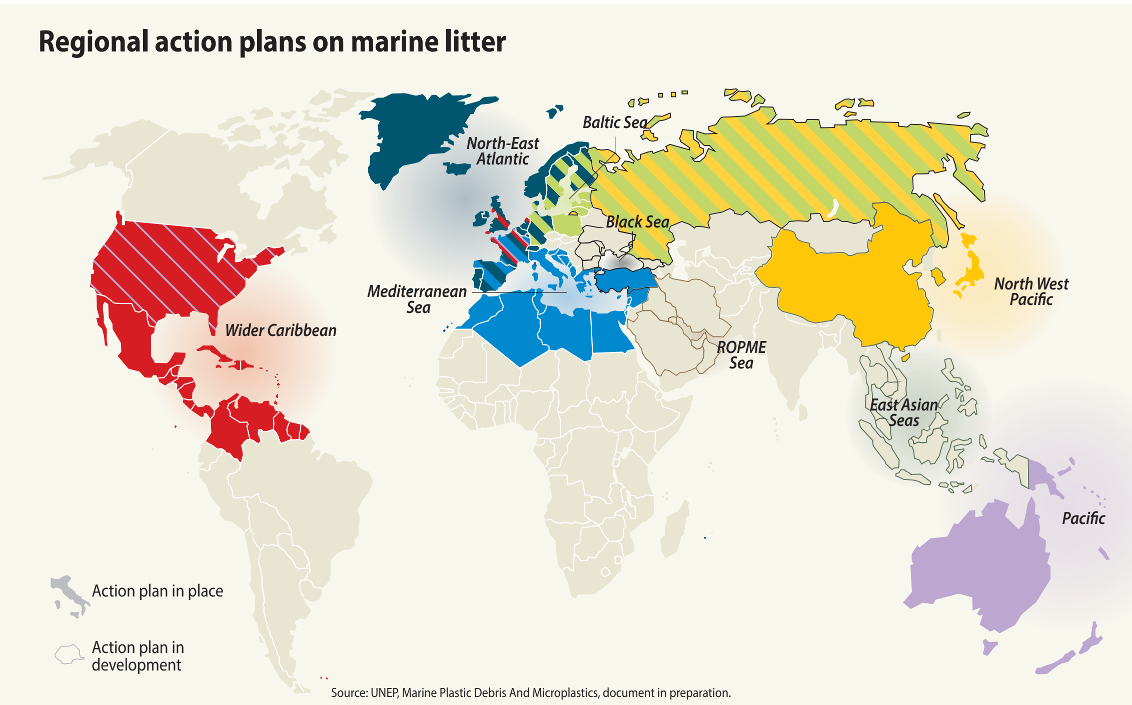
2.3

REGIONAL COOPERATION

Regional seas bodies

Regional Seas Conventions and Action Plans (RSCAPs) play a critical role in encouraging cooperation and coordination amongst countries sharing a common resource. There are 18 Regional Seas Conventions and Action Plans, six of which are administered directly by UNEP: Mediterranean (Barcelona Convention), Wider Caribbean (WCR), East Asia Seas, Eastern Africa (Nairobi Convention), Northwest Pacific (NOWPAP), and West and Central Africa (WACAF). The RSCAPs are instrumental in supporting the implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) at regional levels. Several RSCAPs have developed or are in the process of developing regional action plans on marine litter (see Box 2.8, Figure 2.2).

Figure 2.2 **Regional action plan for marine litter**



Regions developing Action Plans for marine litter. Taken from Marine Litter Vital Graphics (in preparation)

Box 2.8

REGIONAL ACTION PLANS ON MARINE LITTER

- Strategic framework on the management of marine litter in the Mediterranean, adopted in 2012; Regional Plan on the Management of Marine litter in the Mediterranean, adopted in 2013, entered into force in June 2014; Barcelona Convention for the protection of the marine environment and the coastal region of the Mediterranean.

- Regional Action Plan on Marine Litter for the OSPAR Convention: Convention for the Protection of the Marine Environment of the Northeast Atlantic. Marine litter also forms a key part of OSPAR's regional action, monitoring and assessment programme. A specific Action Plan for marine litter was agreed in 2014. The initiative 'fishing for litter' forms part of OSPAR's Regional Action Plan, mostly as a process to highlight the issue to fisheries stakeholders, although in the process, litter is being removed from the seabed when it is brought up in nets.
(www.ospar.org/html_documents/ospar/html/marine_litter_unep_ospar.pdf)

- Regional Action Plan on Marine Litter for the Helsinki Convention: Convention on the Protection of the Marine Environment of the Baltic Sea Area. The Action Plan was adopted in March 2015. The Helsinki Commission has adopted several recommendations directly or indirectly related to marine litter. www.helcom.fi

- Regional Action Plan on Marine Litter for the Wider Caribbean Region (RAPMaLi), approved in 2008 and revised in 2014.

- Northwest Pacific Action Plan on Marine Litter (2008).

- South Pacific: CLEANER PACIFIC 2025: Pacific Regional Waste and Pollution Management Strategy 2016-2025. Marine debris has been identified as a priority area in this strategy.

The regional action plans have been developed taking account of the specific environmental, social and economic context of each region. They vary in the degree of detail and the extent to which actions are required or recommended by States. For example, the strategic framework adopted on the management of marine litter in the Mediterranean contains legally-binding obligations to take measures to prevent and reduce the impacts of litter in the Mediterranean from land and sea sources. In contrast, HELCOM has adopted several specific recommendations directly or indirectly related to marine litter:

i. **Recommendation 28E/10** on application of the No-special-fee system to ship-generated wastes and marine litter caught in fishing nets in the Baltic Sea Area and agreement to raise public awareness on the negative environmental and socio-economic effects of marine litter in the marine environment;
ii. **Recommendations 10/5** concerning guidelines for the establishment of adequate reception facilities in ports (1989);
iii. **Recommendation 10/7** concerning general requirements for reception of wastes (1989);
iv. **Recommendation 19/14** concerning a harmonized system of fines in case a ship violates anti-pollution regulations (1998);
v. **Recommendation 19/9** (supplemented by 22/1) concerning the installation of garbage retention appliances and toilet retention systems and standard connections for sewage on board fishing vessels, working vessels and pleasure craft (1998); and
vi. **Recommendation 31E/4** concerning proper handling of waste/landfilling (2010).

Major transboundary river basins

River systems and other types of waterway represent a major route for carrying waste, including plastics, to the ocean (Chapter 5.6). When a waterway crosses a national boundary it is defined as a transboundary waterway. Almost half the Earth's land surface (excluding Antarctica) falls within transboundary basins (including ground water and lakes) and there is a large number of multilateral agreements dealing with transboundary river basins, some of which address environmental concerns[15]. Such agreements provide a mechanism which, potentially, could be utilised to reduce the introduction of plastic and microplastics to waterways and hence reduce their introduction to the ocean. For example, the International Commission for the Protection of the Danube (ICPDR) provides an overall legal instrument for cooperation and transboundary management of the Danube[16]. It covers a range of issues including water quality and the transboundary transport of hazardous substances, and has been ratified by 15 contracting parties. The ICPDR Joint Action Plan includes measures to reduce water pollution.

Regional Fisheries Management Organisations and Arrangements (RFMO/As)

RFMO/As have a responsibility to sustainably manage living resources, either for a specific highly migratory species (e.g. bluefin tuna) or for resources more generally in a particular geographic region. The Commission for the Conservation of Antarctic Marine Living Resources[17] (CCAMLR) is an example of the latter type. It was established in 1982, with the objective of conserving marine life, and ensuring controlled harvesting is carried out within an ecosystem-based approach. The subject of the management of marine debris, in order to monitor and minimize the impact of fisheries related activities in the Convention Area, has been an integral part of the CCAMLR agenda since 1984. Each year since 1989, members have collected data on beached debris, entanglement of marine mammals, marine debris associated with seabird colonies and animals contaminated with hydrocarbons at various sites around Antarctica (Chapter 6/10). CCAMLR has also been instrumental at introducing mitigation measures to reduce the impact of marine debris on marine life (Chapter 9).

European Union

The European Union (EU) has adopted a number of measures on waste management, packaging and environmental protection that are relevant to the reduction in marine plastic debris. These apply to all 28 Member States of the EU. An overview of European Commission (EC) policies, legislation and initiatives

15 http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Trans-boundaryWaterManagement

16 http://www.icpdr.org/main/

17 https://www.ccamlr.org/en

related to marine litter was published in 2012 (EC 2012). These relate both to specific initiatives within the EU and overarching international obligations. For example, the requirement for States to provide port reception facilities, under MARPOL Annex V, is enshrined in a Directive of 2000 (EC 2000).

One of the most relevant pieces of European legislation is the Marine Strategy Framework Directive (MSFD)[18] in which marine litter is one of eleven 'descriptors' of the environmental state of European Seas. The MSFD includes provision for setting indicators, and targets for litter reduction (Chapter 9). The principal aim of the MSFD is to achieve Good Environmental Status (GES) of EU marine waters by 2020. The Directive defines GES as: 'The environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive'.

A 'European Strategy on Plastic Waste in the Environment' was published as a Green Paper in 2013 (EC 2013). This looked at aspects of plastics production, use, waste management, recycling and resource efficiency, posing a series of questions to facilitate the development of more effective waste management guidelines and legislation. This has been followed by revision of existing legislation, for example on reducing the consumption of lightweight plastic bags (< 50 µm thick), adopted in April 2015 (EC 2015).

The EC has commissioned several studies on the generation of marine litter, more specifically marine plastic litter, and potential impacts and mitigation measures. These are referred to in the report where appropriate (Chapters 5, 6, 9).

Other examples of regional cooperation.

The East Asia Civil Forum on Marine Litter
This is a network of non-profit organizations devoted to addressing the marine litter issue in Asia[19]. The current membership consists of organisations from South Korea, Japan, China (mainland and Taiwan), Bangladesh, Philippines and Brunei, and an English-version newsletter is published twice per year.

The Community of Portuguese-Speaking Countries (CPSC)
The CPSC has recognised the importance of marine litter, highlighted the key economic and environmental impacts and recommended a number of actions. These are contained in the CPSC Lisbon Declaration, approved in June 2015[20]. The CPSC consists of representatives from Angola, Brazil, Cape Verde, Guinea-Bissau, Equatorial Guinea, Mozambique, Portugal, São Tome and Principe, and East Timor.

ASCOBANS
Marine litter is also a concern of regional conservation bodies such as the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, North and Irish Seas (ASCOBANS)[21].

Photo: © NOAA Marine Debris Program

18 http://ec.europa.eu/environment/marine/eu-coast-and-marine-policy/marine-strategy-framework-directive/index_en.htm

19 www.osean.net

20 http://www.cplp.org/id-2595.aspx

21 http://www.ascobans.org/en/publication/oceans-full-plastic

3

3. SCOPE AND STRUCTURE OF THE REPORT

The report has been designed to address the request from the UNEA to the Executive Secretary '…to undertake a study on marine plastic debris and marine microplastics…'. It is divided into four major sections: Background (Chapters 1-3), Evidence Base (Chapters 4 - 7), Taking action (Chapters 8 - 11) and Conclusions and Key Research Needs (Chapters 12 - 13). The Evidence Base section covers: the nature of synthetic plastics and microplastics; the main land- and sea-based sources; the distribution and fate of marine plastics and microplastics in the ocean; the main social, economic and ecological impacts of plastics and microplastics; and, the social and economic context of sources and impacts. The Taking Action section covers: monitoring and assessment, including the use of indicators; risk-based assessment of impacts and identifying intervention points; and, a series of measures for 'closing the loop', including Best Available Techniques (BATs) and Best Environmental Practices (BEPs). The relationship between the main sections and chapters in the report and the five elements in Resolution 1/6 Paragraph 14 are indicated in Table 3.1. This also provides a guide to the relevant UN SDG Targets. Although the report focuses on the specific UNEA requests, it also provides an introduction to marine plastics and an explanation of the current state of knowledge about the behaviour and impacts of plastics in ocean. This is to provide a more robust evidence base for developing and implementing cost-effective solutions to reduce the input and impact of marine plastic.

In addition to reviewing the extensive published literature on the topic, it was intended that the report should reflect the findings of several related but separate studies supported principally by UNEP:

i. **Core study** focusing on strengthening the evidence base with regard to microplastics (GESAMP 2016);
ii. **Study on the impact** of microplastics on fisheries and aquaculture (FAO/UNEP, in preparation);
iii. **Compilation** of Best Available Techniques (BATs) (UNEP in press a);
iv. **Modelling component** (engaging wider modelling/oceanographic community) (UNEP in press b); and
v. **Socio-economic component** (engaging researchers and universities to look at social aspects/welfare impacts and economic effects) (UNEP in press c), and Market-based instruments (Gitti et al. 2015).

The author of the present report has attempted to capture the most relevant aspects of these more in-depth studies. However, they are being published as separate reports to which the reader is referred.

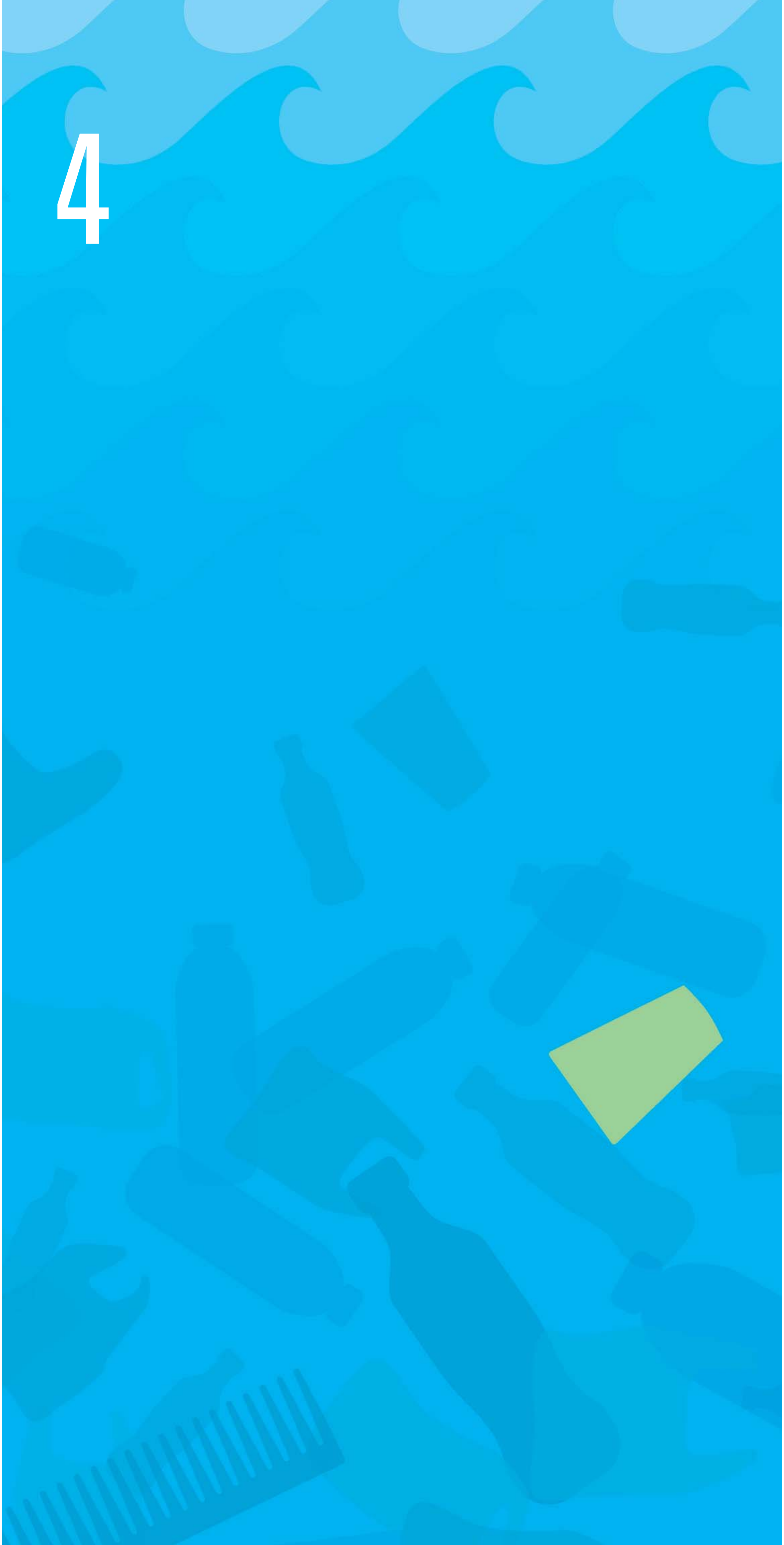
The report does not attempt to quantify the total abundance of plastic debris in the ocean, nor of the overall inputs from all sources. There are too many knowledge gaps about existing and emerging sources to provide a meaningful analysis. In addition, plastic debris covers an enormous size range, from nanometres to several metres in diameter, and occurs throughout the ocean (sea surface, water column, shorelines, seabed, biota), presenting a number of challenges in terms of statistically valid sampling and analysis. A number of estimates have been published on the scale of some sources and the quantities of debris in some categories, and these are referred to in Chapter 5 (sources) and Chapter 6. Such studies are very useful in order to focus further assessment of possible litter reduction measures, investment decisions, monitoring programmes or research. However, all such estimates are limited by: the availability of representative data; the range of sources considered (sea-based, land-based); the type and location of debris included (floating and non-floating, nano- to mega-plastics); and, a reliance on modelling approaches, which necessitate making assumptions about the system being modelled and the reliability of the data. The oft-quoted figure that 80% of marine plastic debris comes from land is based on remarkably little evidence, as are figures for how long it takes various materials to degrade in the ocean. It is a reasonable assumption that all the plastic macro and microplastic debris that has entered the ocean is still these, in one form or another. What can be said with some certainty is that the sources, distribution and impacts of marine plastic debris and microplastics show great regional heterogeneity (Chapters 5 – 7), and that the development of cost-effective reduction measures will need to reflect this (Chapter 9).

Table 3.1

Report section	**Resolution 1/6, Paragraph 14**	**SDG Target**
EVIDENCE BASE		
4. Plastics	(a)	6.3, 12.1, 12.2
5. Sources	(a)	6.3, 12.1, 12.2
6. Distribution and fate	(b)	12.b, 14.a, 14.2
7. Impacts	(b)	14.1, 14.2, 15.5
TAKING ACTION		
8. Closing the loop	(b)	6.3, 11.6, 12.1, 12.2, 12.4, 12.5, 14.1, 14.2, 14.7, 14.1, 14.c , 15.5
9. A selection of different types of measure	(b)	6.3, 11.6, 12.1, 12.2, 12.4, 12.5, 14.1, 14.2, 14.7, 14.1, 14.c , 15.5
10. Risk-based assessment of impacts and interventions	(b)	6.3, 11.6, 12.4, 12.5, 12.b, 14.1, 14.2, 15.5
11. Monitoring and assessment	(b)	14.2, 14.a
CONCLUSIONS & KEY RESEARCH NEEDS		
12. Conclusions	(a)-(e)	All of the above
13. Research needs – environmental, social, economic and legal	(d)	12.b, 14.a, 14.c, 15.5

Relationship between the main sections and chapters of the UNEA report, the five elements of Resolution 6/1 Chapter 14, and relevant SDG Targets

4



4. PLASTICS

4.1

PRODUCTION, TYPES, USES, TRENDS

Plastic types and production

Large-scale production of plastics began in the 1950s. Production increased rapidly responding to an increasing demand for manufactured goods and packaging to contain or protect foods and goods. This was accompanied by an increasing diversification of types and applications of synthetic polymer.

The term 'plastic', as commonly applied, refers to a group of synthetic polymers (Box 4.1). There are two main classes: thermoplastic and thermoset (Figure 4.1). Thermoplastic has been shortened to 'plastic' and, in lay terms, has come to be the most common use of the term. In engineering, soil mechanics, materials science and geology, plasticity refers to the property of a material able to deform without fracturing. Thermoplastic is capable of being repeatedly moulded, or deformed plastically, when heated. Common examples include polyethylene (PE, high and low density), polyethylene terephthalate (PET), polypropylene (PP), polyvinyl chloride (PVC) and polystyrene (PS, including expanded EPS). Thermoset plastic material, once formed, cannot be remoulded by melting. Common examples include polyurethane (PUR) and epoxy resins or coatings. Plastics are commonly manufactured from fossil fuels, but biomass (e.g. maize, plant oils) is increasingly being used. Once the polymer is synthesised, the material properties will be the same whatever the type of raw material used.

About 311 million tonnes of plastic were produced globally in 2014 (Plastics-Europe 2015). Many different types of plastic are produced globally, but the market is dominated by four main classes of plastics: PE (73 million tonnes in 2010), PET (53 million tonnes), PP (50 million tonnes) and PVC (35 million tonnes). There are also appreciable quantities of PS (including expanded EPS) and PUR produced. In addition to the main polymer classes, there has been a proliferation of new polymers and co-polymers to meet new expectations and markets, mostly driven by new combinations of existing monomers. Four regions dominate production: China, Asia (excluding China), Europe and North America. If current production and use trends continue unabated then production is estimated to increase to approaching 2 000 million tonnes by 2050 (Figure 4.2).

Bio-derived plastics

These plastics are derived from biomass such as organic waste material or crops grown specifically for the purpose. Utilising waste material can be seen as fitting into the model of the circular economy, closing a loop in the resource-manufacture-use-waste stream. The latter source could be considered to be potentially more problematic as it may require land to be set aside from either growing food crops, at a time of increasing food insecurity, or from protecting sensitive habitat, at a time of diminishing biodiversity. One current feature of biomass-based polymers is that they tend to be more expensive to produce than those based on fossil fuels (Sekiguchi et al. 2011, Pemba et al. 2014).

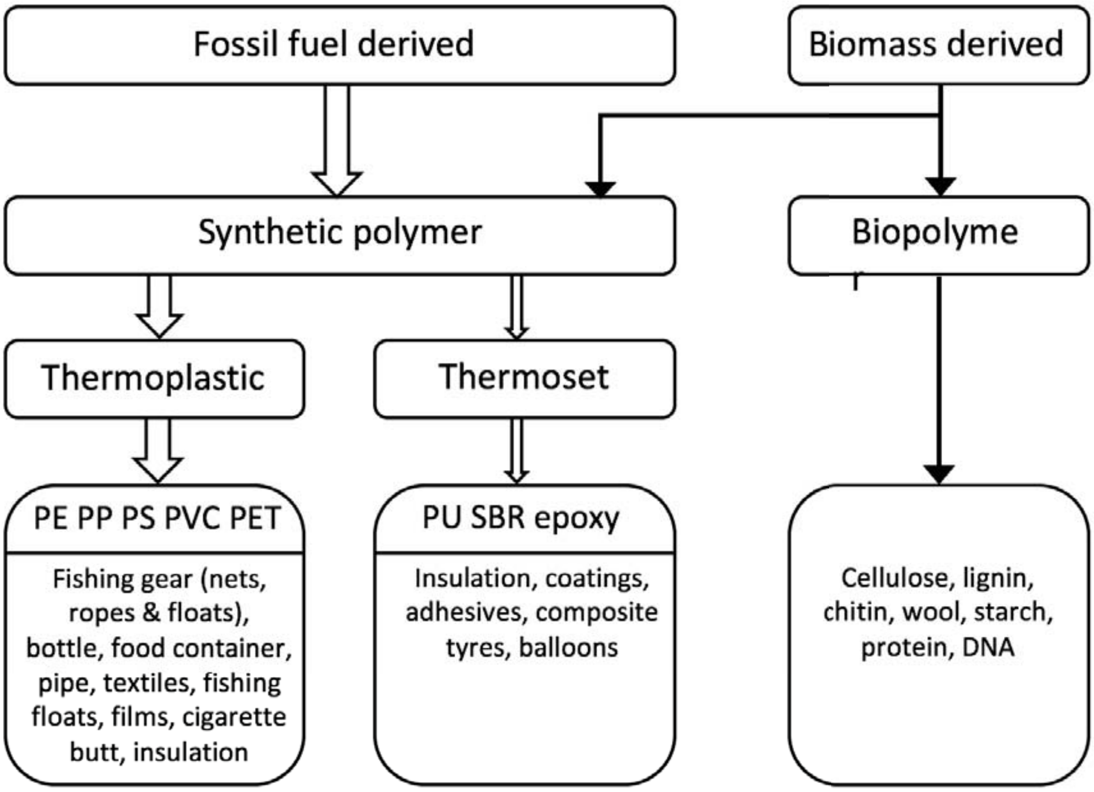
Box 4.1

DEFINITION OF POLYMERS AND MONOMERS

Polymers are large organic molecules composed of repeating carbon-based units or chains that occur naturally and can be synthesised. Common natural polymers include chiton (insect and crustacean exoskeleton), lignin (cell walls of plants), cellulose (cell walls of plants), polyester (cutin) and protein fibre (wool, silk).

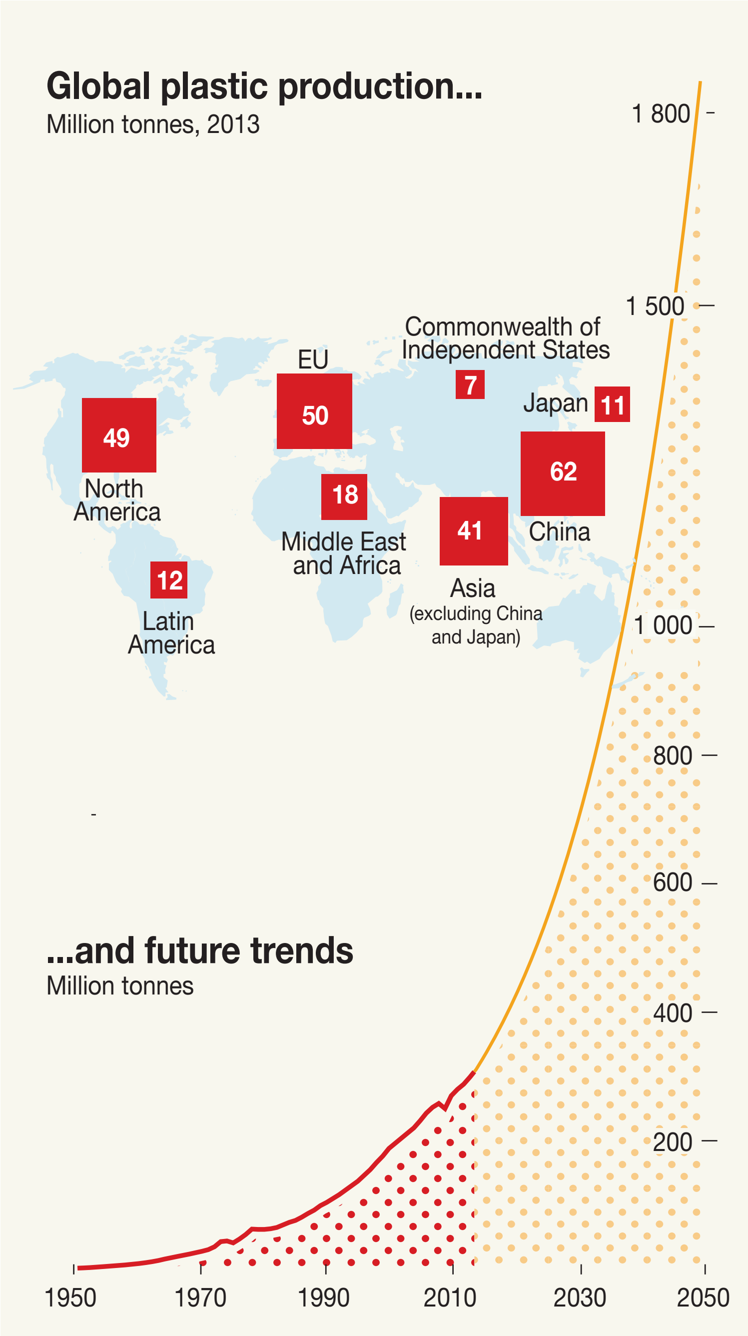
Monomers are molecules capable of combining, by a process called polymerisation, to form a polymer. For example, the monomer ethylene (C2H4) is polymerised, using a catalyst, to form polyethylene.

Figure 4.1



The production of the most common synthetic (plastic) and natural polymers, including some typical applications (adapted from GESAMP 2015)

Figure 4.2



Source: Ryan, A Brief History of Marine Litter Research, in M. Bergmann, L. Gutow, M. Klages (Eds.), Marine Anthropogenic Litter, Berlin Springer, 2015; Plastics Europe

Global plastic production trends (taken from Marine Litter Vital Graphics in preparation)

'Biodegradable' plastics

Some plastics have been designed to be more susceptible to degradation, depending on the environmental conditions to which they are subject. These can range from inside the human body to inside an industrial composter. Such conditions do not exist in the marine environment, and the fate of such materials in the ocean remains unclear. Some common non-biodegradable polymers, such as polyethylene, are sometimes manufactured with a metal-based additive that results in more rapid fragmentation (oxo-degradable). This will increase the rate of microplastic formation, but there is a lack of independent scientific evidence that biodegradation will occur any more rapidly than unmodified polyethylene.

In a recent UNEP report it was concluded that the adoption of products labelled as 'biodegradable' or 'oxo-degradable' would not bring about a significant decrease either in the quantity of plastic entering the ocean or the risk of physical and chemical impacts on the marine environment, on the balance of current scientific evidence (UNEP 2015a). In addition, mixing of such plastics with normal plastics in the recycling stream may compromise the properties of the newly synthesised polymer[22]. The terminology surrounding the degradation of plastics is described in more detail in section 4.2.

Notwithstanding the comments above, there may be marine applications where the use of biodegradable plastics can be justified. Perhaps most obvious is the design and construction of fish traps and pots, with biodegradable panels or hinges, to minimise ghost fishing if the gear cannot be retrieved (Chapter 9.2).

Applications

Plastics have gradually replaced more traditional materials due to their many advantages. One of the principal properties sought of many plastics is durability. This allows plastics to be used for many applications that formerly relied on stone, metal, concrete or timber. There are significant advantages, for food preservation, medical product efficacy, electrical safety, improved thermal insulation and lower fuel consumption in aircraft and automobiles. A summary of types and properties of common plastics has been published recently (UNEP 2015). Examples of products made from different polymer types are shown in Figure 4.1, and the demand by sector in the European market in Figure 4.3.

Microplastics and microbeads

Microplastics have been defined as particles of plastic < 5 mm in diameter (GESAMP 2015). Primary microplastics are particles that have been manufactured to a particular size to carry out a range of specific functions. They are used extensively in industry and manufacturing, for example: as abrasives in air/water-blasting to clean the surfaces of buildings and ships' hulls; as powders for injection moulding; and, more recently, for 3D printing (Figure 4.4). They are also used in so-called personal care and cosmetic products (PCCPs), often to improve the cleaning function or impart colour, and are sometimes referred to as microbeads. PCCPs containing microplastics/microbeads include toothpaste, cosmetics, cleansing agents and skin exfoliators (Napper et al. 2015).

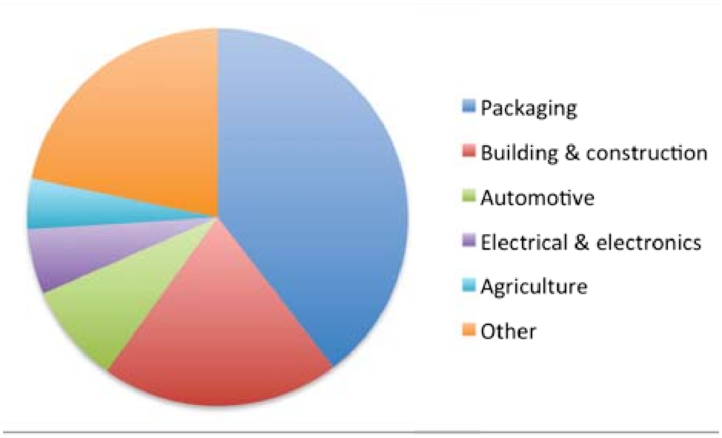
An additional important category of primary microplastics comprises plastic resin beads. These are spherical or cylindrical, a few mm in diameter, and are the form 'raw' plastics are produced in, for transport to production facilities for further processing. The influence of particles on the potential impact of microplastics on marine organisms is discussed in section 7.

Additive chemicals

Many plastics often contain a wide variety of additional compounds that are added to modify the properties of the finished item. For example, these may help to make the polymer more flexible, resist UV-degradation, add colour or impart flame retardation (Table 4.1). A comprehensive guide to the occurrence, uses and properties of hazardous substances in plastics is provided by Hansen et al. (2013). Of these, Perfluorooctanoic acid (PFOA) and similar compounds and Alkanes C10-13 (Short Chain Chlorinated Paraffins SCCP) are both proposed to be listed in Stockholm Convention.

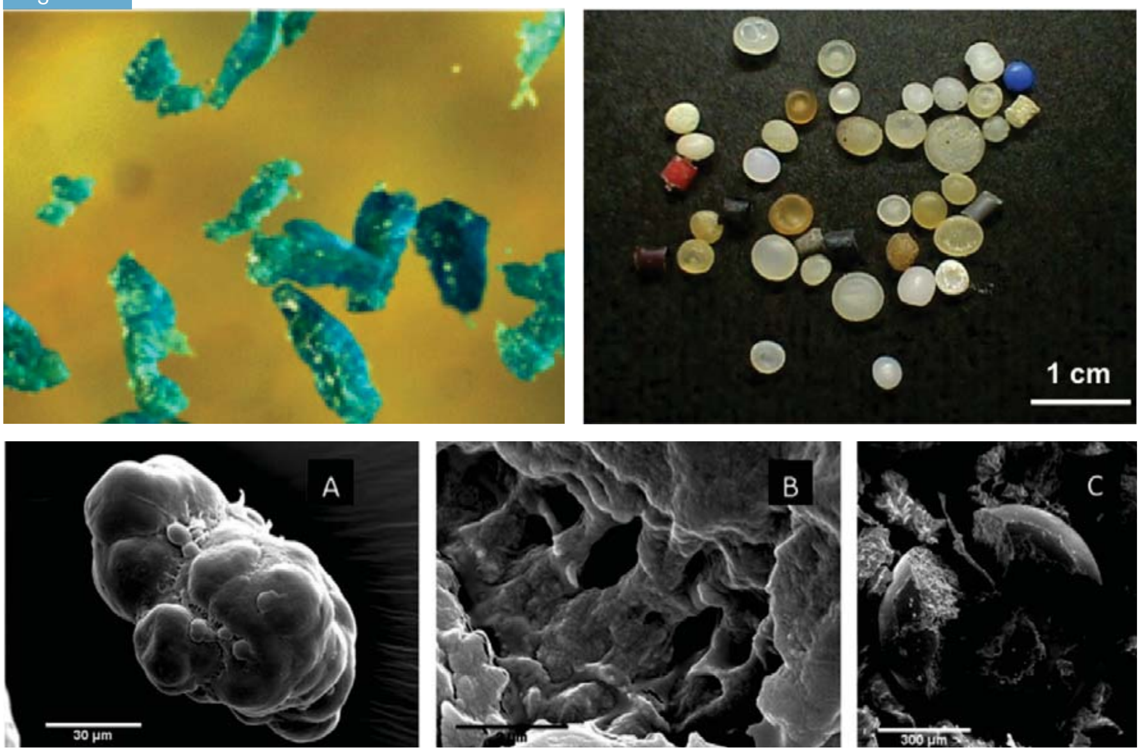
22 http://www.plasticsrecycling.org/images/pdf/resources/Position_Statements/APR_Position_Degradable_Additives.pdf

Figure 4.3



European plastics demand by segment 2013 (data from Plastics-Europe 2014)

Figure 4.4



Primary microplastics: a) abrasive microplastics extracted from toothpaste (image courtesy of Joel Baker); b) plastic resin pellets collected from the shoreline (image courtesy Hideshige Takada); c) scanning electron micrographs of plastic microbeads extracted from facial scrubs (image courtesy of A. Bakir & R. Thompson)

Table 4.1

Short form	**Full name**	Examples of function
DBP	Dibutyl phthalate	Anti-cracking agents in nail varnish
DEP	Diethyl phthalate	Skin softeners, colour and fragrance fixers
DEHP	Di-(2-ethylhexyl)phthalate	Plasticizer in PVC
HBCD	Hexabromocyclododecane	Flame retardant in durable goods
PBDEs	Polybrominated diphenyl ethers (penta, octa & deca forms) nonylphenol	Flame retardants in durable goods (e.g. electronics, furnishings) Stabilizer in PP, PS
Phthalates	Phthalate esters	Improve flexibility and durability

Common additive chemicals in plastics (adapted from GESAMP 2016).

Table 4.2

Plastic type	Common applications	Density (kg m-3)
Polyethylene	Plastic bags, storage containers	0.91–0.95
Polypropylene	Rope, bottle caps, gear, strapping	0.90–0.92
Polystyrene (expanded)	Cool boxes, floats, cups	1.01–1.05
Polystyrene	Utensils, containers	1.04–1.09
Polyvinyl chloride	Film, pipe, containers	1.16–1.30
Polyamide or Nylon	Fishing nets, rope	1.13–1.15
Poly(ethylene terephthalate)	Bottles, strapping, textiles	1.34–1.39
Polyester resin + glass fibre	Textiles, boats	>1.35
Cellulose Acetate	Cigarette filters	1.22–1.24
Pure water		1.000
Seawater		1.027
Brackish water (Baltic Sea, Feistel et al. 2010)		1.005 – 1.012

Densities and common applications of plastics found in the marine environment (GESAMP 2015)

Some of these additive chemicals are quite benign, whereas others have been shown to have significant toxicological effects on human and non-human populations through ingestion, inhalation, and dermal contact. This is discussed further in section 7. Additives that are mixed into the plastic during manufacture may be released into the environment over time, especially when the plastic begins to degrade. These chemicals may then be re-absorbed to other plastic particles or to lipids (fats) and hence enter the food chain by a secondary route. The relative proportion of these additives varies greatly by polymer type and intended application. In addition, some monomers used in the production of certain plastics have a tendency to desorb. The known example is bisphenol A (BPA), used in the production of polycarbonate and some epoxy resins, for example, used to line food containers. BPA acts as a synthetic oestrogen and is readily absorbed by the body. Most of the population of developed countries have detectable levels of BPA, but the degree to which it causes health effects is a matter of intense debate.

4.2

BEHAVIOUR IN THE OCEAN

Floating or sinking

Different types of polymers have a wide range of properties, and this influences their behaviour in the environment. Of these, one of the most important is its density relative to that of seawater. Densities of common plastics range from 0.90 to 1.39 (kg m-3) (Table 4.2). The density of pure water is 1.00 and for seawater approximately 1.027 (1.020 – 1029 kg m-3), depending on the temperature and salinity which vary geographically and with water depth. On this basis, only PE and PP would be expected to float in freshwater, with the addition of EPS in seawater. However, the buoyancy of a plastic particle or object will be dependent on other factors such as entrapped air, water currents and turbulence. This explains why drinks bottles made of PET (density 1.34 – 1.39 kg m-3) can commonly be found both floating in coastal waters and deposited on the seabed

Plastic degradation

Plastics will tend to degrade and start to lose their initial properties over time, at a rate depending on the physical, chemical and biological conditions to which they are subjected. Weathering-related degradation results in a progression of changes: the loss in mechanical integrity, embrittlement, further degradation and fragmentation into ('secondary') microplastics. Further degradation by microbial action is termed biodegradation. Once biodegradation is complete the plastic is said to have been mineralized; i.e. converted into carbon dioxide, water and other naturally occurring compounds, dependent on the surrounding environmental conditions (Box 4.2). National and international standards have been developed to define terms such as 'compostable' and 'biodegradable' which refer exclusively to terrestrial systems, most typically to industrial composting in which temperatures are expected to exceed 50oC for extended periods of weeks or months (UNEP 2015a).

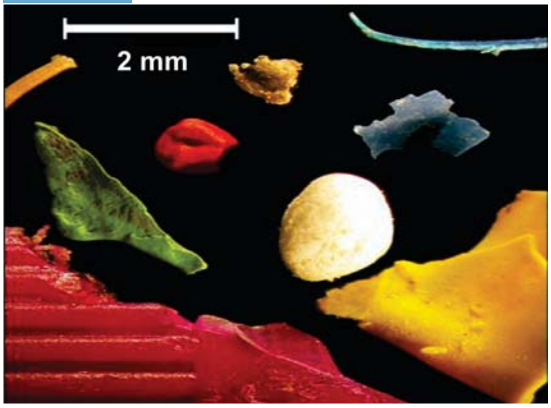
Photo: © Heidi Savelli / UNEP

Box 4.2

DEGRADATION OF PLASTICS – SOME DEFINITIONS

Degradation	The partial or complete breakdown of a polymer as a result of e.g. UV radiation, oxygen attack, biological attack. This implies alteration of the properties, such as discolouration, surface cracking, and fragmentation
Biodegradation	Biological process of organic matter, which is completely or partially converted to water, CO2/methane, energy and new biomass by microorganisms (bacteria and fungi).
Mineralisation	Defined here, in the context of polymer degradation, as the complete breakdown of a polymer as a result of the combined abiotic and microbial activity, into CO2, water, methane, hydrogen, ammonia and other simple inorganic compounds
Biodegradable	Capable of being biodegraded
Compostable	Capable of being biodegraded at elevated temperatures in soil under specified conditions and time scales, usually only encountered in an industrial composter (standards apply: ISO 17088, EN 13432, ASTM 6400)
Oxo-degradable	Containing a pro-oxidant that induces degradation under favourable conditions. Complete breakdown of the polymers and biodegradation still have to be proven. UNEP 2015

Figure 4.5



Microplastic fragments from the shoreline near Plymouth UK (image courtesy of M. Browne & R. Thompson, Plymouth Univ.)

Figure 4.6

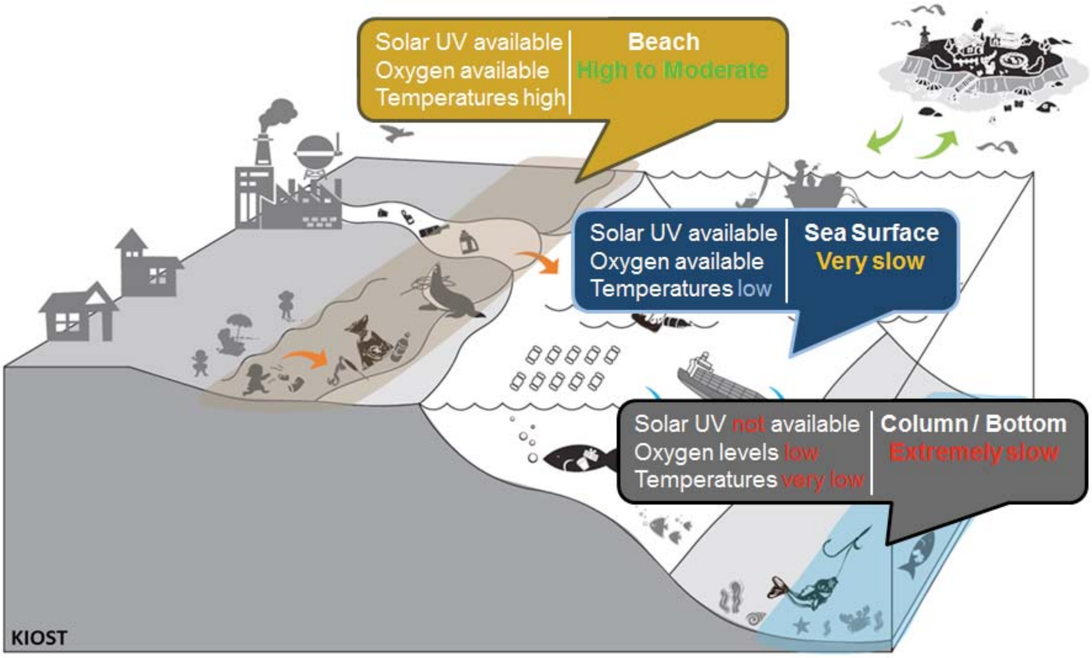


Figure 4.6 Factors affecting the degradation and fragmentation of plastic in different ocean compartments (GESAMP 2015)

In an ocean setting the principal weathering agent is UV irradiation. This is most pronounced on shorelines, especially in equatorial regions, and weathering is accelerated by physical abrasion due to wave activity. Secondary microplastics are formed from the fragmentation of larger items through a combination of physical, chemical and biological processes (Figure 4.5). For example, mechanical abrasion during the washing of synthetic clothing and other textiles causes the breakdown and release of plastic fibres to wastewater. Mechanical abrasion of vehicle tyres made from synthetic rubber produces dust that is washed into drains and waterways.

The extent to which biodegradation takes place in the ocean is difficult to estimate but is considered to be extremely slow. Once plastic becomes buried, enters the water column or gets covered in biological and inorganic coatings, which happens rapidly in seawater, then the rate of degradation becomes extremely slow (Figure 4.6). This is due to decreased UV exposure, lower temperature and lower oxygen levels. Objects such as PET bottles and fishing gear observed on the seafloor often do not appear to be degraded (section 6.2).

Chemical characteristics

The ocean is contaminated with a wide range of organic and inorganic compounds as a legacy of decades of industrial development and economic growth. Transport in the ocean and atmosphere has carried pollutants to all regions of the planet. Many organic pollutants are lipophilic, meaning they sorb readily to fats and oils in fish, mammals and other organisms. This includes pollutants classified as POPs under the Stockholm Convention, as well as other emerging Persistent, Bioaccumulating and Toxic compounds (PBTs). Plastics have similar properties to natural fats, acting as a 'sponge' to remove and concentrate contaminants from the water column. If an animal, such as a fish, bird or marine mammal, ingests plastic particles then there is the potential for transfer of these absorbed chemicals into the tissue. Because of the persistence of such compounds, humans and other animals continue to be exposed long after a chemical has been withdrawn from production (e.g. PCBs).

Some additive chemicals, such as PBDEs, are not strongly bound within the matrix of the polymer. They can be present in relatively high concentrations and can desorb out of the plastic, acting as a source of contaminants (section 7).

5

5. SOURCES OF MACRO AND MICROPLASTICS

5.1

GENERATING PLASTIC WASTE

The drivers of plastic use include food provision, energy demand, transport, housing provision and leisure pursuits, which will tend to vary as a function of the social and economic climate. Current economic models tend to measure economic success in terms of the rate of economic growth (e.g. GDP), with less attention paid to the extent to which consumption patterns and societal demands are sustainable in the longer term. This will influence, in turn, the direction on technological innovation, political decisions (e.g. trade agreements), product design, consumer demand, waste generation and treatment. Unfortunately, there has been a failure of the market economy to take into account environmental externalities, in this case the social, ecological and economic impacts of marine litter. The current 'plastic economy' has been characterised by a linear pattern of production and consumption, generating unprecedented volumes of waste, which ultimately is very inefficient economically (Figure 5.1; Defra 2011, WEF/EMF/MCKINSEY 2016). Leakage of plastic to the ocean can occur at every stage in this process, and the response has been generally patchy and ineffective.

Our continuing failure to take account of the unsustainable nature of the present 'plastic economy', in terms of the increasing levels of marine plastic debris, appears to make it inevitable that future generations will be deprived of at least some ecosystem services we now take for granted. Clearly, this failure is not confined to plastics production and use, but is symptomatic of a more pervasive tendency, of pursuing economic growth whilst neglecting the impact on ecosystems and society (Turner and Fisher, 2008).

5.2

LAND-BASED SECTORS GENERATING MACROPLASTIC LITTER

Sources in brief

The main types of land-based sources of macroplastics, and the pathways by which macroplastics reach the ocean, are shown in Figure 5.2. Pathways may be via waterways, the atmosphere or direct into the ocean (e.g. from shoreline littering). There are very significant regional differences in the degree to which waste is subject to collection and management, either as wastewater or solid waste. The quantities that reach the sea, on a global scale, are unknown. Table 5.1 provides a summary of the main sectors involved, the types of plastic products or waste and the typical entry points to the ocean.

Plastic recyclers

The plastic recycling sector regards plastic as a valuable resource, rather than something to be used and then discarded. Losses from this sector are unquantified but can be expected to be relatively low, provided good waste management practices are followed. However, losses may be much greater from poorly-managed municipal facilities and the informal waste recycling sectors.

Figure 5.1

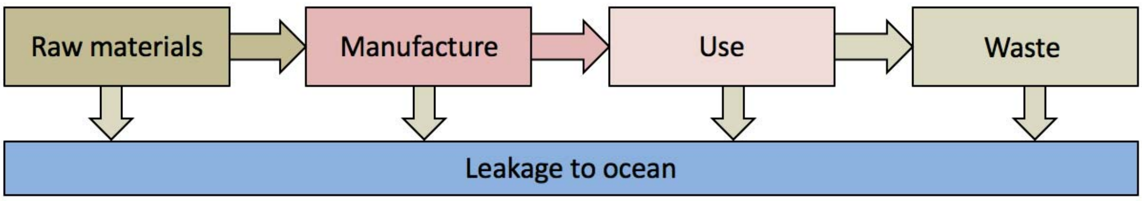
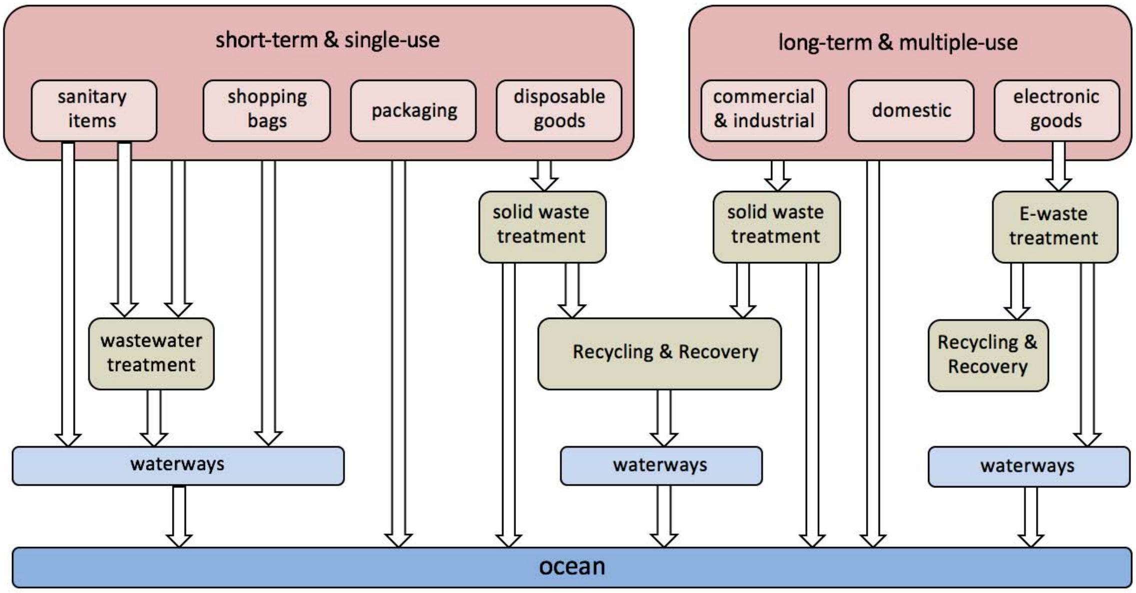


Figure 5.1 Simplified representation of a linear approach to plastics production and use, indicating potential leakage points to the ocean (original by P. J. Kershaw).

Figure 5.2



Land-based sources of macroplastics and pathways to the ocean (original by P. J. Kershaw)

Table 5.1

Sector	Description	Entry points	Relative importance*
Retail	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	High
Food and drink	Single-use packaging	Rivers, coastal, atmosphere	High
Households	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	High
Tourism industry	Packaging, household goods, consumer goods,	Rivers, coastal, atmosphere	High
Plastic recyclers	Packaging, household goods, consumer goods	Rivers, coastal, atmosphere	Medium
Construction	EPS, packaging,	Rivers, coastal, atmosphere	Low
Agriculture	Films/sheets, pots, pipes,	Rivers, coastal, atmosphere	Low
Terrestrial Transportation	End-of-life vehicles and tyres	Rivers, shorelines	Low

Potential land-based sources of macroplastics by sector, examples of plastic waste, common entry points to the ocean and probable importance (adapted from GESAMP 2016)

* qualitative estimate, likely to be regionally-dependent; variables include the extent and effectiveness of solid waste and wastewater collection and treatment, and storm water overflow capacity

Packaging

Around 40% of all plastic production is used for packaging. A substantial proportion of this is used to package food and drink and there are clear benefits in doing so, to minimise food wastage and avoid contamination (FAO 2011). In some regions, for example in Sierra Leone, Ghana and Ecuador, the population relies on plastic bottles or bags for the provision of clean drinking water. Clearly this is a case of utilising these products as a necessity, rather than casual consumer choice. Food and drink packaging is also widely used for convenience and in fast food containers, often when consumers are away from home where waste disposal may be poorly developed, such as at the beach. Such items are frequently found as marine litter (OSPAR 2007, Ocean Conservancy 2013).

Agriculture

Plastics are used in many aspects of agriculture, including: irrigation pipes, planting containers and protective meshes and sheets. There have been reports of such materials ending up in the ocean and, in at least one instance, being ingested by marine organisms (de Stephanis et al. 2013). In addition, synthetic polymers are being used increasingly to encapsulate fertiliser pellets to ensure controlled release (nutrient 'prill', Gambash et al. 1990), with clear benefits both for crop production and a reduction in excessive nutrient concentrations in rivers and coastal waters. To what extent more conventional and newer uses of plastics in agriculture contribute to the marine litter burden is unknown.

Construction

The construction industry is a major user of plastics (Figure 4.3), although its potential as a source of marine litter has not been well defined. Construction plastics will enter the solid waste stream and the degree to which it contributes to marine plastics will depend on the effectiveness of solid waste management. Joint sealants (polymer-based) used in the construction industry in the 1950s-1980s used to contain PCBs. This has been identified as a significant diffuse source of PCBs to the environment (Kohler et al. 2005). Concentrations of PCBs in the blubber of cetacean strandings on UK shorelines have plateaued after declining up til the mid 1990s, and it is believed this is due to this plastic-related source (Law et al. 2012).

Coastal tourism

Coastal tourism is based around a variety of sought after amenities, such as beaches, sunshine, water, marine biodiversity, food, and cultural and historic heritage. This leads to the creation of services, jobs and infrastructure (e.g. hotels, resorts, restaurants, ports, marinas, fishing and diving outlets). Unfortunately, coastal tourism has been recognised as a significant source of plastic waste, very often by direct deliberate or accidental littering of shorelines (Arcadis 2012). The range of activities and facilities involved mean that there are multiple routes by which littering can take place. Tourism continues to grow in most countries. In 2014 the total export earnings from international tourism were estimated to be US$ 1.5 trillion (US$ 1.5 x 1012), spread between Europe (41%), Asia and the Pacific (30%), the Americas (22%), the Middle East (4%) and Africa (3%). What proportion of this is focussed on coastal tourism is unclear. However, countries bordering popular destinations such as the Mediterranean will have a greater proportion of coastal tourists, both international and internal. Some areas which feature as popular destinations are also areas with high biodiversity or sensitive habitats (Conservation International, 2003). Tourism is expected to expand from 940 million (2010) to 1.8 billion by 2013, expressed as international tourist arrivals (UNWTO 2015).

5.3

LAND-BASED SECTORS GENERATING MICROPLASTICS

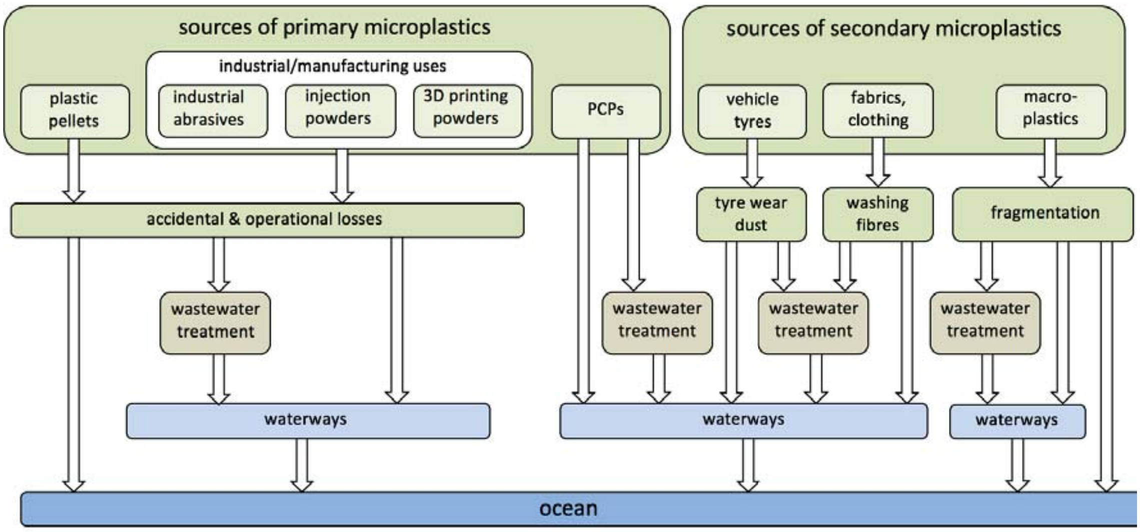
Sources in brief

The main land-based sources and entry points of primary and secondary microplastics to the ocean are shown in Figure 5.3. The type of material involved is summarised in Table 5.2. There are no reliable global estimates of the total quantities of microplastics entering the ocean. However, there have been several in-depth national reports published recently that provide a useful summary of the relative proportions and absolute quantities of material involved (section 5.7).

Cosmetics and personal care products

Microplastic particles are widely used as abrasive agents and fillers in a wide range of cosmetic products and personal care and cosmetic products (PCCPs), such as facial scrubs and shower gels, while nano-

Figure 5.3



Land-based sources of macroplastics and pathways to the ocean (original by P. J. Kershaw)

Table 5.2

Sector	Primary microplas-tics	Secondary microplastics	Entry points	Relative importance*
Tourism industry		Fragmented packaging, household goods, con-sumer goods,	Wastewater, rivers, coastal, atmos-phere	High
Food and drink		Fragmented single-use packaging	Wastewater, rivers, coastal, atmos-phere	High
Plastic producers	Plastic resin pellets		Wastewater, rivers, coastal	Medium
Retail		Fragmented packaging, household goods, con-sumer goods	Wastewater, rivers, coastal	Medium
Households		Fragmented packaging, household goods, con-sumer goods	Wastewater, rivers, coastal	Medium
	Personal care and cosmetic products (PCCPs)		Wastewater	Medium
Terrestrial Transportation		Tyres wear dust	Wastewater, rivers	Medium
Cleaning ships' hulls, buildings	Abrasive powders		Wastewater, rivers, coastal	Medium
Manufacturing	Powders for injection moulds, powders for 3D printing		Wastewater, rivers	Low
Plastic recyclers		Fragmented packaging, household goods, con-sumer goods	Wastewater, rivers	Low
Construction		Fragmented EPS, pack-aging,	Wastewater, rivers, coastal	Low
Agriculture		Fragmented films/sheets, pots, pipes,	Rivers, coastal, atmosphere	Low

Potential land-based sources of microplastics by sector, examples of plastic waste, common entry points to the ocean and probable importance (adapted from GESAMP 2016).

* qualitative estimate, likely to be regionally-dependent; variables include the extent and effectiveness of solid waste and wastewater collection and treatment, and storm water overflow capacity.

particles are used in sunscreens (Sherrington et al. 2016). They are sometimes referred to as microbeads. These particles will inevitably be released to wastewater systems upon washing or directly to aquatic environments via recreational bathing. The total numbers of microplastics in a typical cosmetic product can be considerable; for example, it has been estimated that 4 600 – 94 500 microbeads may be released per application of a skin exfoliant (Napper et al. 2015). It is considered inevitable that substantial numbers of microbeads will enter waterways, depending on the existence and efficacy of wastewater treatment facilities (Magnusson and Norén 2014, Essel et al. 2015, DEPA 2015). However, some modern plants in Sweden and St Petersberg, for example, are reported to retain over 96% of microplastics by filtration[23]. Although the use of microplastics in PCCPs may appear to represent a significant source, it is relatively small compared with other sources or primary and secondary microplastics in to the environment, in terms of tonnage involved (Sundt et al. 2014).

Textiles and clothing

Release of fibres from textiles and clothing is recognised as a major potential source of microplastic sized pieces, especially during mechanical washing[24]. As in the case of microplastics in PCCPs, a variable proportion will be retained by wastewater treatment plants, depending on the existence, design and efficacy of treatment facilities. However, it is apparent that a significant number of textile fibres do enter the marine environment, being found in relatively large numbers in shoreline and nearshore sediments close to urban population centres (Browne et al. 200, Karlsson 2015). Significant regional differences may be expected due to differences in choice of fabrics (synthetic vs. natural, length of spun threads), access to mechanical washing facilities, the type of detergents used and frequency of washing.

Terrestrial transportation

The emission of plastic particle dust (mainly < 80 micrometer) from tyre wear has been recognised recently, in Norway, the Netherlands and Germany, as potentially a major source of microplastic contamination to the sea (NEA 2014, Verschoor 2014). Part of the dust flies as particulate matter into the air, the rest lands directly on the soil around the roads, rainwater flows into the sewer or ends up in surface waters and in the sea, or becomes incorporated with snow and may be re-distributed if the snow is removed. Car tyres are largely made of styrene-1.3-butadene rubber (SBR) and recycled products made from tyre rubber. Every year, an estimated quantity of 17 000 tonnes of rubber tyre-wear is released into the Dutch environment (Verschoor 2014). Annual emission estimates of tyre rubber dust for Norway, Sweden and Germany are 4 500, 10 000 and 110 000 tonnes respectively (NEA 2014). Average emissions of car tyre dust for the mentioned countries range between 1 and 1.4 kg capita-1 year-1.

Plastic producers and fabricators

The plastics industry tends to produce and transport plastics as circular or cylindrical resin pellets, a few mm in diameter. These are transported to other facilities where the plastic is further processed and ultimately used in the manufacture of either a finished product or component for a more complex product. There have been many instances of accidental loss of resin pellets during transport, transhipment or at manufacturing facilities. Resin pellets have become widely distributed in the marine environment as a result. Examples are provided in section 5.6.

Ship maintenance and ship dismantling

Ship hulls need to be cleaned regularly to remove biological growth and allow re-painting. Traditionally this would have involved air blasting with sand grains, but plastic particles are now sometimes used (Browne et al. 2007). They are also used to clean the inside of tanks. This gives the potential for two types of microplastic to be released to the environment: the original plastic abrasive powder (primary), and flakes of paint (secondary), which often contain a polymer base.

Approximately 70% of commercial ships are dismantled in South Asia (India, Bangladesh and Pakistan), very often on exposed shorelines, with a further 19% in China. The main materials recycled are steel and other metals, with hazardous substances including oils being removed. Although plastics represent a small fraction of the total mass of material, plastics and plastic fragments (such as paint flakes) will occur and will enter the ocean unless prevented (Reddy et al. 2006).

23 https://portal.helcom.fi/meetings/MARINE LITTER CONFEREN CE-317/default.asp

24 http://life-mermaids.eu/en/

5.4

MANAGEMENT OF WASTE FROM LAND-BASED SOURCES

Plastics in wastewater

Wastewater provides a pathway for dissolved chemicals as well as solid particles to be transported into aquatic habitats. This includes macroplastics and microplastics. Large solid items enter the wastewater system with sewage via toilets and can include nappies, tampons, contraceptives and cotton buds. Theoretically these should be removed by primary sewage treatment preventing their entry to the environment. However, in conditions of heavy rainfall sewage systems can become overwhelmed by the volume of water passing through them and material can escape to water courses untreated via overflows. For example, this happens frequently in London, a 21st Century city with 19th Century sewers (Cadbury 2003). As a consequence, items of sewage related debris are commonly reported in marine litter surveys. In addition to macroplastics, microplastic particles originating from cosmetics or from washing of textiles (Browne 2011, Karlsson 2015) can be carried via wastewater, and there is evidence (Browne 2015) that some of these small particles have the potential to pass through sewage treatment into aquatic habitats. In some cities in areas of high winter snowfall, such as Helsinki in Finland, accumulated snow may be dumped directly into coastal waters, bypassing the usual wastewater treatment system and providing an additional pathway for microplastics to the ocean[25].

There are very significant regional differences in the extent to which wastewater is collected and in the degree of subsequent treatment. In some European countries nearly 100% of municipal wastewater is collected and subject to some form of tertiary treatment. In contrast, it is estimated that approximately 90% of all wastewater generated in developing countries is discharged without primary treatment (Corcoran et al. 2010). Primary wastewater treatment is usually designed to remove relatively large solids and would not be expected to capture microplastics. Secondary treatment is designed to remove dissolved and suspended biological matter. At this stage it would be possible to introduce more effective filtration for microplastics, but the justification might be difficult to make in terms of cost-benefit, depending on the social and economic context of the municipality or country. Tertiary treatment provides options to disinfect and remove nutrients and pharmaceuticals. It is relatively expensive for many countries and may only be carried out when there is a sensitive habitat or question of human health involved.

25 https://portal.helcom.fi/meetings/MARINE%20LITTER%20CONFERENCE-317/default.aspx

Plastics in solid waste

Plastics form approximately 10% (7-13%) of municipal solid waste globally (Hoorweg and Bhada-Tata 2012, D-Waste 2014). Waste management options can range from open waste tips or dumps to landfill, varying levels of incineration, waste to energy conversion and/or recycling. However, even within a waste stream some material can escape to the environment. For example, unless dumps or landfill sites are contained, waste will be transported away by winds, and may subsequently enter rivers or the sea. In addition, there are coastal dumps where waste is deposited close to or directly on the shoreline and then carried away by the sea. The collection of solid waste is often inadequate, partly due to the littering activities of individuals, even where waste collection facilities have been provided. In many countries, the informal waste recycling community may intercept significant quantities of plastic packaging. For example, one study estimated that recovery rates were up to 90% in Egypt, Lebanon and Morocco (BiPRO 2013).

An estimate has been made of the possible contribution of mismanaged municipal waste to the input of marine plastics by country (Jambeck et al. 2015). The authors used published data from the World Bank (Hoornweg and Bhada-Tata 2012) on solid waste generation, coastal population density and economic status to estimate the proportion of plastic in the waste stream, the proportion of waste that was mismanaged and hence the quantity of plastic available for transport into the ocean. Inevitably there are large uncertainties associated with this approach, but it does serve to demonstrate the relative importance of this source and expected regional differences. For the year 2010, the authors estimated the generation of 275 million tonnes of plastic waste by countries with a coastal border, with 4.8 to 12.7 million tonnes entering the ocean. They predicted this would double by 2025, without significant improvements in waste management. This figure also assumes that production, use and discarding of plastic will continue unabated.

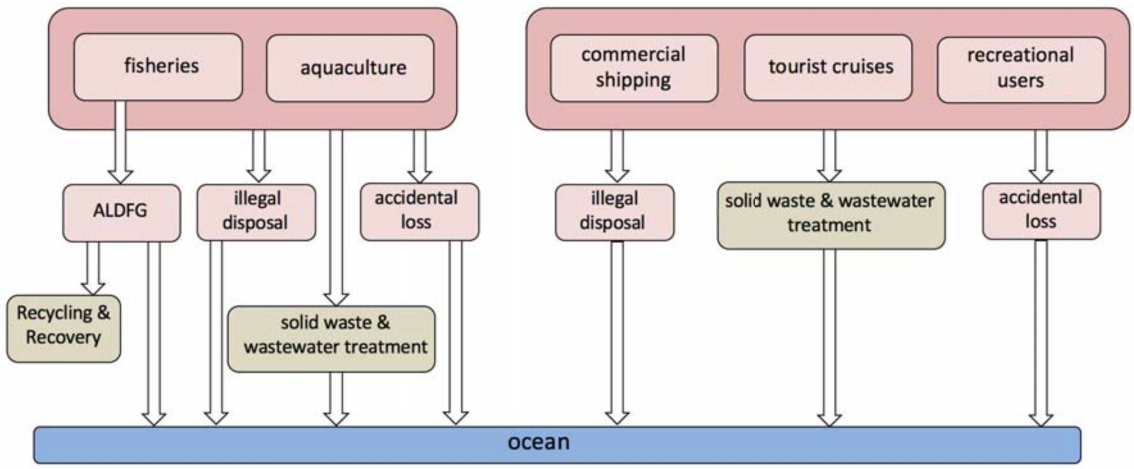
Table 5.3

Source sector	Description*	Entry points	Relative importance**
Fisheries	Fishing gear, strapping bands, storage boxes, packaging, personal goods	Coastal, Marine	High
Aquaculture	Buoys, lines, nets, structures, storage boxes, packaging, personal goods	Coastal, Marine	Medium
Shipping/ Offshore industry	Cargo, packaging, personal goods	Coastal, Marine	Medium
Ship-based tourism	Packaging, personal goods	Coastal, Marine	Medium

Sources of macroplastics by maritime sector

*combines waste specific to the sector and waste generated by those involved in the sector
**qualitative estimate, likely to be regionally-dependent

Figure 5.4



Sea-based sources of macroplastics and pathways to the ocean (original by P. J. Kershaw)

5.5

SEA-BASED SECTORS GENERATING MACROPLASTIC LITTER

Types of materials involved

Maritime activities utilise a wide variety of different types of plastics, both those intended for short-term use (e.g. packaging) and longer-term use (e.g. fishing gear, ropes). The principal sources and entry routes are illustrated in Figure 5.4, and the types of material are further described in Table 5.3.

Sectors such as fisheries or aquaculture may use particular types or quantities of plastics more than other sectors, but a cruise ship, carrying several thousand passengers more represents a medium-sized floating community or town, with a similar scale of demands for goods and services and potential to generate waste.

Fisheries

The commercial fisheries sector has adopted plastics widely, because of the many advantages plastics offer over more traditional natural fibres. Losses in the fisheries sector comprise loss of fishing gear (e.g. nets, ropes, floats, fishing line), loss of ancillary items (e.g. gloves, fish boxes, strapping bands), galley waste and release of fibres and other fragments due to normal wear and tear (e.g. use of ground ropes). Fishing gear may be lost at sea by accident, abandonment or deliberate disposal. This is commonly referred to as abandoned, lost or otherwise discarded fishing gear (ALDFG), and probably represents the largest category in terms of volume and potential impact out of all the sea-based sources (Figure 5.5). Abandoned, lost or otherwise discarded fishing gear can have a significant impact both on depleting commercial fish and shellfish stocks and causing unnecessary impacts on non-target species and habitats. The importance of this issue was recognised formally at the 16th meeting of the FAO Committee on Fisheries in 1985, and led to publication of a key report by FAO and UNEP (Macfadyen et al. 2009). The quantities of ALDFG lost each year are not well known. A very crude estimate based on Macfadyen et al. (2009) gives a global figure of 640 000 tonnes per year.

Regional differences in the type and quantities of fisheries-related marine litter will be due to many factors, including:

- **The existence and effectiveness** of governance and management (e.g. artisanal vs. large-scale commercial fisheries; Illegal, Unreported and Unregulated (IUU) fishing)
- **The type of fishing gear**
- **Gear conflicts**
- **Fishing environment,** including seabed conditions (e.g. hard ground), water and weather conditions
- **Working with very long nets** or fleets of nets
- **Working with more gear** than can be hauled regularly
- **Education and training** levels of the crew

Aquaculture

Marine-based (coastal) aquaculture includes production operations in the sea and intertidal zones as well as those operated with land-based (onshore) production facilities and structures (FAO, 2014). Although inland aquaculture growth has outpaced marine aquaculture growth since 1980, global

Figure 5.5

Examples of different types of derelict fishing gear (Image: Karen Grimmer, MBNMS, NOAA)

production has continued to expand (FAO, 2014, Campbell, 2013).

Aquaculture structures are either suspended from the sea surface (generally in waters of 10-50 m depth) or placed in intertidal and shallow subtidal zones directly on the bottom. The majority of activities use lines, cages or nets suspended from buoyant structures, often consisting of plastics (air-filled buoys), and EPS (expanded polystyrene). These structures also require many lines (mostly non-buoyant plastics) and cages of various types (thin and thick filament net plastics, buoyant or non-buoyant). Aquaculture structures are lost due to wear and tear of anchor ropes, because of storms, and due to accidents/conflicts with other maritime users. Severe weather conditions can cause widespread damage to aquaculture structures, at times generating large quantities of marine debris (Lee et al. 2014).

Commercial shipping and offshore industries

There should be no deliberate disposal of plastics from ships, or offshore structures, under the terms of Annex V of the MARPOL Convention. This includes waters outside national jurisdiction. Unfortunately, there is evidence to suggest that this practice still continues. There is an inherent difficulty in enforcing regulations. In addition to illegal disposal there have been many occurrences of loss of cargo, particularly containers which in some cases resulted in spillages of pellets. A review into the reasons for container loss concluded that there were several contributory factors: overloading of individual containers, fixings in poor condition, placing heavy containers on top of lighter ones, and a lack of appreciation by crews of the additional loadings placed on container stacks in heavy seas and winds leading to a failure to adjust ship speed and heading (Frey and De Vogelaere 2014; see section 5.6, shipping routes).

Maritime–based tourism

A cruise ship typically houses several thousand people. It is rather like a large floating village and generates an equivalent amount of macro and microplastic waste. Modern vessels have very sophisticated liquid and solid waste management systems, but very often solid waste is put ashore at ports on small islands with inadequate waste infrastructures. In addition, some cruise companies also indulge in the dubious practice of multiple balloon releases, despite the clear ecological damage this can cause. A growing trend in 'eco-tourism' has led to increasing number of vessels visiting more remote locations, including the Antarctic. To what extent such tours result in contamination by macro or microplastics is unclear.

Recreational activities

Many recreational users of the ocean, particularly those in the diving and surfing communities, take an environmentally responsible approach to their activities. Indeed, some have been at the forefront of leading anti-litter and recovery campaigns (section 11.6). Unfortunately, there are others with a less responsible approach. Fishing line and hooks from recreational fishers are commonplace in some regions, such as NW Europe and the Korean Peninsula, although the actual quantities lost are not known.

5.6

SEA-BASED SECTORS GENERATING MICROPLASTICS

Types of material involved

A number of maritime activities result in the release of microplastics directly into the ocean. A summary of the main sea-based sources of primary and secondary microplastics is shown in Figure 5.6 and types of material involved in Table 5.4.

Primary microplastics

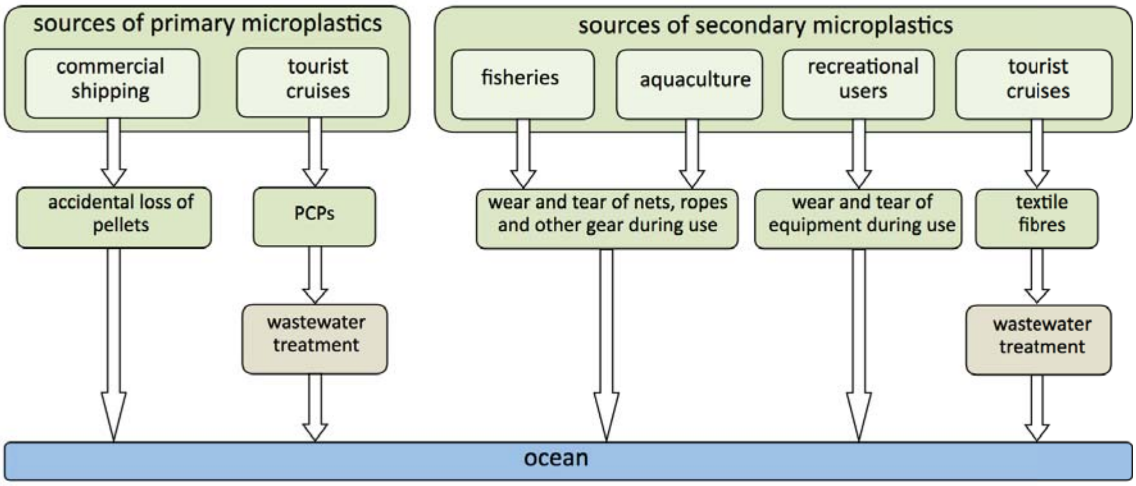
The main source of primary microplastics at sea is due to the introduction of plastic resin beads as a result of accidental loss of cargo. A more minor source is represented by the use of PCCPs, most notably by passengers on cruise ships.

Secondary microplastics.

Routine wear and tear of fishing gear and other equipment will result in the introduction of a variety of secondary microplastics. The use of groundropes on some types of bottom trawls, such as otter trawls[26],

26 http://www.fao.org/fishery/geartype/306/en

Figure 5.5



Sources of sea-based primary and secondary microplastics (original by P J Kershaw)

Table 5.4

Source sector	Primary microplastics	Secondary microplastics	Entry points	Relative importance*
Fisheries		Fragments and fibres from operational use of fishing gear, ropes	Coastal, Marine	High
Aquaculture		Fragments and fibres from operational use of nets, ropes and (EPS) buoys	Coastal, Marine	Medium
Shipping	Accidental loss of plastic resin pellets		Coastal, Marine	Medium
Ship-based tourism	PCCPs		Coastal, Marine	Low

Sources of microplastics by maritime sector

* qualitative estimate, likely to be regionally-dependent

to project the main fishing gear may be a significant source of synthetic fibres in some regions but robust evidence is unavailable.

5.7

ESTIMATING LAND-BASED INPUTS OF MACRO AND MICROPLASTICS TO THE OCEAN – A REGIONAL PERSPECTIVE

Patterns of waste generation

Urbanised communities

Approximately half the world's population lives within 60 km of the ocean, with 75% of all large cities located on the coast (GESAMP 2016). In China and Southeast Asia 260 million and 400 million people, respectively, live within 50 km of the coast. Many others live adjacent to rivers or waterways and so are connected indirectly to the sea. Given known patterns of plastic use it is reasonable to assume, to a first approximation, that the influx of plastic to the ocean from urbanised communities will be in proportion to the density of the population (Figure 5.7).

The absolute quantities and relative proportions of different types of plastics and microplastics being generated, and the percentage that reaches the ocean, will also depend on the nature of the industrial and commercial sectors, and the social practices of the population. There have been three comprehensive studies of the generation of microplastics in European countries, in Germany (Essel et al. 2015), Denmark (Lassen et al. 2015) and Norway (Sundt et al. 2014) (Box 5.1). All three studies emphasised that dust from vehicle tyres represented the largest single source of microplastics. This was a previously overlooked contribution. It would be possible to estimate regional and global patterns of microplastic generation from this source by correlating with car numbers, or average mileages per vehicle.

Figure 5.7

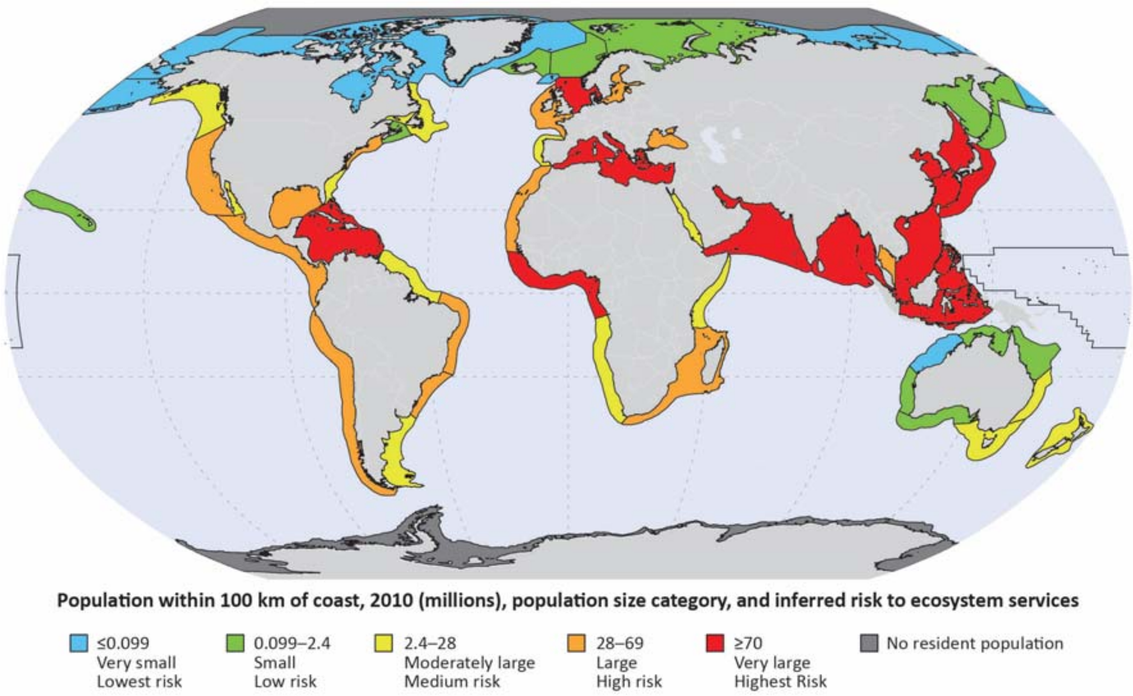


Figure 5.7 Coastal population within 100 km of the coast (2010 millions), displayed on an outline of Large Marine Ecosystems (taken from TWAP 2016)

Table 5.5

Source group		**Upstream source (tonnes)**	**Pathway to sea**	**Probable share to sea***	**Fraction to sea (tonnes)**
Consumer products, all		40	Drain past STP	Small	**4**
Commercial products, all		100	Drain, sea	Medium	**50**
Transport spill		250	Sea	Large	**225**
Production discharge		200	Drain or sea	Large	**180**
Ship paint		330	Sea, coastal	Large	**297**
Marinas		400	Sea, coastal	Large	**360**
Building repair		270	Sewer, dump	Medium	**135**
Laundries		100	Drain	Medium	**50**
Household	Laundry	600	Drain past STP	Small	**60**
	Dust	450	Drain, air	Small	**45**
City dust outdoor	Road paint	320	Sewer, air	Medium	**160**
	Exterior paint	130	Sewer, air	Small	**13**
	Tyre dust	4500	Sewer, air	Medium	**2250**
Indoor city	Dust	130	Sewer, air	Small	**20**
Illegal dumping, paint		100	Soil, sea	Large	90
Biowaste		336	Soil, water	Small	34
Paper recycle		60	Water		54
WEE and ELW		10	Air, water	Medium	5

*** Estimated sources of microplastics, pathways to the sea and fraction entering the sea in Norway (adapted from Sundt et al. 2014)**

* small = 10%, medium = 50%, large = 90%

Inputs via rivers and other waterways

Rivers represent a key entry point of macro and microplastics to the ocean. From the limited data available, it would appear that river catchments, especially those draining areas with high population densities and industrial development, can carry a significant plastic load to the ocean. A summary of observed concentrations of microplastics in rivers is provided in Annex III. However, there is a great lack of information on the quantities entering the ocean globally by this entry point, which sources are most important, what measures may be effective at controlling these sources and how all these aspects differ regionally.

The effectiveness of wastewater and solid waste management will be an important factor in modifying the input to waterways, whatever the nature of the land-based sources concerned. For these reasons, significant regional differences may be expected. Concentrations of microplastics reported for rivers are highly variable (up to a factor of 109, Dris 2015). This may be due partly to variations in the methodologies used but also due to the proximity of sources and whether sampling sites were upstream or downstream from cities and industrialised centres. Many rivers experience significant variation in flow rates, on a diurnal, weekly, monthly, annual or multi-year basis. For example, a high rainfall event after a period of drier conditions may result in higher than average quantities being transported during a limited period (van der Wal et al. 2015). In contrast, seasonal fluctuations in the flow rate of the Pearl River appear responsible for observed variations in plastic occurrence in Hong Kong (Fok and Cheung 2015).

A comparative study of four major European rivers found significant variations in the quantities and characteristics of plastic litter (van der Wal et al. 2015; Box 5.2, Table 5.5). River water was sampled using a combination of floating nets and screens and pumped water samples and particle numbers counted and a proportion were characterised chemically.

What is striking is that even for a catchment which is relatively remote (i.e. River Dalålven), with a low resident population density (250 000), the river appears to contain a large number of microplastics. In this case it is thought that it may be due partly to the popularity of the region for recreational angling, supported by the higher number of nylon fibres. The composition of the particles varied between rivers, but in each case was dominated by PE. The authors estimated annual load of 530 tonnes being delivered to the Black Sea is more than a factor of two below that of Lechner et al. (2014). But it is important to stress that achieving representative sampling of large river catchments, reflecting temporal and spatial variations in flow, multiple source inputs and the influence of previous events, is extremely challenging. The published figures should be treated as an indicator of possible loadings, with large uncertainties.

Table 5.6

River	Annual discharge (m3 s-1)	Receiving sea	Catchment area (km2)	Catchment characteristics
Rhine	2 378	North Sea	200 000	Highly urbanised and industrialised
Dalålven	~ 300	Baltic Sea	29 000	Nature reserve
Danube	~ 6500	Black Sea	800 000	Agricultural catchment of the tributary of the Siret River
Po	1 470	Mediterranean Sea	71 000	Moderately urbanised

River inputs case study – characteristics of four European river catchments (Van der Wal et al. 2015)

Table 5.7

River	WSF[27] sampler (> 3.2 mm) Particle numbers a-1	WSF1[27] sampler (> 3.2 mm) Tonnes a-1	Manta net (>330 µm) Particle numbers a-1
Rhine	8x107 – 3x108	20 – 31	10x1010 – 3x1011
Dalålven*	-	-	5x1010
Danube	1x1010	530	2x1012
Po	7x108	120	7x1011

Marine input plastic particles

Estimated annual input of plastic particles to the sea from four European rivers. The sampling methods are described in section 11 (adapted from van der Wal et al. 2015)

* Unable to operate the WSF sampler at the study site.

Plastic litter is also transported along the river bed, although this is much harder to quantify. A study in the upper estuary of the River Thames in London, using bottom-anchored nets (‘fyke’ nets designed to catch eels) captured considerable quantities of debris, most of which was plastic and over 20% comprised sanitary items (Morritt et al. 2014).

Extreme flooding events have the potential to mobilise plastic that would not otherwise be transported to the ocean. The effects of heavy rainfall are exacerbated by unsustainable land-use practises (e.g. deforestation, compacted soils). There is evidence that extreme events are becoming more common as a consequence of global warming.

27 https://wastefreewaters.wordpress.com/

Plastic resin pellets

Rivers will be particularly important where the catchment serves urbanised populations and industrial development. For example, resin pellets have been observed in abundance deposited on the engineered banks of the highly industrialised estuary the Westerschelde in the Netherlands, and in amongst floating vegetation (Figure 5.8; personal communication, Tanka Cox, Fauna & Flora International). The Port of Antwerp, which lies upstream of the sampling site, is the location for one of Europe's largest petrochemical and plastics production hubs.

Resin pellets have been reported to occur in large quantities in the River Danube, together with a variety of other drifting plastics (Figure 5.9; Lechner et al. 2014). In the Danube study, the authors estimated a total transport of over 1 550 tonnes a^{-1} into the Black Sea, claiming this was likely to be an underestimate based on under-sampling of microplastics < 500 µm, under-sampling of larger items (> 50mm), and less effective wastewater treatment in countries downstream of Austria. Sampling took place in 2010 and 2012, with significant differences in the variety and quantities sampled. For example, industrial pellets, spherules and flakes represented 64% of the total load (number of items) in 2010 and 31% in 2012. The Danube is the most transboundary of any river, draining 19 countries, with a catchment of over 800 000 km-2. A wide variety of sectors make use of the river, including plastics production, and it is heavily used for transportation. All these factors will make introducing reduction measures very challenging.

Plastics production is a global industry but there are clear regional patterns, China is the single largest producer, with the rest of Asia, Europe and North America each a few per cent lower. This is likely to influence the occurrence of resin pellets in the environment near production and manufacturing sites. However, the trade in plastics is also global so pellets produced in one country may be transported to another for further processing, with the potential for losses en route due to accidental release.

Figure 5.8

Plastic resin pellets in the Westerschelde, Netherlands (images courtesy of Tanya Cox and Fauna & Flora International).

Figure 5.9a

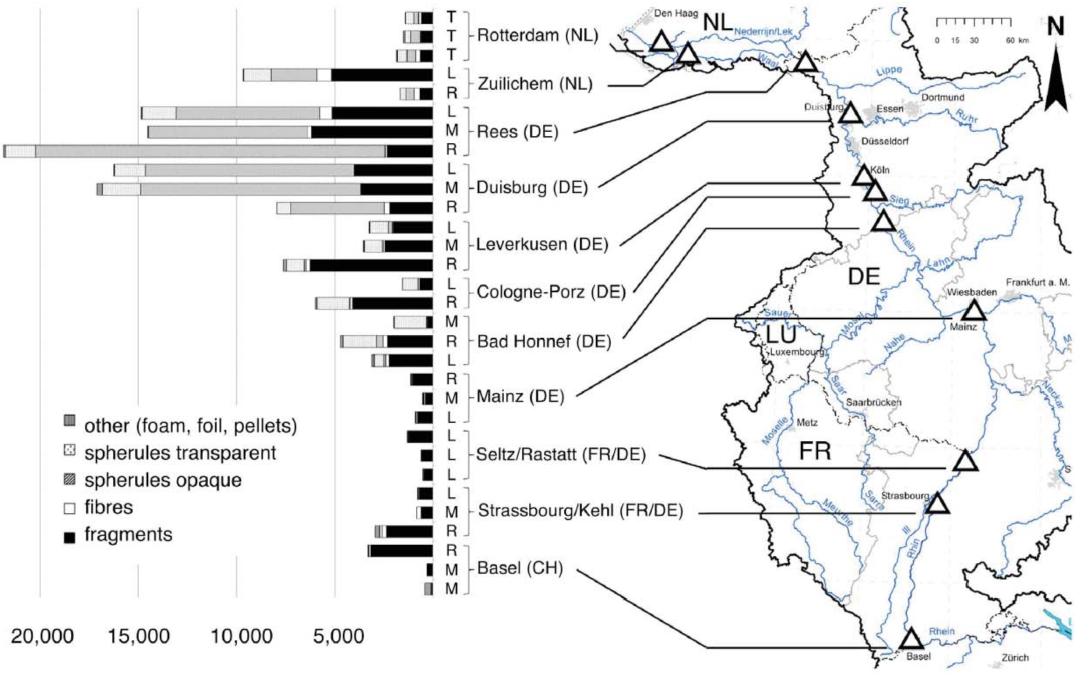
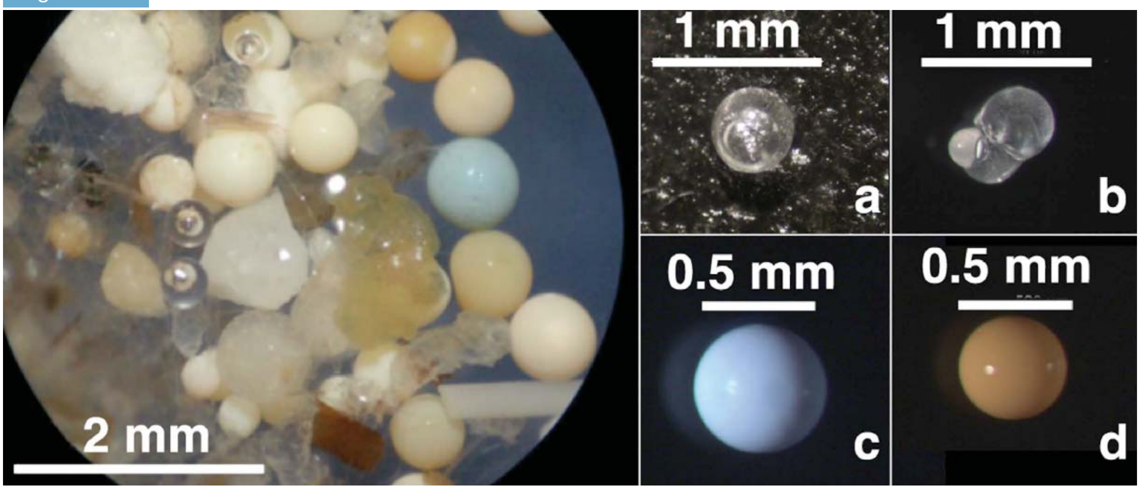


Figure 5.9a



Occurrence of microplastics in the River Rhine: a) Number of microplastic particles (300 µm–5 mm) 1000 m−3 in categories at all sampling sites (Δ). The horizontal columns present microplastic abundance 1000 m−3 and the respective fraction of categories. L: left bank, M: mid-river, R: right bank, T: transect (position in the river cross section); b) Typical microplastic categories in the Rhine. Left: Duisburg sample consisting of 65% opaque spherules, further fragments and fibres, bar: 2 mm. (a/b) transparent spherules with gas bubbles, polymethyl-methacrylate (Zuilichem), bars: 1 mm; (c/d) opaque spherules, polystyrene (Duisburg, Rees), bars: 500 µm. (reproduced from Mani et al.2015, courtesy of ICPR, 2011)

Solid waste management and the global waste trade

State of economic development

The state of economic and social development will have a significant influence on a number of factors related to both the generation and management of waste. To some extent this can be defined in indicators such as GDP per capita and the Human Development Index (HDI), which is a composite indicator encompassing the degree of poverty, literacy and other social measures. Although the HDI has increased globally over the past 25 years, significant regional differences remain (Figure 5.10). Increasing use of plastics has been linked to rising relative incomes, although GDP has risen at a much faster rate than the HDI[28]. This implies the capacity to manage waste effectively has not kept pace with the buying power of consumers.

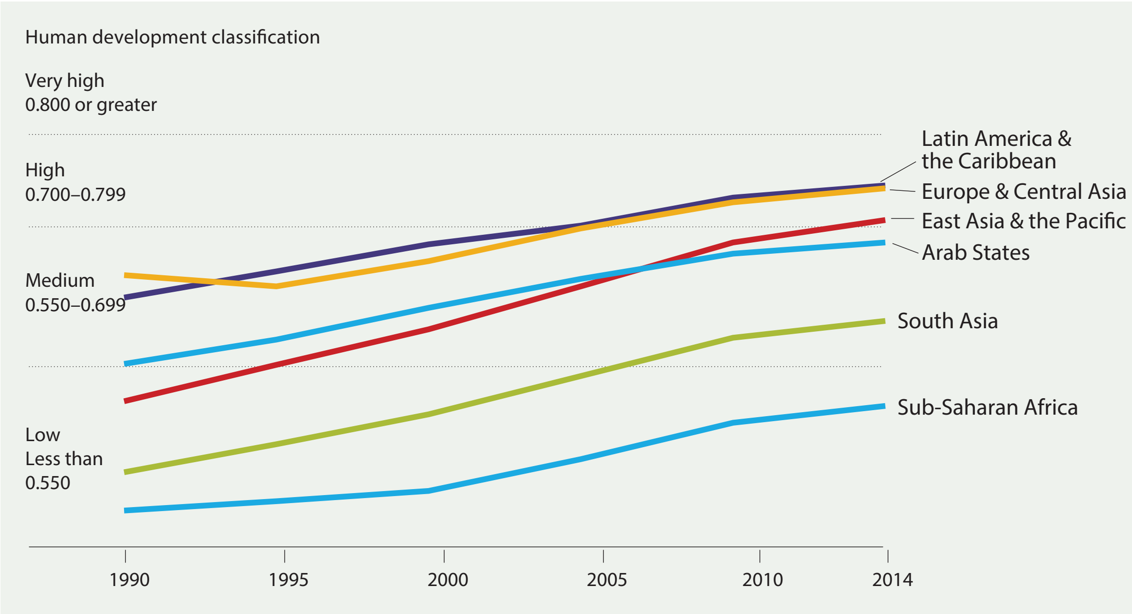
The quantities of waste produced by each country depend on the per capita waste generation and the population. There is a general pattern for richer countries to have higher per capita waste generation, which may be offset by larger populations in some poorer countries (Hoornweg and Bhada-Tata 2012)[29]. Inadequate waste management occurs on every continent. Some current practices in developing countries that are now condemned (e.g. burning plastic coatings from copper wire), were commonplace in the richer countries of North America and Europe just a few decades ago. To a certain extent, the improvement in waste management in richer countries has been achieved by exporting waste to third countries.

The sophistication of waste management practices varies enormously between countries, from well-controlled sanitary landfills to poorly controlled open dumpsites. A comprehensive guide to the fifty waste dumps considered to be of greatest concern globally has been published recently (D-Waste 2014). These are distributed mainly in Africa (18) and Asia (17), but are also found in Latin America (8), the Caribbean (5) and Europe (2) (Figure 5.11). However, they may contain waste that has been imported from other regions, so it could be argued that responsibility for

28 http://www.pelicanweb.org/solisustv04n12.html

29 https://agenda.weforum.org/2015/08/which-countries-produce-the-most-waste/

Figure 5.10



Changes in the UNDP Human Development Index by region, 1975-2004 (Human Development Report 2015, Work for Human Development, UNDP 2015)

improving waste management at such sites may be shared by many countries. Many of these sites are close to the coast or to waterways.

A helpful development would be for countries to map and quantify the extent of informal and illegal waste dumps and poorly controlled landfill sites, especially where these are adjacent to the coastal or other water bodies.

The trade in waste

Tighter regulation on waste management in many developed nations, especially for electrical and electronic goods, has led to a burgeoning market for waste materials. This includes the legitimate trade in end-of life plastics, for example from Europe to China, for large-scale recycling. However, it has also led to the more dubious practice of exporting 'second-hand' (legal) and discarded (illegal) electronics goods to developing countries, particularly in West Africa and Asia. Key reasons for this are the lower wage costs, a lack of scrutiny, and a lack of consideration and enforcement of adequate human and environmental protection policies. Thus the domestic appliance taken for 'recycling' at an established waste treatment centre in North America or Europe can end up in the informal recycling sector in West Africa where waste is discarded and transferred to large open dumpsites. Incidents of illegal transport, often motivated by greed, are reported regularly and have led to prosecutions. The transfer of toxic and hazardous wastes is controlled under the Basel Convention (Chapter 2). The plastics associated with electronic waste often contain high concentrations of certain chemicals, in particular flame retardants. Poorly managed sites act as sources of contaminated plastics to nearby waterways and hence to the ocean, both directly and via the atmosphere.

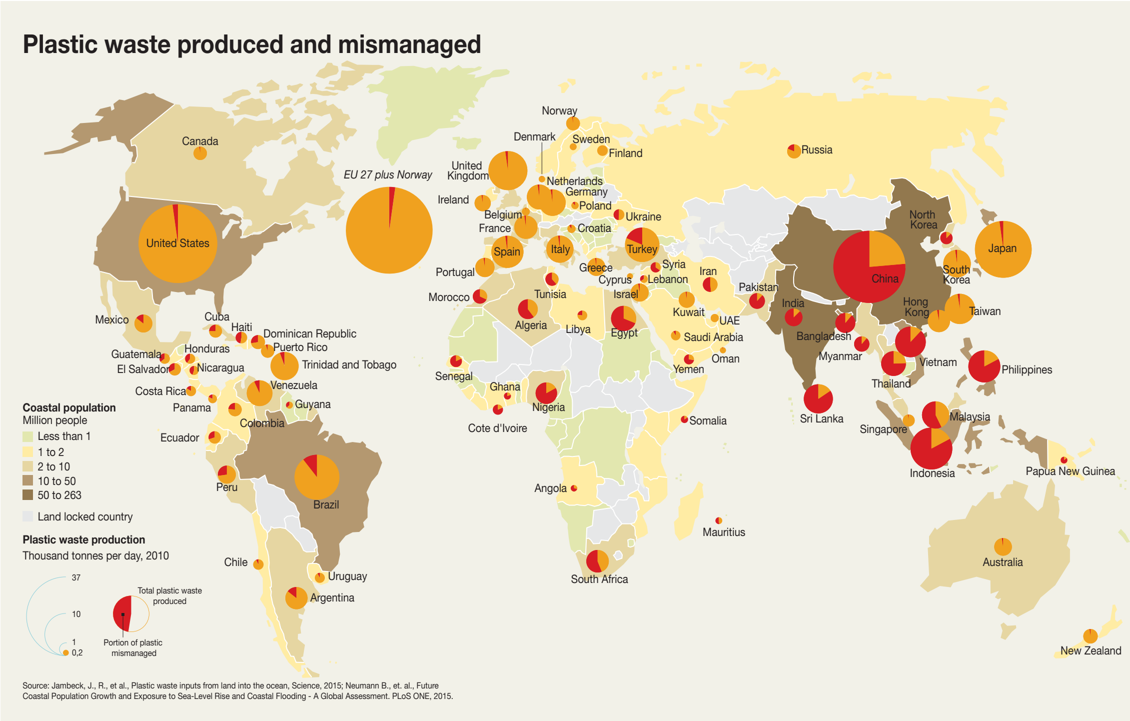
Jambeck et al. (2015) estimated that 16 of the top 20 contributors to plastic marine litter were from middle-income countries, where economic growth is rapidly occurring (Chapter 5.4). The top five countries (China, Indonesia, Philippines, Sri Lanka and Vietnam) accounted for more than 50% of 'mismanaged' plastics, on the basis of this analysis (Figure 5.12).

SIDS can face particular problems with managing waste related to: remoteness; small and sparse populations with limited potential economies of scale; a shortage of land for sanitary landfill; limited institutional and human resources capacity; and, the state and pace of economic and social development (Box 5.3). They can also be subject to tsunamis and other extreme events, leading to the potential for increased inputs to the ocean.

Figure 5.11

Distribution of the 50 largest dumpsites (D-Waste 2014)

Figure 5.12



Plastic waste produced and mismanaged. Taken from Marine Litter Vital Graphics (in preparation)

Box 5.3

WASTE MANAGEMENT IN PACIFIC SIDS

The Secretariat for the Pacific Regional Environment Programme (SPREP) has overseen a number of initiatives to improve waste management, and helped to develop the Pacific Regional Waste Management Strategy 2010-2012. This was adopted at the 20th SPREP meeting (Samoa) on 18 November 2009 by: American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, France, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, New Zealand, Niue, Northern Mariana Islands, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tuvalu, United States of America, Vanuatu, Wallis and Futuna.

www.sprep.org

Figure 5.13

Kroo Bay slum, Sierra Leone, where debris is used to reclaim land for building makeshift homes ©United Nations/OCHA/IRIN/Nicholas Reader

Waste and informal land reclamation

In some coastal regions, such as Sierra Leone, vehicle tyres and other debris have been used to reclaim land, where land for housing is in short supply or too expensive. The Kroo Bay slum in Freetown, on the coast, is adjacent to two rivers and floods frequently (Figure 5.13). According to the IRIN news agency 'Kroo Bay…is a squalid slum so littered with rubbish that the paths are made of compressed plastic, cans and toothpaste tubes, and patches of bare orange earth are a rare sight…the average life expectancy is 35 years'[30]. Clearly the slum is the source of plastics to the ocean. This experience is far removed from that of many of those investigating the impacts of marine litter and seeking potential solutions. But it does illustrate the reality of the lives of many people, in which concern for litter may come a long way down their list of priorities.

Coastal tourism

Coastal tourism represents a major source of litter in many regions, with major 'hot spots' including the Mediterranean, greater Caribbean, South-east Asia and several SIDS. Casual recreational use near urban conurbations adds to the problem. Coastal littering causes social, economic and ecological impacts. The problem is exacerbated by poor waste management, a lack of resources in some regions and a disconnect between those benefitting from the activity (e.g. tourists, restaurant owners, tour operators) and those having to deal with the consequences (e.g. local communities). Catering for tourists in SIDS can lead to the importation of very large quantities of food and other consumer goods, with the accompanying packaging creating a huge challenge for effective waste management.

30 http://www.irinnews.org/report/79358/sierra-leone-rampant-disease-washes-in-with-flood-water

5.8

ESTIMATING SEA-BASED INPUTS OF MARINE PLASTICS AND MICROPLASTICS TO THE OCEAN – A REGIONAL PERSPECTIVE

Shipping

Globalisation and the growth in shipping

Shipping represents a continuing source of marine litter, both due to accidental release (collisions, storm damage) and illegal disposal of plastics at sea, in breach of Annex V of the MARPOL Convention. Shipping accounts for approximately 90% of global trade. The introduction of containerised cargo handling in the 1960s brought about a step-change increase in the efficiency and decrease in the cost of shipping goods. The change was pioneered on busy routes between North America and Europe, where the high capital investment was offset by a reduction in high labour costs, and gradually spread to developing economies, especially in Asia (Figure 5.14). There has been a tendency to increase capacity by building larger vessels. There has been a great expansion of trade in manufactured goods from Asia to Europe and North America, a significant fraction being composed of plastics, with most being transported by container vessels.

Shoreline surveys adjacent to busy shipping routes (Figure 5.14), such as the southern North Sea approaching Rotterdam, reveal a higher proportion of shipping-related debris (van Franeker 2010). Some of this material may be casually thrown overboard, but some arises from accidental losses.

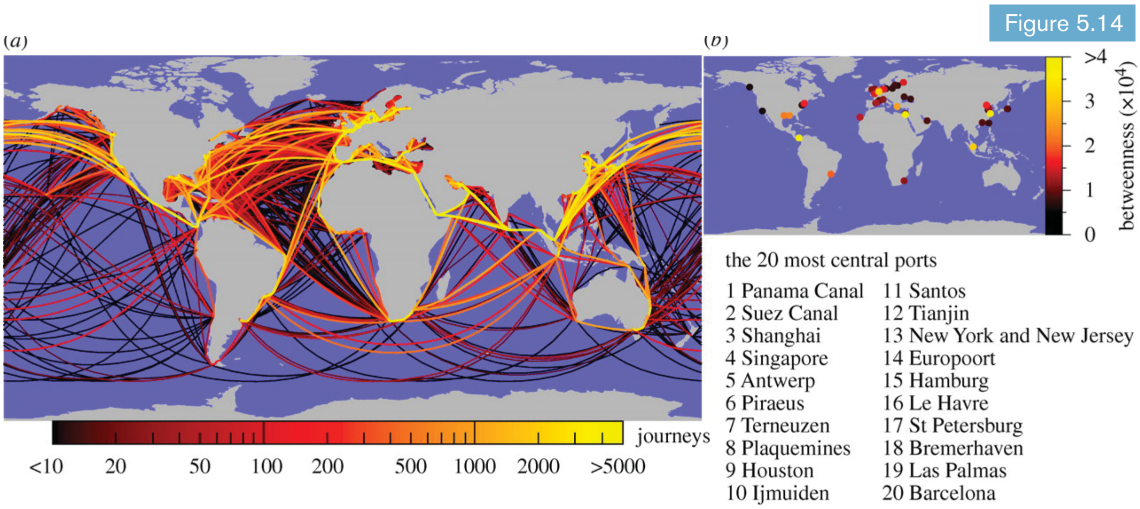
The number of containers lost each year is disputed, but was reported by the World Shipping Council (2014)[31] to be approximately 550 per annum on average, not counting catastrophic losses (regarded as losses of > 50 containers in one incident). In 2011 there was the grounding of the M/V Rena off New Zealand (Figure 5.18; 900 containers) and in 2013 there was the complete loss of the MOL Comfort in the Indian Ocean (4 293 containers).

The impact of major accidental losses can be significant locally (Figure 5.15). On a lighter note, many incidents have been reported in the media of familiar items being washed up on shorelines; for example, Nike™ training shoes (west coast of North America, Ebbesmeyer and Sciano 2009), bath toys including plastic ducks (Hohn 2011) and pieces of Lego™ (SW England[32]). The pattern of shipping accidents roughly correlates with shipping traffic density, with the top five regions for accidents being the seas of east Asia (Korea, Japan, eastern China), the seas of southeast Asia, the eastern and western Mediterranean and the waters of the Bay of Biscay and NW European shelf seas (Butt et al. 2011).

31 http://www.worldshipping.org/industry-issues/safety/Containers_Lost_at_Sea_-_2014_Update_Final_for_Dist.pdf

32 http://www.bbc.co.uk/news/magazine-28367198, accessed 1 February 2016

Figure 5.14



Global shipping density (Kaluza et al 2010)

Figure 5.14

Loss of containers in shipping accidents:
a) Containers fall from the deck of damaged cargo ship MSC Chitra in the Arabian Sea off the Mumbai coast August 9, 2010 (Reuters/Danish Siddiqui);
b) People look at cargo shed from the ship MSC Napoli at Branscombe, on the southern English coast, January 2007 (Reuters/Luke MacGregor

Figure 5.16

Pre-production PP pellets washed ashore in Hong Kong, following a shipping accident in 2012 (Reuters/SiuChiu)

Microplastics

Shipping accidents have also resulted in the introduction of microplastics directly into the ocean. Probably the best-known incident was the loss of six shipping containers from a freighter off Hong Kong, during Typhoon Vincente in July 2013. It is thought that 150 tonnes of pre-production PP pellets were lost initially, with many washing up on local beaches[33]. This initiated a remarkable clean-up campaign, largely based on volunteers. It is thought about 70% of the lost pellets were recovered.

Disposal of sewage sludge and dredged sediments
The disposal of sewage sludge and dredged sediment is permitted under MARPOL Annex V, subject to certain conditions. Sewage sludge is likely to contain plastic fragments, fibres and particles that were not removed during initial treatment. In one Swedish study it was concluded that >99% of microplastics entering the wastewater treatment plant were retained in sludge Magnusson and Norén 2014). Sewage sludge is often used as an agricultural fertiliser and a method using the presence of synthetic fibres has been proposed as an indicator that sludge has been applied (Zubris and Richards 2005). The quantities involved will depend partly on the upstream management of waste streams, the shape, size and density of the particles, and the existence and sophistication of wastewater treatment.

Maintenance dredging is an essential activity to allow ports to function and provide safe passage for shipping. Currently there are no guidelines on the composition of material considered suitable for sea disposal that include the plastic content. A report on the topic

33 http://plasticfreeseas.org/plastic-pellets.html

has been prepared[34] and is being considered by the Scientific Group of the LC and LP (March 2016). Although little information is available on the plastic content of dredged sediment, high levels of plastics, including plastic pellets and fibres, have been reported in shoreline and harbour sediments (Browne et al. 2010, Claessens et al. 2011). Although it is not possible to provide accurate figures on the input of plastic via this route, it can be surmised that the quantities will vary dependent on factors such as shipping intensity, coastal population density and the degree of coastal industrialisation.

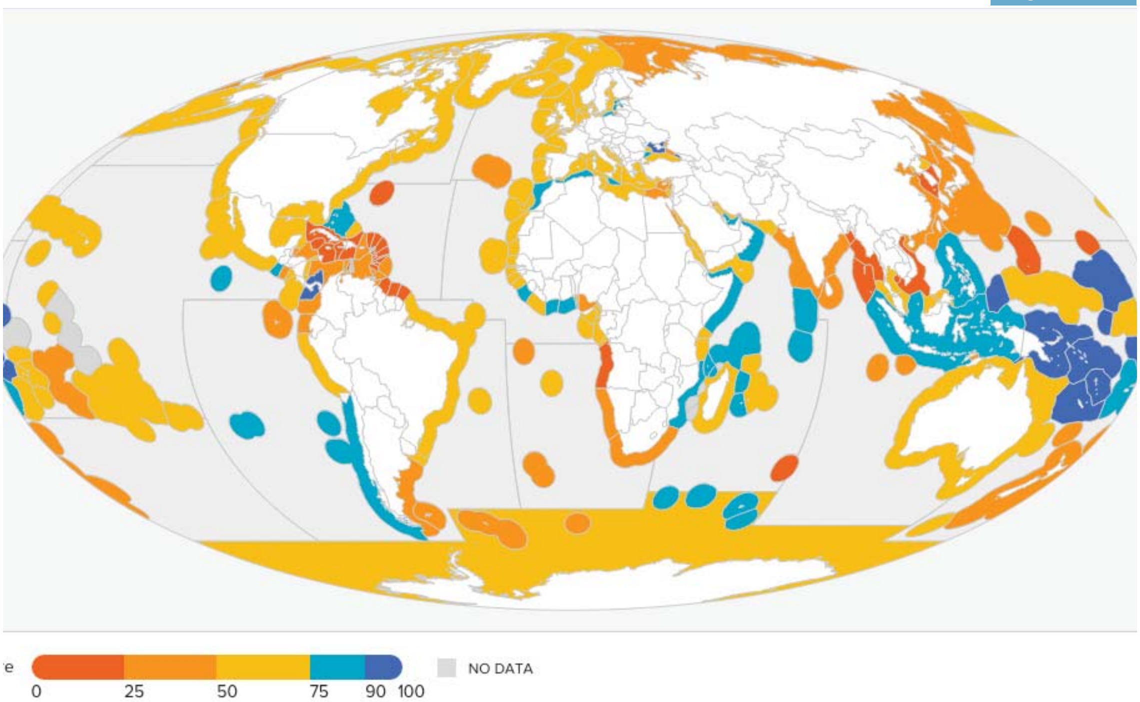
Fisheries

Wild fish capture is an important source of high quality protein in many regions, but in particular in Southeast Asia and Pacific SIDS, parts of the Indian Ocean, Northern and Western Africa, the Caribbean and Chile (Figure 5.17).

Macfadyen et al. (2009) provided a summary of estimates of ALDFG losses in different regions (Table 5.6). Clearly it is a global problem, but the incidence is likely to be influenced by a number of regionally dependent factors, such as: the type of gear, the education level of the crew, inefficient fishing methods, gear conflicts with other fishers and maritime users, the value of the catch compared with the cost of the net and the extent of IUU fishing (Gilman 2015). A new study covering ALDFG from marine gillnet and trammel net fisheries describes methods to estimate ghost fishing mortality and synthesizes estimates of mortality rates (Gilman et al. in press). This study also assesses related measures of regional fisheries bodies and arrangements for monitoring and managing ALDFG and ghost fishing.

34 IMO LC/SG 39/8/1 Annex

Figure 5.17



Regional food provision by wild fisheries capture, displayed as a relative scale by EEZ (oceanhealthindex)

Table 5.7

Examples of gear loss /abandonment/discard indicators from around the world

Region	Fishery/gear type	Indicator of gear loss (data source)
Atlantic Ocean		
North Sea & NE Atlantic	Bottom-set gill nets	0.02-0.09% nets lost per boat per year (EC contract FAIR-PL98-4338 (2003))
English Channel & North Sea (France)	Gill nets	0.2% (sole & plaice) to 2.11% (sea bass) nets lost per boat per year (EC contract FAIR-PL98-4338 (2003))
Baltic Sea (Poland & Lithuania)	Set nets	1 630 set nets lost in 2009 (Szulc 2013)
NW Atlantic	Newfoundland cod gill net fishery	5,000 nets per year (Breen, 1990)
	Canadian Atlantic gill net fisheries	2% nets lost per boat per year (Chopin et a., 1995)
	Gulf of St. Lawrence snow crab	792 traps per year
	New England lobster fishery	20-30% traps lost per boat per year (Smolowitz, 1978)
	Chesapeake Bay	Up to 30% traps lost per boat per year (NOAA Chesapeake Bay Office, 2007)
Caribbean	Guadeloupe trap fishery	20,000 traps lost per year, mainly in the hurricane season (Burke & Maidens, 2004)
Mediterranean		
Mediterranean	Gill nets	0.05% (inshore hake) to 3.2% (sea bream) nets lost per boat per year (EC contract FAIR-PL98-4338 (2003))
Indian Ocean		
Indian Ocean	Maldives tuna longline	3% loss of hooks/set (Anderson & Waheed, 1988)
Gulf of Aden	Traps	c. 20% lost per boat per year (Al-Masroori, 2002)
ROPME Sea Area (UAE)	Traps	260,000 lost per year in 2002 (Gary Morgan, personal communication, 2007)

Pacific Ocean		
NE Pacific	Bristol Bay king crab trap fishery	7,000 – 31,000 traps lost in the fishery per year (Stevens, 1996; Paul et al, 1994; Kruse & Kimker, 1993)
Australia (Queensland)	Blue swimmer crab trap fishery	35 traps lost per boat per year (McKauge, undated)
Southern Ocean		
Southern Ocean	Toothfish longline	0.02-0.06% hooks lost per longline set per year (Webber and Parker 2012)

Global statistics for lost fishing gear (adapted from Butterworth et al. 2012; original data Macfadyen 2009; additional data Szulc 2013, E. Grilly CCAMLR pers. comm., January 2016)

A comprehensive analysis of floating macro-debris (> 200 mm diameter) revealed that 20% by number and 70% by weight was fishing–related, principally floats/buoys (Eriksen et al. 2014, Chapter 6.2). This was based on 4 291 visual observations from 891 sampling locations in the North and South Pacific, North and South Atlantic, Indian Ocean, Bay of Bengal, Mediterranean Sea and coastal waters of Australia.

Fishing-related debris is also common in the Southern Ocean and is consistently the most frequent category of litter associated with wandering albatross colonies (CCAMLR 2015).

70% by weight of floating macroplastic debris, in the open ocean, is fishing-related

(Eriksen et al. 2014)

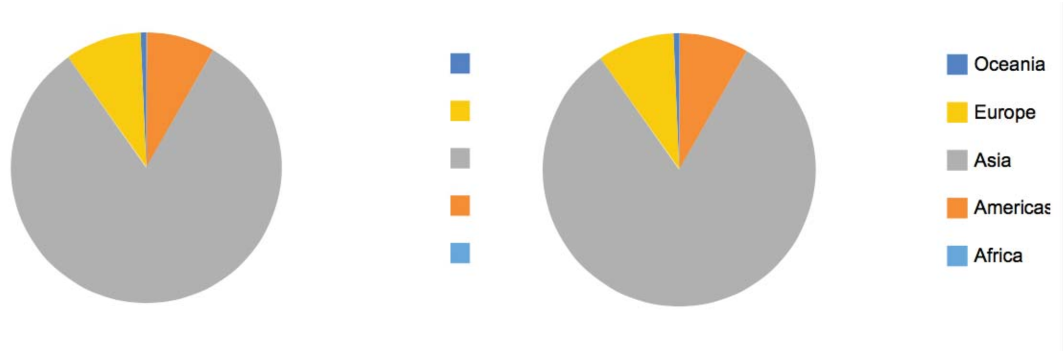
Photo: © Sustainable Coastlines

Aquaculture

Geographically Asian countries have been highlighted in terms of both production and consumption of cultured food (Figures 5.19). China is the number one producer among them (FAO, 2014 #86). Mussel culture is common in North America, southern Chile and the Atlantic coast of Europe. Oysters are cultured extensively in Asia, North America and parts of Europe. Scallop culture is concentrated in subtropical regions, and clam culture is common in many parts of Asia and North America. Shrimp cultures are most extensive in estuarine environments of tropical and subtropical regions. Fish culture is common in Canada, NW Europe and southern Chile. Aquaculture provides an important source of protein in many countries (Figure 5.18).

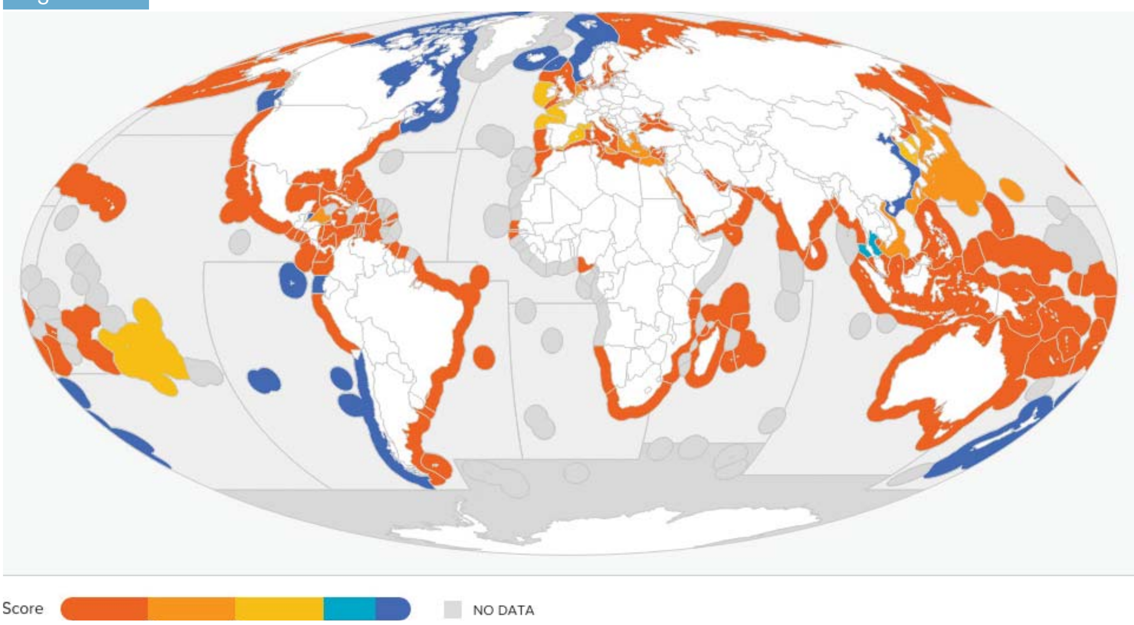
The quantities of equipment lost generally have not been quantified. Regional differences may be expected due to the type of culture, the selection of designs and materials, and exposure to adverse conditions. For example, EPS buoys are used extensively in some regions of Asia for the hanging culture of mussels and oysters. Loss and damage is particularly intense following the passage of tropical storms (Chapter 6.2, Lee et al. 2014).

Figure 5.18



Global aquaculture production by continent (left) and by country within Asia (right) (FAO data)

Figure 5.19



Regional food provision by marine aquaculture, displayed as a relative scale by EEZ (oceanhealthindex)

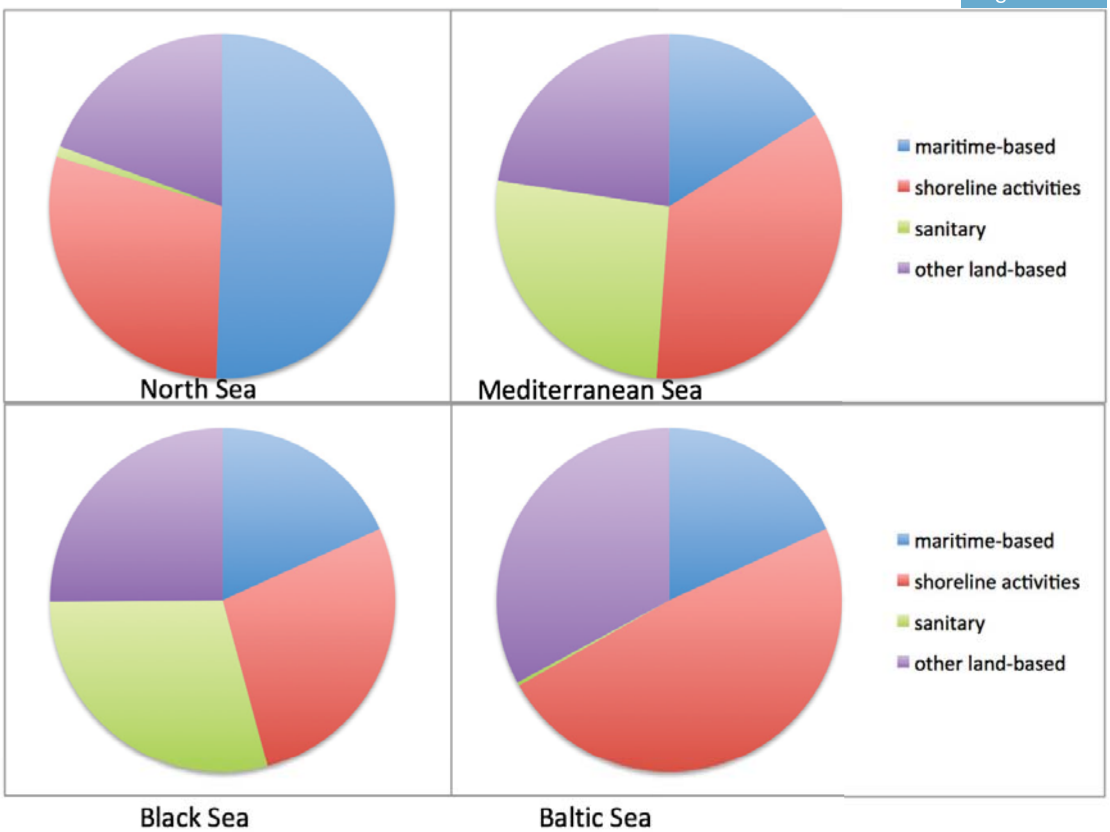
5.9

REGIONAL CASE STUDY – RELATIVE CONTRIBUTIONS OF DIFFERENT SOURCES

It is sometimes possible to gain an indication of the source of marine litter by carefully examining the type of material encountered in surveys. Beach surveys offer an opportunity to investigate spatial and temporal trends in a relatively cost-effective manner, provided harmonised sampling and analysis techniques are adhered to. In a pilot study commissioned by the EC, four shoreline locations were selected for a careful examination of the probable origin (i.e. sector) of marine litter items, one in each of Europe's four marginal seas (ARCADIS 2012): i) Oostende (Belgium) – North Sea; ii) Constanta (Romania) – Black Sea; iii) Riga (Latvia) – Baltic Sea; and, iv) Barcelona (Spain) – Western Mediterranean (Figure 5.20, Table 5.7).

Details of the methodology for site selection and data collection and analysis are provided by ARCADIS (2012). The study included stakeholder workshops and the development of potential measures to close loopholes in the 'plastic cycle'.

Figure 5.20



Probable source of marine litter items from shoreline surveys at four pilot sites: Oostende, North Sea; Constanta, Black Sea; Riga, Baltic Sea; and Barcelona, Western Mediterranean (adapted from ARCADIS 2012)

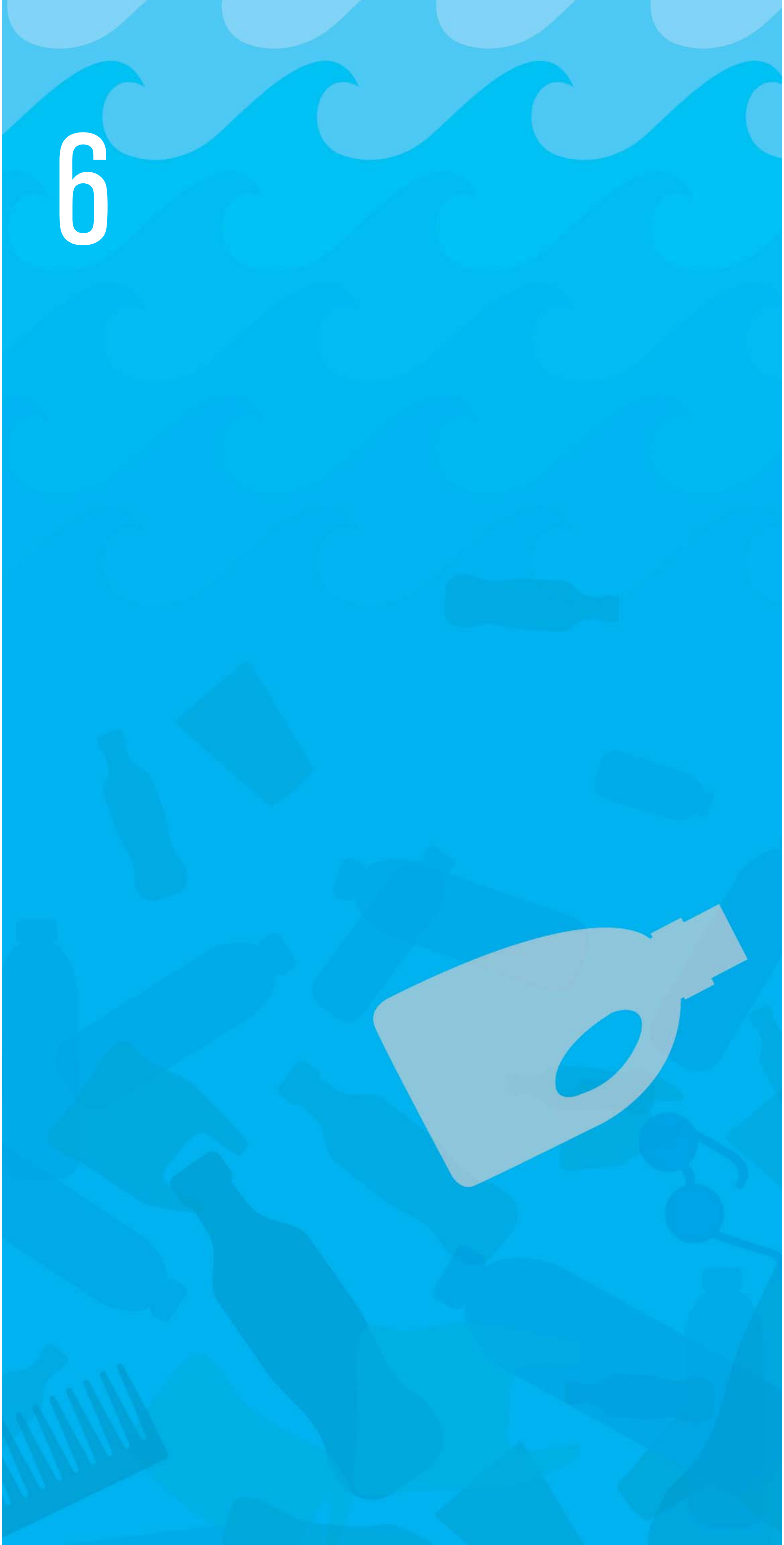
Table 5.8

Broad sector category*	Oostende North Sea	Constanta Black Sea	Riga Baltic Sea	Barcelona Mediterranean
Maritime-based	50.51	18.2	18.18	16.08
Shoreline-based	29.11	48.58	27.69	35.09
Land-based	20.36	33.23	54.4	48.82

Table 5.7 Sources of shoreline marine litter from four pilot locations, grouped by major source categories
*** maritime based = fishing, shipping, ports, recreational boating, aquaculture and other activities**
shoreline-based = coastal/beach tourism and recreational fishing
land-based = sanitary, general household, waste collection and transport, construction and demolition, other industrial activities, agriculture and dump sites/landfill

The results showed some clear contrasts. About 50% of litter at Oostende was thought most likely to have come from maritime-based sectors, with a further 29% from shoreline-based activities. In contrast, maritime-related sectors account for 16 – 18% at the three other sites. Both Riga and Barcelona had significant quantities of sanitary (toilet) waste, showing the inadequacy of wastewater treatment in these cities. Constanta alone had large quantities (46%) of litter from recreational fishing. This was a pilot study and it would be inappropriate to extrapolate the results from one location to a whole sea area or region. However, the study did illustrate that significant differences in the sources of litter do occur, requiring different approaches to bring about reductions (Chapter 9).

6



6. DISTRIBUTION AND FATE

6.1

MARINE COMPARTMENTS AND TRANSPORT PATHWAYS

Ocean circulation

The circulation of the surface waters of the ocean are characterised by a broad pattern of persistent surface currents (Figure 6.1). These tend to dominate the passive transport of any floating objects. The ocean circulation is driven by the complex interaction of atmospheric forcing (winds), the Coriolis force due to the Earth's rotation, density differences (temperature and salinity) and deep-water formation in the Arctic and sub-Arctic seas and Southern Ocean (Thermo-Haline circulation due to the sinking of cold, dense water, produced through the formation of freshwater ice) (Lozier 2015). In coastal regions river outflows will influence currents at a more local scale. Within these broad patterns the circulation is highly complex and variable, on multiple scales in space (mm – 100s km) and time (s – decades) (Figure 6.2). This will have a significant influence on the distribution of floating plastics, providing an explanation for some of the spatial and temporal variability in concentrations that have been observed. The water column is not uniform in temperature and salinity. The upper few metres of the ocean will be mixed by wave action episodically. Attempts to measure and interpret the distribution and abundance of floating plastics in the surface ocean need to be placed in the context of this natural variability.

Transfer between compartments

The ocean can be divided into five compartments: coastline, surface/upper ocean, the main water column, the seabed and biota (Figure 6.3). Plastics occur in all five compartments, and there will be processes acting both within and between compartments which will affect the fate and distribution of the plastic material. Plastics that are inherently buoyant (e.g. PE) can be expected to remain in the upper ocean, unless there is a change in density, for example by the attachment and growth of sessile organisms. The degree to which this may occur is unknown. Other

Figure 6.1

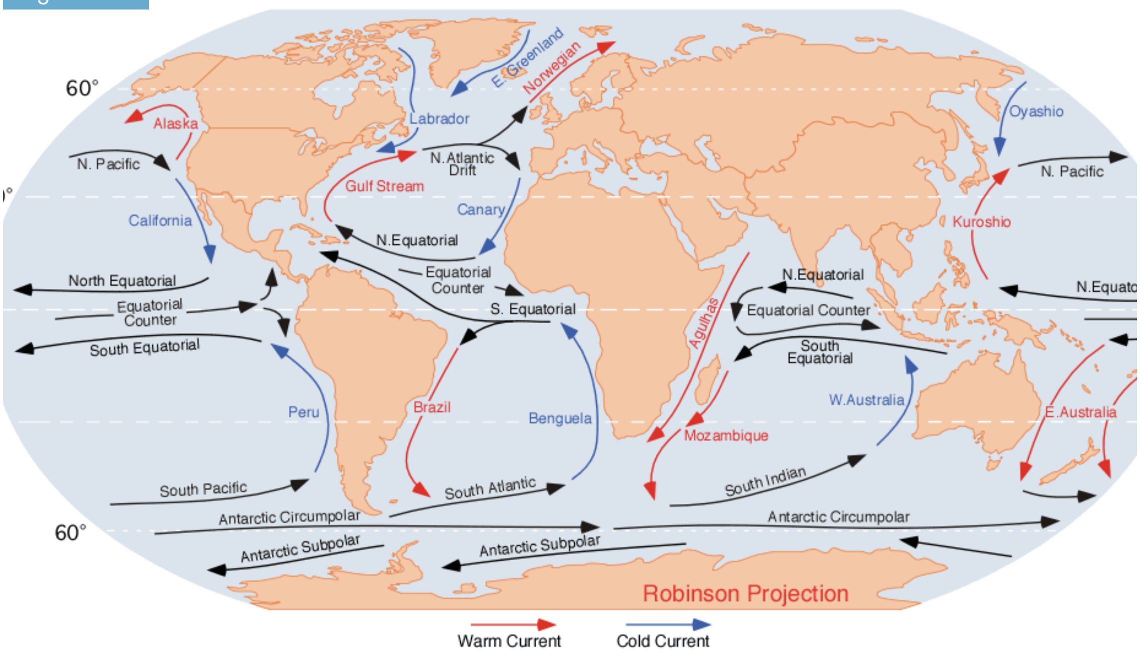


Figure 6.1 Surface ocean circulation, showing main currents and the location of the sub-tropical gyres in the North and South Pacific, Indian, and North and South Atlantic Oceans, and the Norwegian Current transporting material from the NE Atlantic to the Arctic (image courtesy of Dr. Michael Pidwirny (see http://www.physicalgeography.net) [http://skyblue.utb.edu/paullgj/geog3333/lectures/oceancurrents-1.gif original image], Public Domain.

Figure 6.3

Mesoscale eddies - false colour image of ocean water colour, from NASA's Aqua MODIS satellite, showing the complexity of the surface ocean circulation, which will influence the distribution of floating plastics. Image courtesy of NASA-GSFC. The circular blue in the middle left is approximately 100km in diameter[35].

plastics are denser than water so may be expected to occur on shorelines and the seabed. This difference in physical properties clearly will have a considerable influence on both the observed and modelled distributions (Chapter 6.2). Plastics of all types may be found in the biota compartment.

The degree of transfer of plastics between these compartments is largely unknown. Transfer of material on and off shorelines is likely to be considerable in some regions but often episodic, in response to wave action, wind and rainfall events, the proximity of sea- and land-based sources and the exposure of the coastline. Non-buoyant plastic objects (e.g. fishing nets) that are supported by buoyant objects (e.g. fishing floats) will continue to float in the water column or upper ocean until the buoyancy becomes ineffective, then will sink to the seabed. Transport from the near-shore environment to the deep seabed may be facilitated by the presence of canyons and debris slides (e.g. NW Mediterranean). Material may behave differently once fragmented. The relative importance of such transfers will be regionally dependent.

35 http://www.gfdl.noaa.gov/ocean-mesoscale-eddies

Figure 6.3

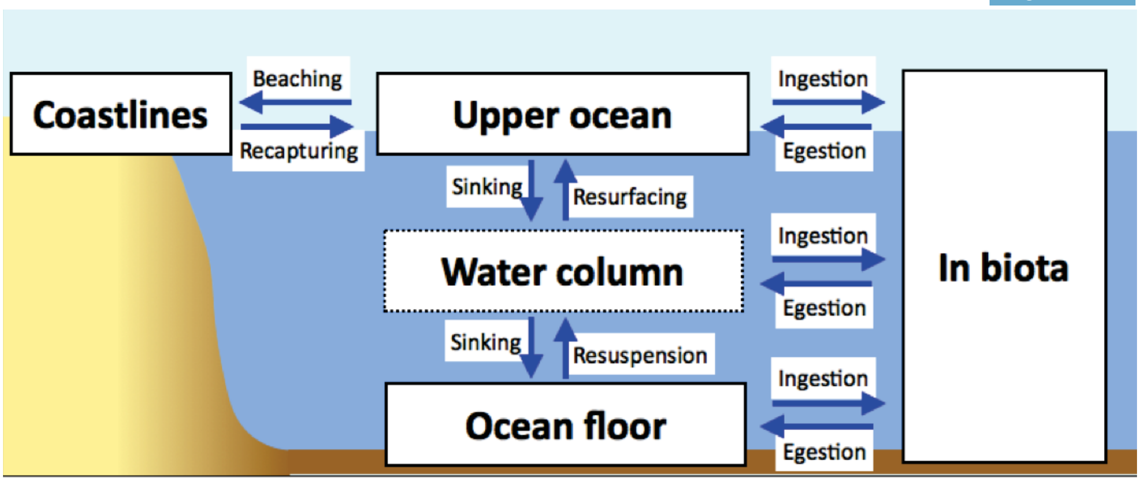


Figure 6.3 Overview of compartments and fluxes of marine plastics (figure based on a version by Erik van Sebille, taken from GESAMP 2016).

6.2

REGIONAL PATTERNS AND 'HOT SPOTS'

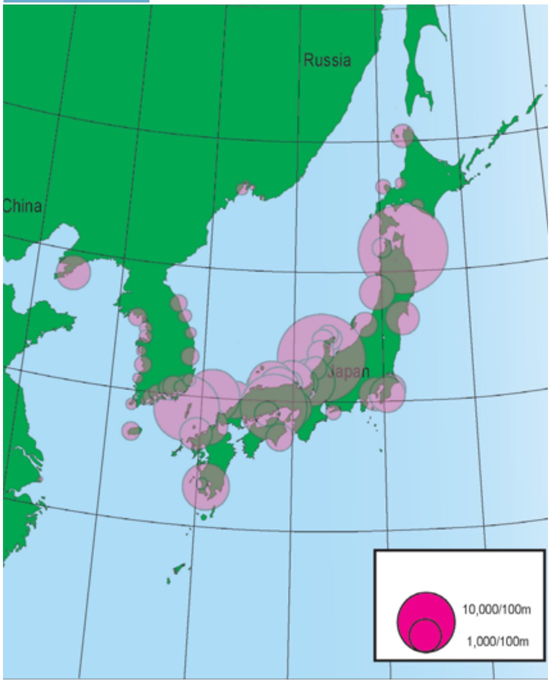
Shoreline and nearshore 'hot spots'

Macro and microplastics are found on shorelines throughout the world's oceans. The debris is a mixture of locally-derived material and debris that has been transported by wind and wave action and surface currents, sometimes for several thousand kilometres. A number of consistent patterns have emerged from routine beach surveys, including the significant increase in shoreline litter adjacent to urban centres and adjacent to nearshore shipping routes (Figure 6.4).

Data from the Ocean Conservancy annual international clean-up programme reveal the influence of tourism and beach use on the type and quantities of plastic litter found on the shoreline (Ocean Conservancy 2014). The International Coastal Clean-up (ICC) counts the number of items, rather than the quantity of litter (volume and mass) so provides a rather partial picture of the relative significance of different items. For example, no fishing-related plastics were recorded in the top ten items found most often (Table 6.1). However, it does represent one of the most comprehensive sets of data, recording relative distributions and trends on shorelines.

What remains uncertain is whether these local 'hot spots' (Figure 6.5) act as sources for longer-distance transport or more permanent accumulation zones. Undoubtedly, local oceanographic conditions will play a key role. In some cases, higher concentrations are due to the presence of poorly controlled or illegal waste dumps, sometimes immediately adjacent to the shoreline (D-Waste 2014).

Figure 6.4



Results of shoreline surveys in the NOWPAP region (units: number of items/100m shoreline) (NOWPAP CEARAC)

Table 6.1

Order	Description	Number	Order	Description	Number
1	Cigarette ends	2 248 065	6	Miscellaneous plastic bags	489 968
2	Food wrappers	1 376 133	7	Shopping bags	485 204
3	Plastic drinks bottles	988 965	8	Glass drinks bottles	396 121
4	Plastic bottle caps	811 871	9	Metal drinks cans	382 608
5	Straws & stirrers	519 911	10	Plastic cups & plates	376 479

Top ten items collected during the 2014 annual International Coastal Clean-up, covering approximately 22 000 km of coastline, with 561 895 volunteers in 91 countries, collecting 735 tonnes of debris (data taken from the Ocean Conservancy website).

Figure 6.5

Coastal community in Papua New Guinea, surveyed for litter in 2015 ©Sustainable Coastlines Papua New Guinea

Coastal debris surveys often report an increase in beach deposition of litter following tsunamis (Figure 6.6), storms or river basin flooding, (Frost and Cullen 1997; Gabrielides et al. 1991; Vauk and Shrey 1987) further supporting the importance of local contributions to marine litter.

Coastal waters and Large Marine Ecosystems

Coastal waters in many regions can be expected to have higher concentrations of marine plastics being the receiving body for land-based plastics and the zone where fisheries, aquaculture, commercial shipping and other maritime activities are concentrated. 'Hot spots' of floating plastic have been observed in coastal waters adjacent to countries with high coastal populations and inadequate waste management in South–east Asia (Peter Ryan 2013). The Strait of Malacca has a combination of high shipping densities, fisheries and coastal population densities. Large quantities of floating plastic debris have been observed several tens of kilometres off the coast (Figure 6.7; Ryan 2013).

The Mediterranean experiences high volumes of shipping, has high coastal populations and a very well developed tourist industry. It also has a very restricted exchange with the Atlantic. The high levels observed of floating, shoreline and seabed plastics are not unexpected. In the western Mediterranean the continental shelf is very narrow, with submarine canyons extending from close to the shore into deep water. These have the function of channelling waste deposited in coastal waters, directly or via river inflows, leading to significant 'hot spots' of plastics both in the canyons and on the deep seafloor (Galgani et al. 1996, 2000).

Long-distance transport of floating litter and mid-ocean hot spots

Reports of floating plastic fragments in open ocean waters started to appear in the peer-reviewed scientific literature in the early 1970s (Carpenter et al. 1972). Such observations were made as an addition to the prime purpose of the study, which was usually concerned with either the dynamics of plankton or with fisheries research. In contrast, sampling for plastic occurrence in some open ocean regions, such as the

Figure 6.6

Debris from Japan, resulting from the 2011 tsunami, on the west coast of North America (NOAA Marine Debris Program, courtesy of Kevin Head)

Figure 6.7

Plastic debris in surface waters of the Strait of Malacca (images courtesy of Peter Ryan)

Indian Ocean, South Pacific and South Atlantic, has only taken place relatively recently (Ericksen et al. 2014, Ryan 2014).

Long-distance transport of floating plastics occurs by a combination of ocean circulation and winds (for larger objects). The surface circulation has been well defined in terms of the overall circulation patterns and relative transport rates. A feature of all the major ocean basins (North Pacific, South Pacific, North Atlantic, South Atlantic and Indian Oceans) is the formation of sub-tropical gyres, regions of slower currents where material tends to collect and stay for some time. Many studies have now confirmed that the gyres are characterised by relatively high concentrations of floating plastic (Figure 6.8). The term 'The Great Pacific garbage patch' was coined for the North Pacific sub-tropical gyre. This description is rather misleading, but it has entered the public lexicon (Box 6.1). Although the overall accumulation patterns are quite consistent there are very large variations in concentration at smaller scales (Law et al. 2014), due to the complexity of ocean dynamics and interactions with the wind.

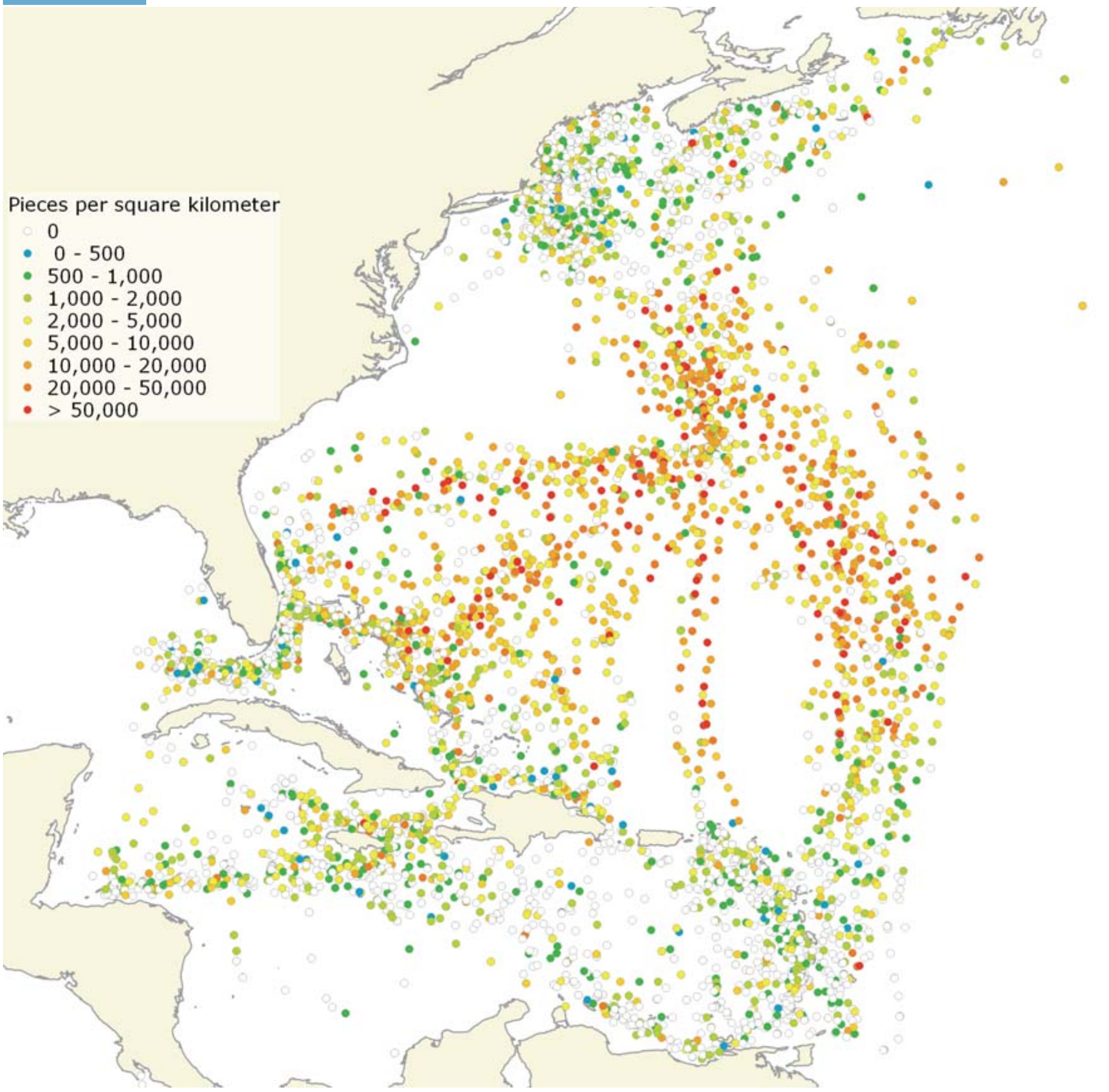
Box 6.1

'THE GREAT PACIFIC GARBAGE PATCH'

This term was coined following the discovery of an 'accumulation zone' of floating plastic debris in the North Pacific in the late 1990s. It became widely used in the media and by advocacy groups to raise awareness of what had been a poorly recognised phenomenon. Unfortunately, use of the term also generated a misconception on the part of the public as to what the 'garbage patch' consisted of, with visions of large piles of floating debris forming an 'island', variously described as being 'the size of Texas' or other popular unit of area, and assumed to be visible from space.

In reality most of the plastic debris is too small to be seen easily from the deck of a ship, and has to be sampled by towing a fine-mesh net (e.g. 330 µm). Concentrations are often presented as numbers per unit area of sea. Although the number of particles may be recorded as over 200 000 km-2 (e.g. Law et al. 2010), that equates to less than one microplastic particle m-2. Larger items do occur but much less frequently, and they are subject additionally to wind forcing and so may have different transport rates and pathways, often being blown ashore. The phenomenon is not unique to the North Pacific and has been described for the five main sub-tropical gyres, where small free-floating objects will tend to converge (Figure 6.1). Generally, material is quite dispersed, but with very significant variations in concentration in space and time, due to the differing scales of ocean circulation and turbulent mixing by waves. Microplastics also occur in the surface ocean outside the gyres, although in lower concentrations

Figure 6.8



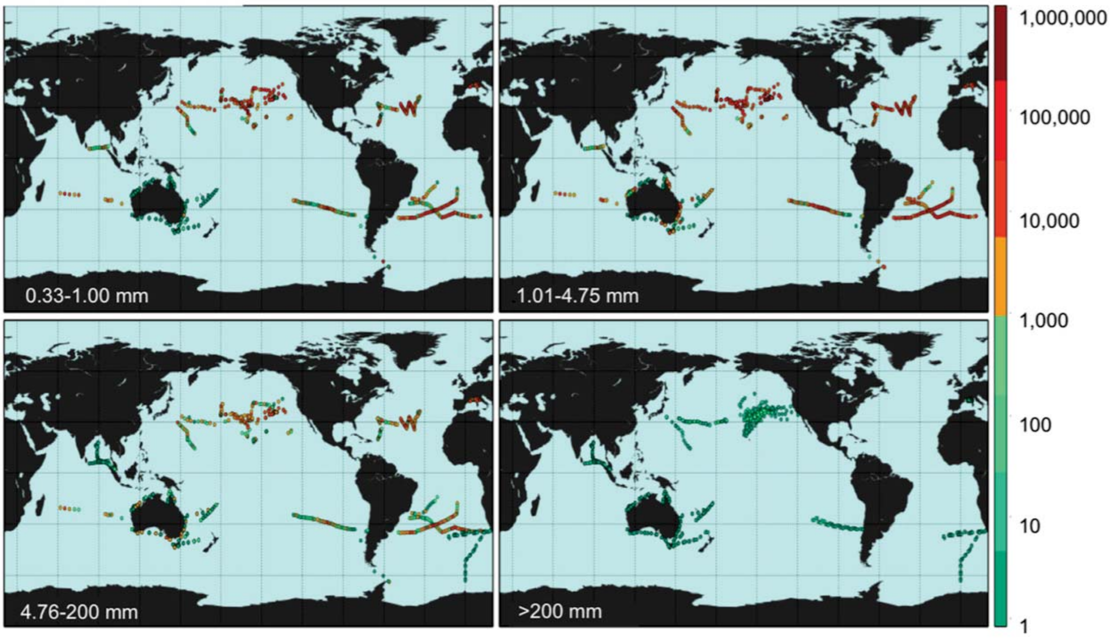
Western North Atlantic sub-tropical gyre showing elevated concentrations of microplastics (pieces km-2) at each sampling site from a 20-year data set; described by Law et al. 2010 and re-plotted by IOC-UNESCO.

Ericksen et al. (2014) have produced the most comprehensive collation of available data on macro and microplastic distribution so far, using both towed nets (usually using a 330-micron mesh) and direct observations of larger items to produce the first global representation of our current knowledge of the distribution of floating plastic, based on observations (Figure 6.9, Table 6.2). The data set comprised 1571 sampling locations from 24 expeditions (2007-2013). These covered the five ocean gyres in the North Pacific, South Pacific, South Atlantic, North Atlantic and Indian Ocean, the Mediterranean Sea, Bay of Bengal and coastal waters of Australia, combining surface net tows (n=680) and visual surveys of large plastic debris (n=891).

It is interesting to note that fishing-related debris accounted for 20% of the total by number but 70% by weight, with floats/buoys predominating. Such items are a common component of shoreline debris in mid-ocean islands. These data have formed the basis of a modelling study to estimate the total quantities the sampling represents (see below). In some cases, it is possible to prove the provenance of the fishing gear from gear marking. For example, debris from the Oregon Dungeness Crab fishery has been found washed up in Hawaii (Ebbesmeyer et al. 2012).

Buoyant plastics will tend to float at the sea surface during calm conditions. However, wave action can mix the water column, and smaller items of plastic, to

Figure 6.9



The distribution of floating plastics (pieces km-2) in four size categories (0.33 – 1.00 mm, 1.01 – 4.75 mm, 4.76 – 200 mm and >200 mm) based on either net tows or visual observations at 1 571 sampling locations (from Ericksen et al. 2014)

Table 6.2

Category	Subcategory	Items	% count	% weight
Plastic fishing gear	Buoy	319	7.4	58.3
	Line	369	8.6	11.1
	Net	102	2.4	0.9
	Other fishing gear	70	1.6	0.1
Other plastics	Bucket	180	4.2	15.0
	Bottle	791	18.4	4.9
	Foamed polystyrene	1 116	26.0	8.0
	Plastic bag/film	420	9.8	0.8
	Misc. plastic	924	21.5	0.8
Total		4 291	100	100

Categories of large floating plastic debris (> 200 mm) based on observations by visual surveys of 4 291 items in the North Pacific, South Pacific, South Atlantic, North Atlantic, Indian Ocean, Bay of Bengal, Mediterranean Sea and coastal waters of Australia (Eriksen et al. 2014).

depths of several meters (Lattin et al. 2004, Lusher et al. 2015, Reisser et al. 2015). This introduces some uncertainty into some of the observations of smaller plastics collected with towed nets. This phenomenon has been studied using both modelling (Kukulka et al. 2012) and observations with vertically stacked trawl nets (Reisser et al. 2015). The sea state will also affect the reliability of direct observations of larger items. Both problems can be addressed provided sampling protocols are designed with this in mind (Chapter 11).

Utilizing modelling techniques to simulate the distribution of macro and microplastics

Model simulations provide a useful interpretation of the distribution and relative abundance of floating plastics, filling in gaps in the distribution in the absence of observations, allowing investigation of the relative importance of different processes and testing scenarios. Ocean circulation models are based on a very good understanding of ocean physics and are validated with robust scientific data (e.g. satellite observations, oceanographic measurements of temperature and salinity, current meter arrays, neutrally-buoyant floats). However, all models are based on sets of assumptions, the structure and complexity of the model and the state of knowledge of the system that is being investigated. Modelling the ocean in three dimensions (i.e. including multiple depth layers) is challenging computationally. A model will always be a simplification of reality, which is both an advantage and a disadvantage. When considering the use of models it is worth remembering the adage: 'All models are wrong, but some are useful' (Box 1976)

> **'All models are wrong, but some are useful'**
>
> **(Box 1976)**

A fundamental weakness with many global-scale current modelling approaches is that they do not account for several important factors:

a) **non-buoyant plastics**
b) **fragmentation**
c) **vertical transport** to the seabed
d) **other environmental reservoirs** (biota, seabed, water column, shoreline)
e) **sea-based sources** such as fisheries and aquaculture
f) **land-based sources** such as coastal tourism

Such weaknesses do not invalidate the usefulness of the modelling approach, but do introduce large uncertainties into the results, something which is readily admitted by the modelling community (e.g. van Sebille et al. 2015).

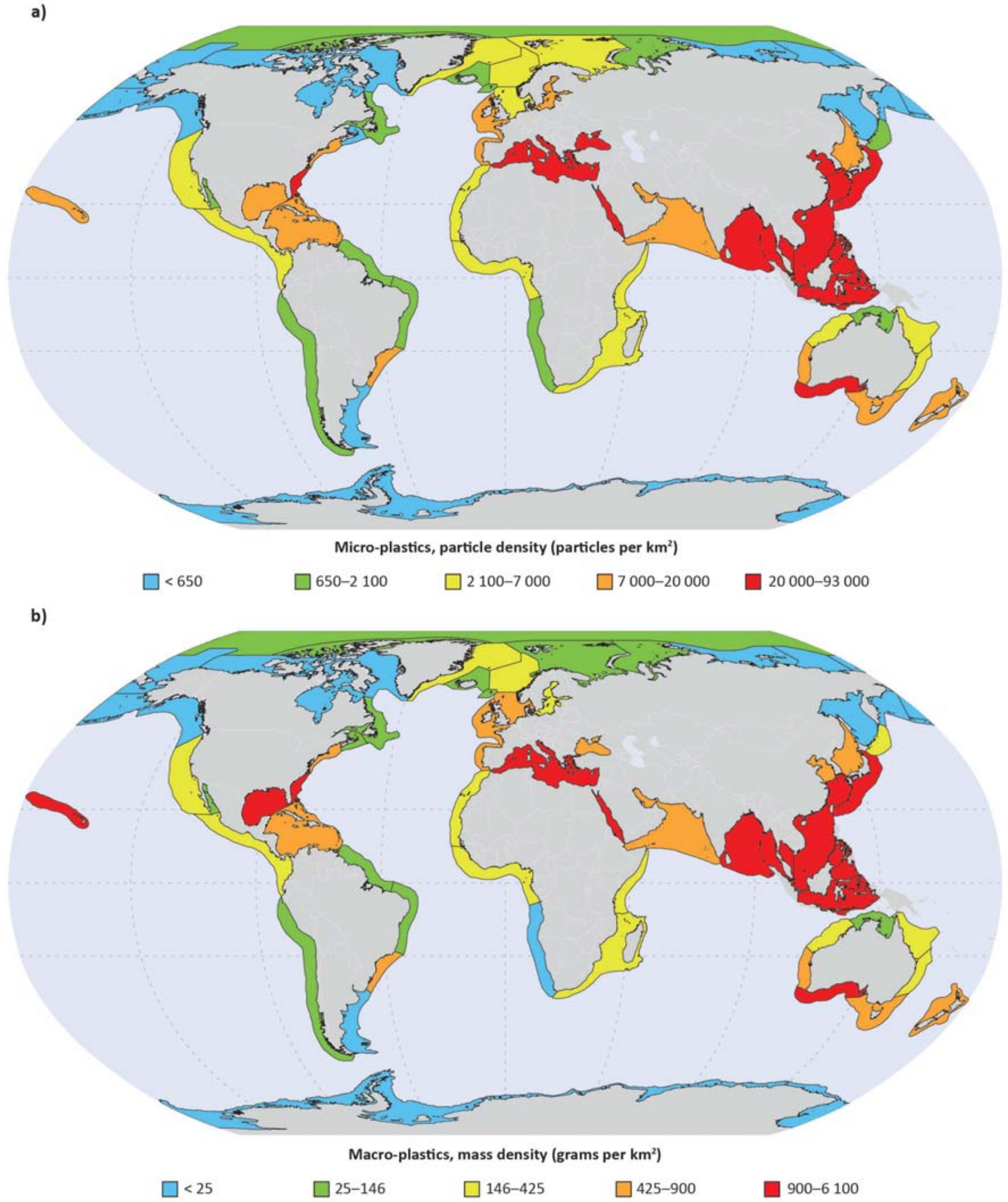
Modelling the influence of different sources

Modelling can provide a means to investigate the relative importance of different sources, where more accurate data is absent. Lebreton et al. (2012) used this approach to generate the relative contribution of floating plastics from three sources, based on proxy indicators: coastal population density, proportion of urbanised catchment (i.e. liable to more rapid run-off) and shipping density. The authors simulated the resultant distribution of plastics in coastal and open ocean waters using an ocean circulation model, into which particles could be introduced in proportion to the three indicators. The distributions were spatially resolved to fit the outlines of the 64 Large Marine Ecosystems (LME) and then placed in five categories of relative abundance. Figure 6.10 shows the distribution of microplastics by LME, with concentrations varying from highest to lowest in the order red-orange-yellow-green-blue.[36] Highest concentrations occurred in SE Asia, around the Korean peninsula, the Bay of Bengal and the Mediterranean. This is consistent with the available observations.

A second modelling study (UNEP 2016b) simulated the distribution of floating plastic based on the estimated influx of plastic due to inadequate waste treatment, as defined by Jambeck et al. (2015). Figure 6.11 shows the simulated distribution of floating plastics originating from countries in SE Asia, indicating significant transboundarytransport across the Bay of Bengal.

36 This study was a contribution to the GEF Transboundary Waters Assessment Programme (IOC-UNESCO and UNEP 2016; www.geftwap.org).

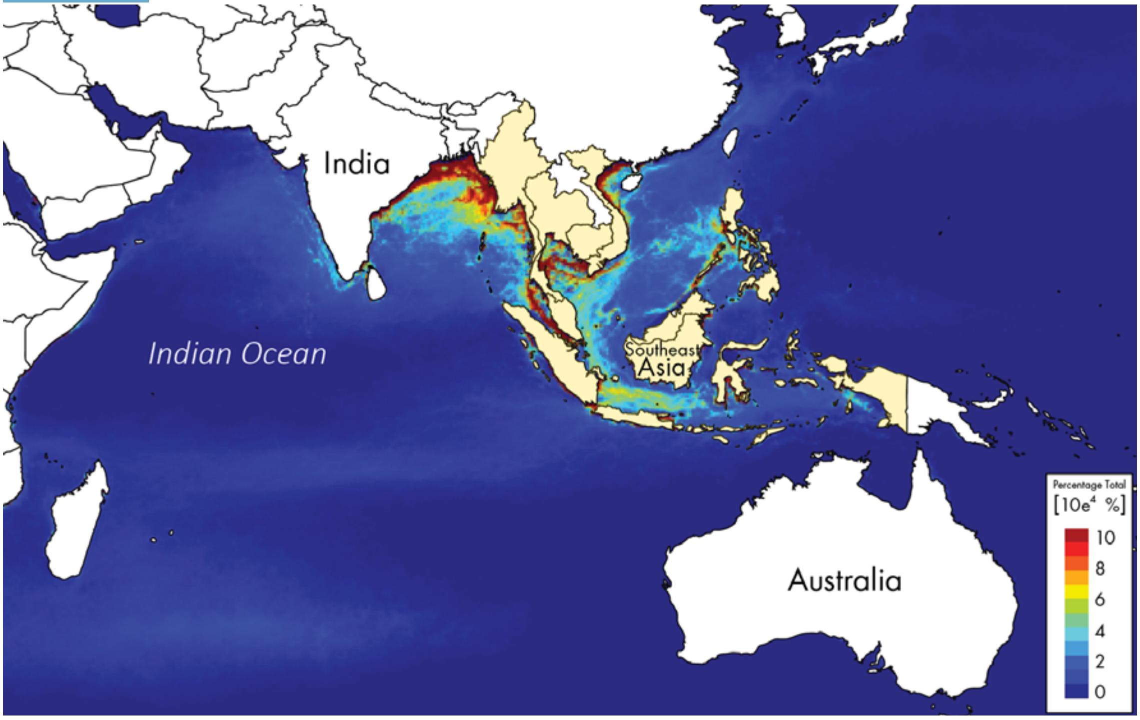
Figure 6.10



LMEs were separated into five categories of relative abundance, based on model estimates using proxy sources; based on Eriksen *et al.* (2014) and Lebreton *et al.* (2012).

Estimated relative distribution of microplastic abundance in 64 Large Marine Ecosystems, based on Lebreton et al. 2012. Inputs of plastic 'particles' in the model were based on three proxy indicators of probable sources: coastal population density, proportion of urbanised watershed and shipping density. Concentrations were divided into five equal-sized categories of relative concentration, varying from highest to lowest in the order red-orange-yellow-green-blue. (IOC-UNESCO and UNEP 2016)

Figure 6.11



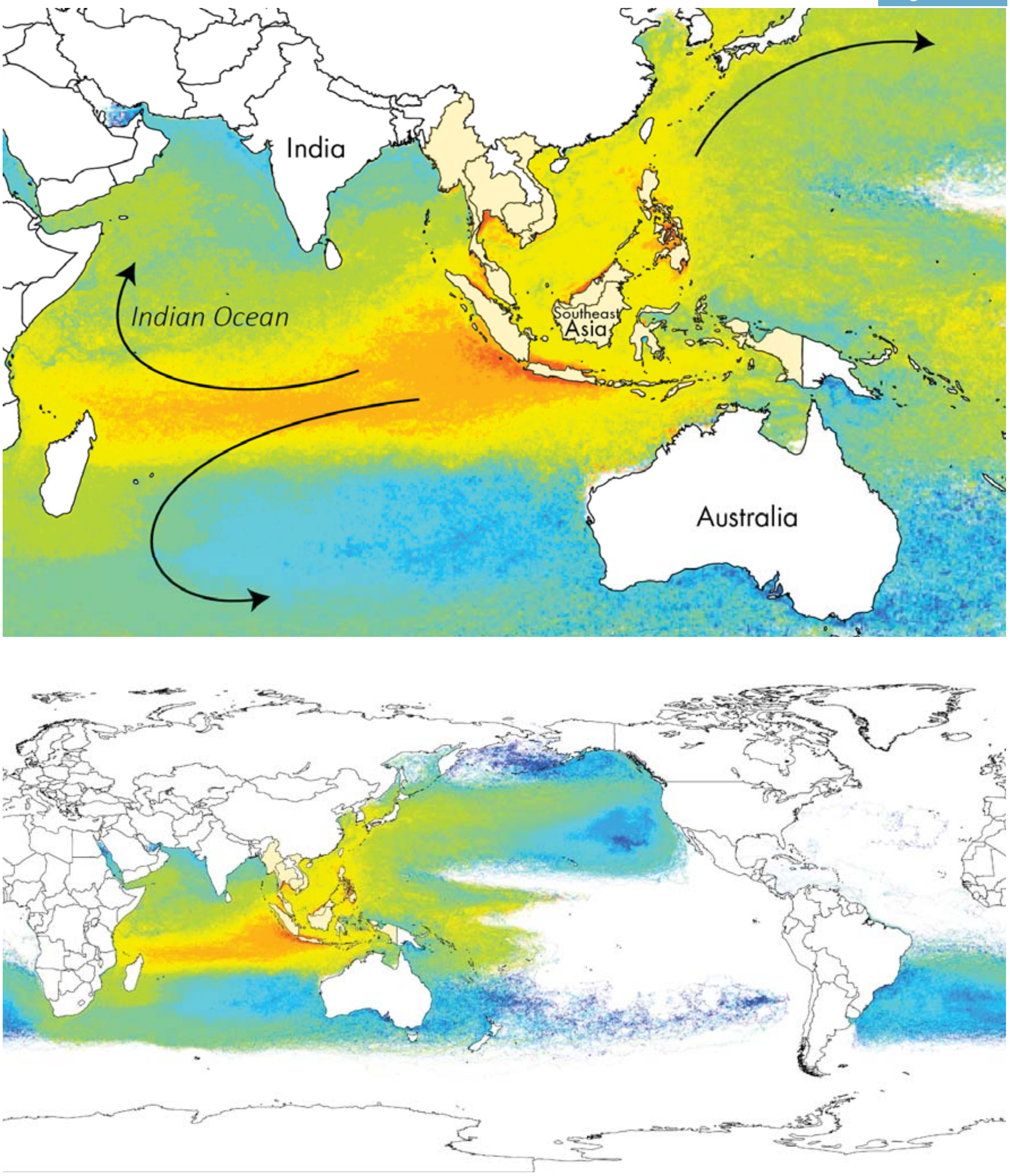
Simulated distribution of floating plastic. Showing high concentrations in coastal waters, using as the source term the estimated influx of plastics from SE Asia due to 'mismanaged waste' (based on Jambeck et al. 2015), from 2004-2014 (from UNEP 2016b)

Modelling transport times

It can be difficult to assign how long plastic debris has been in the ocean and where it has come from, but models can be very useful in indicating probable transport pathways and the average time taken from source to sampling site (Lebreton et al. 2012, Maximenko et al. 2012, UNEP 2016b, van Sebille et al. 2015); Figure 6.12).

These estimates can be compared with the results of other investigations into the pathways and transport times of other passive water-borne tracers (e.g. radiotracers, CFCs). For example, several studies have modelled the transfer pathways and transport times of caesium (134Cs, 137Cs), technetium (99Tc) and other radionuclides discharged from nuclear reprocessing sites in the NE Atlantic, with subsequent transport to the Arctic (Karcher et al. 2004). The accident at the Fukushima Daiichi nuclear plant in Japan, in 2011, provided another opportunity to examine transport of surface and mid-waters in the North Pacific on the basis of measurements of dissolved 134Cs and 137Cs.

Figure 6.12



Simulation of the transport of particles originating in South East Asia showing the relative age of particles (1994-2014) in the Indian and Pacific Oceans (top) and globally (bottom). Red indicates 1 year and dark blue 10 years from release (from UNEP 2016b).

Estimating ocean plastic budgets

Despite the increasing number of sampling expeditions, the total number of observations of floating macro and micro-plastics is rather small, and large areas of the ocean have not been sampled at all, particular in the Arctic, South Pacific, Indian Ocean and the Southern Ocean. It is possible to generate budgets of ocean plastics on the basis of model simulations, but these need to be validated by observational data. Eriksen et al. (2014) collated data on the number and mass of floating plastic particles/items from 24 expeditions (2007 – 2013, Figures 6.13 and 6.14). These covered the five ocean gyres, the Mediterranean, Bay of Bengal and coastal waters of Australia, combining surface net tows (n=680) and visual surveys of large plastic debris (n=891). The data were used to calibrate an ocean circulation and particle-tracking model (HYCOM/NCODA, Cummings 2005) which was then used to estimate budgets of floating macro and microplastics.

Using the validated model, it was estimated that the total number of floating plastic pieces, in the four size categories, was 5.25 trillion (5.25 x 1012), with a mass of 268 940 tonnes.

A recent analysis of the performance of three models of floating plastic distribution, which can be considered the state of the art, revealed similar overall patterns in predicted abundance, but significant differences in many regions of the ocean (van Sebille et al. 2015). This illustrates the difficulty in providing accurate predictions of the distribution and quantities of floating plastics. From this study, van Sebille et al. (2015) estimated the total number of floating microplastics (i.e. excluding macroplastics) to be 15 – 51 trillion (1.5 – 5.1 x 1013) pieces, weighing 93 – 236 thousand tonnes.

A recent study estimated the total number of floating macro and microplastic pieces in the open ocean to be 5.25 trillion, weighing 269 000 tonnes

(Eriksen et al. 2014)

Modelling different types of plastic

Most model simulations of plastic particle transport have been applicable to floating plastic only. This is appropriate for plastic objects with entrapped air, such as a fishing float, or for particles and fragments of some polymers such as PE, PP or EPS. However, many other common polymers are denser than seawater so will tend to sink (Chapter 4.2). The behaviour of different types of microplastic particle has been investigated within the European research project MICRO (van der Meulen et al. 2015)[37]. The Delft 3D model[38] was utilised to model the distribution of particles with densities equivalent to the polymers PE (0.91), PS (1.05) and PET (1.40). The model was configured to represent the southern North Sea and English Channel (Figure 6.15), with particles being introduced with major river inputs (Box 6.3). The particles were assumed to be spherical. There was a very clear difference between the behaviour of PE and PET. PE particles were restricted to surface waters and occurred in greatest concentration in a broad band extending from coast of France, Belgium, Netherlands, Germany and Denmark. PET particles were absent from the surface but prevalent in bottom waters, with higher concentrations in a restricted zone close to the coast and in a tongue extending north east from the coast of East Anglia, in eastern England. The region has a vigorous tidal- and wind-driven circulation and the water depth is quite shallow, so bottom transport of sediment is common. The PS particles, being closer to the density of seawater, showed features of both the PE and PET particle distributions.

Future developments

Despite their current shortcomings, models can provide extremely useful insights and help to expose knowledge gaps and focus future research needs. They also provide a means of testing scenarios, such as the likely outcome of implementing litter reduction measures. But current models cannot supply, on their own, a realistic estimate of the total current standing stock of plastic in the ocean, including plastic on the seabed. Allowing for additional sources will be relatively easy to simulate, given sufficient input data, but issues of vertical transport and particle fragmentation will be much more challenging.

37 http://www.ilvo.vlaanderen.be/micro/EN/Home/tabid/6572/Default.aspx

38 http://oss.deltares.nl/web/delft3d

Figure 6.13

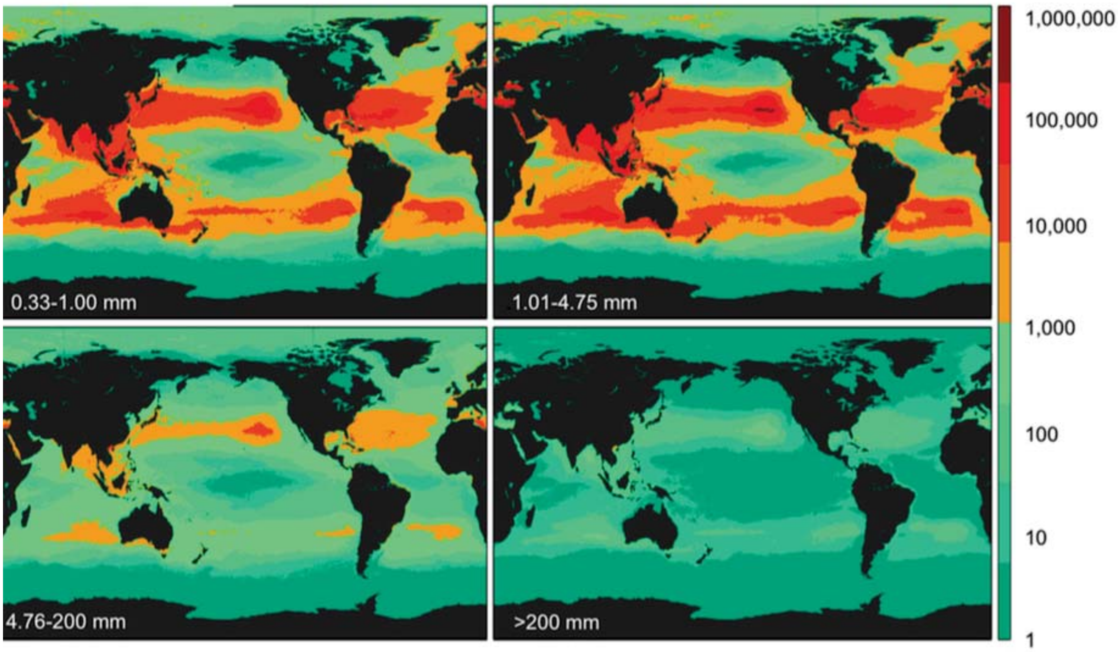


Figure 6.13 Model prediction of the distribution by global count (pieces km-2, see colour scale bar) of particles/items for each of four size classes: 0.33 – 1.00 mm, 1.01 – 4.75 mm, 4.75 – 200 mm, and >200 mm (Eriksen et al. 2014)

Figure 6.14

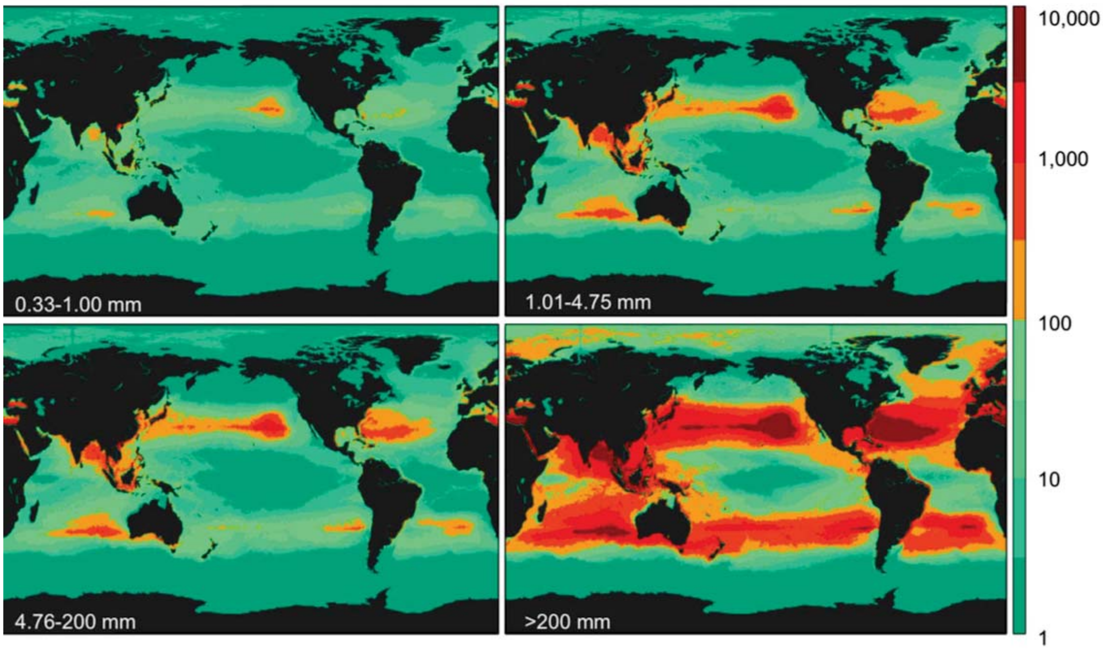
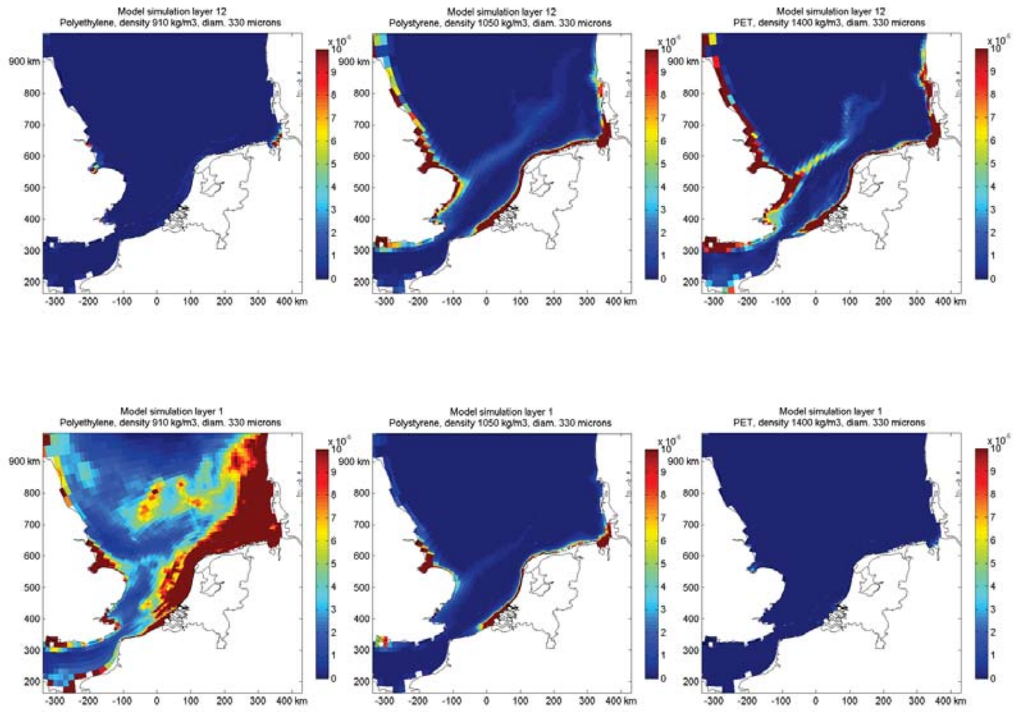


Figure 6.14 Model prediction of the distribution by weight density (g kg-1, see colour scale bar) of particles/items for each of four size classes: 0.33 – 1.00 mm, 1.01 – 4.75 mm, 4.75 – 200 mm, and >200 mm (Eriksen et al. 2014)

Figure 6.15



Model simulations (Delft-3D) of plastic particle transport in the southern North Sea and the English Channel, for spherical 330 µm diameter particles with densities of 0.91 (PE), 1.05 (PS) and 1.40 (PET), showing the mean concentration distribution in model layer 1 (surface waters) and layer 12 (bottom waters), using particle inputs from rivers (Box 6.x). Conducted as part of the EU MICRO project[1]. (images taken from van der Meulen et al. 2015, numerical modelling by Ghada El Serafy, Dana Stuparu, Frank Kleissen, Dick Vethaak and Myra van der Meulen, Deltares)

SIDS and mid-ocean island hot spots

Mid-ocean islands are generally characterised as having low population densities and low levels of industrial development. This would suggest a low generation of waste compared with many mainland centres although, in some cases, tourism does increase the generation of waste. Unfortunately, many mid-ocean islands, such as Easter Island and Midway Atoll, receive a disproportionate burden of plastic marine litter as a result of long distance transport by surface currents. The Hawaiian Islands lie on the southern edge of the North Pacific sub-tropical gyre and are particularly susceptible to receiving floating debris. ALDFG is a particular problem in the Northwestern Hawaii Islands (Papahānaumokuākea Marine National Monument) (Figure 6.16). The impact of this is described in Chapter 7 and the programme to remove ALDFG in Chapter 11. Samples from isolated beaches in the outer Hawaiian Islands contained around 1.2 kg of plastic fragments m^{-3} sediment (McDermid and McMullen 2004). This is similar to patterns found on Easter Island, which adjoins the higher concentrations found in the sub-tropical gyres in the southern Pacific (Hidalgo-Ruz and Thiel 2013).

Some SIDS fall into the category of mid-ocean islands, others occur closer to continental margins and may be subject to a greater range and quantity of plastics, generated internally, transported from nearby countries or resulting from maritime activities such as fisheries or tourism. For example, SIDS in the Caribbean are dependent on tourism for economic development but bear a disproportionate burden in dealing with the waste from the cruise ship sector.

Table 6.3

Countries served by the catchment	River	% input
UK	Dee	1.1
	Tay	4.2
	Earn	0.7
	Forth	1.9
	Tweed	1.9
	Tyne	1.7
	Tees	1.2
	Humber	8.3
	Ouse	2.1
	Yare	1.8
	Thames	3.1
	Stour	0.4
France	Seine	10.4
France, Belgium, Netherlands	Scheldt	3.2
Switzerland, Lichtenstein, Austria, Germany, France, Netherlands	Rhine	33.9
Germany	Weser	9.3
Poland, Czech Republic, Austria, Germany	Elbe	14.7
	Total	100

Percentage river contributions of particles used in the Delft 3D model simulation in the English Channel and North Sea

Figure 6.16a

Figure 6.16b

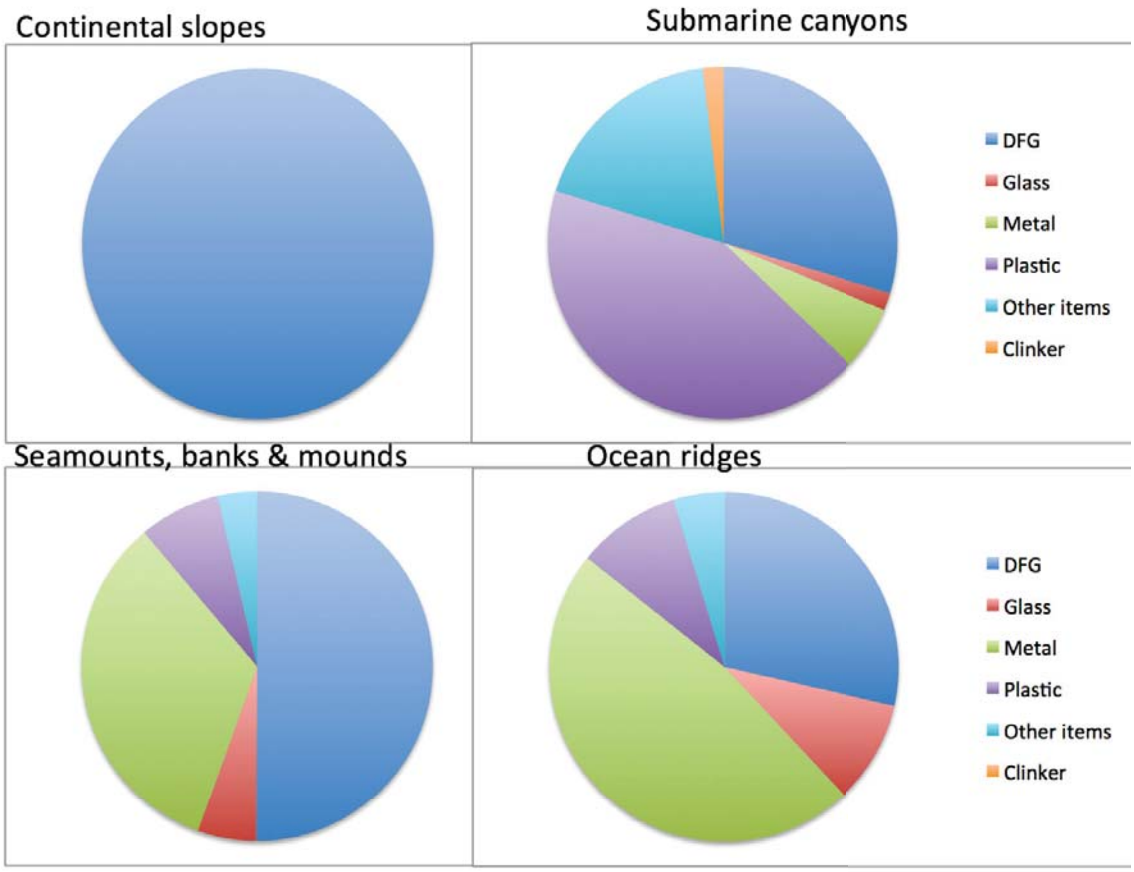
Plastic accumulation on mid-ocean islands in the North Pacific: a)Hawaiian monk seal hauled out on derelict fishing gear on Lisianski Island in the Northwestern Hawaiian Islands. (image: NOAA Marine Debris Program); b) Miscellaneous debris washed ashore on Laysan Island in the Hawaiian Islands National Wildlife Refuge in Papahanaumokuakea marine national monument (image: Susan White, US Fish & Wildlife Service).

Waste is an important and growing issue for many SIDS. This is due to a range of internal and external influences. Most waste collected is disposed of in sanitary landfill rather than being recycled (UNEP 2012). But, in the absence of adequate and disposal facilities, waste is often disposed of casually by burial, burning or discarding into the surrounding land or sea, Population growth, urbanisation, changing consumption patterns and increasing numbers of tourists are all contributory factors (UNEP 2014a). It has been argued that a lack of appreciation of the need for a proper waste management strategy is damaging the environment and compromising the viability of some communities, with the situation on some Pacific islands being described as 'a waste disaster' (Veoitayaki 2010).

Water column

Very few measurements have been reported of plastics in the water column beneath the top few meters of the surface ocean. There are two key factors involved: plastics will tend to float if buoyant and sink if non-buoyant in seawater; capturing sinking particles in the water column is resource intensive so the number of observations is limited, and these are usually made in relation to carbon cycling. The sinking rate will be determined by the relative density of the particle and its size and shape. Incorporation of plastic particles into faecal pellets may result in more rapid sedimentation rates. However, the vertical transport of particles is quite complex and may be multi-stage, with faecal pellets being re-used as an energy source by mid-water organisms.

Figure 6.17



Relative proportion of litter in six categories observed on the seabed of the North-east Atlantic and Mediterranean Sea (adapted and re-drawn from Pham et al. 2014).

Seabed

Plastics and microplastics have been reported in marine sediments worldwide (Claessens et al. 2011; Van Cauwenberghe et al. 2014 and 2015, Woodall et al. 2015) but the first report in subtidal sediments dates back to 2004 (Thompson et al. 2004). Deep sea sediments were demonstrated more recently to also accumulate microplastics (Van Cauwenberghe et al. 2014 and 2015, Woodall et al. 2015) with composition that appears different from surface waters as fibres were found at up to four orders of magnitude more abundant in deep-sea sediments from the Atlantic Ocean, Mediterranean Sea and Indian Ocean than in contaminated sea surface waters (Annex V; Woodall et al. 2015). Sediments are suggested to be a long-term sink for microplastics (Cozar et al. 2014, Eriksen et al. 2014, Woodall et al. 2015). Macroplastics have been observed on the seabed at many locations in the NE Atlantic and Mediterranean Sea (Pham et al. 2014).

Transport pathways near the deep sea floor will differ from those at the surface, and generally will be weaker. Predicting the most likely areas for accumulation will be more problematic. Submarine topographic features may also favour sedimentation and increase the retention of macro and microplastics at particular locations such as canyons and deeps or smaller scale structures (holes, rocks, geological barriers, etc.). For larger debris, the proximity of human activities is likely to be more influential. For example, relatively high levels of fishing-related debris were found on ocean ridges and seamounts, reflecting more intensive fishing efforts in those areas (Figure 6.17; Pham et al. 2014).

Deposition patterns will depend on many factors including the size and density of the plastic objects and particles, the water depth, the strength of surface and bottom currents, wave action, the seabed topography and the variation in the sources. For example, in the shallow Lagoon of Venice, microplastics were found to accumulate where the currents were weakest (Vianello et al. 2013). Higher concentrations of microplastics have been found in coastal regions and adjacent to harbours (Claessens et al., 2011, Bajt et al., 2015).

Hot spots related to fisheries and aquaculture

Case study – shellfish aquaculture in southern Korea
EPS buoys are used extensively in southern Korea for the hanging culture of mussels and oysters. Buoys are used at a density of 500-1000 Ha-1. It is estimated that approximately 1.8 million are discarded into the marine environment annually (Lee et al. 2014). Each 62-litre EPS buoy can generate 7.6 million micro-size EPS fragments of < 2.5 mm diameter, or 7.6 x 1021 nano particles of < 250 nm diameter. Consequently, EPS buoys and fragments were found to be the most common item, with EPS accounting for > 10% of marine debris on 94 Korean beaches in 2008 (Figure 6.18; Lee et al. 2014). A participatory process is underway to find solutions to this problem (Chapter 9).

Large quantities of fishing–related debris occur on the seabed in the same region of the South Sea of Korea (mean abundance 1 110 kg km-2), although the highest quantities of debris are found in harbours (Lee et al. 2006).

Figure 6.18a

Figure 6.18b

Figure 6.18c

Figure 6.18d

Large-scale mariculture for oysters in southern Korea, using ropes hanging from EPS buoys: a) typical configuration of buoys; b) beached EPS buoys following passage of a typhoon; c) EPS fragments floating in coastal waters; and d) EPS fragments on shoreline. (images: Jong Ho, OSEAN)

Case study – demersal fisheries in North Sea

A significant quantity of marine plastic debris results from maritime activities such as fisheries. In addition, many plastics are denser than water so will sink to the seabed once any trapped air is released. Fishing gear debris has been found to be widespread in areas such as the North-east Atlantic and Mediterranean (Pham et al. 2014). Conducting seabed surveys is much more resource intensive than sampling shorelines of the ocean surface. However, in many regulated demersal (bottom) fisheries there is a requirement to carry out regular trawl surveys to assess the state of the fish stocks. This provides an opportunity to record the type and quantity of litter collected incidentally as part of the survey (Figure 6.19). This practice is being encouraged as a cost-effective method for routine seabed monitoring on fishing grounds. Results to date indicate a relatively high proportion of fisheries-related litter.

Biota

Macro and microplastics have been found associated with a wide variety of organism, from small zooplankton to the largest whales, from worms burying in the seabed to seabirds feeding in the upper ocean (GESAMP 2015, 2016). A comprehensive dataset of laboratory- and field-based observations of meso- and microplastic particles and fragments, in a wide variety of organisms, has been compiled by GESAMP (GESAMP 2016) is reproduced in Annex VI. The size of this reservoir of plastic particles is unknown. In terms of the overall budget of marine plastics this compartment is rather small. Of more immediate concern is the potential physical and chemical impact due to ingestion or entanglement and this is discussed further in Chapter 7.

Figure 6.19

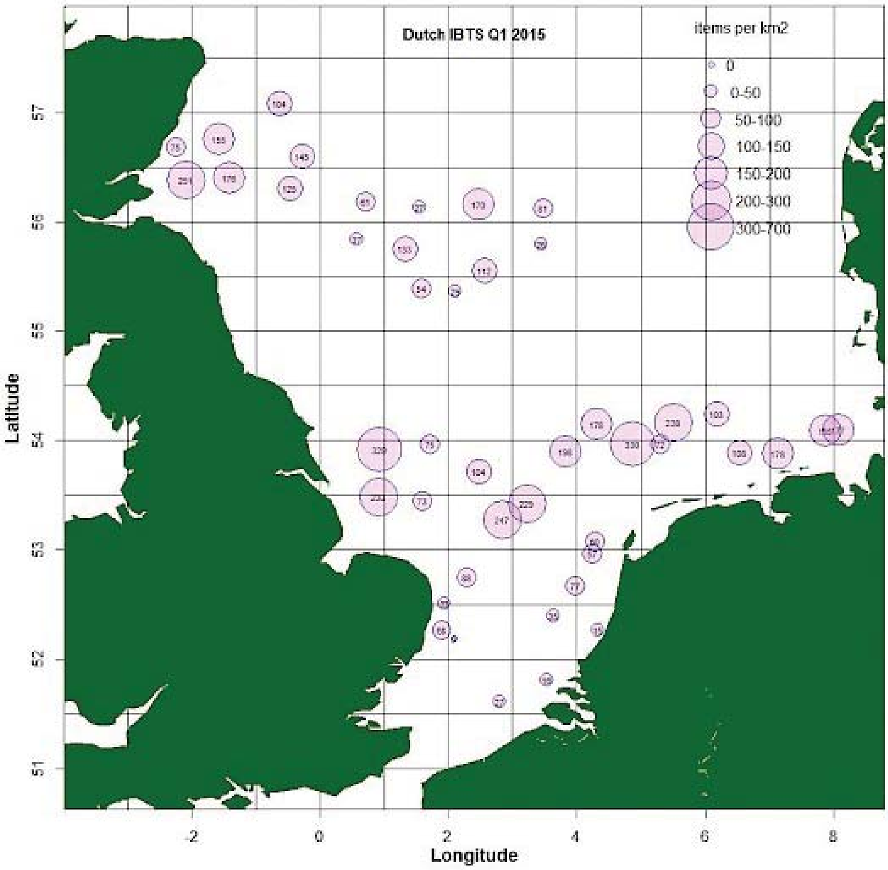


Figure 6.19 Seabed distribution of marine debris in the greater North Sea collected during a routine ground-fish survey by the Netherlands, for fisheries management purposes. Much of the debris found in this region can be attributed to fisheries (IMARES).

7

7. IMPACTS

7.1

ECOLOGICAL IMPACTS

Macroplastic debris and individual organisms

Entanglement
The impact of marine debris on individual animals is most obvious when dealing with entanglement in floating debris, very often but not exclusively related to fishing gear (Table 7.1). This is a global problem that affects all higher taxa to differing extents (Figures 7.1, 7.2). Incidents of entanglement have been widely reported for a variety of marine mammals, reptiles, birds and fish. In many cases this leads to acute and chronic injury or death (Moore et al. 2006, Allen et al. 2012, Butterworth et al. 2012, Waluda and Staniland 2013, Thevenon et al. 2014). Up to 50% of humpback whales in US waters show scarring from entanglement (Robbins et al. 2007). It is estimated that between 57 000 and 135 000 pinnipeds and baleen whales globally are entangled each year, in addition to the countless fish, seal, birds and turtles, affected by entanglement in ingestion of marine plastic (Annex VI; Butterworth at al 2012). Injury is both a welfare issue and a cause of increased mortality, for example in seals (Allen et al. 2012) and turtles (Nelms et al. 2015), and may be critical for the success of several endangered species. A comprehensive review of marine litter impacts on migratory species has been published for the Secretariat of the Convention on Migratory Species (CMS 2014a).

Figure 7.1c

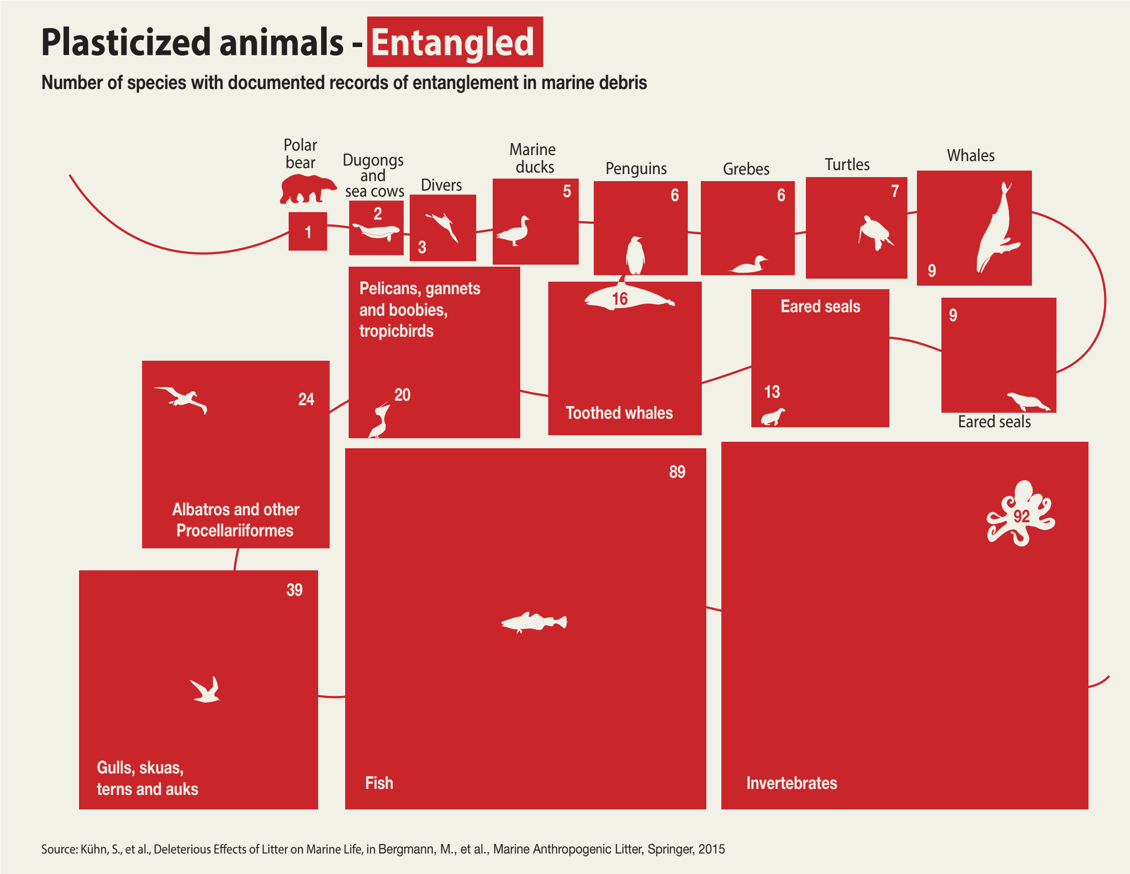
Figure 7.1b

Examples of entanglement by fishing debris: a) a entangled seal (John Vonderlin via Flickr); b) a sea turtle entangled in a ghost net, (Doug Helton, NOAA/NOS/ORR/ERD); c) northern gannets using fishing net debris as nesting material in the North Sea – note entangled corpses (Andreas Trete, www.photo-nature.de); d) nurse shark (deceased) entangled in monofilament fishing net and washed onto rocks, Jamaica (Aaron O'Dea).

Figure 7.1a

Figure 7.1d

Figure 7.1



Entanglement by species. Taken from Marine Litter Vital Graphics (in preparation).

Table 7.1

Type of material	Summer	Winter	Total
Packaging band	287	287	442
Synthetic line	149	112	261
Fishing net	128	52	180
Plastic bag/tape	31	32	63
Rubber band	16	5	21
Unknown	46	20	66
Total	657	376	1 033

Type of material entangling seals at Bird Island, South Georgia 1989 – 2013

Despite the growing evidence of effects on many species at an individual level, it is difficult to quantify the possible population-level effects; i.e. will the impact of plastic debris be sufficient to cause a decline in the population of a particular species through direct injury and death, or by reducing their foraging and reproductive success, for example. An approach using expert elicitation has been used to estimate the impacts of different types of plastic objects on wildlife (Wilcox et al. 2016). This is a critical part of devising appropriate and cost-effective mitigation measures (Chapter 9) to target items that have the greatest impact but may be more difficult to see (e.g. derelict fishing pots/traps), rather than items that may be more obvious but have a lower impact (e.g. drink bottles). An internet-based survey was developed using existing protocols devised by the WWF, IUCN and Bird Life International, and the results are presented in Table 7.2.

Table 7.2

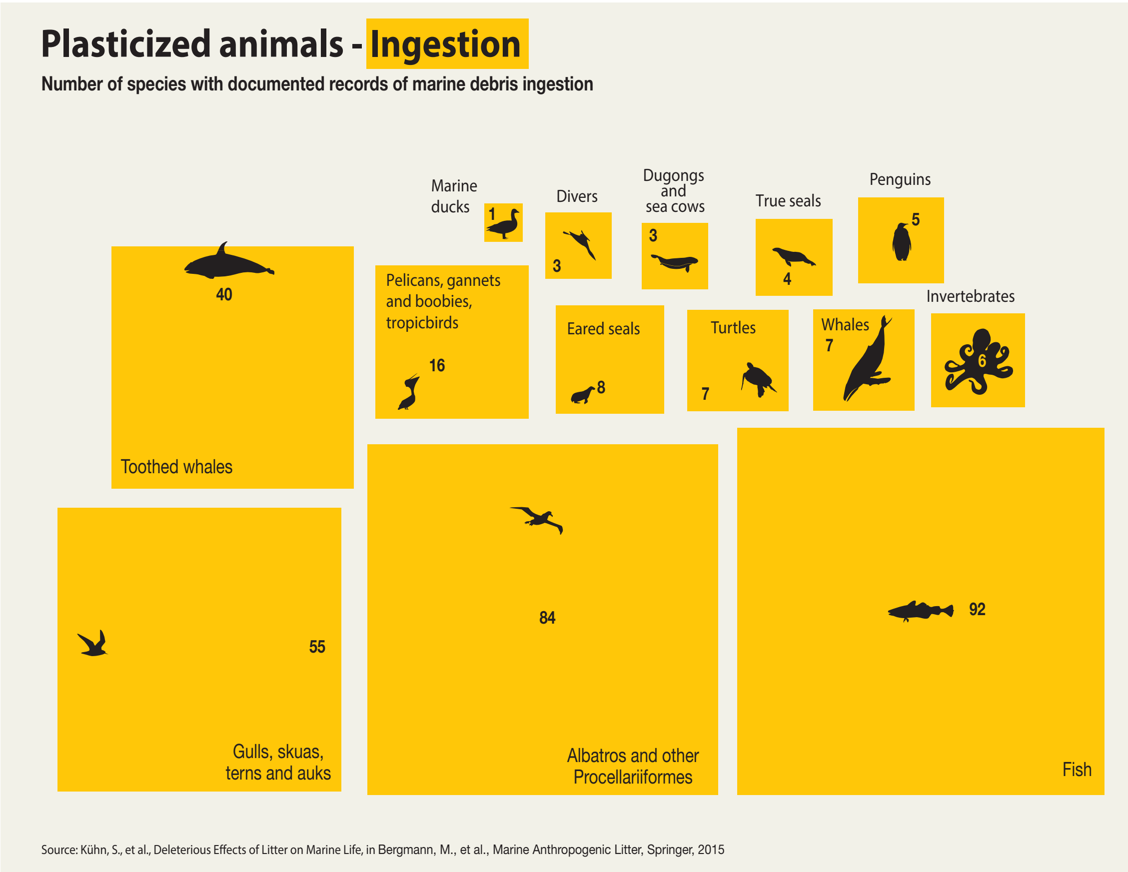
Item	Rank of expected impact			
	Mean	Bird	Turtle	Mammal
Buoys/traps/pots	1	1	1	1
Monofilament line	2.3	3	2	2
Fishing nets	2.7	2	3	3
Plastic bags	5.7	4	9	4
Plastic utensils	5.7	7	4	6
Balloons	6.7	8	5	7
Cigarette butts	7.3	5	12	5
Caps	7.7	9	6	8
Food packaging	8.7	10	7	9
Other EPS packaging	9.7	11	8	10
Hard plastic containers	11.3	6	13	15
Plastic food lids	11.3	13	10	11
Straws/stirrers	12.3	14	11	12
‘Takeout’ containers	15.3	15	18	13
Cans	15.7	17	14	16
Beverage bottles	16	12	17	19
Unidentified plastic fragment	16.3	16	19	14
Cups & plates	16.7	18	15	17
Glass bottles	17.7	19	16	18
Paper bags	20	20	20	20

Rankings of marine debris items by expected impact on marine animals, based on most severe expected impact across three impact mechanisms (adapted from Wilcox et al. 2016)

Ingestion

Examples of ingestion have been widely reported for a variety of marine mammals, reptiles, birds and fish (Figure 7.3). Evidence of ingestion often comes from the dissection of beached carcasses, which represent an unknown proportion of the total number of individuals affected. Turtles and toothed whales frequently are found to have large quantities of plastic sheeting and plastic bags in their gut compartments (e.g. Campani et al. 2013, de Stephanis et al. 2013, Lazar & Gracan, 2011, CMS 2014a). Plastics have been found in the guts of Loggerhead turtles in the Adriatic Sea (Lazar and Gracan 2011) and western Mediterranean (Camedda et al. 2014), the eastern Atlantic around the Azores (Barreiros and Raykov 2014) and in the SW Indian Ocean around Reunion Island (Hoarau et al. 2014). The physiology of some species of turtles and toothed whales makes it extremely difficult for the animal to eliminate the material once ingested. Ingestion of debris has been reported in 46 (56%) of cetacean species with rates as high as 31% in some species (Baulch & Perry, 2014). The differing feeding habits of closely related species can influence their susceptibility. For two species of dolphin off the coast of Brazil, far more specimens of the bottom-feeding Pontoporia blainvelli contained plastic than the surface feeding Sotalia guianensis in the same area (Di Beneditto and Ramos 2014).

Figure 7.3



Ingestion of plastics. Taken from Marine Litter Vital Graphics (in preparation)

Seabirds appear to be particularly susceptible at mistaking plastics for their natural prey (CMS 2014a). Most dead laysan albatross (Phoebastria immutabilis) chicks on Midway Atoll in the Pacific Ocean have been found to contain plastics in their guts (Figure 7.4), with items such as disposal cigarette lighters, toys and fishing gear[39]. The incidence of plastic fragments in the guts of the northern fulmar (Fulmarus glacialis) is so prevalent that this has been adopted as a reliable indicator of plastic pollution in the OSPAR region (Chapter 11.2, van Franeker 2010, van Franker and Law 2015). Evidence has emerged recently of the transfer of plastics from prey to predator, specifically from examination of regurgitated food pellets from a colony of the seabird the great skua (Stercorarius skua). Pellets containing the remains of northern fulmars had the highest prevalence of plastic (Hammer et al. 2016).

Population level impacts

While the impact of plastic debris on individuals of many species is beyond doubt, it may be more difficult to assess the impact at a population level. A review commissioned by the Scientific Technical and Advisory Panel (STAP) of the GEF, in collaboration with the Secretariat of the Convention on Biological Diversity (CBD 2012), concluded that 663 species had been reported as having been entangled in or ingested plastic debris, an increase of 40% in the number of species since the previous global estimate (Laist 1997). Plastic debris was responsible for 88% of recorded events; 15% of species affected were on the IUCN Red List. Of particular concern were the critically endangered Hawaiian monk seal Monachus schauinslandi, endangered loggerhead turtle Caretta caretta, vulnerable northern fur seal Callorhinus ursinus and vulnerable white chinned petrel Procellaria aequinoctialis. Two studies have suggested population level effects for the northern fulmar Fulmarus glacialis (van Franeker et al. 2011) and the commercially important crustacean Nephrops norwegicus (Murray and Cowie 2011).

39 http://www.fws.gov/refuges/mediatipsheet/Stories/201012_MarineDebrisThreatGrows.html

Figure 7.4

Plastic in the gut of a laysan albatros chick, Green Island, Papahanaumokuakea Marine National Monument in the Northwestern Hawaiian Islands. (Photographer Claire Fackler NOAA National Marine Sanctuaries)

Habitat damage

Coral reefs

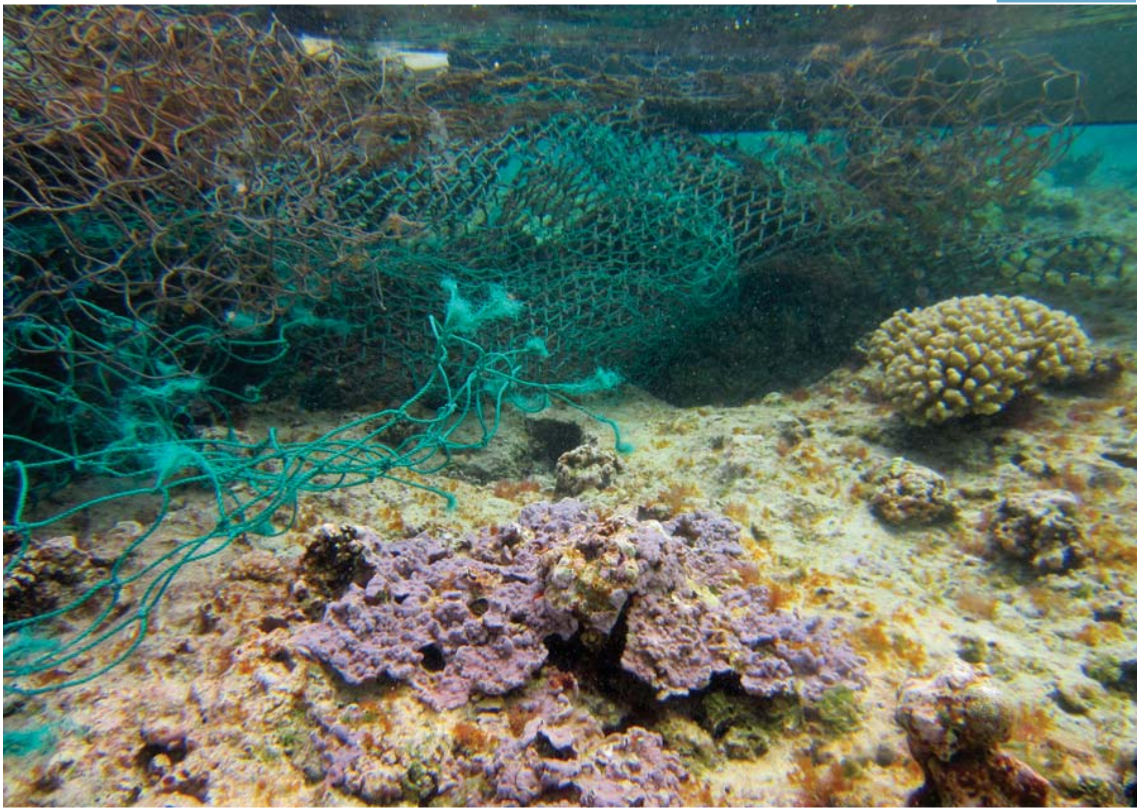
Coral reefs are very susceptible to damage from ALDFG. It is most obvious in shallow tropical reefs, but also occurs in cold water reefs located on many continental margins (Figure 7.5; Hall-Spencer et al. 2009). The movement of nets and ropes under the influence of winds or tidal currents can cause extensive damage.

Mangroves

Studies have shown that marine litter will tend to collect in mangrove forests, and that such habitats may act as a partial sink for plastics (Ivar do Sul et al. 2014).

Figure 7.5a

Figure 7.5b



Impacts of ALDFG on coral reefs: a) fishing net and rope, entangled with cold water coral reef (Lophelia pertusa), 700m water depth NE Atlantic (image courtesy Jason Hall-Spencer, Univ. Plymouth); b) fishing nets entangled in shallow warm water reef (image courtesy of NOAA)

Impacts of ingested microplastics and associated chemicals

Physical effects

The type of plastic fragments that are ingested by biota will depend on the characteristics and behaviour of the organism as well as the range of particle types it is exposed to. Particles in the microplastic size range are common in the gut contents of dead seabirds, such as the northern fulmar (F.glacialis, Figure 7.6), and there is evidence that this can be transferred to predators, such as the great skuu (Stercorarius skuu) (Hammer et al. 2016). Filter-feeding sessile bivalves close to population centres may be expected to ingest a higher proportion of synthetic clothing fibres than those at more remote locations. As yet there is insufficient data to detect such patterns. There is limited evidence that some organisms may selectively egest plastic particles (Wright et al 2013) but it is not possible to quantify the extent of this process. There is some evidence of trophic transfer in the field; i.e. a transfer of microplastics from prey to predator (Eriksson and Burton 2003). The potential physical impacts of microplastics on marine organisms have been subject to recent review (Wright et al. 2013, GESAMP 2015).

Ingested nano- and microplastics have been observed to cause inflammatory and other responses in several types of organism under laboratory conditions (Table 7.3).

Figure 7.6

Example of ingestion of microplastics: stomach contents of an individual northern fulmar (F.glacialis) from Svalbard in the Arctic. Scale bar indicates 10 mm (Trevail et al. 2015)

Table 7.3

Particle type	Size range	Species and transfer route	Evidence of effect	Reference
HDPE	>0–80 µm	Incorporation into epithelial cells lining the gut of M. edulis	Histological changes	Von Moos et al 2012
PS	2.0, 3.0 & 9.6 µm	Translocation across the gut wall of M. edulis	Transfer of particles from gut to circulatory system (haemolymph)	Brown et al 2008
PS	24-28 nm particles	Carassius carassius (Crucian carp), ingestion via zooplankton	Behavioural change, change in lipid metabolism	Cedervall et al. 2012

Particle uptake and internal transfer in marine organisms under laboratory conditions.

The ability of nano-sized material to cross cell membranes is quite well established. But there is a lack of information about the occurrence of plastic particles in this size range in the environment.

Associated chemicals

Plastic debris may contain a combination of additive chemicals, present since manufacture, and POPs and PBTs absorbed from the surrounding seawater (Rochman et al. 2013). This may raise concerns about the potential impact of such chemicals when particles are ingested, either to individual organisms or to larger populations. However, it is important to note that many organisms already contain organics contaminants as a consequence of the widespread distribution of POPs in the ocean seawater and sediments, through normal foodchain interactions (Teuten et al. 2009, Rainbow 2007; Vallack et al. 1998). There is convincing evidence that the health and breeding success of some populations of orcas, dolphins and porpoises are negatively impacted by loadings of 'legacy' pollutants such as PCBs (Jepson et al. 2016, Murphy et al. 2015). The key question is whether ingested plastic particles will add significantly to the existing contaminant load.

In general, it is very difficult to ascribe the proportion of a contaminant found in the tissue of an organism with the route of entry, in most cases. The most convincing field-based evidence that transfer of contaminants from plastic particles to the organism can occur comes from studies of the distribution of certain PBDE flame retardants, present in relatively high concentrations in some types of plastic. Evidence for this transfer mechanism is provided by a study of the short-tailed shearwater (Puffinus tenuirstris) sampled in the northern North Pacific (Tanaka et al. 2013) and species of lanternfish (myctophids) (Rochman et al. 2014). However, there is no field-based evidence that the transfer has caused any negative impacts at an individual level.

Laboratory-based studies have indicated that fish fed a diet that included plastic particles contaminated with PAHs, PCBs and PBDEs (following exposure to ambient concentrations in San Diego Bay, USA) did suffer liver toxicity and pathology (Rochman et al. 2013). This demonstrates a causal relationship but it is still not clear whether similar effects occur in a natural setting, where exposure to plastic particles is likely to be lower. Clearly this is an area requiring more attention.

Rafting

The transport of organisms attached to floating natural materials, such as wood, macro-algae and pumice, is well reported and is commonly referred to as rafting. Floating plastics have provided an additional substrate. However, floating plastics have much greater longevity than most natural materials and so the range over which rafting now occurs has been greatly extended. This has the potential to alter the distributions of marine organisms (Goldstein et al. 2012).

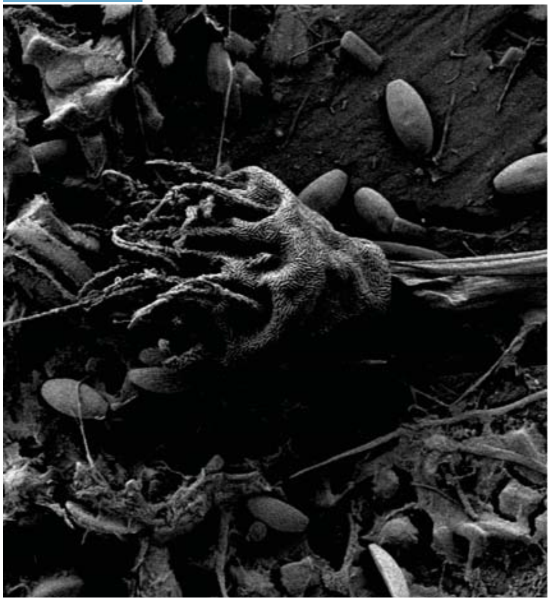
Macro and microplastic debris hosts a diverse assemblage of species, some distinct from surrounding seawater (Zettler et al. 2013), through the creation of novel habitat which may drift long distances and pose an ecological impact via transport of non-native species (Barnes et al. 2005, ref NOAA Japanese tsunami). The availability of microplastics for settlement has become an important issue, offering opportunities for settlement in areas where natural sources of flotsam are uncommon.

Many species of marine organisms are known to attach to marine plastics (Barnes 2002; Barnes and Milner 2005; Astudillo et al. 2009; Gregory 2009; Goldstein et al. 2014) and there is some evidence that microplastics translocate non-indigenous species. Although many of these reports refer to plastic pieces larger than 5 mm, they include species that could easily be transported by microplastic.

In the smaller size range, microplastic in seawater quickly develops a slimy biofilm that includes a diverse community of microbes (Figure 7.7). This biofilm is a miniature ecosystem that includes primary producers, consumers, predators, and decomposers and has been described as a "complex, highly differentiated, multicultural community" analogous to "a city of microbes" (Watnick and Colter 2000). The microbial biofilm encourages the attachment of larger organisms that use chemical and/or physical characteristics as a cue to settle (Zardus et al. 2008; Hadfield et al. 2014).

Microplastics may also allow the dispersal of pathogens that can pose threats to humans and marine animals (Snoussi et al. 2008). For example, Zettler et al. (2013) demonstrated that species of the bacteria Vibrio are commonly attached to microplastics. Vibrio sp. infections can cause serious gastrointestinal disorders and septicaemia via open wounds in humans (Baker-Austin et al. 2013).

Figure 7.7



Scanning Electron Micrograph of the surface of a piece of microplastic from the Atlantic Ocean. Cracked surface showing biofilm of attached microbes including heterotrophic bacteria (smallest rods), photosynthetic diatoms (ellipses), and a predatory suctorian cilate (centre with "tentacles") (taken from GESAMP 2016; image courtesy of E. Zettler/SEA)

Duarte et al. (2012) pointed out that the increase in human structures in the ocean may be contributing to the increase in jellyfish blooms. Calder et al. (2014) identified 14 species of hydroids on debris from the March 2011 Japanese tsunami that washed ashore on the west coast of the United States. At least five of these had not previously been reported from that coast. The proliferation of microplastic particles provides substrate for attachment and development of jellyfish hydroid life stages. Because pelagic surface waters are typically substrate limited, microplastic represents another factor that could be contributing to jellyfish blooms.

DNA sequences extracted from microplastic in the Atlantic had hits for a number of jellies that have both medusa and attached polyp stages (GESAMP 2016). The proliferation of the giant jellyfish Nemopilema nomurai in the waters around the Korean peninsula has been attributed, in part, to the increase in floating plastic debris (Figure 7.8). Experimental data suggest preferential attachment of planulae to PE sheets compared with a range of natural substrates (personal communication, Shin-ichi Uye, Univ. of Hiroshima). The increase in outbursts of this species has caused considerable social and economic losses to the fisheries.

Figure 7.8a

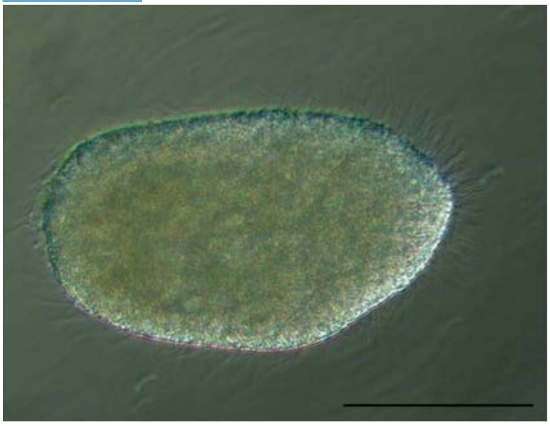


Figure 7.8b

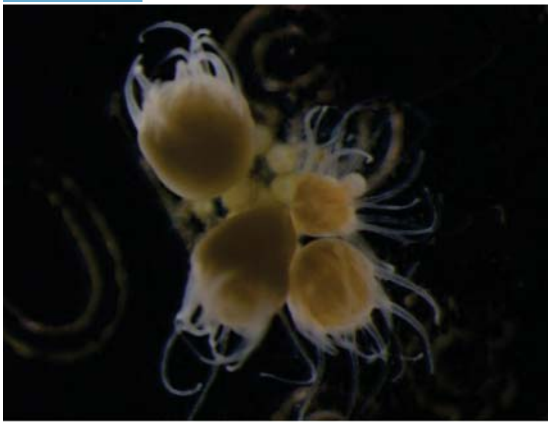


Figure 7.8c

Life stages of the giant jellyfish Nemophiliema nomurae, a) planula, b) polyps and c) medusa (images courtesy of Shin-ichi Uye, Univ. Hiroshima)

7.2

IMPACT ON FISHERIES AND AQUACULTURE

Macroplastics

The most important impact of macroplastic debris on fisheries is from ghost fishing from ALDFG. Ghost fishing is so called because the abandoned nets and traps continue to catch fish and shellfish, causing significant levels of mortality to commercial stocks which, in many cases are already under pressure. There have been several studies of the impact of ADLFG, most of which have identified gill nets and trammel nets as most problematic in terms of quantity lost and ghost fishing capacity. Trammel nets are made up of two or three layers of netting with a finer mesh sandwiched between two wider meshes. They are often fixed with floats and ground weights, and are very effective at trapping fish, and so tend to be rather non-selective with higher levels of bycatch. For these reasons they are especially damaging as ALDFG. Gill nets and trammel nets are used worldwide by coastal, artisanal and small-scale fisheries, and account for about a fifth of global fish landings. Pots and certain types of long-line fisheries also pose a threat to marine biodiversity when gear becomes lost or abandoned.

Some studies have attempted to quantify the loss of the target species due to ghost fishing. For example, it has been estimated that there is an annual loss of 208 tonnes of Antarctic toothfish (Dissostichus mawsoni) due to lost longlines (Webber and Parker 2012). An intense programme to remove derelict crab pots in Chesapeake Bay on the east coast of the USA, is thought to have increased landings of blue crab by 27% (13 504 tonne). Applying these results to all major crustacean fishes it is estimated that removing 9% of derelict pots and traps would increase global landings by 293 929 tonnes (Scheld et al. 2016), with a significant increase in revenue (Table.

Microplastics in commercial fish

Field studies have demonstrated microplastic ingestion by many commercial fish species, both pelagic and benthic (bottom dwelling); for example, from the English Channel (Lusher et al. 2013), the North Sea (Foekema et al. 2013) the Indian Ocean (Kripa at al. 2014) and the North Eastern Atlantic (Neves et al. 2015). However, the quantities observed in fish guts are generally very low, in the range < 1- 2 particles individual^{-1}. A comprehensive compilation of results for commercial fish and shellfish species is provided in Annex VI. Information is also available for non-commercial species (e.g. Boerger et al. 2010; Jantz et al. 2013) many of which may constitute as prey for larger fish. Similar findings from the Mediterranean Sea (Avio et al. 2015), the Arabian Sea (Sulochanan et al. 2014) and the south Atlantic (Dantas et al. 2012) confirm the perception that fish are globally exposed to and ingest plastic particles.

Microplastics have been found in many commercial fish species but concentrations are generally very low (<1 – 2 particles per individual)

Although it is clear microplastics are ingested by many species of commercial fish, we know little about the impact of their consumption. Microplastics may be egested along with faecal material, retained within the digestive tract, or translocate between tissues (this is more likely for nano-sized plastics). The retention and possible translocation of microplastics might raise some concern about the possible transfer of chemicals associated with microplastics into organisms' tissues, if microplastics were ingested in sufficient number and retained for long enough for transfer across the gut to take place. Currently there is insufficient evidence to assess the potential for transfer of these contaminants to the fish flesh, and hence be made available to predators, including humans. At present we can only extrapolate results from laboratory feeding studies using non-commercial fish species looking at contaminant transfer and endpoints, such as accumulation in the tissues and altered predatory behaviour. Generally, there is a mismatch between the quantities of microplastics specimens are exposed to in laboratory experiments with the much lower levels encountered in nature.

Mesopelagic fish are an important component of the oceanic ecosystem (Gjosaeter and Kawaguchi, 1980). They have recently been identified as potential target species for fishmeal. Their high lipid content would benefit the growing demand from aquaculture for fish protein and oil (FAO, 2010). With a global biomass estimated between 600 to > 1,000 million tonnes (Gjosaeter and Kawaguchi, 1980; Irigoien et al. 2014), this fisheries resource is still underutilised. Davison and Asch (2011) estimated that mesopelagic fish in the North Pacific ingest 12 000 – 24 000 tonnes^{-1}. Such estimates are of interest but have to be treated with some caution, given the rather small sample size involved in the Davison and Asch study (141 individual fish representing 27 species). It is possible that the presence of microplastics in the mesopelagic fish community (Davison and Asch 2011, Lusher et al, 2015) could have consequences for the mesopelagic ecosystem, as well as fisheries and aquaculture. However, there is little evidence that this is realistic at present. This is another area of research that warrants further attention, especially as the numbers of microplastics in the ocean will continue to increase for the foreseeable future.

Microplastics in commercial bivalves and molluscs

Microplastic ingestion

Microplastics have been observed in many commercial species, including mussels, clams, oysters and scallops. Many bivalves and molluscs are filter feeders, typically inhabiting shallow water coastal areas, and are likely to be exposed to higher concentrations of microplastics than non-sessile or more mobile organisms. Research approaches have included laboratory exposure, ingestion by wild and cultured organisms, and the presence of microplastics in organisms sold in retail stores from Europe, North America and Asia (De Witte et al. 2014; Li et al. 2015; Van Cauwenberge and Jansen 2014; Rochman et al., 2015; Vandermerrsch et al. 2015) (Annex VI).

Microplastics have been found in many commercial shellfish species, mostly < 1 particle but up to 75 particles an individual^{-1} for some species, depending on location.

Microplastics identified in shellfish range in size from 5 µm - 5 mm and are composed of fragments, pellets and fibres. For example, in eight out of nine species of shellfish sampled from an Asian fish market, fibres constituted more than 52% of items per species, with the exception of A. plicata where pellets were most abundant, 60% (Li et al., 2015). In a European study of M. edulis synthetic fibres were also the dominant microplastic and range from 200µm up to 1500µm size (De Witte et al. 2014).

Both wild and cultured Mytilus edulis have been found to ingest microplastics, under natural conditions, at typical concentrations of 0 - 34 particles g-1 (wet weight) (Li et al. 2015, Vandermeersch et al. 2015, De Witte et al. 2014, Van Cauwenberghe and Jansen 2014, Van Cauwenberghe et al. 2015). In contrast, average concentration of micro-fibres in farmed and wild M. edulis from Nova Scotia, Canada were significantly higher (average 178 fibres per farmed mussel compared to 126 microfibres per wild mussel; Mathalon and Hill 2014). In Belgium microplastics were observed in mussels collected at department stores (mussels ready for human consumption) and in open sea and sheltered points along the Belgian coastline (Van Cauwenberghe and Janssen 2014). The brown mussel Perna perna is another shellfish with commercial value susceptible to microplastic contamination. In one study, 75% of brown mussels from Santos Estuary, a highly urbanized area on the Southeast coast of Brazil (São Paulo state), contained microplastics (Santana et al. submitted).

Potential impacts

As with finfish, there is little information regarding the effects of microplastics on shellfish, but it is likely to vary as a function of species and particle types and exposure. For example, the transfer of contaminants in plastic particles has been demonstrated for the mussel M. galloprovincialis under laboratory conditions. The mussel can ingest and assimilate polyethylene and polystyrene particles, which when contaminated with polycyclic aromatic hydrocarbons can transfer this pollutant to mussels after being ingested (Avio et al. 2015). Cellular effects associated with such intake included alterations of immunological responses, neurotoxic effects and the onset of genotoxicity.

Ingestion impacts have also been observed for P. perna. Under laboratory conditions, this species retained particles of PVC in the gut and within the haemolymph for 12 days after a single exposure (Santana et al. in prep), and had signs of stress due to the ingestion of PVC and PE microparticles. Brown mussels expressed stress proteins, had signs of lipid peroxidation and DNA damage; and effects on lysosomal integrity (Santana et al. submitted; Ascer et al. in prep.). In oyster, preliminary work on the exposure of the Pacific oyster (Crassostrea gigas) to microplastics indicated effects on reproduction (Sussarellu et al. 2014).

These reactions to exposure to microplastics have been made in experimental set-ups, in which concentrations of microplastics may be much greater than might be experienced under more natural conditions.

Microplastics in commercial crustacea and echinoderms

Crustacea

Commercially important crustaceans are also known to ingest microplastics. Green crabs (Carcinus maenas) were observed to ingest microplastics under control conditions (Farrell and Nelson, 2013; Watts et al. 2014). Such intake was observed through contaminated food (mussels artificially contaminated with microplastics), thereby suggesting the possibility of microplastic trophic transfer. Farrell and Nelson (2013) identified the plastics assimilation and persistence within the crabs over 21 days. Microplastics were also found in the stomach, hepatopancreas, ovary and gills of the crabs (Farrell and Nelson, 2013). Watts et al. (2014) did not record microplastics assimilation but identified the ventilation of gills as another uptake pathway of microplastics for crabs. Lobsters (Nephrops norvegicus), sampled from the Clyde Sea (Scottish coast), also had microplastics in their stomachs (Murray and Cowie, 2011). About 83% of the individuals examined had ingested plastics that ranged in volume and size, but were mainly composed of monofilaments (Murray and Cowie, 2011).

Natural populations of brown shrimp (Crangon crangon), sampled across the Channel area and Southern part of the North Sea (between France, Belgium, the Netherlands and the UK), were also contaminated with microplastics (Devriese et al. 2015). The majority of the microplastic was synthetic fibres (96.5%, ranging from 200µm up to 1000µm size), which was ingested by 63% of the individuals assessed (Devriese et al. 2015). Shrimp from different locations did not have a significant difference between the plastic content (Devriese et al. 2015). The sampled C. crangon had, on average, 1.03 fibres g-1 w.w. but the large inter-individual variation of microplastic contamination among sampling points indicates the need of larger sampling efforts (Devriese et al. 2015). The amount of microplastics ingested by C. crangon varied temporally, possibly due to seasonal fluctuations on the occurrence of plastic (Devriese et al. 2015). The authors also investigated the relationship between the condition of the shrimp and the level of contamination of microplastics within an individual. However, no relationship was found, indicating that microplastic contamination does not affect the nutritional condition of the shrimp C. Crangon (Devriese et al. 2015).

Echinoderms

Information on this group is only available from laboratory experiments. Sea urchins, Tripneustes gratilla, exposed under laboratory conditions to microplastics in various concentrations (1-300 particles per ml, with an exposure duration of 1- 9 days) ingested but also egested particles (Kaposi et al. 2014). The impact of ingestion was not investigated. However, earlier research on sea cucumbers found that Holothuria sp. selectively ingested particles in preference to food items (Graham and Thompson 2009). The commercial market targets the body of the organism and removes their gut. If microplastics are translocating from the gut to the tissue of the organisms there could be concerns relating to bioaccumulation in the food chain. However, the data available suggests that microplastics are removed along with faecal material.

7.3

SOCIAL IMPACTS

Human health and food safety

Health impacts associated with poorly regulated waste management

There are several human health concerns associated with poorly managed waste collection and treatment. Higher levels of plastic-related compounds, including flame retardants, have been observed in people involved in, or living adjacent to, informal and poorly managed plastics recycling facilities, especially in the informal electronic and electrical waste recycling sector (Lee et al. 2015, Tang et al. 2014, Siniku et al. 2015). Littering can block wastewater drains, leading to sewage contamination of communities and areas of stagnant water. Plastic debris left lying outside can prove to be a very effective, if unwelcome, way of collecting rainwater, thereby becoming a vector for

Box 7.1

PLASTIC LITTER AND THE SPREAD OF DISEASE – AEDES AEGYPTI AND ZIKA VIRUS

The mosquito Aedes aegypti is one of several species of mosquito that breeds opportunistically in stagnant water, and can carry human disease. A. aegypti has been implicated in the spread of dengue fever, chikungkuya virus and, most recently Zika virus. A Zika virus outbreak in 2007 in west Africa has since spread rapidly throughout the tropics and sub-tropics, mostly recently into the Americas. It is strongly linked to the incidence of microcephaly in newborn babies by transmission across the placenta in the womb and neurological conditions in infected adults. A. aegypti appears to thrive in artificial habits created by discarded tyres, cans, plastic containers and other temporary reservoirs, and advice has been issued to minimise these potential breeding sites*. The rapid spread of Zika in South America and the Caribbean in 2015 and 2016 may have been exacerbated by a lack of effective waste collection and management. The American Administration asked Congress, on 6 Feb 2016, for more than US$ 1.8 billion in emergency funding for use both domestically and internationally.

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Microplastics and seafood safety

For the present purposes, 'seafood' includes: finfishes, crustaceans, molluscs, amphibians, freshwater turtles and other aquatic animals (such as sea cucumbers, sea urchins, sea squirts and edible jellyfish) produced for the intended use as food for human consumption (FAO 2014). It is evident that humans are exposed to micro and nano-plastics through the consumption of marine food stuffs, such as shellfish, shrimp, small fish species such as sprat and potentially other species such as sea urchins, tunicates and sea cucumbers, that are consumed as whole-animal foods including the gastrointestinal tract. Consumption of filter feeding invertebrates, such as mussels or oysters, appears the most likely route of human exposure to microplastics, but a wide variety of commercial species appear to be contaminated with microplastics. One study has attempted to estimate potential dietary exposure based on observed microplastic concentrations in seafood and assumed consumption rates. This study estimated dietary exposure for high mussel consumers in Belgium to range between about 11 000 (Van Cauwenberghe et al. 2014) and 100 000 MPs a-1 (GESAMP 2015).

Although it is evident that humans are exposed to microplastics through their diet (Table 7.4), and the presence of microplastics in seafood could pose a threat to food safety (Van Cauwenberghe and Janssen 2014, Bouwmeester et al. 2015), our understanding of the fate and toxicity of microplastics in humans constitutes a major knowledge gap.

Chemical exposure and seafood safety

Before considering the potential human health aspects of chemical contaminants associated with marine plastic debris, it is important to note that there are well-recognised links between the concentration of plastic-related chemicals in humans and exposure during plastic production, use and disposal. Many of the additives used in plastics intended for durable applications in the construction, automotive and electronics sectors have toxic and ecotoxicology effects

Table 7.4

Species	number kg-1 (wet weight) or l-1 product	Reference
Blue mussel (North Sea)	260 –13 200	Van Cauwenberghe and Jansen 2014 de Witte et al. 2014 Leslie et al. 2013
Brown shrimp (North Sea)	680	De Vries et al. 2015
Honey (various branches)	0.09 –0.29	Lieberzeit and Lieberzeit. 2013
Beer (Germany)	2–79 fibres 12–109 fragments 2–66 granules	Lieberzeit and Lieberzeit. 2014
Table salts (China): Sea salts Lake salts Rock/well salts	 550–681 43–364 7–204	Yang et al. 2015

Examples of microplastic concentration in foodstuffs* (taken from GESAMP 2016)

*Note different methods have been used in each of these studies which may have affected the detection limits

(Hansen et al. 2013). Particular concern is directed at compounds that can interfere with neurological development and the endocrine system (Table 7.5). This is quite different for plastics used for food packaging and water supply, where regulatory frameworks are in place to control exposure to potentially harmful chemicals.

Endocrine disrupting chemicals are of particular concern for a number of reasons: they can affect the unborn foetus, children at early developmental stages and adolescents, as well as the general population. The effects may be of great significance to the individual but may be difficult to detect on the wider population without extensive epidemiological studies (Weiss 2006, EEA 2013, North and Halden 2014). Endocrine disruption has been demonstrated for some of the chemicals most widely used in the plastics industry (e.g. BPA, phthalates, brominated flame retardants; Talsness et al. 2009) and for many organic contaminants that are readily absorbed by plastics (e.g. PAHs, PCBs). Clearly this may have implications for human health if plastics containing these chemicals are introduced into the body, either deliberately for medical purposes or accidentally as a result of ingestion or inhalation (OECD 2012). Exposure to flame retardants, such as PBDEs, in household dust correlates with body burdens, especially in children (Wu et al.2007).

Evidence that chemicals associated with plastics may cause harmful effects in the human population has been contested (e.g. Weiss 2006) or deemed insufficient to warrant further regulation (Hubinger and Havery 2006). Reported research findings may show apparent bias, depending on the source of funding for the study, as has been suggested for industry-funded research on BPA (EEA 2013). However, it has been argued that guidelines based on more traditional toxicity testing, using exposure to relatively high contaminant concentrations of a single substance, are not appropriate to pick up more subtle changes that can affect a large proportion of the population, with mixtures of plastic-related compounds (Talsness et al. 2009); this includes the association between the levels of certain plasticisers and organic chemicals and the widespread increase in metabolic syndrome (obesity, type-2 diabetes, hypertension; OECD, 2012).

Chemicals inherent in microplastics or chemicals sorbed and transported by microplastics may contribute to human health impacts. The toxicity of some of their components to humans, especially plasticizers and

Table 7.5

Additive/ Monomer	Function	Potential effect	Evidence from non-human studies	Evidence from human studies
Monomer				
BPA	A monomer used in the manufacture of polycarbonates and epoxy resins	Reproductive and developmental impairment, kidney and liver function impairment	Evidence from animal models – EFSA 2015	Minimal impact from food consumption – WHO 2009, FDA 2014, EFSA 2015 Suggested effects – EEA 2013, North and Halden 2010
Additives				
phthalates	Improve flexibility and durability	Impairment of reproductive function	Impairment of reproductive function – animal models - Swan 2008	Testicular development - Sharpe 2011
DBP dibutyl phthalate	Anti-cracking agent in nail varnish	See phthalates		
DEP diethyl phthalate	Skin softeners, colour and fragrance fixers in cosmetics	See phthalates		Minimal risk when used in fragrances – EU 2007
DEHP di-(2-ethylhexyl) phthalate	Plasticizer in PVC	Metabolic syndrome See phthalates		Exposure from medical uses and multiple sources – North and Halden 2013
nonylphenol	Stabilizer in PP, PS	Endrocrine disruptor	Feminisation of aquatic organisms – Soares et al. 2008	Endocrine disruption, effects on metabolism – Sonnenschein and Soto 1998
PBDEs Polybrominated diphenyl ethers (penta, octa & deca forms)	Flame retardant	Endrocrine disruptor	Transfer to seabirds – Takada et al 2013 Transfer to fish – Rochman et al 2013	Inhalation of house dust and air – Wu et al. 2007
				Transfer from consumer products – Hubinger 2010

Examples of microplastic concentration in foodstuffs* (taken from GESAMP 2016)

*Note different methods have been used in each of these studies which may have affected the detection limits additives (Flint et al. 2012; Oehlmann et al. 2009), and the possible leaching of toxic chemicals, may be considered as a potential human health hazard. But, on the basis of the available evidence, it appears that absorbed persistent organic pollutants (POPs) and leachable additives of dietary exposure to microplastics will have a relatively minor impact on contaminant exposure (Bouwmeester et al. 2015). However, this conclusion is mostly based on larger-sized microplastics, and there is a large knowledge gap on the possible effects of nano-sized plastics.

From the limited information available on the occurrence of microplastics in seafood, the uptake of plastic-associated chemicals in humans due to inadvertent ingestion of microplastics in seafood appears likely to be no more significant than other human exposure pathways of these chemicals. However significant knowledge gaps and uncertainties remain, particularly for nano-sized material, and this may justify a more precautionary approach.

Nano-plastics and seafood safety

The commonly used analytical techniques introduce a bias in the state of our knowledge, since they are only able to detect plastic particles well above the nano-size range (Bouwmeester et al. 2015; GESAMP 2016). It is plausible that these smaller particles pose a greater risk than the larger particles (> 1 micrometer) due to their smaller size, higher surface to volume ratio and associated increased chemical reactivity of the nano-sized group. Particles at the smaller end of the size spectrum (nano scales) have been shown to cross membranes into cells, in controlled laboratory experiments. Experimental evidence with rodents shows that microplastics > 1 micrometer may reach the blood circulation via lymph, but cannot penetrate deeply into organs (Bouwmeester et al. 2015; GESAMP 2016). They might cause local effects on the gut epithelium, the immune system, inflammation, encapsulation (fibrosis) and cell damage (Bouwmeester et al. 2015; GESAMP 2016). Unlike microplastics, nanoplastics may reach and penetrate all organs, including placenta and brain (Bouwmeester et al. 2015; see also GESAMP, 2015).

It is possible that nano-plastics pose a greater chemical risk than microplastics due to their larger surface-volume ratio: sorption of polychlorinated biphenyl (PCBs) to nano-polystyrene was shown to be 1–2 orders of magnitude greater than to micro-polyethylene (Velzeboer et al. 2014). Due to the absence of knowledge on nano-plastic exposure to humans, their potential chemical risk, especially after translocation into tissues and cells remains a 'black box'. It is possible that these internalized and/or encapsulated particles would deliver plastic-associated POPs and additive chemicals to different tissue types and locations than those resulting from uptake from food and water. This so-called 'Trojan horse' vector effect could pose an as yet unquantified risk, especially for very small plastic particles that can cross membranes.

Microplastics as a vector for pathogens

As described above, plastic particles may also harbour pathogenic microorganisms (bacteria, viruses), which could be potentially harmful to fisheries, aquaculture and human health.

Risk from injury or death

Floating plastic macro-debris represents a navigation hazard. It can lead to injury or death following loss of power, due to entangled propellers or blocked water intakes; and, collision with floating or semi-submerged objects, including (plastic) insulated shipping containers (Frey and De Vogelaere 2014). For example, in 2005, the USA coastguard reported that collisions with submerged objects caused 269 boating incidents, resulting in 15 deaths and 116 injuries (USCG 2005). In South Korea, 9% of all Korean shipping accidents involved marine debris from 1996-1998. In the worse case a ferry capsized after both propeller shafts and the starboard propeller became entangled with derelict fishing rope, resulting in 292 deaths (Cho 2005).

Injury or death to people can occur due to entanglement when swimming and diving. This represents a higher risk when associated with the rescue of entangled live animals such as whales, seals and turtles, justifying the need for a specialist and professional response (Chapter 9).

Loss of income

Loss of income is considered as a social cost, in this analysis, as it directly affects individuals and communities. In the fisheries sector the presence of plastic with the catch may contaminate or damage the fish, lowering its value, and more time may be required to clean and repair nets. If consumers perceive that seafood contains microplastics there is the potential that their interpretation of the relative risks involved may result in behaviour change (i.e. reduction in seafood consumption), whatever 'experts' or responsible authorities may say. There are precedents for this, particularly in the field of radioactive contamination of seafood from routine discharges and after major accidents. Clearly this would result in a loss of income for the seafood industry, and a loss of safe nutritious protein for the consumers. This emphasises the need for improved education and communication in the field of risk assessment and risk perception (Chapter 10).

The tourism sector is both significantly affected by marine litter and a major contributor to the problem. The presence of marine litter can discourage visitors from going to certain beaches, thus reducing visitor numbers, which in turn leads to lost revenues and jobs in the tourism industry (see UNEP 2014a). These impacts can be quite significant in certain cases, particularly where local economies are heavily dependent on tourism. For example, in Geoje Island (South Korea) the presence of marine litter on the beaches following a period of heavy rainfall is estimated to have led to between USD 27.7 and 35.1 million (KRW 29 217–36 984 million) of lost revenue in 2011 as a result of over 500 000 fewer visitors. The presence of beach litter on the Skagerrak coast of Bohuslan (Sweden) has been estimated to lead to an annual loss of approximately USD 22.5 million (GBP 15 million) and 150 person-years of work to the local community from reduced tourist numbers.

Loss of intrinsic value and the moral dimension

The loss of intrinsic value encompasses our response to being aware of a degradation of the environment, whether this is litter on a deserted shoreline or images of injured or dead iconic species, such as turtles, birds and marine mammals. It is very difficult to quantify the impact reliably, except in the case where a change in behaviour apparently linked to the degree of degradation be observed, as in the tourism examples above. It can be surmised that the closer the relationship individuals feel to the example of litter-induced degradation then the greater will be the sense of loss. This may undermine some of the benefits associated with coastal and marine environments (e.g. improved physical health, reduced stress and improved concentration, GESAMP 2016, UNEP 2016c). Attempts have been made to develop methodologies for quantifying non-use values (e.g. UNEP 2011), but such analyses are often hindered by the lack of relevant and reliable data. Different forms of contingent valuation may be used (e.g. stated preference, willingness to pay), based on a rather limited number of studies, which are then applied globally, to dissimilar social and economic settings, not taking into account local attitudes and values (UNEP 2014b). Therefore, such figures as do exist should be treated with some caution if taken out of context. But such analyses do serve to illustrate the likely extent of external costs (Figure 7.9)

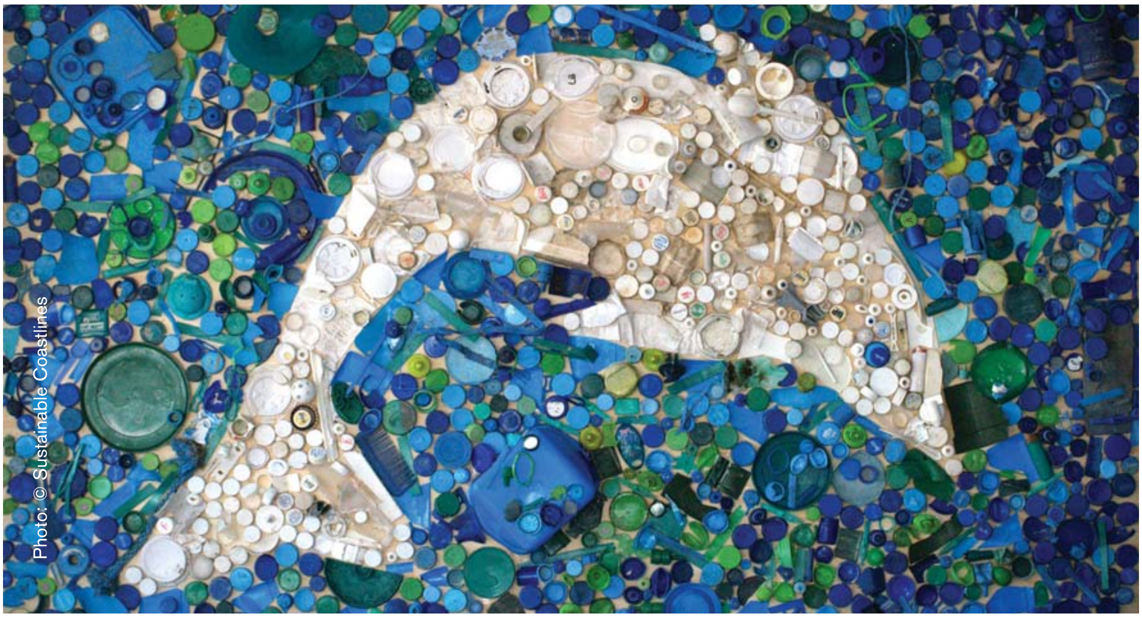
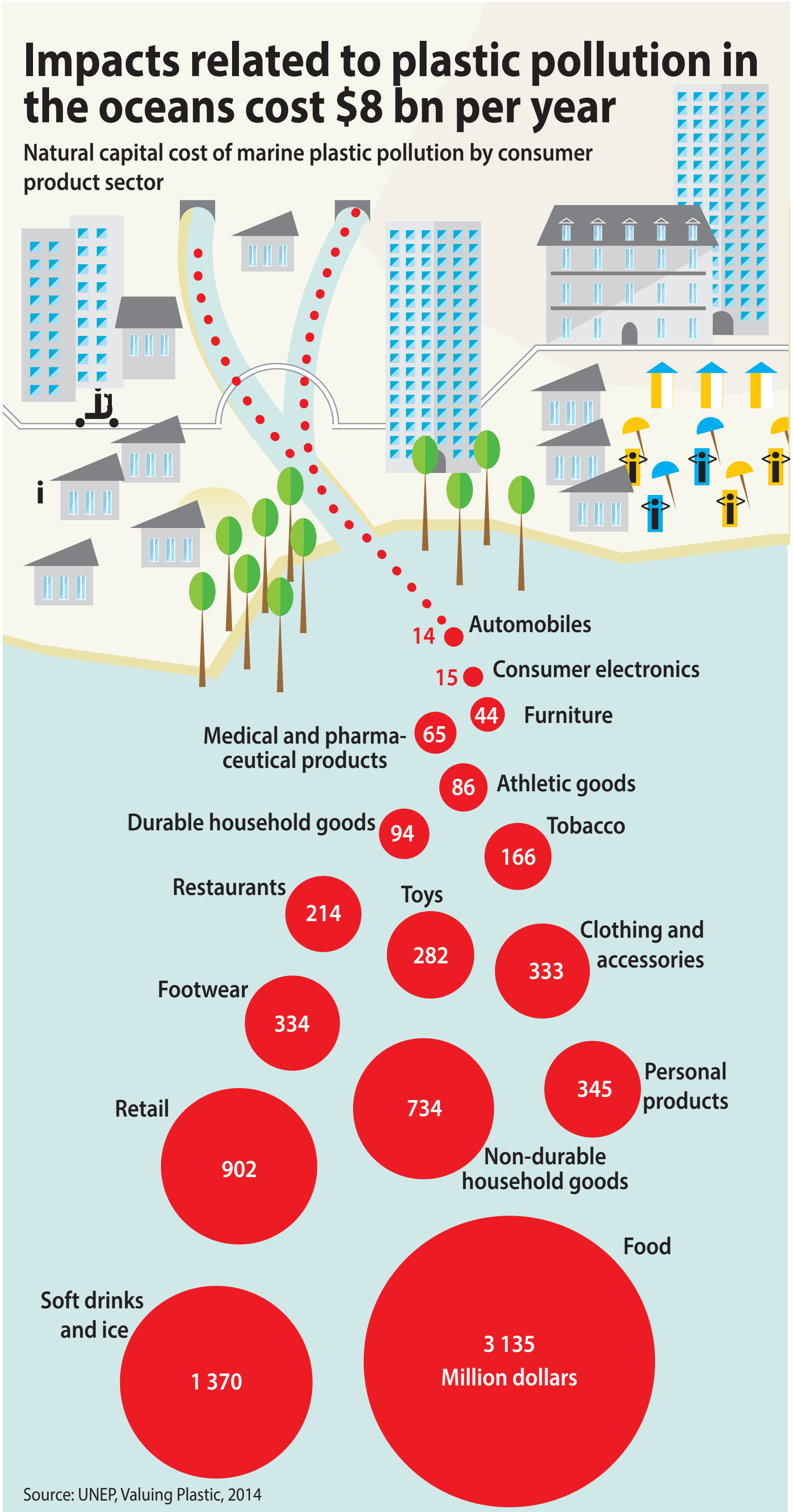


Photo: © Sustainable Coastlines

Figure 7.9



Estimates economic impact related to plastic pollution in the ocean (taken from Marine Litter Vital Graphics in preparation

It can be argued that there is an important moral dimension to the debate about the presence of litter in the ocean and the need to introduce measures to reduce inputs and mitigate the effects of litter already present. This means society may decide that we should prevent litter from entering the ocean because it does not belong there, irrespective of whether there is an economic argument for doing so or that major impacts from plastics or microplastics cannot be proven.

There is an important moral dimension to the debate about whether, and how, society tackles pollution from marine plastics and microplastics.

Under this philosophical outlook an unpolluted ocean is considered to have a value in and of itself. This can be expanded to include other forms of non-use values, which can be defined as: i) altruistic value - knowledge of the use of resources by others; ii) existence value - knowledge of the existence of the resource; and, iii) bequest value – knowledge of passing on the resource to future generations (UNEP 2014b).

7.4

IMPACTS ON MARITIME ECONOMIC SECTORS

From ecosystem impacts to economic consequences

The degradation of ecosystems due to marine litter can have both direct and indirect socio-economic impacts. For example, marine litter can lead to economic costs in the commercial shipping sector due to damage caused by entanglement or collision with marine litter in general. Loss of cargo can introduce plastic debris into the environment and lead to compensation payments. Other economic costs may be more difficult to quantify, such as the impact litter may have on changing people's behaviour. Under the auspices of the G7, Germany has commissioned a report on an economic cost-benefit analysis of the prevention and removal of marine litter, and the most urgent fields of action to reduce marine litter. The following sections provide some examples of economic costs in a variety of sectors.

Fisheries and aquaculture

Direct impacts

The impact of marine litter on the fishery sector includes damage to fishing vessels and equipment and contamination of the catch with plastic debris. The direct impact is mostly due to floating plastic debris affecting engine cooling systems and becoming entangled in propellers (McIlgorm et al. 2011, Takehama 1990, Cho 2005). Information on the related costs is not systematically collected by marine authorities, and it can only be estimated. Takehama (1990) estimated the costs of marine litter to fishing vessels based on insurance statistics at US$ 40 million (Y4.4 billion) in 1985, i.e. about 0.3% of total annual fishery revenue in Japan. The total cost of marine litter to the EU fishing fleet has been estimated to be nearly US$ 65.7 million a-1 (€61.7 million a-1), representing 0.9% of the total revenues (Annex VII; Mouat et al. 2010, Arcadis 2014).

Indirect impacts

Indirect impacts include loss of target species due to ghost fishing from ALDFG, although the total losses are unknown. Gilardi et al. (2010) investigated the Dungeness Crab fishery in Puget Sound and estimated that targeted removal of derelict gill nets yielded a cost-benefit ration (cost of removal versus increased landings) of 1:14.5. More recently, Scheld et al. (2016) estimated that the annual loss due to derelict pots and traps for nine species of crustacea amounted to US$ 2.5 billion (US$ 2.5 x 109) (Table 7.6), using data from a derelict pot removal programme in Chesapeake Bay. The authors argued that targeted removal campaigns, paying operators from the fishing community, during downtime, can be a cost-effective measure (Chapter 9). A theoretical cost to the industry would be if the presence of microplastics in some way reduced the organisms' fitness or reduced reproductive capacity. However, there is no evidence that this is the case given current measured concentrations in fish and the environment (Chapter 7.1).

Tourism

Costs of inaction

The visible presence of marine litter has an impact on the aesthetic value and attractiveness of beaches and shorelines for recreational purposes (Fanshawe and Everard 2002). For example, damage to marine ecosystems and the presence of marine litter affects recreational activities such as diving and snorkelling, fouling propellers and jet intakes of recrea-

Table 7.6

Species	Annual gear loss (% deployed)*	Landings (MT)	Revenues (US$)	Major producers
Blue swimmer crab Portunus pelagicus	70	173 647	199 million§	China, Philippines. Indonesia. Thailand, Vietnam
American lobster Homarus americanus	20-25	100 837	948 million	Canada, USA
Blue crab Callinectes sapidus	10-50	98 418	152 million	USA
Queen crab /snow crab Chionoecetes opilio	na	113 709	401 million	Canada, St Pierre & Miquelon (France), USA
Edible crab Cancer pagurus	na	45 783	49 million∞	UK, Ireland, Norway, France
Dungeness crab Metacarcinus magister	11	35 659	169 million	USA, Canada
Spiny lobster Panulirus argus	10-28	34 868	500 million	Bahamas, Brazil, Cuba, Nicaragua, Honduras, USA
King crab Paralithodes camtschaticus	10	10 137	99 million	USA
Stone crab Menippe mercenaria√	Na	2 502	24 million	USA
Total		615 560	2.5 billion	

Gear loss and global landings for major crustacean pot and trap fisheries (from Scheld et al. 2016)

*estimates from Bilkovic et al. (2012), §based on an average price of US$ 1.15 kg-1, ∞based on 2012-2014 average price of US$ 1.07 kg-1, √claws only tional boaters and affecting recreational fishers in terms of contamination of catch, restricted catch and damaged gear.

Marine litter can thus discourage visitors from going to certain beaches. Reduced numbers of coastal visitors leads to lost revenues for the tourism sector, which in turn leads to a loss of revenue and jobs in the local and regional economy. This can have short-term (e.g. where a specific natural incident such as a flood or tsunami washes up marine litter) and/or long-term impacts. This may occur where consistent levels of marine litter damages the reputation and image of the area as a tourist destination thus discouraging private sector investment in new tourist developments (McIlgorm et al. 2011). These impacts can be quite significant in certain cases, particularly where local economies are heavily dependent on the tourism sector. For example, Hawaii and the Maldives are facing declines in tourist numbers and associated revenues due to marine litter, particularly plastics, that threaten to affect the reputation of islands as sought-after tourist destinations (Thevenon et al. 2014). Some studies provide quantitative estimates of the costs to the tourism sector of marine litter (Annex VIII).

Costs of action

Clean-up costs can be significant and in some cases can pose an undue burden on local authorities. For example, the estimated coastline clean-up cost for the Ventanillas municipality in Peru is double the annual budget of the municipality for all public cleaning (Alfaro, 2006 cited in UNEP, 2009). Some examples of clean-up costs from Europe, the USA and the APEC region are provided in Annex VIII.

Box 7.2

COMPENSATION FOR CONTAINER LOSS

Monterey Bay National Marine Sanctuary, USA

The loss of 14 containers from the MV Med Taipei on 24 February 2004 led to the shipping company involved paying US$ 3.25 million in compensation to the MBNMS. This amount included the estimated environmental damage, as assessed by NOAA, and legal fees.

UNEP 2016c

Commercial shipping

Collisions with marine litter can cause significant damage to vessels and even pose a threat to human health. Firstly, lost containers represent a particular hazard to mariners because of their size and ability to float for up to several weeks, particularly for refrigerated containers fitted with foam lining. Smaller items of waste at sea can also damage ships, with costs associated with repairing fouled propellers or blocked outages. High levels of traffic in harbours and ports increase the risk of collision with waste. Consequently, many port authorities actively remove marine litter in order to ensure facilities are safe and attractive to users (Mouat et al. 2010). One study of the removal of debris from harbours reported costs as high as USD 86 695 (GBP 57 300) in one year for Esbjerg Harbour in Denmark (Hall 2000). Costs are also incurred due to the loss of cargo. The average value per container is estimated to be US$ 20 000 - 24 500 but can be significantly higher if carrying personal electronic goods, for example (UNEP 2016c). Cargo loss can also result in compensation and insurance payments (Box 7.2)

The process of generating, and the presence of, marine litter (including both waste originating and not originating from vessels) bring costs to the commercial shipping sector. The main costs are associated with: the accidental loss of cargos; collisions with marine litter; and indirect costs relating to operational costs, disruption of service, and public image. Clean up costs in harbours may also indirectly fall on the shipping sector. One estimate placed the total value of litter damage to shipping at USD 279 million per year (APEC 2009).

While it is difficult to collate all the economic costs associated with marine plastic debris and microplastics it is quite clear, from those studies that have been carried out, that the economic impact, together with associated social and ecological dimensions is considerable. The costs could be reduced substantially if the concept of the circular economy was developed further and implemented with regards to plastics production and utilisation. The great advantage of pursuing this philosophy is that a precautionary approach can be adopted without incurring excessive cost. This is discussed further in Chapter 9.

8
TAKING ACTION

8. CLOSING THE LOOP

8.1

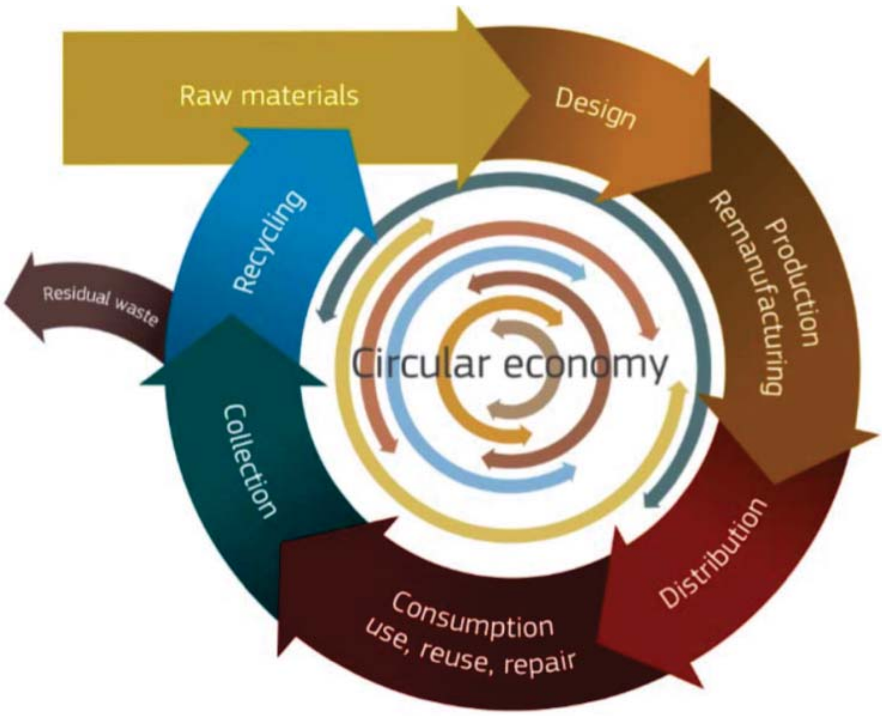
TOWARDS A CIRCULAR ECONOMY

In many situations, especially in developing economies, the most urgent short-term solution to minimising marine litter inputs is likely to be improved waste collection and management (Ocean Conservancy 2015). In the longer term a more sustainable solution will be to move towards a more circular 'plastic economy', in which waste is minimised by being designed out of the production cycle (Figure 8.1; McDonough and Braungart 2013, EMF 2014, WEF/EMF/MCKINSEY 2016, EC 2014, EC 2015). This might be more easily understood by the general public as adopting the six 'Rs': Reduce (raw material use) – Redesign (design products for re-use or recycling) – Remove (single-use plastics when practical) – Re-use (alternative uses or for refurbishment) – Recycle (to avoid plastics going to waste) – Recover (re-synthesise fuels, carefully controlled incineration for energy production).

However, creating a 'circular economy' which works effectively, and is accepted by business and the public, requires a great many intermediate stages, including introducing appropriate infrastructure and investment, and facilitating behavioural change throughout the supply chain. Without these changes the concept is likely to remain for many as an aspirational target rather than become an everyday reality. The goal of a circular economy is to severely restrict both the use of new raw materials and the production of residual waste. A fundamental requirement is to reduce overall consumption, recognising that the present per capita use of energy and other resources is extremely unequal.

The concept of a circular economy is not new, but it has received renewed impetus in the past five years (McDonough and Braungart 2013). One of the main promoters of the concept has been the Ellen MacArthur Foundation (EMF 2014, WEF/

Figure 8.1



Conceptual representation of the circular economy (EC 2014)

Box 8.1

THE CIRCULAR ECONOMY IN THE EUROPEAN UNION

The circular economy package was introduced to the European Commission and adopted in December 2015. The package includes a number of measures aimed at tackling the issue of plastics and marine litter:

a) a mandate to develop by 2017 an EU integrated strategy on plastics;
b) a target on plastic recycling/reuse in the legislation (55% by 2025 recycling/reuse of plastics from packaging);
c) inclusion of litter prevention in the waste management plans as well as in the producer res ponsibility schemes (producers will have to financially contribute to action to prevent littering);
d) a connection between the fees paid by the producer and the true/full waste management cost and the recyclability of their products – an economic encouragement to use more easy to recycle materials when possible…; and
e) a confirmation of the necessity to implement an aspirational target of „reducing marine litter by 30% by 2020 for the ten most common types of litter found on beaches, as well as for fishing gear found at sea, with the list adapted to each of the four marine regions in the EU.

The EC is intending to address the issue of marine litter from ships, in the context of the 2016 revision of the EC Directive on port reception facilities, and examine options to increase the delivery of waste to port reception facilities and ensure adequate treatment.

EMF/MCKINSEY 2016), working with a number of major companies and institutions, such as the World Economic Forum. Some individual manufacturers, such as Groupe Renault (motor vehicles), have begun the transition and reported significant financial benefit[40]. At a regional level, a circular economy package was adopted by the European Commission in early December 2015. It acknowledges that large quantities of plastics end up in the oceans, and that the 2030 Sustainable Development Goals include a target to prevent and significantly reduce marine pollution of all kinds, including marine litter (Box 8.1). The EU-funded project CleanSea[41] (2013 – 2015) produced a series of policy options for encouraging litter-free seas which revolved around the circular economy concept (CleanSea 2015).

Plastic production and use has tended to follow a linear flow, from extraction of raw materials (i.e. oil) to generation of waste, partly because of a failure to appreciate the social, economic and ecological cost of waste generation and include this externality in economic forecasts. A simple conceptual model of a circular economy for plastic production and use in a closed loop, illustrating potential intervention points and the flow of materials and energy, is shown in Figure 8.2. In this model energy recovery is included as a way of closing the loop. But, waste generation should be designed out of the plastic cycle wherever possible. Promoting an economy for after-use plastics will encourage the development of improved collection infrastructure. The design of materials and products can be improved to increase the end of

40 https://group.renault.com/en/news/blog-renault/circular-economy-recycle-renault/

41 http://www.cleansea-project.eu/drupal/index.php

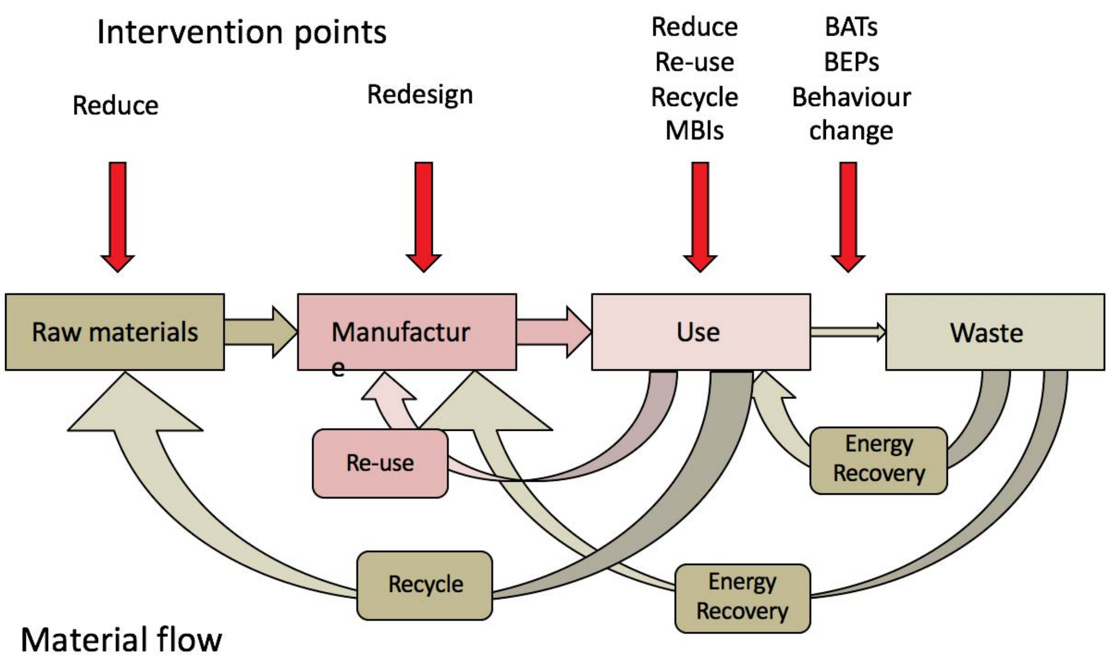
life value and hence provide an incentive to prevent leakage, especially for those working in the informal waste sector (WEF/EMF/MCKINSEY 2016).

The removal of plastics from the production and use cycle can be achieved by minimising the availability of single-use plastic products, where appropriate alternatives can be made available. A simple example is the replacement of disposable cutlery, plates and drink receptacles in sit-down cafes, with metal and crockery. Another is the provision of drinking water dispensers so that individuals can re-fill containers rather than rely on single-use plastic bottles or bags. Re-use and recycling of materials can be made more straightforward by improved design. This can be extended to the selection of materials that are intrinsically less toxic (e.g. thermoplastic polyurethane (TPU) rather than PVC) or contain fewer added toxic compounds (e.g. selection of non-hazardous dyes in textiles) (McDonough and Braungart 2013). Fewer precautions will be required in handling them and there will be less risk of contamination, for example, of food- or child-safe plastics by accidental or deliberate mixing of waste streams. The re-use or 'upcycling' of materials can range from the creation of inspirational art from marine debris[42]; the production of bags and other craft items and goods from waste items, such as plastic bags[43]; taking unwanted or leftover materials to create fashion or promotional goods[44]; and, re-using items directly in refurbished goods, such as in the automotive industry. Recycling rates vary greatly by region and country, with rates even in developed economies varying between <10% (USA) to >90% (Switzerland) (Box 8.2).

Another key consideration for increasing the quantity and value of recycled plastic is by clearly marking the type of plastic, minimising the use of products composed of more than one polymer, reducing the use of bright pigments, and discouraging the inclusion of so-called 'biodegradable', 'compostable' or 'oxo-degradable' plastics, as these will reduce the utility of the recyclate if pres-

42 http://australianmuseum.net.au/ghost-net-art
43 http://www.trashybags.org/index.htm
44 http://www.globehope.com

Figure 8.1



Conceptual representation of the circular economy (EC 2014)

ent even in only small quantities (> 2%, UNEP 2015a). International standards do exist to define the conditions under which 'biodegradable' and 'compostable' plastics should degrade under favourable (i.e. non-marine) conditions (Chapter 4), but this is not necessarily apparent to those utilising products marked in this way. Some form of improved labelling would be helpful to minimise mishandling, and to indicate the conditions under which the plastic can be expected to degrade.

Treating waste as a resource can be encouraged by the use of MBIs. Some of these can be very simple, such as introducing a bottle deposit scheme for PET bottles and lids. This can be particularly effective in countries with a high dependence on bottled water for the safe supply of potable water. Unfortunately, leakage of economic value can occur due to a loss of quality in materials being recycled. Even for relatively pure waste streams such as PET it has been estimated that only 20-30% of recycled PET can be used for bottle production and 50% in thermoformed products, which generally are not recycled (EMF 2014). Increasing the purity of the waste stream, by improved manufacture, collection and recovery processes could increase the downstream value, according to EMF, by up to US$ 4.4 billion per annum.

Energy recovery

The use of energy recovery for the majority of plastic waste should be considered as a temporary measure. Longer-term use of energy recovery is justified provided the other elements of the Redesign-Reduce-Re-use-Recycle cycle have been fully implemented. Waste-to-energy technologies are quite widely used in Japan and some European countries, to close part of the plastic loop. They are operated to modern standards within well-developed regulatory frameworks. However, incinerating plastics can be highly problematic. Without adequate financial investment, education and capacity building, there is a risk that use of incinerators to generate energy in some countries will produce serious human health consequences and environmental damage. Concerns include: excessive cost for a facility that would meet modern emission standards; a lack of transparency and oversight to ensure standards are met in some countries; and, the neglect or diminished support for

Box 8.2

PLASTIC RECYCLING RATES

The rate of plastic recycling varies considerably by region and country. Within Europe (EU28 plus Norway and Switzerland) the average utilisation of waste plastic in 2014 was 30% recycled, 40% energy recovery and 30% landfill. However, there are very significant differences between the best and worst performing European nations (Plastics Europe 2015). The USA is a major producer and user of plastic but achieves only a 9% recycling rate (www.epa.gov). China is the world's largest producer of plastics (26% of global production in 2014) and the world's largest importer of waste plastic. The latter is intended only to be used for recycling. The total recycling rate is thought to be approximately 25% (www.mofcom.gov.cn). Recycling rates in South Africa are in the region of 20% (www.plasticsinfo.co.za) and 9% in Singapore (www.nea.gov.sg). In Japan, the total plastic utilisation rate is 82%, split between 25% recycling and 57% energy recovery. Clearly there is scope to improve the utilisation rate of waste plastics in many countries.

Box 8.3

EXTRACT FROM THE 10-YEAR FRAMEWORK OF PROGRAMMES ON SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS

‘(c) The 10-year framework should affirm a common vision that:

(vi) Protects natural resources and promotes a more efficient use of natural resources, products and recovered materials;
(vii) Promotes life cycle approaches, including resource efficiency and sustainable use of resources, as well as science-based and traditional knowledge-based approaches, cradle to cradle and the 3R concept (reduce, reuse and recycle) and other related methodologies, as appropriate;…’

Rio+20 A/CONF.216/5

alternative strategies to minimise single-use plastics and promote the philosophy of redesign-reduce-reuse-recycle[45].

Reducing consumption
Waste prevention, and sound resource management, must involve a reduction in our consumption of materials. A circular economy will not be possible if we do not cut consumption. This does not necessarily mean that the supply of goods and services need be restricted, but that there are cleverer ways of delivering them. For example, by moving away from single-use plastics as the default, and substituting other materials we can ‘dematerialise’ our way of living (WEF/EMF/MCKINSEY 2016). This need to promote more sustainable production and consumption patterns is recognized within many UN documents and international declarations.

‘Governments, international organizations, the business sector and other non-state actors and individuals must contribute to changing unsustainable consumption and production patterns.’

Agenda 2030

At Rio+20, the 10-year Framework of Programmes on Sustainable Consumption and Production Patterns was adopted, and endorsed by the UNGA on 27 July 2012 (Resolution A/RES/RES/66/288, paragraph 226). Two of the items mentioned in the common vision refer to the more efficient use of resources, including the cradle to cradle and 3R concepts (Box 8.3). SDG 12 also reflects the need for sustainable consumption and production patterns.

In order for these concepts to become a reality, there is a need for people to make a connection between their consumption patterns and the consequences in terms of environmental degradation, and the potential loss of ecosystems services. This requires that we

45 http://www.no-burn.org/downloads/Technical_critique_Stemming_the_Tide_report.pdf

better understand the motivations and assumptions governing behaviour, both with regard to consumption and waste management/littering (Chapter 9.1).

8.2

THE PRECAUTIONARY APPROACH AND ADAPTIVE MANAGEMENT

The need for a precautionary approach was discussed at the United Nations Conference on Environment and Development in June in 1992 and adopted as Principle 15 of the Rio Declaration on Environment and Development[46]:

'In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.'

Principle 15 of the Rio Declaration 1992

There is overwhelming evidence that marine plastics are widespread in the oceans and that they have caused a range of social, economic and ecological impacts. What is unknown is the overall quantitative impact, on different social systems, economic sectors or species and habitats. But there is a sufficient body of knowledge to argue convincingly of the need to invoke the precautionary approach, in reducing the input of plastics into the ocean and minimising the risk.

The Precautionary Principle can be viewed as an extension of the precautionary approach, placing it as a principle in Law. It is not as widely accepted by countries, but the EC adopted the Precautionary Principle into EC law in 2000, and it has informed a variety of environmental legislation, including the incineration of waste (Recuerda Girela 2006). The EC Communication contained guidance on when and how the Principle should be applied (Box 8.3)

'The Precautionary Principle should be considered within a structured approach to the analysis of risk which comprises three elements: risk assessment, risk management and risk communication. The Precautionary Principle is particularly relevant to the management of risk.'

EC 2000

The EC advised that the Precautionary Principle should be placed with a structured approach to the analysis of risk (Box 8.4). The use of risk-based management to reduce the impact of marine plastics and microplastics is described in Chapter 10.


Photo: © Romeo Ranoco / Reuters

46 http://www.un.org/esa/documents/ecosoc/cn17/1997/ecn171997-8.htm

Box 8.4

GUIDANCE ON THE APPLICATION OF THE PRECAUTIONARY PRINCIPLE IN EUROPEAN LAW

'Where action is deemed necessary, measures based on the precautionary principle should be, inter alia:

- **proportional to the chosen level of protection**
- **non-discriminatory in their application**
- **consistent with similar measures already taken**
- **based on an examination of the potential benefits and costs of action or lack of action (including where appropriate and feasible, an economic cost/benefit analysis)**
- **subject to review, in the light of new scientific data**
- **capable of assigning responsibility for producing the scientific evidence necessary for a more comprehensive risk assessment'**

EC 2000

Table 8.1

	Evidence-based action (comprehensive understanding of the system)	**Precautionary approach (removal of all tangible threats)**
Advantages	Reduces scientific uncertainty	Anticipatory: acknowledges the scientific uncertainty
	Attractive to legislators and industry	Ensures the capacity to adapt to unforeseen problems
Disadvantages	Science and information base may be insufficient	A hard sell as costs of implementation may be high
	Reactive	Difficult to assess areas where precaution is warranted
	Costs of monitoring are high and require long-term government buy in	Makes an assumption that impacts are inevitable
Public face	Science-based indicators often difficult to understand	Public may seek alternative products and services when costs spiral

Comparison of alternate approaches for achieving Good Environmental Status, in European Seas (based on Mee et al. 2007)

Pros and cons of the precautionary approach
There are advantages and disadvantages to adopting the precautionary approach, as recognised in a European study comparing alternative visions of achieving 'Good Environmental Status' in European seas (Table 8.1; Mee et al. 2007). These need to be anticipated and factored into an overall strategy for implementing marine plastics reduction measures.

A brief history of unrecognised risk
The societal benefits of the widespread use of plastic are widely recognised (Andrady and Neal 2009). However, there is a cost associated with most human development and the introduction of plastics has proved to be no exception. There is a long history of new techniques and materials being introduced and rapidly and widely adopted, because of perceived societal benefits, in advance of adequate risk assessment, regulatory frameworks or assessment guidelines. Examples include the widespread use of asbestos, X-ray 'therapy', tetraethyl lead in petrol, thalidomide to alleviate morning sickness in pregnant women, tributyl tin as an anti-foulant on ships' hulls, certain plasticizers in medical or domestic items and, most recently, nanomaterials (North and Halden 2014, EEA 2001, 2013). This can lead to social and economic uncertainties when attempts are made to properly assess and mitigate the potential harm being caused, either to humans directly or to the environment.

Adaptive management
Given the present level of uncertainty, actions need to be proportional and incremental. Regional differences in socio-ecological systems are significant; i.e. a good solution in one area may be inadequate (or make things worse) in another. This indicates the importance of utilising local knowledge with the introduction of new practices or techniques. Solutions need to be workable and acceptable, which will demand good communication and dissemination.

Management strategies will be based on the current level of understanding. But to be effective in the longer term, it is essential for management to be adaptive. It should not be restricted by the introduction of well-meaning but counterproductive rules and regulations that may be difficult to alter. As the state of knowledge improves so management strategies and reduction measures, within an adaptive approach, can be adjusted.

8.3

IMPROVED GOVERNANCE

The existing international legal framework of relevance to regulating the transport and disposal of waste, including plastics, was summarised in Chapter 2.2. UNCLOS is a key instrument with regard to marine littering, because it is the only international convention covering land-based sources. Under the General Obligation 'States have the obligation to protect and preserve the marine environment', and Article 194 declares '… prevent, reduce and control pollution from any source'. Clearly this has not been sufficient to stop plastic entering the ocean. This is largely for two reasons: i) the existing framework as currently utilised does not deal adequately with all the key sources and entry points (e.g. transboundary rivers); and, ii) where existing legislation is appropriate there is a failure of implementation and enforcement. This is exacerbated by a lack of standards, more precise obligations and regulation, lack of enforcement and the vast 'policy space'. Regional-scale governance frameworks can provide the means for transboundary sources and inputs of plastics and microplastics. Examples include UNEP Regional Seas organisations and river basin Commissions, such as the International Commission for the Protection of the Danube (Chapter 2.3).

The whole problem with marine debris in general, and marine macro and microplastic debris in particular, could be considered a 'common concern of humankind' (Chavarro 2013). This would require increased international cooperation and common efforts, and is a concept which is increasingly being applied under international law.

Marine macro and microplastic debris could be considered a 'common concern of humankind'

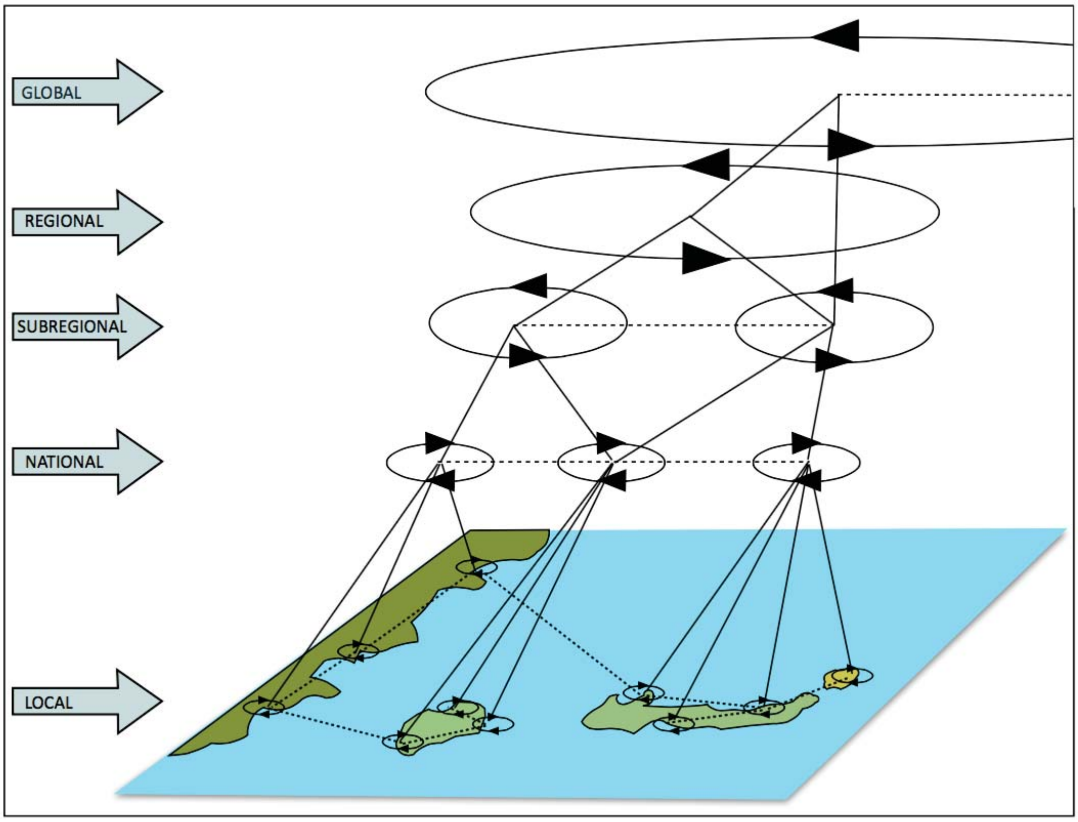
Regulation can be difficult to enforce in some maritime sectors. For example, MARPOL Annex V prohibits the discharge of plastics from ships and other offshore platforms anywhere in the ocean. This prohibition has been supported by the need to maintain a garbage record book on the ship and for ports to provide adequate shore-side waste disposal facilities. But, it is very difficult to enforce the prohibition on plastic disposal at sea without the willing consent of all seafarers. There is sufficient circumstantial evidence, from surveys of marine plastic adjacent to shipping routes (Van Franeker et al. 2011, Schulz and Matthies 2014), to conclude that there is widespread flouting of this legislation. As enforcement would be difficult to achieve by technical or other policing means, solutions need to rely on encouraging behaviour change, and to educate seafarers to accept the need for and embrace the requirements of MARPOL.

Regulation of other aspects of commercial shipping may be easier to implement. Improved governance arrangements to reduce losses of containers at sea are being pursued through the leadership of IMO, in collaboration with the International Labour Organisation (ILO), the UN Economic Commission for Europe and the International Organisation for Standardisation (ISO). These cover technical issues related to the packing and securing of containers.[47] Poorly managed landfill sites or illegal waste dumps can lead to the atmospheric transport of plastic debris, exacerbated by open burning of waste. There is the potential for longer-range atmospheric transport of microplastics and associated hazardous chemicals. This is an area of waste management that may justify additional regulatory scrutiny.

Regulation of marine litter sources can take place at different scales, from local to global. The transport of marine plastics is commonly a transboundary phenomenon, and impacts (ecological, social and

47 http://www.worldshipping.org/industry-issues/safety/Containers_Lost_at_Sea_-_2014_Update_Final_for_Dist.pdf

Figure 8.3



Proposed governance framework for connecting local, national, regional and global scales of governance, showing links (non-binding or legal) (adapted and re-drawn from Fanning et al. 2007)

economic) may be due to plastic originating from outside the jurisdiction where they occur. This limits the extent to which the state experiencing the loss of an ecosystem service can increase measures to alleviate the situation. This illustrates the need to consider marine litter on larger regional and global scales, so that efforts can be coordinated and a 'level playing field' established. Several Regional Seas Conventions and Action Plans have developed marine litter monitoring and assessment programmes (e.g. OSPAR, NOWPAP, MAP, HELCOM) which have helped to establish harmonised techniques, indicators and baselines appropriate to each region. These have been used by member states to implement joint litter reduction actions and measure their effectiveness.

A framework for linking multi-level governance institutions has been proposed at the regional seas scale (Figure 8.3). This was designed for application to the Greater Caribbean Region, extending from the northeast coast of Brazil to Cape Hatteras in North Carolina and including the Gulf of Mexico (Fanning et al. 2007, 2013). However, it has much wider potential for establishing or improving governance frameworks at a regional scale.

The framework is also very relevant to SIDS, at local, national and regional (i.e. SIDS groupings) scales. The SAMOA Pathway (SIDS Accelerated Modalities of Action) has been developed to provide a platform to encourage and sustain partnerships. These are a key requirement for pursuing the SDGs and *'to ensure accountability at all levels'*[48].

Financing improvements in governance

A key element of meeting the UN SDGs is adequate investment in appropriate tools and actions, including those aspects relevant to reducing the input and impact of marine plastic debris. This was emphasised in the Addis Abada Action Agenda of the Third International Conference on Financing for Development, meeting in July 2015[49]. The conference concluded by encouraging the UN Secretary General to convene an inter-agency task force. This would include major institutional stakeholders and the UN system, together with funding and programmes. It is suggested that this may form a suitable framework for addressing the structural reforms needed in many developing nations in order to tackle waste management in general and marine plastics in particular.

The Blue Ribbon Panel of the Global Partnership for Oceans (GPO), for which the World Bank acted as Secretariat from 2012 to January 2015, produced a series of criteria (GPO 2013) for selecting investment options with respect to five principles:

1. **sustainable livelihoods, social equity and food security;**
2. **healthy ocean and sustainable use** of marine and coastal resources;
3. **effective governance systems;**
4. **long-term viability;** and
5. **capacity building and innovation.**

Although the GPO has been dismantled, it can be argued that the selection criteria for improved governance are still valid and equally applicable in the current circumstances of the SDG ambitions. These were proposed to measure the degree to which the investment:

1. **describes a viable** approach for sustaining impact beyond the initial [GPO] investment (through risk analysis and the identification of actions and tactics to mitigate potential risks);
2. **includes an analysis** to evaluate the return on investment, net present value, benefits and costs, and economic, social, and political risks;
3. **addresses major obstacles** to sustainable ocean economies;
4. **has the potential** to create assets that can be invested in or securitized;
5. **develops or introduces** innovative financial tools and structures that support investments in maintaining or improving the health of the ocean, related ocean services, and ocean-based economies;
6. **includes dynamic design** elements that build resilience to future conditions such as climate change, population growth, technology evolution, and geo-political changes;
7. **and is replicable** or has the potential to be self-sustaining from demonstration projects so that other communities or institutions can adopt it without [GPO] funding.

48 http://www.sids2014.org/

49 https://sustainabledevelopment.un.org/frameworks/addisababaactionagenda

8.3

STAKEHOLDER ENGAGEMENT

The term 'stakeholder engagement' has become popular short-hand for the concept of involving of all those parties, or representatives of such parties, who may be in some way able to contribute to, be affected by or otherwise have an interest in a decision or process. It is a term familiar to many in business, government and the UN system. However, it is worth remembering that it may be unfamiliar, and possibly meaningless, to members of the public being considered as stakeholders. It is also important to recognise that when stakeholders are invited to contribute to a process there needs to be a perceived benefit to those who are often giving up their time voluntarily, and sometimes losing income as a result. There is a danger of 'stakeholder fatigue' if the same individuals or organisations are repeatedly asked to contribute (SRAC 2005).

Whatever the terminology used, 'buy-in' for all parties who are somehow affected by or responsible for causing or alleviating a marine litter-related problem is essential to maximise the likelihood of success. Stakeholders can contribute by helping to:

i) **accurately describe** the social and economic context;
ii) **identify the various** elements of the risk assessment adequately;
iii) **suggest appropriate** and relevant measures;
iv) **achieve acceptance** of the measures;
v) **successfully implement** the initiative/instrument(s); and
vi) **monitor the change** in state in response to the measures being introduced.

At the 1992 Earth Summit Agenda 21 recognised the need to engage with stakeholders to facilitate the UN goals relating to sustainable development[50], and identified nine 'major groups' (Box 8.5).

The importance of these groups was reaffirmed at Rio+20, in 'The Future We Want' report, and is included in the Agenda 2030 goals (paragraphs 84 and 89). Paragraph 84 refers to the intention for the High Level Political Forum (HLPF) to carry out regular reviews that 'shall provide a platform for partnerships, including through the participation of major groups and other relevant stakeholders'. Paragraph 89 states that: *'the HLPF will support participation in follow-up and review processes by the major groups and other relevant stakeholders…'*. The development of stakeholder partnerships is viewed as essential in order to achieve the SDGs for the community of SIDS (Chapter 2.1).

Box 8.5

NINE MAJOR STAKEHOLDER GROUPS AS DEFINED AT THE 1992 EARTH SUMMIT AGENDA 21:

1. Women
2. Children and Youth
3. Indigenous Peoples
4. Non-Governmental Organizations
5. Local Authorities
6. Workers and Trade Unions
7. Business and Industry
8. Scientific and Technological Community
9. Farmers

Almost all individuals, community groups and organisations utilise or are affected by plastic products to some degree. However, a number of major categories of stakeholder can be identified with regards to leakage of plastics to the ocean, using the DPSIR framework described in Chapter 10.3 (Box 8.6).

It is common for individuals or organisations to be engaged as facilitators in stakeholder engagement events and initiatives. This is because certain skills are required to gain greatest benefit from the time and effort invested. To assist in the process, a Stakeholder Engagement Manual has been published in two volumes, with UNEP support, that lays out some of the guiding principles (SCRA 2005) and provides a detailed Practitioner's Handbook (AccountAbility 2005).

Why demography matters
Demography involves the study of populations. Human populations can be classified in many different ways,

50 https://sustainabledevelopment.un.org/majorgroups

Box 8.6

MAJOR CATEGORIES OF STAKEHOLDER GROUPS IN CONNECTION WITH MARINE LITTER:

1. **Producers of plastic products**
2. **Consumers of durable plastic products**
3. **Users of plastic packaging**
4. **Users of single-use plastic food and drink packaging**
5. **Users and providers of coastal tourism**
6. **Shipping industry**
7. **Fishing industry**
8. **Waste collection and management organisations**
9. **Aquaculture industry**

including in terms of ethnicity, religious background, social status/caste, degree of poverty or wealth, level of education, age structure, birth and death rates, and gender differences. Those factors contributing to human well-being may be measured using individual descriptors or by using a collective indicator such as the Human Development Index[51]. Many aspects of human society are linked to where individuals fit into the demographic structure of their community. For example, there is a culture of certain groups engaging in the informal recycling industry in India or West Africa, which may be defined according to age, gender, income and social status. Such groups may be most exposed to risk as a result, including significant human health consequences involved in handling plastics associated with electronic goods (UNEP 2016). Countries with a high HDI (e.g. OECD) tend to generate more waste per capita but have more effective waste management systems (Jambeck et al. 2015), with less leakage to the environment. Countries with low HDIs may generate less waste per capita but tend to have poorly developed waste management infrastructure, a lack of funding for improvements and less effective governance structures (UNEP 2016). In addition, there is a legal and illegal trade in waste from North America and Western Europe to Asia and West Africa, as it is often cheaper to transport waste from a high-cost country to a lower-cost country, where education levels, governance, environmental standards and compliance may all be lower.

It is important to include demographics when analysing the generation of marine plastic debris and microplastics, the sectors of society which are affected by potential impacts, and when seeking to change behaviours and promote effective reduction measures. This has been recognised by many individuals and groups seeking to raise awareness about marine plastic issues through campaigns and educational initiatives.

Gender-based aspects

Gender is one of several key factors to consider when assessing the societal response to marine plastics and microplastics. However, its importance may be hidden if social categories in an environmental assessment are not differentiated sufficiently. The influence of gender on the frame of reference for environmental inquiry can be demonstrated using a general model of environmental gender analysis (Table 8.1). This approach could be adapted to take account of other societal characteristics.

Photo: © Carlos Jasso / Reuters

51 http://hdr.undp.org/en/content/human-development-index-hdi

Table 8.1

Foundational questions in the UNEP model of integrated environmental assessment	Gender-sensitive version
1 What is happening to the environment and why?	1. What social forces are producing the changes we see in the environment and why? Are those social forces 'gendered'?
2. What are the consequences for the environment and humanity?	2. What are the ecological changes produced, and what are the consequences for social systems and human security? In what ways are those consequences gender-differentiated? What are the larger social consequences of gender-differentiated impacts?
3. What is being done and how effective is it?	3. Who are the actors involved in responding (at many levels) and are men and women equally engaged? Equally effectively engaged? Are there gender differences in weighing what 'should' be done and in weighing the effectiveness of possible actions and solutions?
4. Where are we heading?	4. Where are we heading and will there be different outcomes for women and men? Are there gender-differentiated perceptions of where we're heading?
5. What actions could be taken for a more sustainable future?	5. What actions could be taken for a more sustainable future that will position men and women as equal agents in taking such actions? What socio-economic factors will shape different outcomes and responses for men and women?

A general model of environmental gender analysis (from Seager 2014).

The extent to which gender per se is the main factor in influencing an outcome will depend on other demographic factors, and these are likely to vary widely on a variety of spatial and temporal scales. For example, an increase in relative wealth or educational attainment may alter the relative importance of gender for individuals or communities.

Gender and fisheries

Commercial fisheries and aquaculture are key economic activities in many coastal regions, and artisanal fishing may be vital for food security. It is a sector that both generates and is impacted by marine plastics and microplastics. Many roles in the sector are differentiated by gender. Women participate throughout most parts of the fishing cycle; including post-capture processing, inland-waters and onshore aquaculture, net-mending, processing, and selling. Women fish in the coastal zones, inshore reefs, and mangroves, they glean at low tide, and cultivate fish fry in the shallows (Lambeth, 2014, FAO 2015), but very few participate in open-sea capture fishing. Open-sea, commercial, and large-boat fishing is generally a male domain. This may render women's fishing contributions less visible - it is left out of most data collection efforts, as well as overlooked in conventional government or aid programs that support fishing and fishers (Siason 2010). If there are to be remediation programmes, financing to cope or reduce plastics pollution, or education programs about plastics, a concerted effort to make these gender-inclusive will be essential.

‘Protecting women’s incomes and preventing the deterioration of their status and position in a context of changing political, social, [environmental] and economic circumstances are essential for achieving the objective of creating responsible fisheries and aquaculture systems.’

(World Bank 2009).

Because of possible differences in the role of women and men in fishing-related activities, there may be significant gender differences in the experience of, knowledge of, and impacts of plastics pollution. Debris buildup in littoral and coastal zones can be severe and is different in character than open-sea plastics pollution, as analyses discussed elsewhere in this report demonstrate. This will have a different impact on women’s fishing activities in the near-shore zone than on men’s fishing in open oceans. Loss of economic activity, damage to wellbeing, and mental health aspects of impacts from degraded environments are, in consequence, all likely to be gender-differentiated, more intense for women in the near-shore fishery and for men in the offshore fishery. Given the constraints of gender roles, including family-care responsibilities, women are typically less able than men to be flexible in seeking alternative livelihoods if their main activity, such as inshore fishing, is damaged.

Demographics and behaviour

Individual consumption of goods and services, personal habits (e.g. use of reusable bags and packaging) and waste practices (such as littering) are key drivers of marine litter. Consumer behaviour derives both from individual preferences and tastes, and from corporate strategies and marketing. Microbeads, for example, were introduced into consumer goods as a top-down corporate strategy, not in response to bottom-up consumer demand.

Rather little is known about the demographic factors influencing perceptions and behaviours of relevance to marine litter, but it seems to assume there will be effects in particular circumstances. For example, a recent study in the USA on the purchase of bottled water indicated that age and income were stronger predictors of consumption than gender. In some countries it is the unavailability of safe potable water that drives the demand for bottled water, irrespective of other factors. Littering behaviours are demographically variable, although cross-national comparisons have not been made and it is not clear to what extent gender is relevant (KAB, 2009, Lyndhurst 2013, Curnow 2005). Clearly, sustained and comparative research is needed to understand the demographic drivers of such behaviours, and thus the possible levers for change. Further research into the demographics of consumer behaviour specific to marine plastic pollution, and willingness to change those behaviours, is needed.

8.5

IMPROVING CORPORATE RESPONSIBILITY AND PARTNERSHIP

Public private partnerships

Public-private partnerships (PPPs) are a common feature of solid waste management in developing countries. The benefits of using PPPs in this sector, according to the World Bank[52], include:

1. **regularising informal waste** picking activities;
2. **introducing and promoting** more output-focussed contracts;
3. **involvement of the private sector in treatment** and disposal projects to introduce more technical innovation into sanitary landfill, recycling and waste to energy projects; and
4. **involvement of the private sector in financing** capital investment.

However, it is important to consider local factors which can influence the successful implementation of a cost-effective and safe partnership. A 2013 review of a PPP waste management scheme in Nigeria (Haruna and Bashir 2013) made a number of recommendations relating to:

1. **creating an enabling environment** to allow the participation of community-based organisation and the various stakeholder groups;
2. **capacity building** in both private and public sectors;
3. **awareness campaigns** on the potential dangers to health;

52 http://ppp.worldbank.org/public-private-partnership/sector/solid-waste

4. **encouraging improved** segregation of waste;
5. **implementation** of strict controls; and
6. **the need for support** from donor agencies.

It would be imprudent to assume that the creation of a PPP for waste management would automatically bring about improvements for all the stakeholders involved.

An example of a successful private participation in infrastructure (PPI) is the provision of ATM-style clean water dispensers in the Mathare slum area of Nairobi in Kenya[53]. A smart card is used to buy water from the automatic dispenser, and the card can be topped up using a mobile phone or at a kiosk. This provides unadulterated water at a lower cost than that provided by traditional water vendors. The PPI is between the Nairobi City Water and Sewerage Company and a Dutch water engineering company.

Extended producer responsibility

Extended producer responsibility (EPR) is a variant of another principle, that of the 'polluter pays'. The polluter pays principle may be justified but it can be difficult to enforce, especially in the case of diffuse sources and legacy pollutants. The OECD has produced a number of guidance documents on the use of EPR, including the cost-benefits involved in the waste prevention and recycling sector (OECD 2001, 2005). EPR schemes have been introduced for packaging waste and for e-waste.

Plastic Disclosure Project
The Plastic Disclosure Project[54] is run by the Ocean Recovery Alliance, an NGO based in California and Hong Kong. The objectives are to:

1. **reduce** plastic waste in the environment;
2. **encourage** sustainable business practices vis-à-vis plastic; and
3. **inspire** improved design and innovative solutions.

The means of achieving these objectives are focussed on encouraging businesses to measure, manage, reduce and benefit from plastic waste, thereby adding benefit to both business and the consumer, while protecting the environment. It works on the principle that if you cannot measure something you cannot manage it. The business case for adopting this approach was published in 2014 (UNEP 2014b).

The role of Life-Cycle Assessment

Life-cycle assessments (LCA) can provide useful guidance to increase the sustainability of production, provided the LCA considers the social and ecological consequences of production and is not limited to economic considerations (UNEP 2015). LCA can be used to provide a basis for decisions about optimal use of resources and the impact of different processes, materials or products on the environment. For example, LCA could be employed to assess the use of plastic-based or natural fibre-based bags and textiles. In one LCA –based study of consumer shopping bags, conventional PE (HDPE) shopping carrier bags were considered to be a good environmental option compared with bags made from paper, LDPE, non-woven PP and cotton, but strictly in terms of their carbon footprints (Thomas et al. 2010). In particular, this analysis did not take account of the social and ecological impact that plastic litter may have, such as the injury or death of marine turtles that mistake plastic bags for jelly fish (Chapter 7.1).

Life-cycle analysis is useful for promoting sustainability, but needs to take account of the full social and ecological consequences of production, use and disposal

In a second example, an LCA-based analysis of textiles – that included factors for human health, environmental impact and sustainability – placed cotton as having a much smaller footprint than acrylic fibres (Mutha et al. 2012). However, it is important to examine what is included under such broad terms as 'environmental impact'. In a third study, an LCA-based assessment of textiles concluded that cotton had a greater impact than fabrics made with PP or PET, and a much greater impact than man-made cellulose-based fibres (Shen et al. 2010). This was on the basis of ecotoxicity, eutrophication, water use and land use. Neither textile-based LCAs considered the potential ecological impact due to littering by the textile products or fibres. Clearly, the scope

53 http://www.bbc.co.uk/news/world-africa-33223922

54 http://www.plasticdisclosure.org/

of an environmental LCA can determine the outcome. Ecological and social perspectives should be included in a comprehensive LCA approach, as well as the time-scales involved. Without such evaluation, decisions made in good faith may result in ineffective mitigation measures, unnecessary or disproportionate costs, or unforeseen negative consequences.

As with all such assessment studies, it is very important to consider the scope, assumptions, limitations, motivations, data quality and uncerta,inties before drawing conclusions about the study's validity and wider applicability.

LCA was used in a systems approach to study waste management options in Sweden (Reich 2005). This illustrated that reducing landfilling and replacing with increased recycling of materials and energy led to lower environmental impact and lower consumption of energy resources. However, there were difficulties in applying this approach due to uncertainties in applying system boundaries (e.g. timing of effects) and weighting factors. It was pointed out that (improved) municipal waste management may diverge from existing economic systems.

LCA has also been used, by a major international manufacturer, to guide the introduction of a more sustainable production model. In this case the analysis revealed that the largest source of waste was from packaging, and this led to changes in product design (Box 8.7, UNEP 2016a).

Box 8.7

PRODUCT DESIGN: UNILEVER

To support its 2020 Sustainable Living Plan, Unilever undertook a Life Cycle Analysis of 1,600 products. Through the analysis, it determined that the largest source of its waste is from packaging, which prompted the company to develop several targets aimed at reducing packaging waste.

1. **Reduce the weight of packaging by one-third by 2020;**
2. **Work with partners to increase recycling and recovery rates in its top 14 countries up to 5% by 2015, and up to 15% by 2020; and**
3. **Increase the recycled material content of its packaging to maximum possible levels by 2020.**

Unilever has published internal design guidelines for packaging engineers and marketers to follow that are consistent with the Sustainable Packaging Coalition, of which it is a member. For all new products and packaging, a scorecard needs to be filled out at each stage of approval, to ensure that it meets all the companies' goals – including those around waste. Successes to date include achieving a 12.5% decrease in weight of margarine cartons by reducing the paperboard thickness, and re-designing a salad dressing bottle to reduce the amount of plastic used by 23%.
UNEP 2016a

8.6

Utilising the GPML and GPWM for dissemination of good practice

Dissemination of good practice and technological advances represent a cost-effective way of encouraging the expansion of litter reduction schemes. Environmental NGOs have been at the forefront of raising awareness but several have also been very influential in developing and disseminating good practice.

The GPML and GPWM provide two mechanisms to encourage collaboration between public and private partners, NGOs, industry sectors and the citizen's groups. The Global Partnership on Marine Litter (GPML) was launched in June 2012 at Rio+20 in Brazil following the recommendations contained in the Manila Declaration on Furthering the Implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities. The GPML, besides being supportive of the Global Partnership on Waste Management (GPWM), seeks to protect human health and the global environment by the reduction and management of marine litter as its main goal, through several specific objectives.

The GPML is a global partnership gathering international agencies, governments, NGOs, academia, private sector, civil society and individuals. Participants contribute to the development and implementation of GPML activities. Contributions may be in the form of financial support, in-kind contributions and/or technical expertise.

Specific Objectives of the GPML:

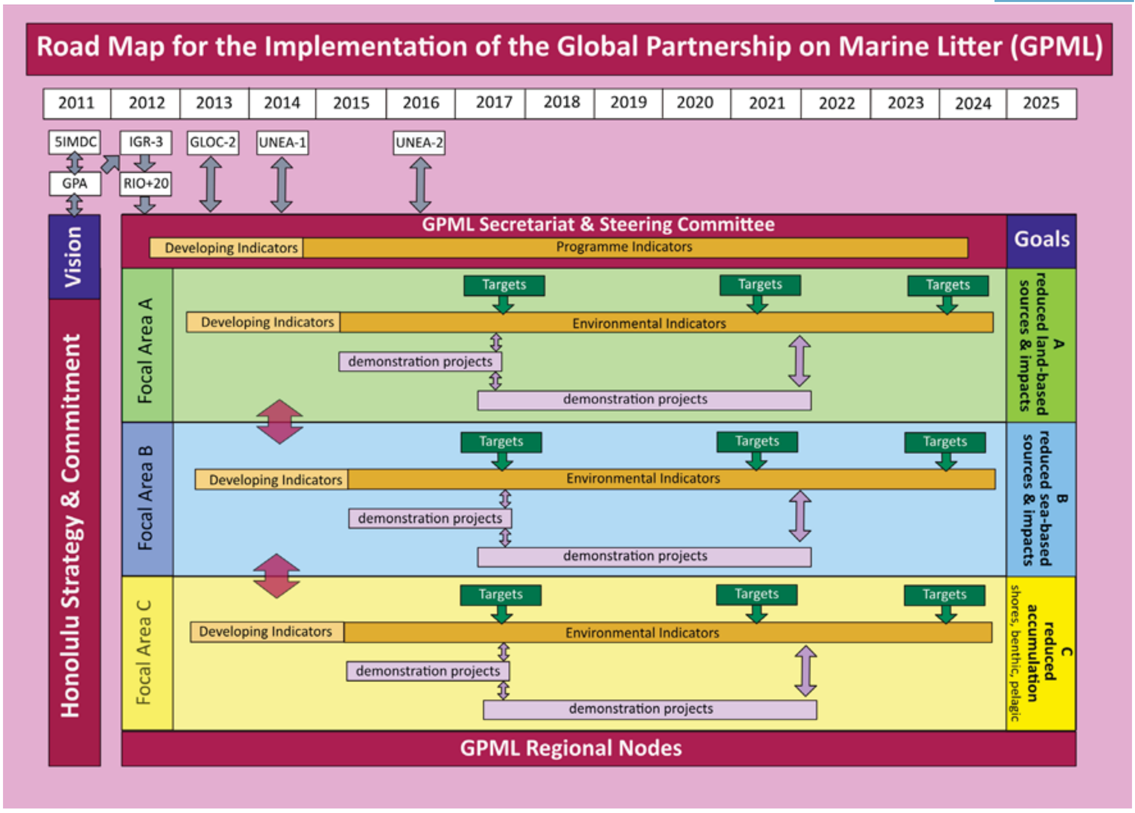
1. **To reduce** the impacts of marine litter worldwide on economies, ecosystem, animal welfare and human health.
2. **To enhance** international cooperation and coordination through the promotion and implementation of the Honolulu Strategy - a global framework for the prevention and management of marine debris, as well as the Honolulu Commitment – a multi-stakeholder pledge.
3. **To promote** knowledge management, information sharing and monitoring of progress on the implementation of the Honolulu Strategy.
4. **To promote** resource efficiency and economic development through waste prevention (e.g. 4Rs (reduce, re-use, recycle and re-design) and by recovering valuable material and/or energy from waste.
5. **To increase** awareness on sources of marine litter, their fate and impacts.
6. **To assess** emerging issues related to the fate and potential influence of marine litter, including (micro) plastics uptake in the food web and associated transfer of pollutants and impacts on the conservation and welfare of marine fauna.

The partnership activities contribute to the GPWM, which will ensure that marine litter issues, goals, and strategies are tied to global efforts to reduce and manage solid waste. The GPML aims to establish a coordinating forum for international organizations, governments, the private sector, and other non-governmental entities, to build synergies and thus to avoid duplication of efforts.

The GPWM is an open-ended partnership for international organizations, governments, businesses, academia, local authorities and NGOs. It was launched in November 2010 to enhance international cooperation among stakeholders, identify and fill information gaps, share information and strengthen awareness, political will, and capacity to promote resource conservation and resource efficiency.

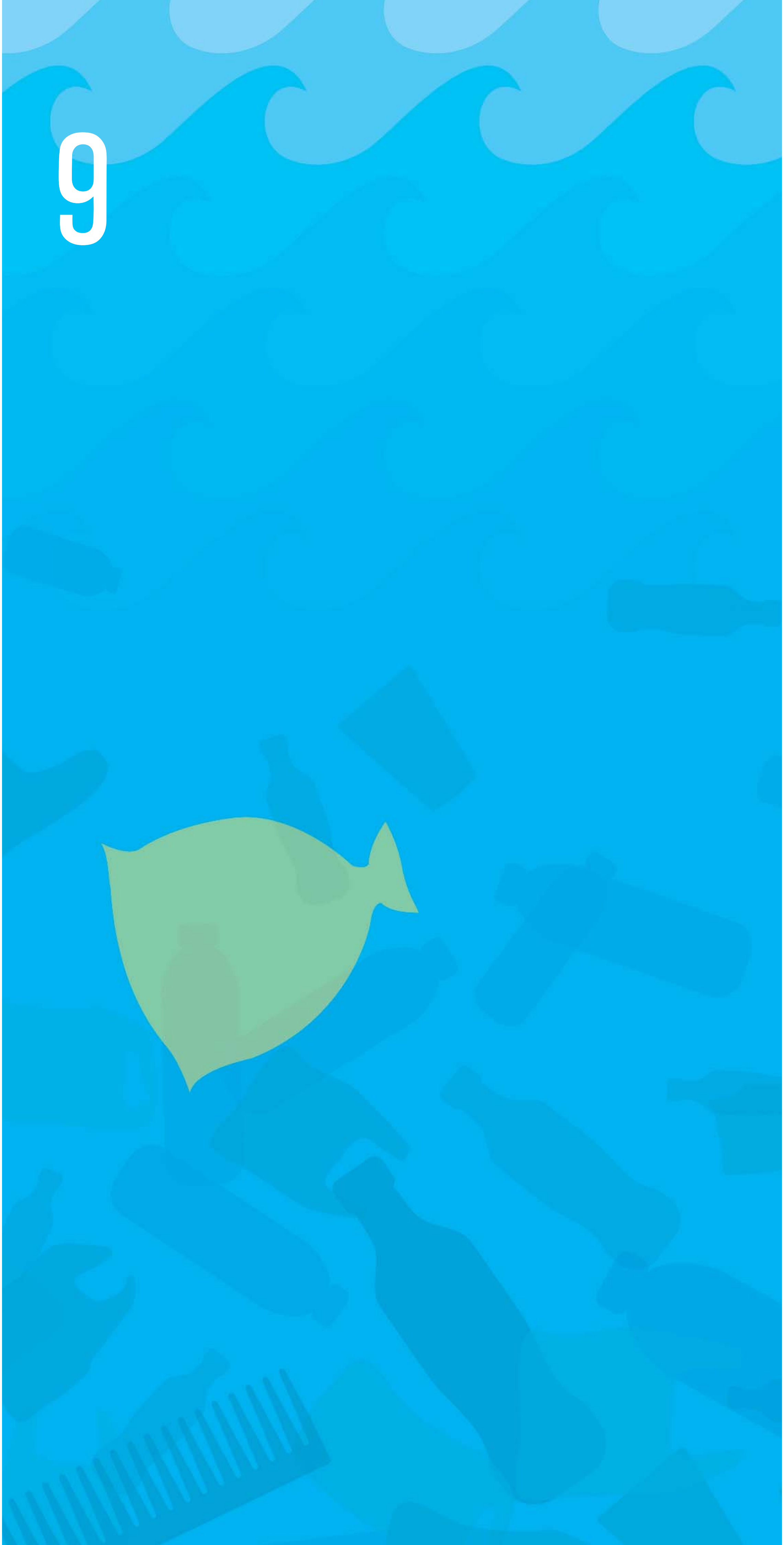
A draft Road Map has been proposed for the implementation of the GPML (Figure 8.4), including the development of indicators and the implementation and testing of potential measures through pilot projects. The Marine Litter Network provides an on-line mechanism to share information. As the GPML continues to develop, the capability of using it to disseminate information and guidance will grow.

Figure 8.4



Draft Road Map for the implementation of the GPML

9



9. A SELECTION OF DIFFERENT TYPES OF MEASURES

9.1

ENCOURAGING CHANGES IN BEHAVIOUR

Attitudes towards marine litter

There is a need for people to make a connection between their consumption patterns and the consequences in terms of environmental degradation (marine litter), and the potential loss of ecosystems services, as stated in Chapter 8.1. There is evidence that at least some sections of the public are aware of our dependency on the marine environment. For instance, as early as 1999, 75% of people in a US survey believed that the health of the ocean is important for human survival (Ocean Project 1999). When focusing on environmental matters related to the marine environment specifically, several environmental topics are of particular interest to the public, such as climate change, chemical pollution and ocean acidification (e.g. Vignola et al. 2013; Peterlin et al. 2005;). Similarly, marine debris is commonly noted as one of the most important issues when people are asked whilst visiting the coast (e.g. Santos et al. 2005; Widmer & Reis 2010). In general, microplastics are not mentioned spontaneously in such surveys. This could indicate either a lack of perceived importance, or simply a lack of knowledge and recognition of this particular environmental issue.

One of the largest scientifically-based assessments of public perceptions was conducted in Europe, in a survey of 10,000 citizens from ten European countries, where respondents were asked to identify the three most important environment matters regarding the coastline or sea (Buckley and Pinnegar 2011). The survey was conducted in the context of assessing perceptions about climate, but allowed the respondents to express their concerns freely. When stating levels of concern for a number of environmental issues, including overfishing, coastal flooding and ocean acidification, the term 'pollution', particularly water and oil pollution, was mentioned frequently. Marine debris-related terms, such as 'litter', 'rubbish' and 'beach cleanliness' were also reported, but much less frequently (Figure 9.1). Such surveys are helpful for catching the public mood, but some caution is warranted. The survey took place in January 2011, just months after the largest oil spill in history, the Deepwater Horizon, took place in the Gulf of Mexico, between April and July 2010. It can be speculated that this may well have influenced the respondents concerns.

In addition to research examining the level of importance individuals place on the marine environment and the various perceived threats to it, some studies have started to explore the public's current understanding about macro marine debris more specifically.

Figure 9.1

Main responses from a multinational sample from 10 countries (n = 10,106) to a qualitative question that asked individuals to state the three main marine environmental matters. Frequency of responses is illustrated by the size of the text, with pollution noted most often (reproduced from Buckley and Pinnegar 2011).

One multinational survey (MARLISCO[55]) explicitly examined perceptions in different societal groups about macro marine debris. A number of sectors were chosen, including: design and manufacturing, maritime industries, policy makers, media organizations, education and environmental organizations. This was not intended to be representative of society in general, but that portion of society that might be considered as being more connected to the issue of marine litter and microplastics. With a sample of just under 4,000 respondents from over 16 mostly European countries, the MARLISCO survey found that the majority of respondents were concerned about marine litter and perceived the marine environment as being highly valuable to society. There was a belief that the situation regarding marine litter was worsening, and that most marine litter was derived from the sea (B. Hartley unpublished data). This survey also found that all groups significantly underestimated the proportion of marine litter items composed of plastic by about 30% (B. Hartley unpublished data). A separate survey on UK commercial fishers found similar patterns in perception, whereby fishers underestimated the proportion of litter that is plastic, and on average, were unsure whether marine litter was increasing or decreasing (Defra report, forthcoming).

At more local scale, a beach visitor survey in Chile revealed that most visitors reported that they did not dispose of litter on beaches, despite a large proportion of marine debris being left by visitors in general (Eastman et al. 2013; Santos et al. 2005). Even though respondents generally claimed not to be individually responsible, they did identify the overall public to be the main source of debris (Santos et al. 2005, Slavin et al. 2012; Eastman et al. 2013). In terms of the effects and impacts of marine debris, the main problems that beach users identified were related to the impact on marine biota, human health and safety, and attractiveness (B. Hartley unpublished data; Santos et al. 2005; Wyles et al. 2014; Wyles et al. under review). Thus, these findings suggest that beach-users and commercial fishers have a basic understanding of marine litter in general.

Changing behaviour

If meeting a litter reduction target depends on anything other than a simple technical solution, then the solution will be much more complex. Very often it will require changes in public perceptions, attitudes and behaviour. The introduction of IMO MARPOL Annex V banned the introduction of plastic waste into any part of the ocean, but it is routinely ignored. Legislation will have limited effectiveness if there is significant non-compliance, combined with low rates of detection and enforcement.

Whatever approach is taken it is very likely that some degree of behaviour change will be required if the measure is to be implemented successfully. In many theories of behaviour change, two key factors are noted as important: i) perceptions of responsibility, and ii) perceived control or efficacy (e.g. Steg et al. 2013, 2014). Out of two people who have limited control over an issue, the one who has higher perceptions of control is more likely to act. Consequently, the marine litter initiatives that provide individuals the facilities and thus the ability to dispose of marine litter (e.g. floating reception barges), or recycle their fishing lines (e.g. Reel in and Recycle initiative) and make these visible, will help to strengthen these perceptions of control thus further encourage the positive behaviour (Steg and Vlek, 2009).

Perceived responsibility is also important in the context of marine litter. Large-scale surveys within the European MARLISCO project showed that general public respondents perceived sectors to vary widely in responsibility. Industry and government / policy makers and commercial users of the coast were seen as high in responsibility. However, the respondents also held themselves responsible. Given the many sectors and actors in society involved in the issue of marine litter, another promising example is the programme Amigos del Mar (Friends of the Sea) in Ecuador, led by the Comisión Permanente el Pacífico Sur (CPPS), which targets students, fishermen and tour operators as key influencers. Therefore, it is necessary to engage all sectors, emphasise their responsibility (e.g. by illustrating the cost of action and inaction) and work cooperatively to help to address the problem of marine litter.

There have been a large number of campaigns directed towards raising awareness and improving education about marine litter issues, and some of these are described below to illustrate the range of approaches that have been used. A collation of marine debris public awareness campaigns has been prepared in support of the CMS (CMS 2014a), together with recommendations of Best Practice in the commercial shipping and fisheries sectors (CMS 2014b).

55 www.marlisco.eu

Fishing industry

A number of campaigns have targeted the fishing industry. CCAMLR has developed several initiatives to educate fishers and fishing vessel operators including the production of posters in multiple languages to be placed on fishing vessels (required to be displayed since 1989) to raise awareness and help to reduce pollution (Figure 9.2). This has been backed up with specific legislation where specific risks have been identified.

Coastal tourism

Initiatives to reduce the impact of coastal tourism in many regions have been initiated by NGOs, local authorities and the tourism industry itself. Discarded cigarettes are one of the commonest items found on recreational beaches, especially near popular tourist destinations (Ocean Conservancy 2014). A number of NGOs have attempted to change public behaviour (Box 9.1). For example, the NGO Marevivo ran a campaign in Italy in which 100,000 reusable pocket-sized ashtrays were handed out to visitors of Rome's beaches[56]. UK-based Surfers Against Sewage run the 'No Butts On The Beach' campaign, featuring a message displayed in an eye-catching manner, as well as a more conventional logo (Figure 9.3).

56 http://www.marevivo.it/mare_cicca2011.php

Figure 9.2

Posters issued by CCAMLR for display of all fishing vessels operating within the CCAMLR region. Reproduced with permission from CCAMLR

Figure 9.3a

Figure 9.3b

Examples of campaign posters: (a) Logo of the 'No Butts On The Beach' campaign, an example of a special interest group, the UK-based Surfers Against Sewage, to reduce the disposal of cigarette butts (or stubs) on beaches[57]; (b) sign on a tour boat in the Galapagos Islands. ©Peter Kershaw;

In Puerto Ayora in the Galapagos, a retired fisherman turned artist has constructed impressive sculptures from cigarette ends (butts/stubs) he picks up from the streets. He displays these at the harbour side and explains to visitors about the damage littering can cause (Figure 9.6).

The release of helium-filled balloons is popular in some cultures and is common on some cruise lines. Several NGOs and farming organisations have campaigned to raise awareness and try to restrict their use. This includes the 'Don't Let Go' campaign, promoted by the UK-based Marine Conservation Society (MCS), to educate the public about the consequences of releasing helium-filled balloons, and encourage good practice.

The tourism industry has also been active in helping to change attitudes and behaviour, and reducing single-use plastics, amongst tourists, hotels and tour operators (Figure 9.5). However, engaging the wider food value chains involved in tourism will be essential to bring about a significant reduction in plastic consumption for vulnerable areas such as SIDS.

Education and citizen science

Informing people about marine litter and the impact it can have is regarded generally as an important step in changing behaviours and instilling a more responsible attitude towards protecting the environment. This can involve both formal education and more informal initiatives. All ages can take part although efforts are often directed towards school-age students in the hope that any changed attitudes will persist and may influence their peers and elders. This educational philosophy informed the development of the European MARLISCO project (Marine Litter in European Seas – Social Awareness and Co-Responsibility). A number of educational activities were developed, including educational packs for different year groups and a video competition for schools. It also included a 'serious game' designed for youngsters, to pro-

57 http://www.sas.org.uk/campaigns/marine-litter/

Figure 9.4

Awareness-raising in Puerto Ayora, Santa Cruz Island Galapagos, to discourage dropping cigarette ends – 'Nico' the cigarette man, and his 'feathered' friend. Created by Miguel Andagana (pictured), a former fisherman who survived 76 days adrift in 1985, and now campaigns to keep Galapagos free from marine litter. ©Peter Kershaw 2015

Box 9.1

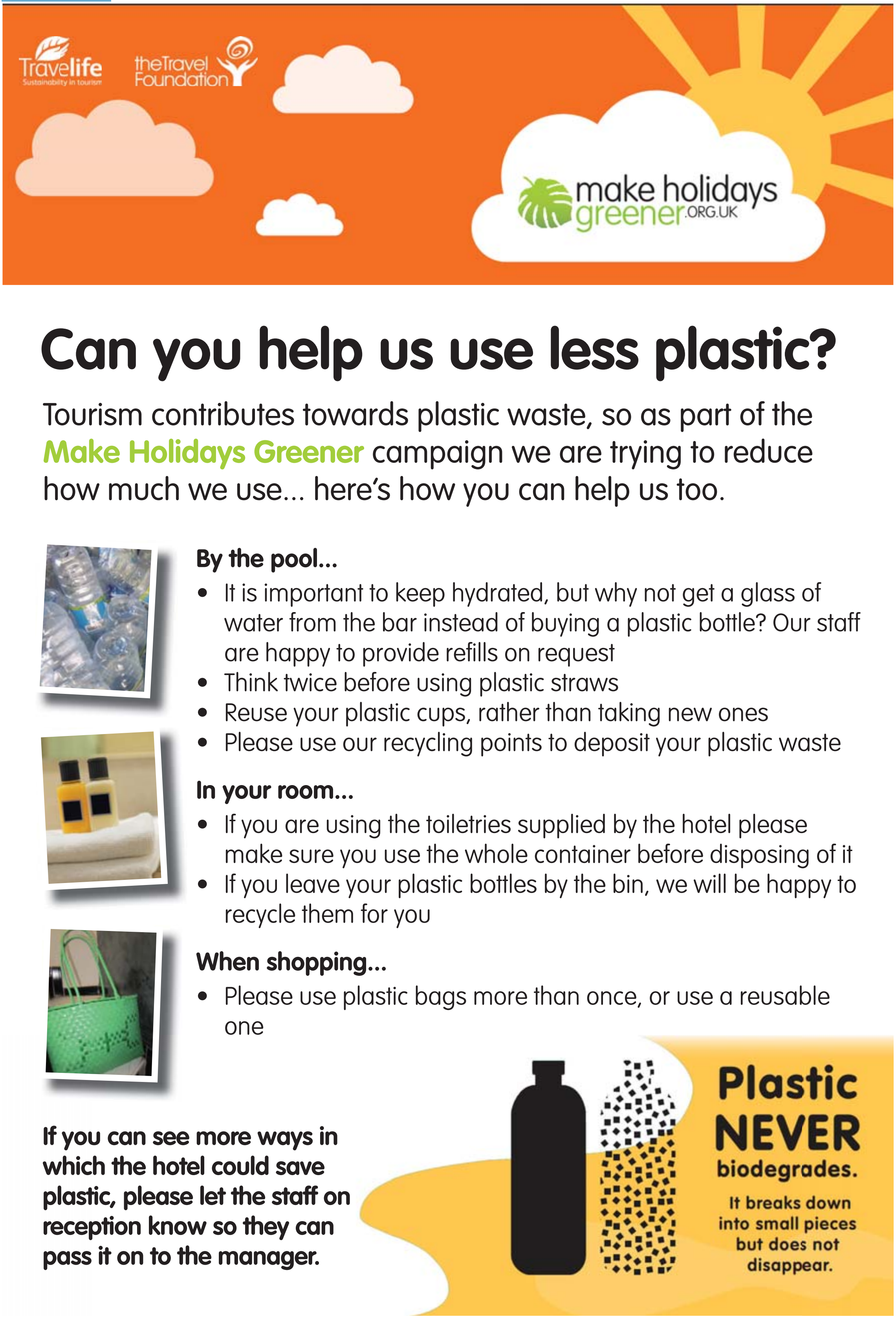
AWARENESS RAISING AND TARGETED EDUCATION CAMPAIGNS

Green Blue initiative (UK), led by the Royal Yachting Association and the British Marine Federation to raise awareness among the recreational boating community, providing education, solutions and toolkits http://thegreenblue.org.uk/About-us

NOWPAP – Guidelines for tourists and tour operators in the NOWPAP region, setting out best practice for activities such as: cruising, fishing, diving, camping and barbequing (NOWPAP 2011)

TreadRight Foundation – encouraging sustainable tourism http://www.treadright.org/
Taken from Gitti et al. 2015

Figure 9.5



Poster issued by a company involved of the tourism[58] sector, with the aim of bringing about more sustainable tourism Reproduced with permission from the travel foundation.

vide the opportunity to help one of eight characters, from different sectors, in a fun way to choose the most responsible behaviour in different situations[59]. The game is available in 15 European languages, so is suitable for use in the Americas and parts of Africa. On a larger scale, UNEP launched a MOOC (Massive Open On-line learning Course) on marine litter in October 2015, in association with the Open University of the Netherlands. Approximately 6000 participants enrolled.

Citizen science is a form of 'learning by doing'. Citizen science initiatives can be very effective at both raising awareness and collecting information and monitoring data about the state of the environment. One of the most impressive examples was an initiative carried out in Chile called the 'National sampling of Small Plastic Debris'. This involved nearly 1000 schoolchildren from 39 schools on mainland Chile and on Easter Island. The organisers approached schools and social organisations that were already part of the citizen science project 'Scientíficos de la Bastura' (Litter Scientists). The sampling protocol and results were reported by Higdalgo-Ruz and Thiel (2013). An important part of the exercise was the publication of a children's storybook 'The journey of Jurella and the microplastics' (Nuñez and Thiel 2011). This 28-page illustrated book, telling the story (in Spanish) of a local Chilean fish confronting the problem with marine litter, was given to each child participating in the scheme. The children also learned important skills in following instructions, carrying out a survey accurately, handling the samples and interpreting the results.

The NGO Thames 21 promotes Thames River Watch, in the UK, providing support and training for volunteers who carry out sampling and analysis throughout the tidal reaches, including the occurrence of plastic litter. The results are published on an interactive webpage[60]. Citizen science has also been used to sample riverine litter in Chile (Rech et al. 2015).

The increased use of mobile phones, and the ability to readily download applications, prompted the development of an app to report marine debris finds by people using the shoreline. This was the result of a collaboration between the NOAA Marine Debris Program and the Univ. Georgia in the USA, and the results can be viewed on-line[61].

Informal groups and NGOs have played an important role in both raising awareness and in promoting citizen science programmes. Good examples include the 5 Gyres organisation[62], who have organised a series of sea-based expeditions and land-based initiatives, including in the Arctic, and the more recent all-female eXXpedition sailing campaign who have been nominated as Gender Heroes under the Stockholm-Rotterdam-Basel Convention Synergies platform[63].

The role of special interest groups

Recreational fishers

Recreational coastal fishing is a very popular activity in many countries and regions (e.g. Font and Lloret 2014). Unfortunately, it results in the deliberate or accidental discarding of large quantities of fishing line, hooks and other paraphernalia (Lloret et al. 2014). In the Republic of Korea, recreational fishing is widespread. The impact of fishing gear on birds is particularly marked, including the internationally endangered Black-faced spoonbill. A variety of measures has been taken to raise awareness of the effects of fishing gear on wildlife amongst this special user group, with the aim of reducing the impact. These have included focussed meetings, a website to report monitoring results, a well-illustrated booklet (Figure 9.6), publications in the scientific literature (Hong et al. 2013) and a Youtube™ video, released to mark the 2014 'International Day for Biological Diversity[64].

Surfers

NGOs with an environmental motivation have been at the forefront of raising awareness about the extent and impact of marine litter. However, other groups with a special interest in the oceans have proved to be very effective. The Surfrider Foundation is active in Europe and North America and has promoted the

58 http://www.thetravelfoundation.org.uk

59 http://www.marlisco.eu/serious-game.en/articles/serious-game.html

60 info@thames21.org.uk

61 http://www.marinedebris.engr.uga.edu/

62 http://www.5gyres.org/

63 http://www.brsmeas.org/ManagementReports/Gender/Gender-Heroes/GenderHeroesExxpedition/tabid/4802/language/en-US/Default.aspx

64 http://www.youtube.com/watch?v=jh7ns2TjP6Y

Figure 9.6

Booklet cover with extracts to illustrate the impact of recreational fishing gear on wildlife, in particular the internationally endangered Black-faced Spoonbill, with best practice guidelines to reduce the impact; acknowledgement of images: top right - Yamashiro Hiroaki, bottom right - Young Jun Kim. Reproduced with permission from OSEAN.

'Rise above plastics' mission, advocating the reduction in single use plastics and improved recycling[65]. Surfers Against Sewage is a UK-based group set up to campaign for improvements in sewage treatment prior to discharge into coastal waters, primarily over concerns about surfers becoming infected by swimming in sewage-polluted water. Their interests have expanded to include sanitary-related and other types of litter, by running a series of striking campaigns; e.g. 'Think Before You Flush', 'Break The Bag Habit', 'Unidentified Floating Objects', 'Mermaids' Tears', 'No Butts On The Beach' and 'Return To Offender' (SAS 2014; Figure 3.8).

9.2

REDUCTION MEASURES – BATS, BEPS, MBIS AND LEGISLATION

Technical measures in brief

This section provides examples of technical measures which can be described loosely as:

1. **Best Available Techniques,** or Best Available Technologies BATs);
2. **Best Practices,** or Best Environmental Practices (BEPs);
3. **Market-based Instruments** (MBIs); and
4. **Legislation –** regulation by governments or Commissions

The section is not intended to provide an exhaustive list of possible measures, but to provide illustrative examples of measures which have proved to be effective, and which have the potential to be more widely applied. In some cases, the measures are enforceable by legislation and in other cases they may be adopted by the public or private sector, as an appropriate response to improving waste management and reducing the flow of plastic to the ocean.

Guidelines for carrying out a risk assessment and selecting appropriate measures are outlined in Chapter 10.

65 http://www.surfrider.org/programs/plastic-pollution

Utilising BATs to reduce loss of fishing gear

Abandoned, lost or otherwise discarded fishing gear can have a significant impact both on depleting commercial fish and shellfish stocks and causing unnecessary impacts on non-target species and habitats. The importance of this issue was recognised formally at the 16th meeting of the FAO Committee on Fisheries in 1985, and led to publication of a key report by FAO and UNEP (Macfadyen et al. 2009). There are several initiatives supported by international and national bodies to reduce the amount of derelict fishing being generated, remove lost and abandoned gear, and develop good practice for reducing ghost fishing and the safe recovery of trapped animals (safe for both the entangled animal and the rescuer; FAO 1993, 1995).

Better marking of gear will allow determination of ownership more readily and is one approach to reducing ALDFG, particularly that element associated with Illegal, Unregulated and Unreported (IUU) fisheries. In addition, technical changes in how gear is constructed and deployed can also reduce gear loss and reduce potential ecological damage (Box 9.2; WSPA 2013). FAO is in the process of developing technical guidelines for the application of an international system for the marking of fishing gear, and the EC has introduced regulations for marking passive fishing gear (EC 2005). Such schemes could be combined with leasing arrangements to encourage the return of unwanted gear rather than deliberate discarding. The IWC has published guidance on gear marking, and details of national initiatives, as it believes there are significant advantages from a cetacean entanglement perspective (IWC 2014).

Using legislation to reduce the impact of fishing activities

The EC has introduced regulations regarding the marking of passive fishing gear (EC 2005) and the retrieval of lost fishing gear (EC 2009), which should act to reduce ALDFG in EU waters. The CCAMLR introduced a Conservation Measure in 2015, covering general environmental protection during fishing (CCAMLR 2015). The Commission acknowledged the impact of fishing-related plastic waste, singling out the significant numbers of fur seals entangled and killed by plastic packaging bands. These are routinely used to tie together plastic bait boxes, used by longline fisheries. The measure made several specific requirements (Box 9.3). This strengthens previous

Box 9.2

EXAMPLES OF TECHNOLOGICAL MODIFICATIONS OF NETS TO REDUCE LOSS:

- **Mandatory lights on gill nets, with strong solar-powered batteries**
- **Technology that makes the net sink or drift at a depth where its impact on animals is likely to be low**
- **Biodegradable materials for making nets (need to be strong and cheap)**
- **Use of steel cables for securing buoys**
- **Labelling of nets (chemicals, colour, tags, transmitters)**

(from: Proceedings of the Untangled symposium, December 2012; WSPA 2013)

legislation which did appear to have reduced the entanglement rate, but a residual level has persisted (Waluda and Staniland 2013).

Utilising BATs to improve solid waste management

A functioning waste collection system helps protect and improve public health, reducing deaths and illnesses related to the presence of waste (UN HABITAT 2010). If waste is not collected, it can end up accumulating in open spaces (informal dumps) and clog drains or waterways. This can attract disease-carrying insects and animals (e.g. mosquitos and rats), cause floods, and is a hazard to people (e.g. children may play with it) (UN HABITAT 2010). Open burning is also very common for uncollected waste as a means to reduce its volume, which can lead to respiratory health problems (UNEP 2016a, UNEP 2015).

Following the Jambeck et al. (2015) analysis of solid waste mismanagement, a study[66] was undertaken to address five questions (Box 9.3) on the sources of land-based plastic and potential measures for reducing inputs to the sea (Ocean Conservancy 2015). The study identified five countries as amongst the largest potential contributors from inadequately managed solid waste, and examined improvement opportunities, that exist today, for each that would be likely to yield the greatest benefit. Five technological solutions emerged as being of most relevance, although there were differences in which were judged most appropriate for each country (Table 9.1).

These 'downstream' measures may have great potential for plugging some of the leaks in plastic management, provided sufficient investment is made, but they will not encourage the minimisation of waste generation. In the longer term there needs to be a movement towards a more circular plastic economy (WEF/EMF/MCKINSEY 2016, Chapter 8.1). The study has attracted some criticism as placing too much emphasis on 'downstream' solutions for plastic waste, especially incineration; i.e. for failing to consider technologies and other measures for significantly

66 'Stemming the tide: land-based strategies for a plastic-free ocean', a study led by Ocean Conservancy with McKinsey Consultants as an initiative of the Trash Free Seas Alliance®

Box 9.3

QUESTIONS ADDRESSED BY THE STUDY 'STEMMING THE TIDE – LAND-BASED STRATEGIES FOR A PLASTIC-FREE OCEAN':

1. What are the cornerstones of a concerted programme for global action to address this issue?
2. What are the origins of ocean plastic debris, and how much does it leak into the ocean?
3. Are there significant differences across regions that require different types of solutions?
4. What leakage-reduction solutions are available, and what are the relative economics and benefits of each?
5. What can be done to trigger the implementation of leakage-reduction measures in the short, medium and long term?

(OCEAN CONSERVANCY 2015)

Table 9.1

BAT option	China	Indonesia	Philippines	Vietnam	Thailand
Collection services	Y	Y		Y	
Close leakage points within the collection system	Y	Y	Y	Y	Y
Gasification		Y	Y		
Incineration	Y			Y	Y
MRF*-based recycling	Y	Y	Y	Y	Y

Assessment of potential BATs for five countries identified as having inadequate waste management practices (Ocean Conservancy 2015).

* MRF- Material-recovery facility, used for separating different materials from the waste stream

Box 9.4

BEST PRACTICE CONSIDERATIONS FOR INTRODUCING RECYCLING BINS IN PUBLIC PLACES:

1. NUMBER OF BINS/MATERIAL STREAMS
   a. Materials generated at that location (quantity and type)
   b. Value of different materials (e.g. mixed recyclables or separate bin for plastic bottles)
   c. Convenience for user

2. CONTAINER
   a. Ease of use (e.g. size and shape of hole, height of bin)
   b. Ease of understanding (e.g. clear banner, logo or sign)
   c. Convenient location
   d. Durability and cost

3. SIGNAGE AND COMMUNICATION
   a. Consistent use of colour for materials (e.g. green for organics)
   b. Use of images
   c. Bold text (e.g. white on colour)

D. USE OF SLOGANS AND HUMOUR

UNEP 2016a

reducing the quantities of waste being produced. This includes solutions currently being developed and promoted in some of the countries highlighted as being the largest contributors of mismanaged waste[67]. The debate sparked by a single report serves to emphasise that BATs, or any other measures, have to be considered as part of an overall waste reduction strategy, with an emphasis on 'upstream' options. This process needs to be guided by a risk-based analysis involving all relevant stakeholders, with due consideration given to short-, medium- and longer-term objectives (Chapter 8.4).

Plastics-to-fuel

In some circumstances an alternative form of energy/material recovery may be feasible. This involves the thermal decomposition (pyrolysis) of waste plastic, breaking down the complex polymer molecules to produce a vapour. This is condensed to form synthetic crude oil or (uncondensed) synthetic gas. This can be further fractionated in a typical refinery and may be appropriate for types of plastic that are more challenging to recycle, such as LDPE, PP, PS and plastic films (ORA 2015).

Provision of bins for recycling and waste collection in public spaces

A key component of resource recovery in public spaces is having the correct waste infrastructure in place as well as using communication tools and education programs to ensure that people participate

67 http://www.no-burn.org/downloads/Technical_critique_Stemming_the_Tide_report.pdf

Figure 9.7

Examples of waste bins in North America. Images by Belinda Li, Tetra Tech EBA, Vancouver, BC, Canada and Geoff LMV CC via flickr CC

and use bins correctly. The material streams collected may also need to vary depending on the location of the bins and the waste generated there. Keeping colour schemes consistent for different material streams and using clear, bold images and text helps users to make a quick decision about where to throw their materials (Figure 9.7). Best practice should incorporate consideration of a number of components (Box 9.4).

Deposit-refund schemes - MBI

Among all the different incentives, one of the most effective is the deposit-refund scheme (Box 9.4): at the purchase the consumers have to pay a small deposit for the objects bought (usually plastic or glass bottles). This sum is given back to the person that returns them (Lavee 2010), and can occur at a national, sub-national or local scale.[68] From an economic perspective deposit-refund schemes are considered to be efficient. In addition, this tool has a potentially wide application – it could be used not just for bottles and plastic bags, but also for food containers, for batteries, electronic equipment, white goods and automobiles (ten Brink et al. 2009). The costs of implementation of such schemes depends on the quantity of materials returned. Furthermore, if the recovery system is managed as a monopoly the costs of the system may rise, reducing its efficiency further (Lavee 2010). However, many European countries have well-established schemes, including the use of automatic 'return-deposit' machines in Germany and Finland, and returns of up to 90% for PET are common.

Payments and subsidies - MBI

One example of a payment or award for action is that of paying fishermen for reporting on and removing of litter. For example, in South Korea in 2001 the government established a compensation 'buy-back' scheme for fishermen that removed nets and other litter from sea.

In the European Union the Directorate General for Maritime Affairs and Fisheries made a call in 2014 to explore the "feasibility and economic viability" of fisherman in the EU fleet to abandon fishing and to reassign some vessels towards addressing marine litter, whether through the collection of litter or awareness raising.[69] The EU would support fisherman by co-financing the

68 http://www.ambiente.gob.ec/ecuador-incremento-la-recoleccion-de-botellas-pet-en-2012/

69 http://ec.europa.eu/dgs/maritimeaffairs_fisheries/contracts_and_funding/calls_for_proposals/2014_24/doc/call-for-proposals_en.pdf

Box 9.5

EXAMPLES OF DEPOSIT SCHEMES AT DIFFERENT SCALES:

National - Ecuador
PET bottles are used extensively in Ecuador for supplying clean drinking water.
A deposit scheme of US$ 0.02 per PET bottle was introduced in 2011. This led to an increase in PET bottle recycling from 30% in 2011 to 80% in 2012, when 1.13 million of PET bottles were recycled out of 1.40 million produced.

Sub-national – State of California, USA
California has had a bottle deposit since 1987, with a rate of US$ 0.05 for bottles, < 0.71 l and US$ 0.10 for bottles > 0.71 l. It is estimated that the scheme has resulted in the recycling of about 300 billion (3 x 1011) aluminium, glass or plastics drinks containers (CalRecycle 2015).

Local - Boronia West Primary School, Victoria South Australia
At the schoolchildren's suggestion, a deposit scheme was introduced for plastic wrappers on goods sold in the school refectory. This was motivated after learning about the impact of plastics on wildlife (personal communication Britta Denise Hardesty 2015)

Taken from Gitti et al. 2015

crew and vessel operational costs for the first year of operations outside of fishing (MARE/2014/24). However, the effectiveness of these kinds of schemes is still not clear, some arguing that they could provide perverse incentives.

Taxes and fees – creating incentive while raising revenues – MBI

Taxes have been considered by economists to be one of the most effective tools as they can offer a disincentive to polluting behaviour and inefficient use or resources and at the same time ensure a revenue for the state, with generally low implementation costs (Oosterhuis et al 2014). Revenues coming from environmental taxes, or at least part of them, can be reinvested for the environment. For example, in 1981 the National Assembly of Cuba approved the Law 81, also known as 'Environmental Law', that allows the use of economic tools such as taxes for the development of activities that positively impact the environment (Whittle and Rey Santos 2006).

Taxes can be applied to different stages of the production process: they can affect the production and consumption phase. They can be designed for general environmental or revenue raising issues (e.g. waste charges to help finance waste management collection and infrastructure), and also motivated specifically by marine litter considerations. One of the longest established examples is the Irish plastic bag levy (Box 9.6)[70] . The EU has adopted a Directive providing definitions and guidance on encouraging the reduction in use of lightweight plastic carrier bags (defined as having a wall thickness of <50 μm) by Member States, including the use of MBIs (EC 2015).

However, the revenues raised from environmental taxes are at risk of decreasing over time. This can

70 http://www.marine-litter-conference-berlin.info/userfiles/file/online/Plastic%20Bag%20Levy_Doyle.pdf

Box 9.6

THE IRISH PLASTIC BAG LEVY

In 2002 the Irish Government added a fee of 15 cents per plastic bag, increased to 22 cents in 2007. After its introduction, sales distribution of bags in retail outlets dropped by 90%. In addition, the money collected thanks to the levy is reinvested in anti-litter initiatives, used to finance the Environmental Protection Agency R&D and the initiatives undertaken by community groups and others for the protection of the environment (e.g. Coastwatch, An Taisce). The levy was also very cost-effective, as stores could use the existing Value Added Tax scheme for collecting and reporting the levy (Convery et al. 2007, Pape et al. 2011)

Taken from Gitti et al. 2015

happen for two main reasons, firstly, if the tax is successful and results in behaviour change, or, if the rate is nominal and erodes with inflation. Indexing taxes with inflation or gradually increasing rates can help to maintain revenues and the positive environmental impacts of a tax (OECD 2011). With all such MBI schemes, there needs to be an assessment of the consequences of their introduction, to ensure there are no perverse incentives or unforeseen negative consequences.

Taxes to meet the needs of SIDS and other small ocean islands

In the Caribbean the waste generated by cruise ships has placed ports of call under stress, and created tension between island authorities and cruise line operators, and furthermore with neighbouring islands as they compete for traffic. The Organisation of Eastern Caribbean States (OECS) and the Caribbean Community (CARICOM) tried several times to face the problem by creating a passenger head tax to cover the costs of infrastructure, including for managing waste, but have been unsuccessful. All those attempts often faced opposition from cruise operators (Chin, 2008). For instance, in 1999 Carnival Cruise Lines boycotted Grenada after they introduced a USD 1.50 per passenger tax to fund a World Bank constructed sanitary landfill for the island (Klein, 2002). More positively, non-Ecuadoran visitors to the Galapagos Islands have to pay a fee of US$ 100 on arrival to help maintain the unique ecology of the archipelago (Box 9.7).

Port reception facilities – MBI

Payments for using port reception facilities to dispose of waste have to be structured so as to recover the cost of providing the service but to avoid creating an incentive to dispose of it at sea (Box 9.8). This is important, for example, for coastal areas close to the busy cruise destinations, such as Miami and Alaska (US), Nassau (Bahamas), Cozumel (Mexico) and several SIDS, that are also likely to experience high concentrations of marine litter associated with discharges of litter from the cruise sector (Brida & Zapata 2010).

If correctly managed, port reception facilities may be one of the most important tools for addressing waste generated at sea from all sectors (Newman et al., 2015). Using port reception facilities to dispose of waste generally includes a fee for the service; the price is often determined by several variables such as the size of the ship, the volume of waste, and the type of waste. This can act as a disincentive (Sherrington et al. 2015). In some cases, reductions may be offered for ships with better-developed waste management strategies (EMSA, 2005).

Box 9.7

GALAPAGOS ARCHIPELAGO (ECUADOR)

In the Galapagos Islands there is a tourist tax that aims to have an incentive effect (limiting the number of tourists and hence pressure on the islands), and raise revenues. The rate of tax depends on the age and provenience of the tourist. For example, the tax for foreign tourists, non-residents of Ecuador over 12 years is of USD $100, while tourists and foreign nationals residing in Ecuador, over 12 years have to pay USD $6. The total revenues coming from this tax are reinvested among several entities: 10% goes to INGALA (Galapagos Immigration), 5 % to the Ecuadorian Navy, 10% to the Consejo Provincial de Galapagos, 25% to the Galapagos Municipalities, 5 % to the Galapagos Marine Reserve, 5 % to Inspection and Quarantine Services and the last 40% to the Galapagos National Park. (Parque Nacional Galapagos Ecuador, 2013).

Additional charges are included in fees for boat charters to certain islands, which are under greater pressure due to the nature of the environment and their popularity, to further control visitor numbers.

Taken from Gitti et al. 2015

In some ports, the costs of waste disposal can act as a barrier to their use and may incentivise dumping. A possible solution to this problem is the application of a 'No Special Fee'. Such a fee includes in the port fee the cost of delivering waste, irrespective of the quantities discharged. The no special fee system effectively prevents cost from becoming a disincentive for using port reception facilities; similarly, the simplicity of the system results in a reduction in administration costs for port authorities.

IWC expert discussions focussed on fee systems that incentivise and streamline waste delivery at port reception facilities and also on the Global Integrated Shipping Information system (GISIS) website[71]. The website, provided and managed by IMO, has the potential to be more up to date in terms of specific identification of those ports and waste management providers that accept and/or recycle end of life fishing gear and could provide additional useful information, such as restrictions on gear and recycling potential.

Imposing fines – part-MBI

Fines are imposed as a penalty for committing an offence. They are not a pure market based instrument (they don't directly impact pricing or costs) and constitute a halfway between a command-and-control and an MBI tool (ten Brink et al, 2009; Ecorys, 2011). Fines can be determined using different parameters (e.g. costs of damage, on an "affordability basis" or on legal limits), can address different activities ending up producing marine litter and may be issued to punish a specific action or inaction (Box 9.9).

In order for this specific tool to be effective, it has to be carefully designed and collection and enforcement must be carefully implemented. For example, in Chile, littering is forbidden by law and subject to fines but the absence of enforcement weakens the efficiency of this measure.

71 https://gisis.imo.org/Public/Default.aspx

Box 9.8

EXAMPLES OF PORT FEES

PORT OF ROTTERDAM

Vessels pay between USD 299 and USD 418 (EUR 225 and EUR 315) for handling 6m3 of waste, dependent on their main engine capacity (MEC) (Port of Rotterdam, 2014).

BALTIC SEA

To face the high levels of illegal waste discharges in the Baltic Sea during the 1990s, HELCOM (Baltic Marine Environment Protection Commission - Helsinki Commission) as the governing body of the Convention on the Protection of the Marine Environment of the Baltic Sea Area, made a Recommendation on the application of the no-special fee system to ship-generated wastes and marine litter caught in fishing nets in the Baltic Sea area (Recommendation 28E-10). Such a fee includes in the port fee the cost of delivering waste, irrespective of the quantities discharged. For instance, in the Port of Gdansk, a fee is applied to boats depending on their type of between USD 0.18-0.82 (EUR 0.14-0.64) per gross tonnage (GT) (Port of Gdansk Authority SA, 2012).

NIGERIA

A private waste management agency (African Circle Pollution Management Ltd.) was given a 20-year contract, in 2000, for operating port reception facilities in Nigeria's six largest ports. By 2012 they had invested an estimated USD 70 million in shipping waste management infrastructure (Obi 2009). At Nigerian ports, in addition to harbour dues, vessels are charged an indirect fee that covers the costs of using port reception facilities. Vessels are charged on the basis of the size of the vessel or its cargo, and then again for the vehicle to transport the waste. Vessels are charged USD 0.12 per tonne of cargo, or USD 4.45 per TEU, and USD 2.76 per vehicle used to transport the waste (NIMASA 2015, NPA 2015).

adapted from Gitti et al. 2015

Box 9.9

EXAMPLES OF FINES

HONG KONG

The Fixed Penalty Ordinance was introduced in 2002, under which an authorized public officer can issue a fine of $1,500 against marine and nearshore littering (Clean Shorelines HK 2013).

CALIFORNIA

The California litter law imposes a fine between USD 250-1000 for people disposing cigarettes butts improperly (Barnes 2011).

9.3

REMOVAL MEASURES – BEPS

Abandoned, lost or otherwise discarded fishing g65ear (ALDFG)

Removal of ALDFG, using environmentally sensitive techniques, can yield several benefits. It provides immediate benefits to marine animals, including cetaceans, by removing gear that is a threat to entanglement and ingestion and has saved thousands of animals (McElwee and Morishige, 2010). In addition to conservation concerns, there can be clear economic benefits to reducing ghost fishing, especially for higher value commercial species such as crustacea, where the cost-benefit ratio of removal costs versus increased fishing yields may exceed 1:10 (Gilardi et al. 2010). It has been argued that paying fishermen to remove derelict gear, in targeted programmes during non-fishing periods, can be cost-effective, as well as educational and hence potentially encouraging more responsible fisheries activity (Scheld et al. 2016). Free-floating ALDFG may be more difficult to locate, but strategies have been developed both for the North Pacific (McElwee et al. 2012) and the Gulf of Carpentaria (Wilcox et al. 2014), involving some combination of ocean circulation modelling and observation (e.g. satellite or airborne remote sensing; Mace 2012).

Global Ghost Gear Initiative (GGGI)
The GGGI was officially launched in September 2015 with the aim to: 'improve the health of marine ecosystems, protect marine animals and safeguard human health and livelihoods'[72]. It represents a cross-sectoral alliance including the fishing industry, private sector, academia, governments, IGOs and NGOs. It brings together a number of existing ghost net removal initiatives and is part of the GPML. The GGGI website provides examples from around the world of initiatives to reduce, remove and re-use ghost nets (Figure 9.8). These range from purely altruistic actions to those that create a financial benefit to local communities (Box 9.8).

Established programmes for recovery of fishing gear
There have been established programmes for ALDFG in many regions for some years (Table 9.2). For example, removal operations have been coordinated by NOAA targeting fish traps off the NW coast of the USA and drift nets off the Hawaiian archipelago (Figure 9.9).

72 http://www.ghostgear.org/

Figure 9.8

Screen shot from the GGGI website showing an interactive map of ghost net initiatives, with an example from the Philippines

Box 9.10

NET-WORKS

This is collaboration between local partners, the Zoological Society of London and two private sector companies (Interface Inc. produces carpet tiles; Aquafil manufactures synthetic fibres). The region of the Danajon Bank (Philippines) is a biodiversity 'hot spot' but has been subject to overfishing and pollution. This initiative has resulted in the removal of 61 tonnes of discarded nets to date with 41 tonnes recycled into carpet tiles.

As a result of the programme there has been a reduction in the deliberate discarding of nets, creating a benefit both to the local community and the natural environment. A new collection hub is being established in Northern Iloilo in the central Philippines and in the Lake Ossa region in Cameroon Central Africa.

Figure 9.9

Recovery of fishing net using free divers and air bags, Papahānaumokuākea Marine National Monument, Northwestern Hawaii Islands (image courtesy Kris McElee and NOAA Marine Debris Program)

Table 9.2

Time frame	Gear Amount Recovered	Project / source	Geographical Area
1996 - 2014	820 metric tons of DFG (and other marine debris)	NOAA's Pacific Islands Fisheries Science Centre	Papahanaumokuakea MNM
2006 - 2012	60+ tons removed	CA lost fishing gear recovery	Coastal California
2004 - 2012	12 000+ nets	GhostNets Australia	Australia
2008 - 2013	161 nets; 28 934 crab pots; 4 202 other pots	CCRM VIMS	Chesapeake Bay, US
2000 - 2006	10 285 tons	Korean coastal cleanup campaigns (Hwang and Ko, 2007)	Korea
Not specified	20 tons fishing nets	Healthy Seas Initiative	North Sea, Adriatic Sea, Mediterranean Sea
Not specified	5 600 traps	Geargrab.org	Gulf of Maine

Summary of total derelict gear removed in organised campaigns (NOAA 2015)

A pilot project in the Baltic in 2011 and 2012, involving fishermen from Poland and Lithuania, investigated the efficacy and safety of a number of gear retrieval methods, recovering large quantities of ALDFG (WWF 2013). It is intended to introduce similar schemes into other regions on the Baltic. A retrieval programme in the East Sea, off Korea, removed approximately 460 tonnes of ALDFG from the seabed, at an average depth of 1 700 m (Cho 2011). Removal operations in such deep waters are inherently more difficult and potentially carry more risk than carrying out recovery in shallower waters.

MARLITT Toolkit for derelict litter projects

MARLITT is a pilot project funded by the EC aimed at developing good practice for the removal of litter and derelict fishing gear from Europe's four regional seas[73]. A Toolkit has been produced which offers practical guidance on setting up locally-based programmes to remove ALDFG (MARLITT 2015a). A second Toolkit provides guidance on preventing litter entering the ocean, with a particular focus on fisheries and ports (MARLITT 2015b).

Nets to energy

The multi-partner marine debris group in Hawaii has been running a successful programme, since 2002, to collect ALDFG nets from beaches, coral reefs and coastal waters. Instead of going to landfill, as happened previously, the nets are chopped into small pieces and then incinerated to produce steam to drive a turbine generating electricity. So far 800 tonnes of nets have been processed, producing enough electricity to power 350 homes for a year[74].

Reducing the impact of ALDFG

The impact of ALDFG can be reducing by improved design, so that ghost fishing can be reduced even if the gear is not retrieved. This is most clearly demonstrated in the design and use of materials in pots and traps. Components such as panels or hinges that are fully biodegradable in seawater can significantly reduce the catching efficiency of the gear (Bilkovic et al. 2012).

73 http://www.marelitt.eu/

74 http://marinedebris.noaa.gov/solutions/hawaii-nets-energy-program

Fishing for litter

The Fishing for Litter initiative was introduced by KIMO International[75], an organisation for local municipalities in NW Europe, to provide a cost-effective solution for dealing with litter that is inadvertently collected during commercial fishing operations. The scheme consists of providing fishing fleets with large bags in which litter can be stored on-board, prior to being deposited on the quayside for proper disposal, at no cost to the fishermen. The scheme runs in four regions of northern Europe: the Baltic, Netherlands, Scotland and SW England. It is supported in the Baltic by HELCOM which also applies the no-special fee system to marine litter caught in fishing nets.

Rescue and recovery of trapped animals – BEP

Several organisations run volunteer or semi-professional programmes to train those who may come into contact with an entangled animal in rescue techniques (Box 9.9). The overall concern is with the welfare of the trapped animal while ensuring the safety of those carrying out the rescue operation. For some endangered species, such as the North Atlantic right whale, the loss of an individual may threaten the survival of the species. There is an inherent danger in a situation involving an often large and distressed animal, floating ropes and nets and human divers. Unfortunately, there have been human fatalities. The IWC has been at the forefront to develop and promote effective and safe rescue techniques[76]. There are also many smaller-scale initiatives to rehabilitate animals that have been rescued and need attention before release.

Shorelines

Countless shoreline programmes have been conducted in recent years, by a variety of special interest and citizens' groups, NGOs and corporations, government agencies and municipalities. Initiatives may be organised at local, national, regional or global scales. They have two functions: one is to raise awareness of the problem of marine littering; the second is to remove material that would otherwise cause potential harm, and

75 http://www.kimointernational.org/Home.aspx

76 https://iwc.int/entanglement

Box 9.11

INITIATIVES TO PROMOTE THE SAFE AND EFFECTIVE RESCUE OF ENTANGLED ANIMALS

International Whaling Commission
The IWC has developed comprehensive principles, guidelines and training courses for large whale entanglement response efforts. The goals are human safety, animal welfare, conservation, data collection and awareness raising. The programme is informed by the IWC Expert Advisory Panel on Entanglement Response

International Fund for Animal welfare (IFAW)
The IFAW trains volunteers in practical techniques to rescue and release trapped cetaceans and seals, using a variety of equipment such as grappling hooks, floating buoys, long cutting poles and special cutting knives and shears (IFAW 2012).

British Divers Marine Life Rescue (BDMLR)
The BDMLR has trained more than 400 British divers in how to use cutting and restraint gear for entangled animals as part of its rescue and rehabilitation training programme (BDLMR 2012).

Whale and Dolphin Conservation (WDC)
The WDC uses whale watching initiatives as a means for research and monitoring the health of populations. This provides a means of reporting animals entangled in floating debris to prompt rescue missions (WDCS 2012).

NOAA
NOAA provides guidance to the public on rescuing trapped or entangled animals (NOAA 2012).

gradually degrade to form microplastics. Some examples of large-scale schemes are given below (EC 2012).

Blue Flag
This began initially in France but has expanded to encompass all of Europe, southern Africa, and the Caribbean. The originally (1985) French concept of the Blue Flag was developed on a European level to include also other areas of environmental management, such as waste management and coastal planning and protection.

Clean Up the World
This is a community based environmental programme that invites community groups, schools, businesses, and local governments to join as Members and carry out community-based activities that address local environmental issues. It engages an estimated 35 million volunteers in 130 countries each year. Clean Up the World is held over the 3rd weekend in September.

International Coastal Cleanup (ICC)
This is a global project co-ordinated by the Ocean Conservancy, a U.S. non-governmental organization. The project involves over 70 countries worldwide in litter surveys and beach cleans over the same weekend in September.

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.

World Environment Day
This UN day is celebrated each year on 5 June and is one of the principal vehicles through which UNEP stimulates worldwide awareness of the environment and focuses political attention and action.

BATs for litter capture and removal in rivers and harbours

Systems to capture floating plastics near the source can prove to be a cost-effective way of preventing plastics reaching the ocean. Several innovative Techniques have been developed and some examples are provided here (Figure 9.10).

Figure 9.10a

Figure 9.10b

Two technical solutions for intercepting floating plastics; a) a floating net array used in a river in Australia, (Image: Bandalong International Pty Ltd) and b) 'Mr Trash Wheel', a floating boom and waterwheel powered by sunlight and water in Baltimore Harbour USA (Image: Adam Lindquist, Waterfront Partnership of Baltimore.)

Korea has been at the forefront of developing practical engineering approaches and infrastructure to address marine debris in Korean water. This includes the development of floatation booms and modified grapple and other devices for removing material from the seabed and sea surface, including ALDFG (Jung et al. 2010). Other developments include a portable volume reduction unit for EPS buoys and a full treatment and recycling plant for marine debris (Figure 9.14).

Removing plastics from mid-ocean

When the headlines 'the Great Pacific Garbage Patch' first emerged there were some individuals who misconstrued this to mean there was a floating island of debris in the middle of the ocean. They thought it contained so much material that it readily could be collected and converted for some other use, perhaps fuel to replace the energy utilised in the collection mission. It took some time to dispel this myth but others have emerged more recently who appear to believe that an ocean 'clean-up' is both practical and desirable. Most prominent of the groups proposing a 'solution' is the Ocean Cleanup Project, initiated in the Netherlands. Currently this consists of a 60 km-wide floating net array deployed in the North Pacific, with plastic collected and stored for 'recycling'. This high profile campaign has high ambitions and expectations, and the organisers make the astonishing claim that: 'A single Ocean Cleanup Array can clean up half the Great Pacific Garbage Patch in 10 years' time[77].

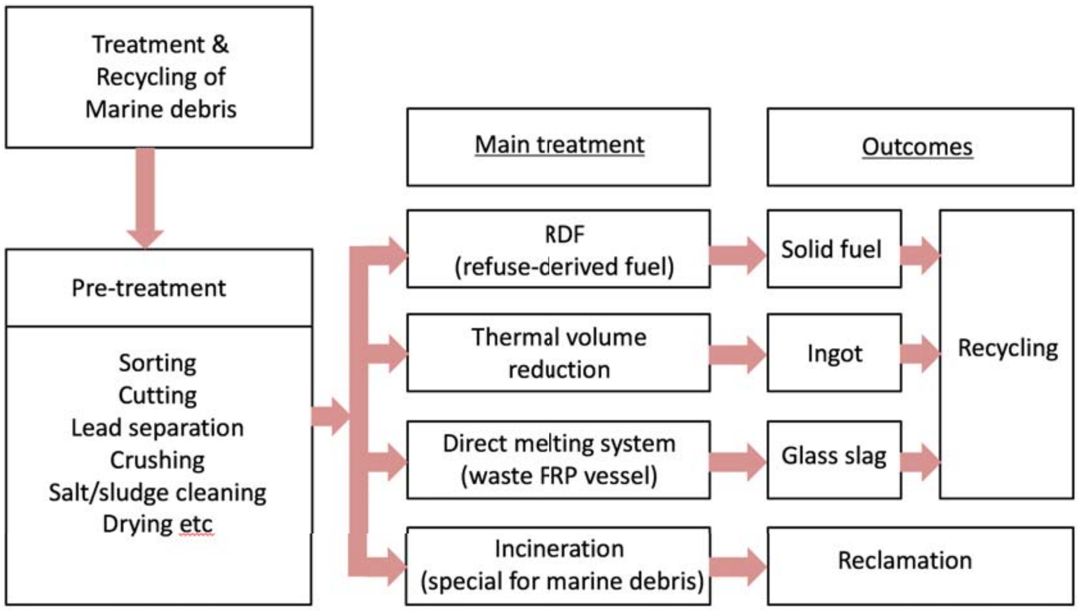
The logic for the efficacy of the OCA system is flawed for several reasons, but most importantly there appears to have been little consideration of the ecological impact of installing a 60 km barrier to free floating organisms, even assuming mobile forms could avoid capture. The overwhelming view of marine scientists who have discussed this issue in open scientific debate, since the idea was first mooted, is that ocean clean-ups, of the sort envisaged by OCA, are at best a distraction from tackling the problem at source and at worst will cause unnecessary harm[78 79]. If such schemes are to be proposed then there must be an onus on the developers to arrange a fully independent environmental impact assessment and LCA, before proceeding with full-scale field trials.

77 http://www.theoceancleanup.com/

78 http://www.bbc.co.uk/news/magazine-29631332

79 http://www.5gyres.org/blog/posts/2015/6/17/5-reasons-why-ocean-plastic-recovery-schemes-are-a-terrible-idea

Figure 9.11



Schematic of the treatment process for marine debris developed in Korea (adapted from Jung et al. 2010)

9.4

IMPOSING PRODUCT BANS

Examples of product bans range from grass roots campaigns to remove goods from a well-defined source, such as shops on university campuses, to bans imposed by national governments on certain types of plastic bags.

Several governments in Africa have introduced, or are planning to introduce legislation to ban or restrict the use of conventional plastic shopping bags, usually below a certain minimum thickness (South Africa, Tanzania, Kenya, Rwanda, Mauritania and Uganda[80]). This has been prompted by the severe problems discarded bags have caused, for example by blocking drains and open sewers or causing the death of livestock, in countries where solid waste disposal is poorly developed and regulated. In other sub-Saharan countries, such as Ghana, Nigeria and Sierra Leone, plastic bags are considered essential to provide clean drinking water and they are much more affordable than plastic bottles. This illustrates why those promoting litter reduction measures have to take account of the economic and social dimensions of the local communities.

Student interventions have been successful in banning the sale of bottled water on several University and College campuses in the USA, accompanied by the refurbishment of drinking water fountains. In the USA a student-led campaign, at the Univ. California Los Angeles, resulted in the removal of all PCCP products containing microbeads[81]. The message of this grassroots campaign has been matched by a number of States in the USA which moved to ban microbeads from PCCPs. However, these efforts have been superseded by the 'Microbead-Free Waters Act', passed unanimously by the US House and Senate in December 2015, and signed into law by President Obama on 4 January 2016. The phase out is due to begin on 1 July 2017.

80 http://www.bbc.co.uk/news/world-africa-20891539

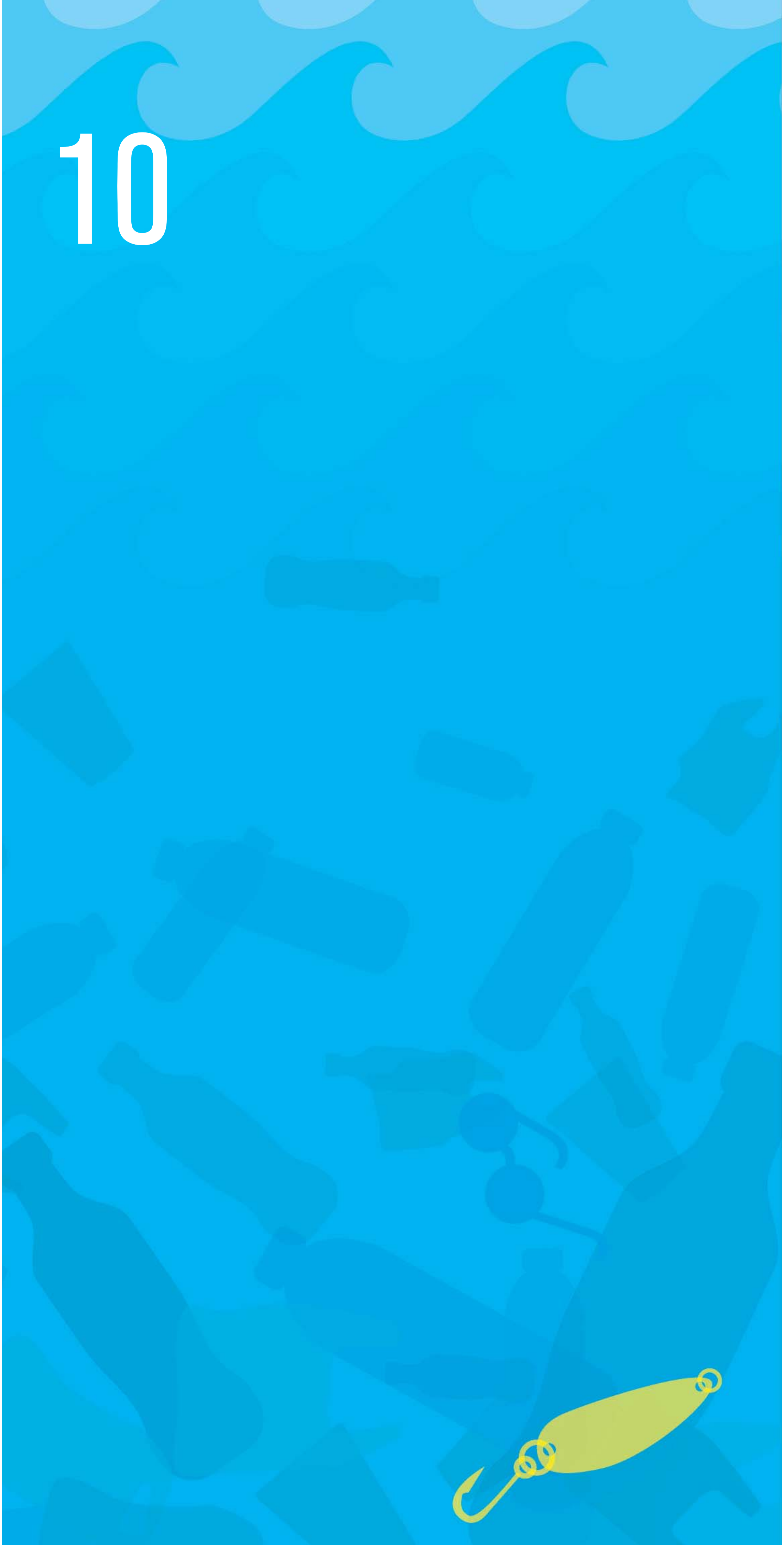
81 http://www.5gyres.org/blog/posts/2015/8/12/ucla

Alternatives to outright product bans are voluntary agreements, which may be easier to achieve. The industry body Cosmetics Europe has issued a recommendation to all its members to phase out the use of microplastics in wash-off cosmetic products by 2020[82].

82 http://www.5gyres.org/blog/posts/2015/8/12/ucla

Photo: © Erik de Castro / Reuters

10



10. RISK ASSESSMENT AND GUIDELINE FOR SELECTING MEASURES

10.1

DEFINING RISK

In simple terms risk is defined as the likelihood (or probability) that a consequence (or hazard) will occur. Terms such as likelihood and consequence may be more familiar to a non-technical audience, whereas probability and hazard are terms that may be preferred by specialists (Box 10.1). It is an approach that is routinely applied in every aspect of human activity, ranging from formal risk assessments, for example in major construction projects, to informal decision-making by individuals, for example on when to cross a busy road.

Risk = likelihood/probability x consequence/ hazard

In the context of marine litter, the hazard is the presence and potential impact of plastic items/particles and the likelihood is the extent or rate of encounter. The earlier sections of this report describe the source and distribution of the potential hazard (macro and microplastics), and the potential impact. Estimating the degree of risk provides a more robust basis for decisions on whether or how to act to reduce the risk, if it is considered unacceptable, than simply reacting to popular appeal or an advocacy group, however well intentioned.

The risk of a significant impact occurring will vary depending on the ecosystem component being assessed, the nature of the hazard and the likelihood of the hazard occurring (Table 10.1)

Table 10.1

Risk category	Risk outcome
High	The risk is very likely to occur
Moderate	The risk is quite likely to be expressed
Low	In most cases the risk will not be expressed
Extremely low	The risk is likely to be expressed only rarely
Negligible	The probability of the risk being expressed is so small that it can be ignored in practical terms

Defining the degree of risk at a generic level (GESAMP 2008)

The hazard descriptions can be adapted readily for other ecosystem components, for example:

- **Injury or death to endangered species**
  – North Atlantic right whale, Hawaiian monk seal
- **Injury or death to rare or iconic species**
  – humpback whale, laysan albatross (Pacific), leatherback turtle, Stellar sea lion
- **Injury or death to indicator species**
  – northern fulmar NE Atlantic), loggerhead turtle (Mediterranean)
- **Damage to sensitive or critical habitat**
  – tropical reef, cold water reef
- **Loss of commercial species due to ghost fishing** (food security)
  – Dungeness crab (NW Pacific)
- **Chemical contamination of commercial species** (seafood safety)
  – shellfish aquaculture (e.g. South Korea)

As an illustration, a risk assessment and risk communication study for coastal aquaculture, in which potential hazards associated with water quality were described in some detail (GESAMP 2008). Hazards were ranked from negligible to catastrophic, and accompanied by a description of the effects (Table 10.2).

Similar tables can be developed for a variety of maritime sectors or ecosystem components (i.e. species, habitats, functional groups) and for a wide range of potential hazards. For example, Lithner et al (2011) developed an environmental and health

Table 10.2

Degree of hazard	Description of hazard
Catastrophic	• Irreversible change to ecosystems performance in the faunal-province [regional] level; or • The extinction of a species or rare habitat
High	• High mortality for an affected species or significant changes in the function of an ecosystem • Effects would be expected to occur at the level of a single coastal or oceanic body • Effects would be felt for a prolonged period after the culture activities stop (greater than the period which the new species was cultured or three generations of the wild species whichever is the lesser time period) • Changes would not be amenable to control or mitigation
Moderate	• Change in ecosystem performance or species performance at a regional or sub-population level, but they would not be expected to affect whole ecosystems • Changes associated with these risks would be reversible • Changes that has a moderately protracted consequence • Changes may be amenable to control or mitigation at a significant cost or their effects may be temporary
Low	• Changes are expected to affect the environment and species at a local level but would be expected to have a negligible effect at the regional or ecosystem scale • Changes would be amenable to mitigation or control • Effects would be of a temporary nature
Negligible	• Changes expected to be localised to the production site and to be of a transitory nature • Changes are readily amenable to control or mitigation

Description of hazards in relation to aquaculture (GESAMP 2008)

hazard classification of a large number of polymers and co-polymers. This was based on the UN Global Harmonised System (UN 2011).

Risk perception

In many cases, a perception of some degree of risk is required to engage people with the issue and trigger behaviour change. Interest in marine plastics and microplastics in the media has increased in the past decade, in both traditional print media and on-line (GESAMP 2015). Articles have highlighted both the problem and potential solutions (GESAMP 2016). In order to promote behaviour change, this is especially important, as individuals need to perceive the relevance of the issue but also how their actions can help (Tanner and Kast 2003). However, empirical research on public risk perception of microplastics and nano-plastics is still lacking.

Nano-plastics

Nano-plastics are an emerging issue because monitoring methods have not been developed yet and the scale of industrial production is unclear. However, there has been a literature around the perception of "nanotechnologies" in the social sciences since the early 2000s. As opposed to other contested issues in new technology development (e.g., GM foods), public opinion on nanotechnologies appears to be largely positive, with 'discussion of risk issues […] relatively limited so far' (Pidgeon & Rogers-Hayden 2007). Satterfield et al. (2009) provide a meta-analysis of recent studies into public perceptions of nanotechnology. Their key findings are that three quarters of people surveyed in the US, UK and Canada believe the benefits outweigh the risks of nanotechnologies, but more than 40% are unsure. This uncertainty is still present in more recent work and has been linked to high fragility and mobility of attitudes (e.g. Satterfield et al. 2012). This is a societal risk because new information or a future risk event has the potential to change public opinion rapidly in the case of such unstable attitudes.

10.2

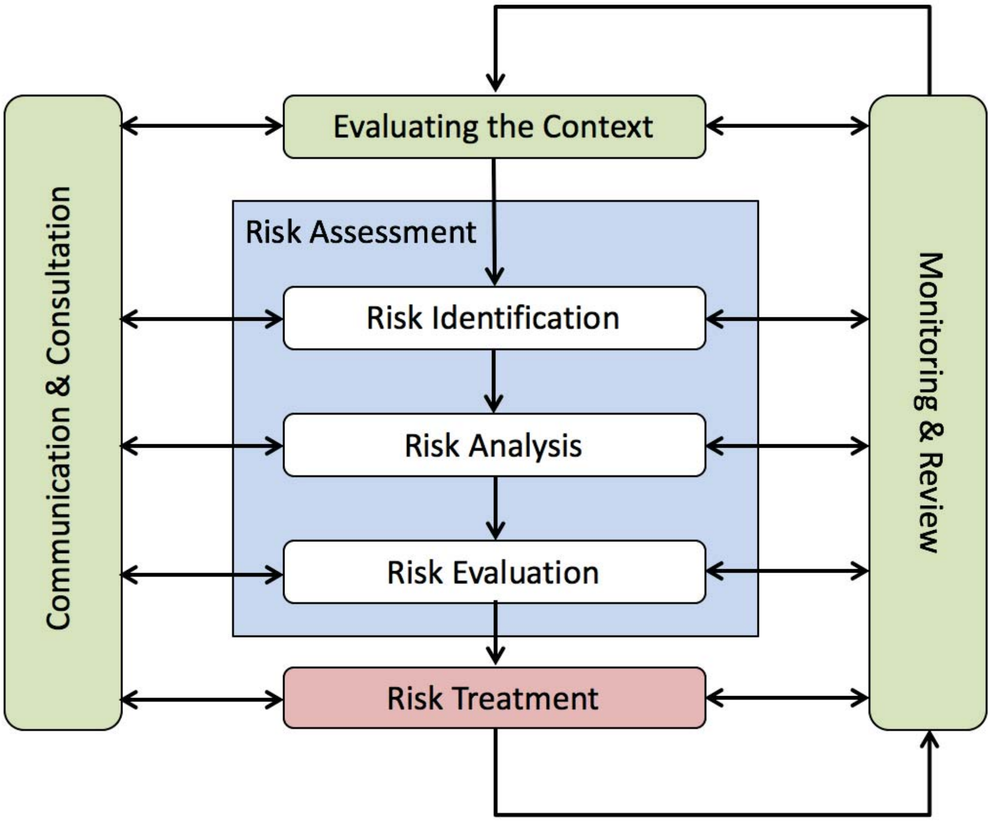
IDENTIFYING INTERVENTION POINTS - RISK ASSESSMENT FRAMEWORKS

Risk assessment frameworks

Risk assessments generally follow a similar set of steps, and a variety of conceptual frameworks have been proposed to illustrate this process. These tend to have a number of common features, beginning with problem identification and formulation followed by a characterization of exposure and effect (GESAMP 2008). Ideally this should lead to the identification of potential intervention points and an evaluation of possible risk management actions, to 'close the loop'. Risk Assessment Frameworks provide a means of formalising the process of examining a system in context, describing possible consequences if a failure in the system occurs and predicting the likelihood of a failure occurring (Figure 10.1). Evaluating the context is an essential first step (Fletcher 2015). This requires communication and consultation with those individual or organisational stakeholders who may be directly or indirectly affected, a process that should be maintained throughout. The risk assessment consists of three stages: risk identification, risk analysis and risk evaluation. A decision can then be made on the best way to treat this risk. The system and risk assessment process needs to be monitored and kept under review so that adjustments can be made. This model can be applied to complex construction projects, such as building a nuclear power station, as well as more straightforward decisions about keeping a beach free from litter. The risk assessment corresponds to the Impact-Response part of the DPSIR framework (Driver-Pressure-State-Impact-Response, Chapter 10.3).

This approach can be applied to a wide range of potential marine plastic impacts. Two examples have been developed to illustrate the approach (Figures 10.2 and 10.3). The first is an actual case involving the entanglement of marine turtles in ALDFG in the Gulf of Carpentaria, in northern Australia. Marine turtles are subject to significant impacts by marine plastic litter, both due to ingestion (Camedda et al. 2014) and entanglement (Wilcox et al. 2014). This represents an additional pressure for taxa whose individuals are routinely caught as by-catch in active fishing gear and whose nesting sites are subject to loss and disturbance (refs). The Gulf of Carpentaria is an important breeding area for several species of turtle (flat- back Natator depressus, green Chelonia mydas, hawksbill Eretmochelys imbricate, loggerhead Caretta caretta, and olive Ridleys turtles Lepidochelys olivacea; Wilcox et al. 2014). The region is subject to an influx of ALDFG from the extensive fisheries of South-east Asia with a consequent loss of turtles due to entanglement. The risk from entanglement has been quantified by mapping the distribution of turtles and predicting the drift trajectories of ghost nets using an ocean circulation model, to estimate probable encounter rates (Wilcox et al 2015). The illustration of the use of a formal risk assessment framework in Figure 10.2 is based on information provided by

Figure 10.1



Risk Assessment Framework (proposed by Fletcher 2015).

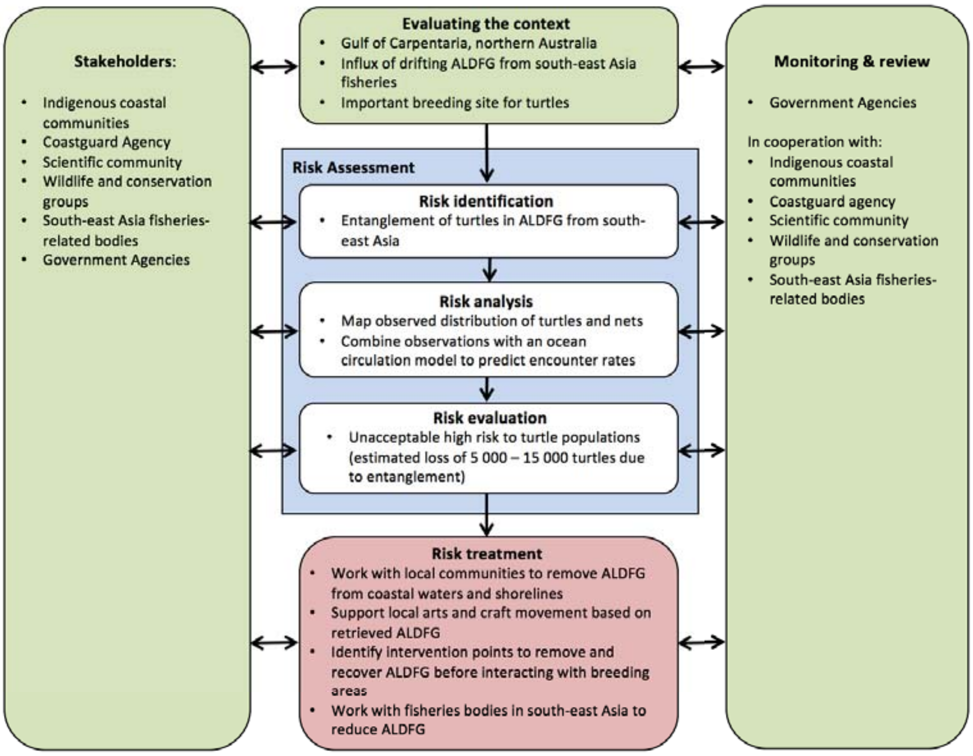
Wilcox et al. (2015a). The second example (Figure 10.3) is of a hypothetical risk assessment of the potential impact of microplastics on bivalve aquaculture, specifically contamination by chemicals associated with the microplastics. In this case the risk from chemicals contamination was evaluated to be within regulatory limits, but action was deemed necessary to minimise changes in consumer behaviour due to a perception of unacceptable risk.

Identifying priority areas for intervention

It is important to ensure that efforts to reduce the leakage of macro and microplastic into the ocean, remove what is already there, or in some other way mitigate the impact, are both well-directed and cost-effective. There are multiple potential areas for intervention but assigning priorities as to which to tackle and how to select an approach need to be guided by the risks or not taking action (i.e. what is the hazard) and the consequences of taking action; i.e. is there a realistic prospect of an intervention being effective, without introducing some unwelcome effect.

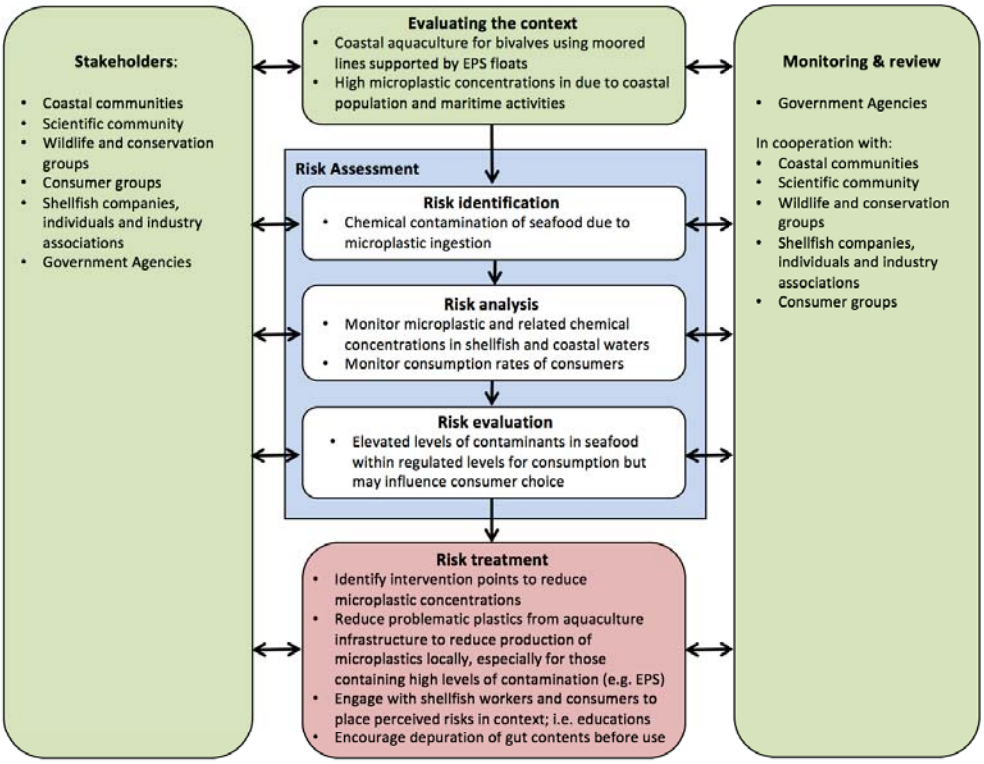
Setting priorities needs to be done at an appropriate governance scale (local, nation, regional) and take account of the social, economic and ecological context. In this report, several sectors have been highlighted as having the potential to leak substantial quantities of macro or microplastics in to the ocean (Chapter 5), or create significant impacts (Chapter 7). However, the relative importance of any of these potential sources, and the pathways by which material reaches the ocean, will be very regionally dependent. There may be cases of being able to 'pick the low-hanging fruit', i.e. implementing a simple low-cost solution which brings about an immediate improvement. In other cases, there may be complex social, political and economic hurdles to overcome. In some cases, technological developments and interventions will be needed.

Figure 10.2



Case study of turtle entanglement by ALDFG in the Gulf of Carpentaria (Wilcox et al. 2014), mapped onto the Risk Assessment Framework developed by Fletcher (2015) (original by P.J. Kershaw).

Figure 10.3



Hypothetical risk assessment of the impact of microplastics on bivalve aquaculture, mapped onto the Risk Assessment Framework developed by Fletcher (2015) (original by P.J. Kershaw).

This report stops short of identifying specific priority areas. But it is hoped that the information and guidance it contains will enable practitioners, policy-makers and the general public to make better-informed choices and choose the most appropriate response (Chapter 10.3).

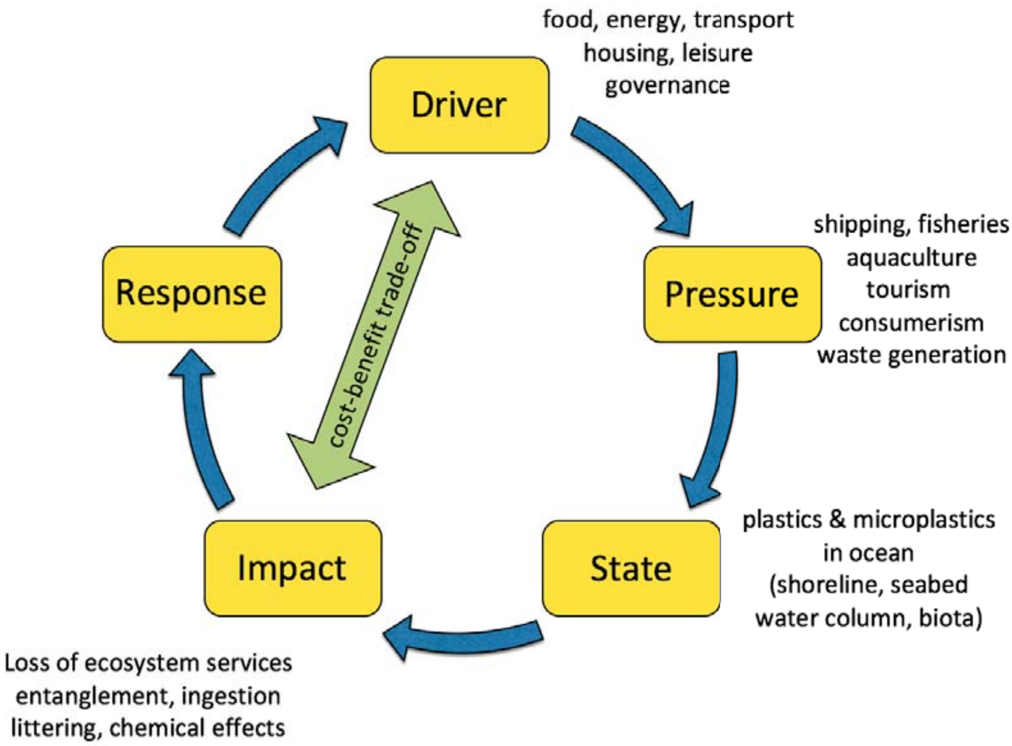
10.1

GUIDELINES FOR SELECTING THE APPROACH

Choosing the Response (DPSIR)

The overarching aim of any approach has to be to reduce the impact of marine plastics, in terms of ecology, society or economics. The main concern may be focussed on one or a combination of all three. The Driver – Pressure – State – Impact – Response (DPSIR) conceptual framework is quite widely used to place activities and their impacts in context, and to map potential responses (Niemeijer and de Groot 2008, Alexander et al. 2015). It is not intended to be a quantitative risk assessment tool, but it does provide a useful tool for structuring communication between scientists and end-users/decision makers (Maxim et al. 2009). Figure 10.4 illustrates the relationships within the DPSIR framework for marine plastic litter between the major Drivers (e.g. food security, energy generation), the Pressures or stressors that are a consequence (e.g. fisheries, shipping), the change in the state of the environment (e.g. plastic litter in the ocean), and the potential impact in terms of a loss of ecosystem services (e.g. navigation hazard to shipping, injury of organism due to ingestion). The impact here is defined in socio-economic terms as a welfare impact; i.e. there is an effect on an ecosystem service that society considers undesirable. Note, there will usually be a cost-benefit trade-off to achieve the desired reduction in welfare impact without undue cost to the underlying driver (Mee et al. 2015). The DPSIR conceptual framework will be further extended, or complemented, for example looking at risks to biodiversity by introducing four spheres of sustainability (environmental, economic, social, and political) (Maxim et al. 2009).

Figure 10.4



The DPSIR framework in relation to inputs and impacts of marine plastic litter (original by P.J. Kershaw).

The selection of appropriate measure must be guided by several processes:

1. **defining the problem** – context and objectives;
2. **carrying out a risk assessment**, to establish the nature of the risk and justify intervention;
3. **establishing which element** of the DPSIR framework should be targeted (Driver, Pressure, State or Impact); and
4. **evaluating the most appropriate response** – selection of measures.

At all stages there needs to be a mechanism in place for consultation and communication, and a process to review and monitor the risk and consequences of introducing the measure. The possible measures to reduce the impact of marine plastics can be categorised broadly as follows:

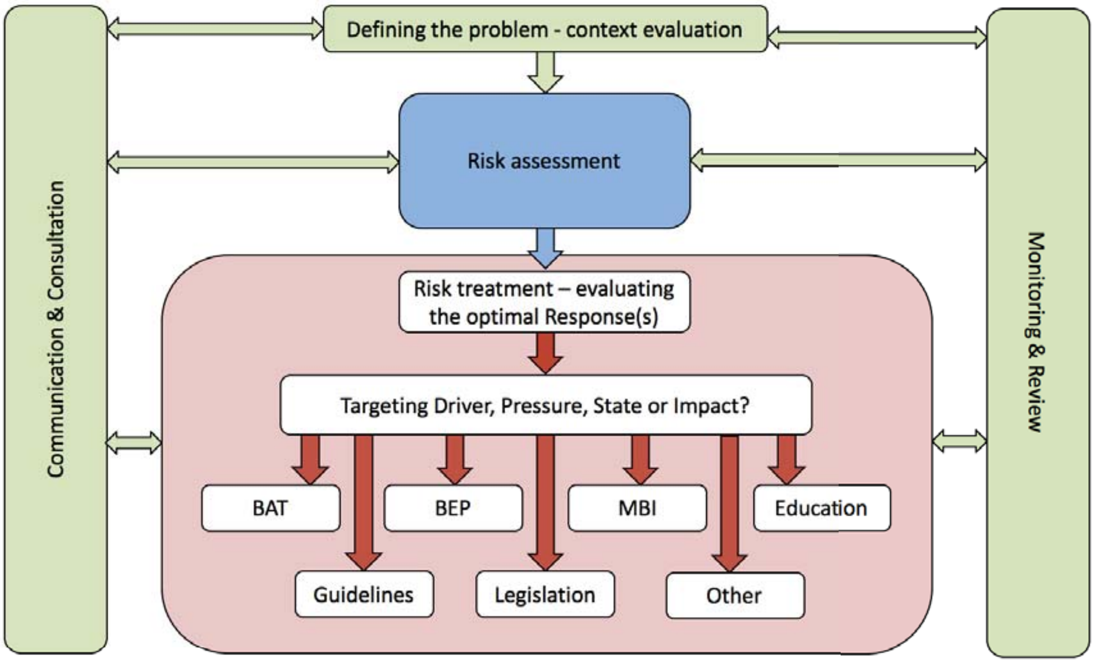
1. **influencing behaviour change** by raising awareness and education;
2. **encouraging best/good practice;**
3. **introducing Best Available Techniques/ Technologies (BATs);**
4. **utilising market-based instruments;**
5. **introducing guidelines** or voluntary agreements and codes of practice; and
6. **introducing legislation.**

A framework for guiding the selection of appropriate measures is presented in Figure 10.4

The DPSIR framework can be used also to illustrate potential measures to reduce the loss of ecosystem services. This is the Response element of DPSIR. The response can involve the driver, pressure, state or welfare elements. Figure 10.4 indicates possible responses to reduce the welfare impact of injury to marine turtles from marine litter resulting from entanglement in ALDFG and ingestion of plastic bags. Each driver will require a specific set of responses and intervention points, some of which may be common and some of which may relate solely to that driver. Both market-based and non-market-based marine litter reduction solutions are described in the following sections.

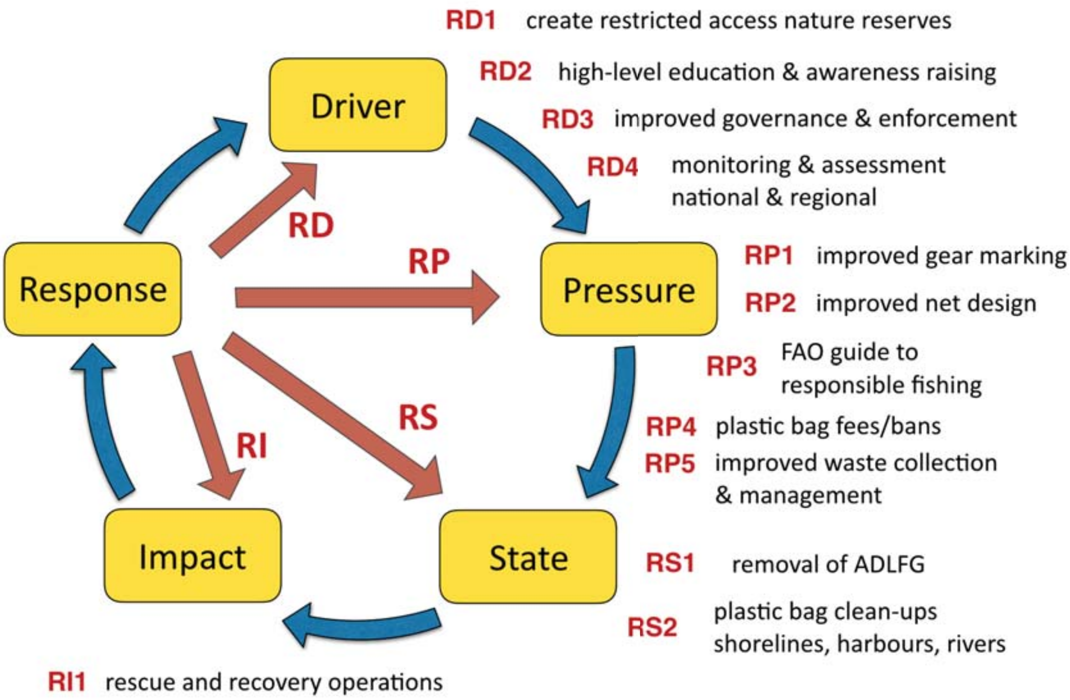
Photo: © Danish Siddiqui / Reuters

Figure 10.5a



A framework for guiding the selection of appropriate Responses to reduce or mitigate against the impact of marine plastic debris (original by P.J. Kershaw).

Figure 10.5b



DPSIR framework showing some potential responses to reduce the impact on sea turtles of entanglement in ALDFG and ingestion of plastic bags; RD – Responses direct at Drivers, RP – Responses directed at Pressures, RS – Responses directed at environmental State, RI – Responses directed at Impacts (original by P.J. Kershaw).

Criteria for evaluating Best Practices

Best Practices (or Best Environmental Practices, BEPs) generally involve lower financial investment than Best Available Techniques/Technologies (BATs). Some BEPs are developed by public or private bodies. Others may be more dependent on volunteering, citizens' groups, special interest groups and NGOs. Dissemination and stakeholder involvement is key to establishing appropriate BEPs and promulgating good practice. The use of the term 'best' can be unhelpful. A practice may be 'good enough' to bring about a worthwhile improvement, even though it may not be the 'best' possible had sufficient resources or time been available.

Many factors contribute to what makes a practice 'good', and one that may be ideal in a certain set of circumstances may be inappropriate in an alternative setting. These factors may include:

1. **Effective communication,** education and willingness to collaborate on the part of the public, authorities and user groups
2. **The availability** of, and willingness to use, local/specialist knowledge
3. **A recognition** of the local and regional social, cultural and economic circumstances
4. **The availability** of start-up funding
5. **A mechanism** to ensure longer term viability, possibly through self-financing

There are many examples of good practice and it can be difficult to judge their relative success. An evaluation tool, DeCyDe-4-MARLISCO, has been designed to provide a means to select optimal solutions for marine litter reduction based on existing good practices (Loizidou et al. 2014). To be successful, the approach requires the active participation of a representative group of stakeholders. Eleven measures were judged to be the most effective out of 73 that were evaluated (Annex IX).

Four evaluation criteria were applied:

1. **Impact –** a measure of the effectiveness of the chosen practice at bringing about a significant reduction when applied as intended to a specific region or case;
2. **Applicability or exploitability** – a measure of the degree to which the practice could be applied more widely;
3. **Sustainability –** a measure of the longevity of the practice, taking account of social, environmental and economic considerations; and
4. **Data and information** availability.

Criteria for selecting Best Available Techniques

A number of criteria have been put forward to evaluate BATs in the waste management sector (Tetra Tech 2015), which may have wider applicability to the selection of BATs in other sectors. The aim is to ensure that the proposed BAT is appropriate to the social and economic setting:

1. **What is the scale** and affordability of the technology for a local government or business? What are the financing opportunities?
2. **Is the technology** a good fit for the types and quantities of waste materials generated in the community?
3. **Does the technology process** include local communities in technology innovation, modification and implementation, providing continuing job opportunities?
4. **Is the technology going to result** in a process that continues to employ or increase job opportunities for local workers, or will it displace people from existing jobs?
5. **Is the technology understandable** without high levels of training? Can it be controlled and maintained by local community members without specialized education?
6. **Is the technology sustainable,** both with respect to the environment and to technology repair and replacement when and if skilled professional support is no longer available?
7. **Will the technology have an adverse impact** on the environment?
8. **Will the technology contribute** to community members working together to improve the quality of life/standard of living?
9. **Is the technology adaptable and flexible?** Can it be adapted to changing circumstances such as increases or decreases in tonnage or more stringent environmental regulations?

Criteria for selecting Market-based Instruments (MBIs)

There is a variety of MBIs that can be used to both reduce the production of waste that could become marine litter and incentivize good behaviour (e.g. avoid littering, illegal waste disposal). Some are explicitly targeted at marine litter, others have multiple or broader foci (e.g. waste reduction in general), and others focus elsewhere but can help address marine litter (e.g. fees for waste management infrastructure and collection services). MBIs must comply with existing national and international agreements and legislation, such as the WTO.

Positive incentives

Economic incentives are implemented to stimulate a specific behaviour that can help reduce marine litter. There are a number of incentives which can be used to address marine litter, involving a number of stakeholders at different levels – including deposit refund schemes as well as payments, subsidies or awards for certain actions.

Disincentives

There are also a number of financial disincentives, these can be applied at several levels. What differentiates the two groups is the fact that disincentives aim at changing behaviours by discouraging bad ones, where incentives are based on promotion of good behaviours.

Criteria have been put forward for testing the suitability of a MBI (UNEP 2016c):

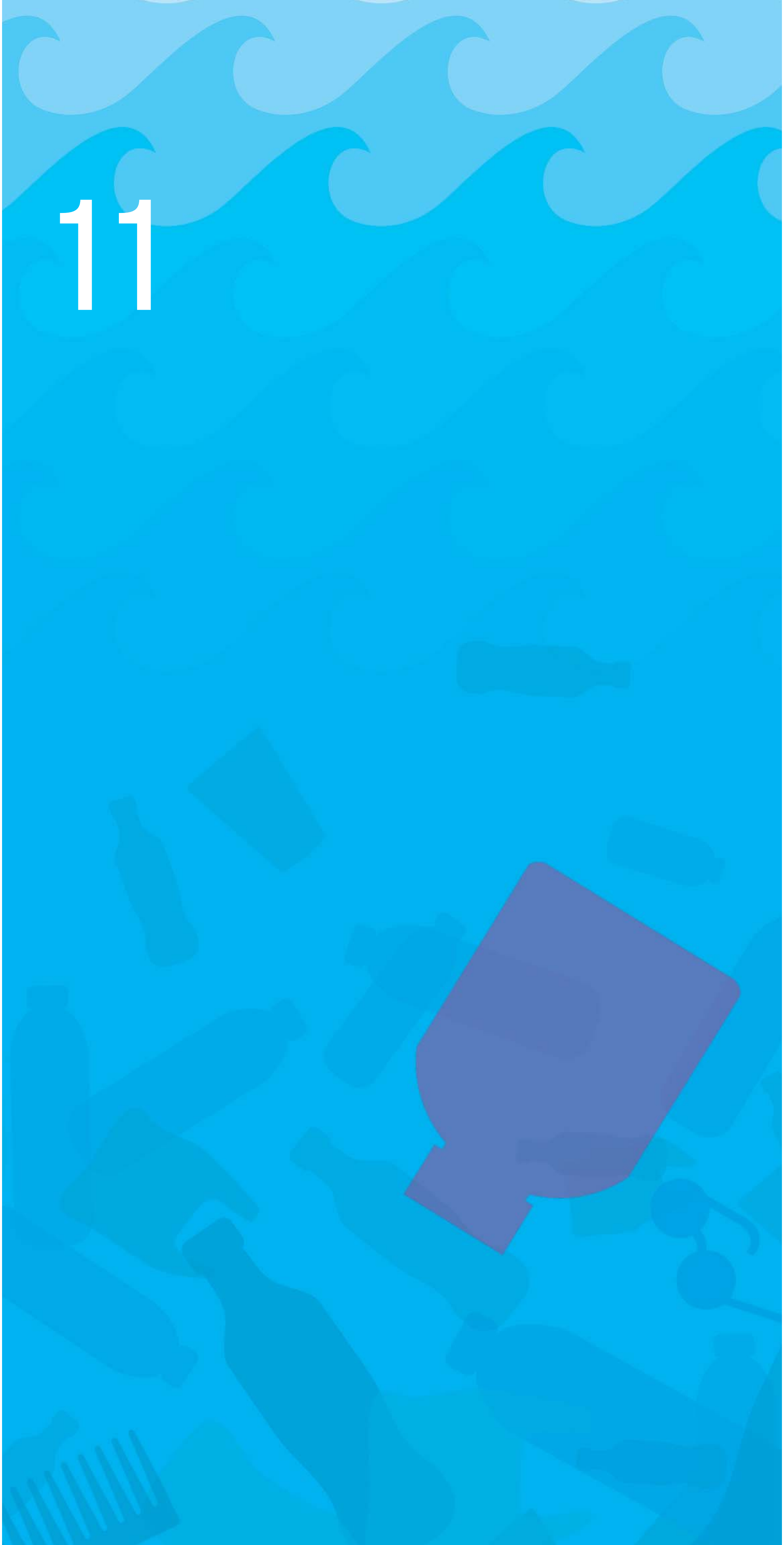
1. **Has it the potential** to be a fair instrument (putting burdens in their due place)?
2. **Will it avoid** unacceptable social impacts?
   - Will it avoid any negative effect on the more vulnerable members of society?
   - Is it affordable?
3. **Is it consistent** with other important economic objectives? (e.g. budget deficit, competitiveness, inflation, and balance of payments)
4. **Is the instrument** likely to be cost-effective? (i.e., more effective than other instruments such as regulatory, educational or other economic instrument; no major additional costs to implement, etc.)
5. **Does the instrument** lead to efficient pricing? (i.e., improve pricing such that the market price is closer to resource / social pricing)
6. **Are the instrument** and the rationale behind it understandable and deemed credible by the stakeholders / public?
7. **Is there capacity** to design, implement and enforce such an instrument by the authorities?
   - Is the available administrative / infrastructural capacity (skills, staff) sufficient?
   - Are there sufficient resources to cover additional administrative costs?
   - Are sufficient data available?

Once the best instrument has been chosen, to make it work effectively, it needs to be well designed and linked to a number of other supporting instruments. It needs to be effectively launched, communicated, supported, enforced and monitored. There needs to be:

1. **Political will,** political acceptability and buy in, which often builds on perceptions of probable success.
2. **Public acceptability** – the public needs to understand why there is an instrument (what problem does it deal with), that various options have been explored and that the choice is fair and appropriate.
3. **Communication** – to ensure public acceptability, awareness of the benefits of responding, awareness of the ways of responding to the instrument, and that the authorities are serious about the instrument.
4. **Regulatory and institutional framework** in place - capacity to monitor and enforce current legislation. This has to be credible to make the instrument work. Monitoring and enforcement require financial support.
5. **Physical infrastructures** in place – e.g., waste collection, management and recycling infrastructures.
6. **National considerations** – economic, political, and institutional – are significant and should not be minimised or underestimated.

In many cases public acceptability is linked to demonstrating a clear link between the imposition of a fee and supposed benefit. For example, revenues from taxes applied on the tourism sector and other recreational users of coastal areas (e.g. car park charges near beaches, fees for recreational fishers) can contribute to funding coastal clean-up, waste collection and treatment, helping to alleviate pressure on local authority budgets. Tourists' willingness to pay such taxes depends on several factors including the age and income of tourists, and whether there is a link between the tax and litter control (Oosterhuis et al., 2014).

11



11. MONITORING AND ASSESSMENT

11.1

SUMMARY OF MONITORING METHODS

Rivers

Obtaining representative samples of macro and microplastics in rivers can be problematic. For surface sampling of microplastics stationary or towed nets have been used. Alternatively, an underwater pump can be used to collect water which is then passed through a net (van der Wal et al. 2015). A floating sampler has been developed in Europe, for larger items (> 3.2 mm), by the organisation Waste Free Water. This is in two parts, with a surface net and a suspension net collecting at a depth of 0.2 to 0.7 m (van der Wal et al. 2015). Measuring the transport of material along the river bed has been undertaken using bottom nets designed for fishing (Mirrit et al. 2014). In addition floating booms have been deployed in rivers, harbours and other waterways to serve as litter traps. River flows can be very episodic, and the quantities of material transported may vary considerably on an hourly, weekly, seasonal or multi-year basis. In addition, flows are not constant across the cross-section of the river.

Shorelines

Sampling macroplastics

Several national and regional bodies have developed protocols for conducting beach surveys (Lippiat et al. 2013, OSPAR 2010, NOWPAP 2007, HELCOM, JRC 2013). These are designed to reduce variability and bias in the observations, by setting down guidelines for demarcating sampling protocols, such as the length and position of transects and recording instructions to place found items in a number of pre-determined categories.

Sampling microplastics

Sampling for microplastics on shorelines usually consists of passing sediment samples through a sieve, either in-situ (Figure 11.1) or in a laboratory (dry or wet sieving). A wide range of sampling techniques are used for monitoring microplastics in sediments (reviewed in (Hidalgo-Ruz et al. 2012, van Cauwenberghe et al. 2015, Rocha-Santos and Duarte 2015). These methods include density separation, filtration and/or sieving Hidalgo-Ruz et al. 2012, Rocha-Santos & Duarte, 2015). To facilitate the plastic extraction among organic components such as organic debris (shell fragments, small organisms, algae or sea grasses, etc.), solutions can be applied to selectively digest and remove the organic material (Galgani et al. 2011, Hidalgo-Ruz et al. 2012, Cole et al. 2014) such as for water samples. These are described in more detail in Annex X.

Upper ocean

Observations of macroplastics at sea

Visual sightings of macroplastics from ship-based observers have been reported since the 1970s (Venrick et al. 1973), and have proved to provide useful information about litter densities and how these compare between regions and over time. There has been an effort to standardise the observational methods used to reduce potential bias in the data. Factors such as wave and light conditions, and the height of the observer relative to the sea face can all contribute to variations in the number of items measured. A simple methodology has been proposed that should greatly improve the robustness of observations, allowing a more coherent picture of the distribution of floating plastic objects to be constructed in time and space (Ryan 2013). This takes account of the minimum size of items counted, the distance of items from the ship, the height of the observer above sea level, and the position of the observer relative to the ship's bow wave. In extreme cases, aircraft or satellite observations may provide a role, particularly in the aftermath of natural disasters, such as the 2011 Tōhoku earthquake tsunami in the North Pacific (NOAA 2015).

ALDFG

A number of strategies are being developed for at-sea detection of floating ALDFG, including using aircraft and satellite observation (Morishige and McElwee 2012), combined with ocean circulation modelling (Wilcox et al. 2013).

Sampling microplastics

Microplastics are usually sampled using towed nets, originally designed for sampling plankton. Manta trawls are commonly used for surface sampling and Bongo nets for mid-water (Figure 11.2). Mesh sizes may vary (0.053 – 3 mm) but most surveys use a 330

Figure 11.1

Sampling for microplastics on a sandy beach by dry sieving, near Busan, South Korea, July 2014. ©Peter Kershaw

µm mesh. Particles below this size are captured but are under-represented. Net apertures vary from 0.03 to 2 m2, depending on the type and shape. Smaller mesh sizes result in increased net resistance and clogging, resulting in under-sampling and potentially ripping. This can be partly lessoned by increasing the surface area of the net. Results are usually reported in number of items or mass of items m^{-2} or m^{-3}. More recently some researchers have started to use on-board filtration of seawater (Desforges et al. 2014). This allows underway sampling while maintaining normal steaming speeds, with filtration to smaller size ranges being possible.

Long-term data from Continuous Plankton Recorders (CPRs), sampling on regular and fixed routes, have also been used to determine relative microplastic abundance, including retrospective evaluation of archived samples and is now considered as a routine part of on-going CPR analysis (Cole, 2011). The CPR samples the water column at about 10m depth, using 280 µm mesh, so the data are not readily comparable with data from standard towed nets.

Seabed observations

As more studies are completed it has come apparent that significant quantities of plastic debris are lying on the seabed in parts of the global ocean. Some studies have been based on direct observation by cameras (Pham et al.), whereas others have been based

Figure 11.2

Towed Manta trawl for sampling the ocean surface for floating microplastics – (NOAA News Archive)

on recovery in towed bottom trawls, as part of routine fisheries management surveys. Many larger items will have been deposited close to the point of release (e.g. from a ship). Others may have floated and been transported before losing buoyancy and sinking (e.g. fishing gear), or been carried to great depth in canyons linking the continental shelf to the ocean floor (Galgani 1996, 2000). In shallower waters, side-scan sonar has been used to locate crab pots in Chesapeake to better target removal operations (Havens 2009).

Sampling biota

There are two main approaches used: i) retrieving and examining dead organisms; and, examining faecal samples of larger living organisms. A wide variety of biota has been examined for the presence of macro and microplastics. However, for monitoring purposes it is important to identify an appropriate indicator species; i.e. is it characteristic of a region and common enough to allow repeated sampling. This is expanded upon below.

Automated systems

There are several advantages to developing automated systems to monitor marine plastics, including greater spatial and temporal coverage. Video-based systems, with image recognition software, have been tested to monitor beach litter in Japan and the conditions under which litter is deposited or removed from the shoreline (Kako et al. 2010). A ship-mounted video system has been developed for use on ships of opportunity in the Mediterranean (JRC 2013). These are still at an early stage of development.

Another approach has been to develop sampling systems for microplastics, to allow water to be pumped on-board while the ship is underway then passing through a filtration system. The next step will be to utilise image recognition to describe particle size and shape and introduce some form of rapid analysis to identify the polymer cost-effectively.

11.2

SETTING BASELINES, INDICATORS AND TARGETS

Baselines

In natural sciences a baseline is usually defined as the state of some element in the environment prior to an event or some expected change. A baseline survey of nutrient levels in seawater might be conducted before the installation of a wastewater treatment plants, or of heavy metal concentrations in seabed sediments or biota prior to the disposal of mine wastes offshore. For marine plastics we can refer to a baseline state (of zero occurrence) in the early 1950s, before large-scale plastics production began. As of 2016 it is reasonable to assume that there is no longer a 'pristine' state, with respect to marine plastics, anywhere in the ocean. Instead we have to set a baseline as the state observed at a particular time or place (e.g. number of plastic items per unit area/volume/mass in sediment/water/biota), from which a monitoring programme can establish whether the littering is increasing or decreasing. This definition differs from a 'baseline' as used in economics, which describes the current direction of some economic measure (i.e. increasing or decreasing).

What makes a good indicator?

In environmental management, indicators are often used to describe the 'state' of the environment; i.e. the degree to which a selected 'descriptor', such as the number of large fish, departs from an optimal state. In most cases this optimal state is not the same as pristine; i.e. before the influence of human activities. Instead, a 'target state' can be selected on the understanding that it will be possible to introduce management measures in order to achieve this (Table 11.1). A good indicator has the following attributes:

1. **Scientifically valid**
2. **Simple to understand** by public and policy makers
3. **Sensitive** and responsive to change
4. **Cost-effective**
5. **Policy-relevant**

A number of other factors will need to be taken into account when identifying appropriate indicators and setting targets:

1. **The purpose of the assessment**
2. **Degree of granularity** in the description of the components selected for monitoring[83]
3. **Spatial variations** in the property being measured – local, national, regional (<1 m – 100s km)
4. **Temporal variations** in the component being measured – daily, weekly, annually, inter-annual, episodic
5. **The availability** of cost-effective sampling and harmonised monitoring techniques and approaches

83 Within the MSFD, 217 separate categories of marine litter have been identified; JRC/EC, 2013.

84 For example, within the European Union this is referred to as 'Good Environmental Status' under the Marine Strategy Framework Directive http://www.msfd.eu/knowseas/guidelines/3-INDICATORS-Guideline.pdf

Table 11.1

Term	Definition	Examples
Indicator	A measure of the State of the environment, subject to a Pressure (i.e. littering)	Number of items of litter on a beach per unit area
Baseline	A reference State, usually based on data obtained by monitoring an indicator in the environment	Number of litter items per unit area
Proxy indicator	An indirect measure of a Pressure	Coastal population density, shipping density, tourist visitor numbers, size and location of fishing fleets, percentage mismanaged solid waste
Target	A preferred State[84], usually defined by a national administration or regional body, with the expectation that effective management measures can be implemented to achieve it	< 'y' items of litter per unit area
Aspirational target	A desired state to be achieved in the future, which cannot be achieved in the short-medium term	

Common definitions of environmental indicators

Box 11.1

DEFINITION OF CRITERIA USED IN DEVELOPING INDICATORS FOR MARINE LITTER IN EUROPEAN SEAS

Level of maturity: high-used extensively for > 1 decade; medium-used systematically for, 1 decade; low-tool under development, further R&D needed

Technical/equipment – requirements in terms of cost: low - €1K-€10k; medium - €10k-€50k; high - > €50k

Expertise: low-trained personnel without specific professional qualifications; medium-trained personnel with specific professional qualifications; high – high skill and expertise required

Cost – total costs incurred: low - €1K-€10k; medium - €10k-€50k; high - > €50k

Level of detail generated: potential of the protocol to generate details and information in terms of material, nature and purpose of the items sampled, which can be attributed to specific and distinct sources.

Geographical applicability: potential of the protocol to be applied in any geographic area/region Limitations: key aspects inherent to the protocol and/or factors that can limit its applicability and/or generation of reliable and comparable data.

Opportunities to reduce costs: opportunities that can improve cost-effectiveness by making use of other monitoring programmes (e.g. for other MSFD descriptors) and/or maritime operations, in which the protocol can be integrated.
(JRC 2013)

Indicators, as defined here, fit within the higher-level indicators and monitoring framework being developed for the UN SDGs, specifically target 14.1 (Chapter 2)[85].

Proposed indicators for marine plastics
A series of indicators for marine plastics has been proposed in connection with the implementation of the Global Partnership on Marine Litter (GPML). These include indicators both of environmental State and 'process' indicators of progress in the implementation of the GPML (Annex XI). These are relatively high-level indicators that can be adapted to meet the particular ecological, social and economic circumstances of the nation or region.

Several Regional Seas Conventions and Action Plans have coordinated implementation of Marine Litter monitoring programmes and developed state and impact indicators related to marine litter with the view to define good environmental status. For example, UNEP/MAP has developed an integrated monitoring and assessment programme based on three region-wide common indicators.

85 https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=2013&menu=35

Within the European Union a Framework Directive has been adopted, providing a Marine Strategy for European Seas (MSFD; EC 2008). Eleven descriptors have been agreed to describe the State of European Seas, with targets to define what is Good Environmental Status (GES) measured by a global indicator framework and associated SDG indicators. One of the Descriptors is marine litter. Detailed technical recommendations and guidelines have been published covering the selection of indicators and appropriate monitoring techniques (JRC 2011, 2013). A set of criteria has been developed to assist in the selection and implementation of appropriate indicators (Box 11.1). These have been applied to a series of indicators for macro and microplastics in seawater, seabed, shoreline and biotas compartments.

Setting realistic targets

Targets are usually set by an administration, so that they have a legal basis within which mitigation measures can be developed and implemented. However, it is only worth setting a target if there is a reasonable likelihood of achieving it. In the case of marine litter, a connection has to be made between the presence of particular items of litter and a specific source(s) that can be controlled. This may be very difficult to establish, as similar items may come from several different sources (land- and sea-based). A further complication is that items may originate from outside the jurisdiction of the administration. For example, a beach survey in the Netherlands indicated that only 42% of items collected had a local origin (van Franeker 2010). This phenomenon is even more marked in the case of mid-ocean islands and SIDS. If it is unsure whether a target can be met within the short- to medium-term then an aspirational target may be set. For example, the EC has adopted an aspirational target of 30% reduction by 2020 in the top 10 items found on beaches and fishing gear found at sea (EC 2014).

It may be considered desirable to call for ‘standards’ for the quantities of macro and microplastics in waste streams or particular environmental compartments. In some cases, it may be practical to do so. If wastewater is subject to tertiary treatment, then setting a standard of > ‘x’% retention may be achievable. In the case of PCCPs, it would be possible to require zero added microplastic particles. However, in most cases targets are more likely to be related to achieving proportional reductions, with ‘standards’ set locally to take account of relevant sources, pathways and the social, ecological and economic context. Standards for contaminants in foodstuffs are already available through application of the Codex Alimentarius[86]. However, there are no standards for the quantities of nano- or microplastics. In order to develop standards, it will be necessary to establish the risk relationship between the number of particles and probable harm, accepting that this will depend on the size, shape, composition, number and exposure pathway. At present there are no accepted standards for measuring the concentration of nano- and microplastics in different media. This is an area requiring further investigation, based on pragmatic risk-based assessments, in order to focus resources on reducing the most significant risks.

Winners and losers

It is also important to consider that there may be ‘winners’ and losers’ from the imposition of management measures. For example, a ruling could be introduced requiring that any litter picked up inadvertently during normal fishing operations be landed in the next port of call. The skipper may then be faced with a bill for waste treatment that affects profit. This does nothing to ‘punish’ those who allowed the litter to be introduced to the marine environment, possibly breaking a law in doing so, but effectively ‘punishes’ someone else who is following the law. Measures sometimes have unintended and undesirable consequences. Substituting glass bottles for plastic bottles in coastal resorts may bring about a decrease in the number of discarded plastic bottles. But, if littering continues, the social consequences may be worse as a result of injuries from broken glass.

Examples of indicators and trends

Establishing trends in plastic abundance requires a combination of selecting an appropriate indicator, developing a robust sampling and analysis strategy, and maintaining a monitoring programme over a sufficient period to establish a time-series to reveal a trend, taking account of any inherent variability in the dataset. Globally there are relatively few examples where these conditions have been met. However, there have been two exceptional studies, both described by van Franeker and Law (2015): i) surface concentrations of floating plastics in the North Atlantic gyre (towed plankton nets); and, ii) the incidence of ingested plastics by the northern fulmar in the greater North Sea.

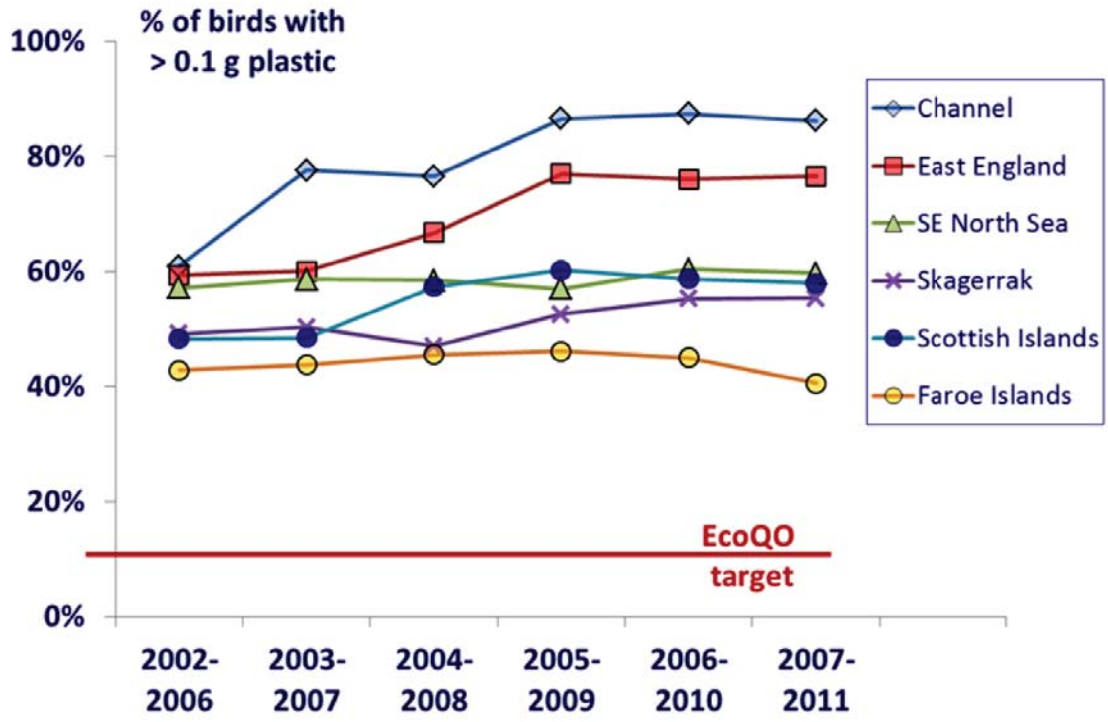
86 http://www.fao.org/fao-who-codexalimentarius/standards/en/

Biological indicators for plastics have tended to focus on common species with life traits that favour indiscriminate feeding, or those that might mistake plastic for food items. Samples are usually taken from animals found beached, to avoid unnecessary culling. Regional surveys will be species-specific, depending on the characteristic fauna. One of the longest-standing biological indicators was developed in the Netherlands, based on the quantities of plastic found in the stomach of the northern fulmar (Fulmarus glacialis). This approach has now become one of the ecological quality assessment markers used by OSPAR to assess both the abundance of plastic debris at sea and regional differences and trends over time (van Franeker et al. 2011). Clearly the selection of a biological indicator will be regionally-dependent. In the Mediterranean the loggerhead turtle (Caretta caretta) has been adopted as the most appropriate indicator species (JRC 2011).

The fulmar indicator clearly shows that the incidence of plastic has been relatively constant in recent years (Figure 11.3), with higher values occurring close to shipping lanes and areas of industrial development. One significant trend has been a steady decline in 'industrial' plastics (i.e. resin pellets). This trend is apparent also in the towed samples from the North Atlantic gyre. However, the overall incidence of plastics shows a high degree of variability, with no statistically significant trend (Figure 11.4).

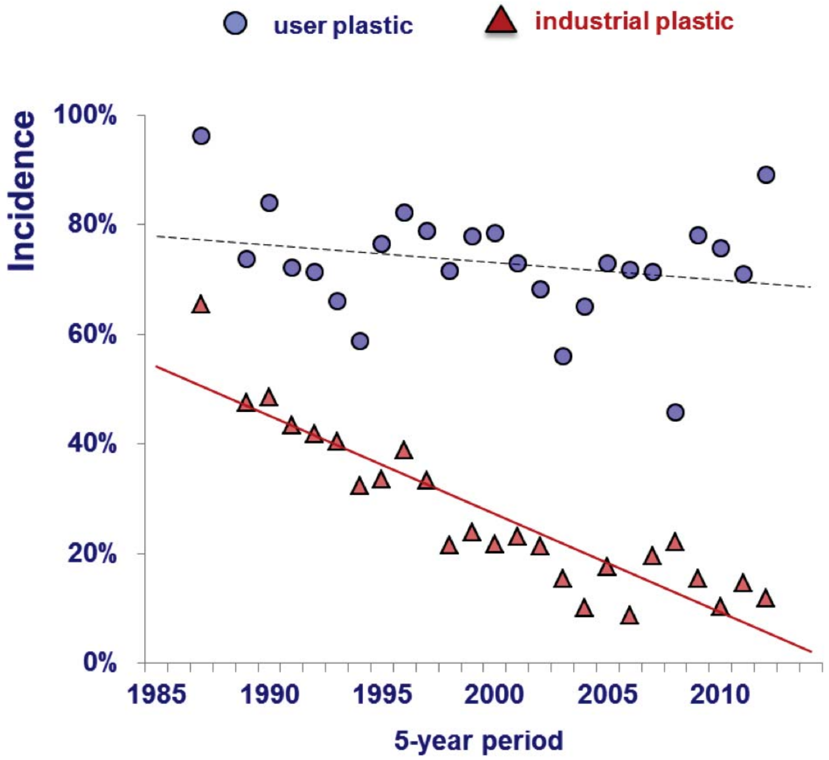
Figure 11.4 Incidence of user plastics and industrial plastics in samples collected from the North Atlantic gyre, using towed plakton nets (van Franeker and Law 2015)

Figure 11.3



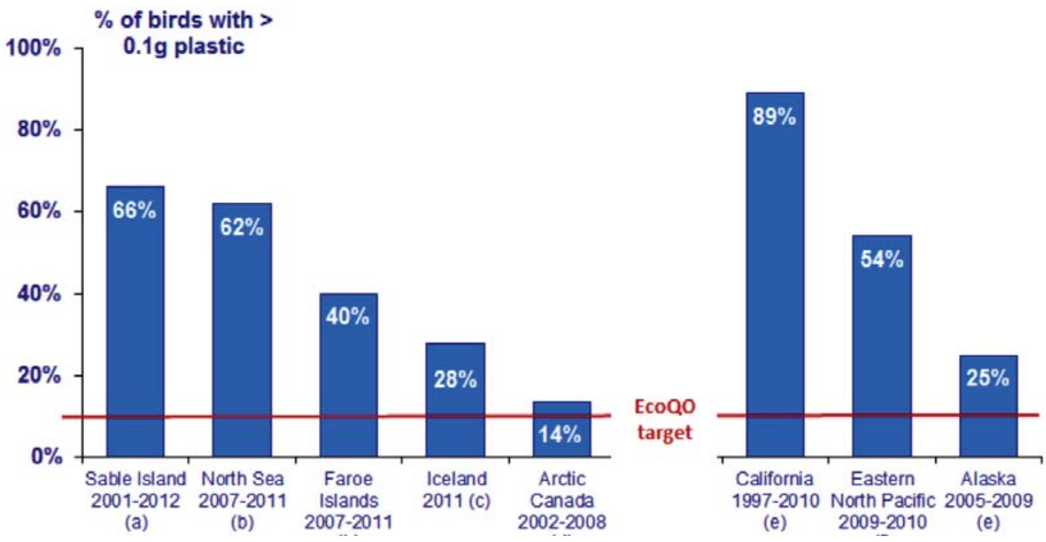
Incidence of plastic fragments in the stomachs of beached northern fulmars in different subregions of the North Sea, shown as a percentage of birds with > 0.1 g of ingested plastics in 5-year rolling means. The Ecological Quality Objective (EcoQO) target level is that no more than 10% of fulmars exceed the 0.1 g level. (van Franeker and Law 2015)

Figure 11.4



Incidence of plastic fragments in the stomachs of beached northern fulmars in different subregions of the North Sea, shown as a percentage of birds with > 0.1 g of ingested plastics in 5-year rolling means. The Ecological Quality Objective (EcoQO) target level is that no more than 10% of fulmars exceed the 0.1 g level. (van Franeker and Law 2015)

Figure 11.5



Latitudinal patterns in fulmar EcoQO performance (proportion of fulmars having >0.1 g plastic in the stomach) in North Atlantic and Pacific Oceans. (a) Bond et al. (2014), (b) van Franeker and Law (2015), (c) Kühn and Van Franeker (2012), (d) combined from Mallory et al. (2006), Mallory (2008) and Provencher et al. (2009) with additional information from the authors, (e) Nevins et al. (2011), (f) Avery-Gomm et al. (2012). (van Franeker and Law 2015)

Van Franker and Law (2015) compiled a dataset using published sources for the incidence of plastic in stomachs of the northern Fulmar from the Pacific and Atlantic. Both datasets showed a latitudinal dependence, lower incidences at higher latitudes (Figure 10.5).

Developing an indicator framework

The value of the indicator approach is enhanced if it takes place within a framework, in which issues such as the monitoring and assessment techniques to be used and the selection of appropriate indicators can be agreed and harmonised. Several frameworks have been developed under the auspices of regional seas bodies (NOWPAP, OSPAR, MAP, HELCOM) and within the EU (Chapter 2.3).

Meeting the UN Sustainable Development Goals

A framework for monitoring and assessment has been proposed to help address progress towards meeting the United Nations Sustainable Development Goals (Figure 11.7; SDSN 2015).

National monitoring is considered the most important level, with national ownership of the process and monitoring designed to meet national priorities and needs. National monitoring of the SDGs should “build on existing national and local mechanisms and processes, with broad, multi- stakeholder participation.” (SDSN 2015). It is recognized that national monitoring can be augmented with more informal programmes, by NGOs and other organisations. Regional monitoring is seen as building on existing institutions where appropriate, such as regional seas bodies. Global SDG indicators are intended to be universal. Some are used to track global commons such as the oceans. Thematic SGD indicators are intended to cover cross-cutting issues such as technology gaps, consumption and production patterns, and the health sector, at a global scale.

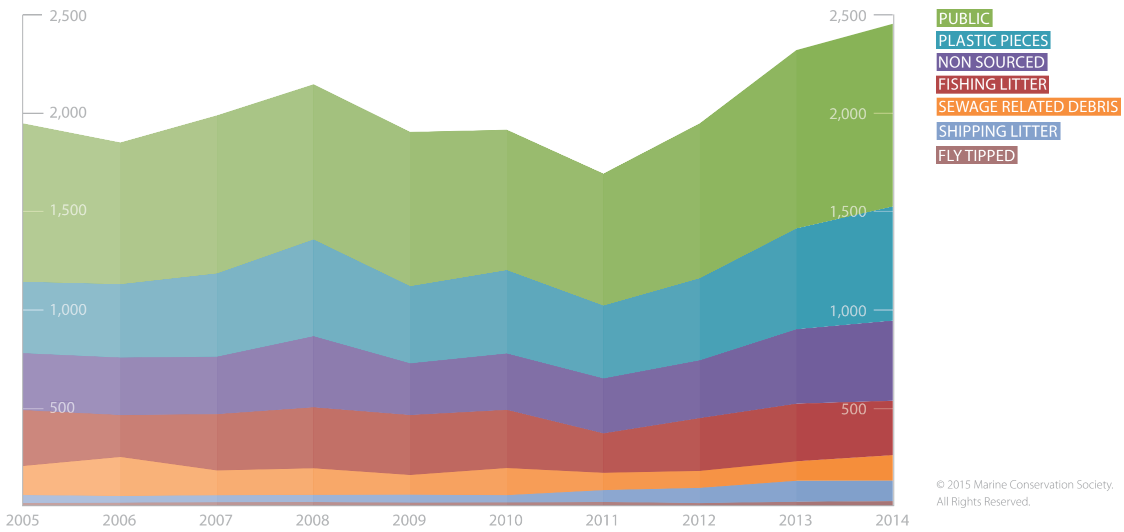
Box 11.2

TEN PRINCIPLES FOR GLOBAL SDG MONITORING INDICES

Limited in number and globally harmonised
Simple, single-variable indicators, with straightforward policy implications
Allow for high frequency monitoring*
Consensus-based, in line with international standards and system-based information
Constructed from well-established data sources
Disaggregated
Universal
Mainly outcome-focussed
Science-based and forward-thinking
A proxy for broader issue or conditions
(SDSN 2015)

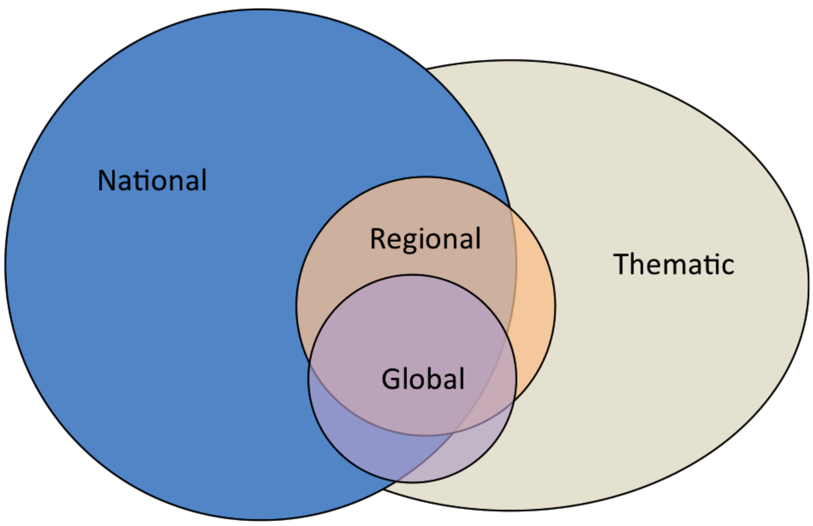
(*it may be appropriate to add the caveat ‘monitoring frequency appropriate to meet needs’)

Figure 11.6



Results of a multi-year monitoring programme organised by the UK NGO the Marine Conservation Society, showing the incidence of litter in six categories from 2005 - 2014 (MCS 2015)

Figure 11.6



Schematic illustration of the indicators for national, regional, global and thematic monitoring, towards achieving the UN Sustainable Development Goals (based on SDSN 2015).

A set of ten Principles has been put forward for setting SDG indicators and an integrated monitoring framework (Box 11.2). These provide a good set of overarching guidelines. But, developing a pragmatic and regionally-relevant set of indicators for marine litter requires further refinement, as described above. Several of the SDG goals appear relevant to aspects of marine litter reduction (Chapter 2). Marine litter is mentioned in SDG Target 14.1 although it is not mentioned in the description of overarching SDG indicators. The ten principles are useful but need to be applied with some consideration for the needs of particular circumstances. An alternative to Principle 3 (Box 11.2, 'allow for high frequency monitoring') might be phrased 'monitoring frequency appropriate to meet needs', which may or may not imply high frequency monitoring was required. What is needed is monitoring optimized to the issue. Factors include the cost of monitoring, management needs and accounting for variability in the system being assessed. So an annual sample may be adequate given changing amounts of litter in different seasons (storms). Changes in the incidence of marine debris are likely to need long-term monitoring in order to observe statistically significant differences.

11.3

HARMONISATION OF APPROACHES

Monitoring and assessment

A major obstacle in developing more comprehensive monitoring and assessment programmes has been the absence of internationally accepted methodologies, for the design and implementation of sampling and analysis techniques. Without this it is more difficult to combine and compare datasets and detect significant changes in the spatial or temporal distributions.

Some progress has been made. UNEP and IOC together have produced generic guidelines for monitoring marine litter (Cheshire et al. 2009). A major effort has been underway to harmonise monitoring and assessment techniques with the European Union, through the introduction of the Marine Strategy Framework Directive. This lays out a number of objectives and tasks that Member States are required to undertake. 'Harmonisation is required to allow comparisons between EU countries and ensure a level playing field' (EC 2013). Regional seas organisations such as MAP (Mediterranean)[87], HELCOM (Baltic Sea)[88] and NOWPAP (NW Pacific)[89] have developed their own region-specific guidelines and recommendations. In addition, MAP, HELCOM and OSPAR are helping their EU Contracting Parties to implement the MSFD so they are part of the harmonisation/comparison process.

Further research on methods needs to consider sampling design in terms of: i) the number and the size of replicates; ii) the spatial extent and the frequency of sampling; iii) the methods used for sampling (sample collection, visual observation); and, iv) the methods used for identification of microplastics (Rocha-Santos and Duate 2015). Although some methods have been proven useful techniques for monitoring (Galgani et al. 2014, Masura et al. 2015) and identifying the composition of microparticles (Dumichen et al. 2015), there is still a lack of analytical methods capable of characterizing and quantifying small sized particles, under 20-30 µm, including nanoparticles from environmental samples and consequently assessing their concentration. There is also a need to harmonize procedures in order to mitigate airborne contamination.

Although harmonisation of methods may be a laudable goal, circumstances may dictate that harmonisation is not readily achievable. For example, regional differences in the nature of marine debris, accumulation zones and technical and infrastructure support available may require a more tailored approach. This should not prevent comparisons being made, provided comparable approaches have been taken.

Data sharing

There is a great advantage to be gained in sharing information about the distribution, fate and impacts of plastics and microplastics in the ocean. It is becoming common practise for the results of research-based field observations of plastics and microplastics to be made available freely to other researchers, via on-line databases. Where the data have been published in the peer-reviewed literature there is a reasonable expectation that the sampling, analysis, quality

87 http://www.unepmap.org/index.php?module=news&action=detail&id=158

88 http://helcom.fi/action-areas/waste-water-litter/marine-litter

89 http://www.nowpap.org/ML-RAPMALI.php

assurance and reporting methods have followed an accepted protocol, and that details are made available with the results, so that the quality and relevance of the data can be put into context. The nature of the data collected will be determined by a wide range of factors, including the primary purpose of the mission, the research questions being addressed and various operational constraints. Nevertheless, there is scope for harmonising some aspects of sample collection and data recording, and at least making sure that all relevant information about sampling, analysis and environmental context (e.g. geographical position, sea state, water depth) is recorded and made available. Such metadata are essential to make full use and re-use of the data collected.

Where monitoring is carried out by a regulatory body the location and frequency of sampling, together with the type of analysis carried out, may be determined by a range of factors, including legal or financial constraints. This may limit the range of information collected. But, the big advantage of a regular monitoring programme is that trends in environmental state can be recorded. This is critical for targeting and measuring the success of interventions. Protocols and standards for data collection and sharing form part of the Action Plans of several Regional Seas Programmes. These provide an excellent example of how nations with shared interests in a region can cooperate with good practice and common approaches, develop appropriate region-specific measures and monitor their success. This can be achieved without setting up complex on-line data repositories, although these may be helpful in the longer term.

12 CONCLUSIONS AND KEY RESEARCH NEEDS

12. SUMMARY OF KEY CONCLUSIONS

1

The moral case:

- **There is a strong** moral case that humanity should not allow the ocean to become more polluted by plastic debris and microplastics.

2

- **There is a clear need** to move towards a more circular economic model for the plastic production cycle:
- **This can be simplified** as the 6Rs concept: Reduce – Redesign – Refuse - Re-use – Recycle – Recover.

3

A Precautionary Approach is justified:

- **The case for making** an intervention should be justified by making a risk-based assessment, backed up by adaptive management;

- **This is to ensure** solutions are cost-effective and to minimise unintended negative consequences;

- **It is likely** that large uncertainties in the extent of ecological, social and economic impacts will remain for some time. These need to be factored into the risk assessment and cost-benefit analysis;

- **There is a great need** to improve techniques for risk communication between technical specialists, stakeholders and the wider public.

4

An improved governance framework is needed:

- **The existing governance landscape provides** a basis for an improved governance framework, taking account of the goals and targets of the Agenda 2030;
- **Greater effort is needed** to make existing governance frameworks more effective, by ensuring full implementation, compliance and oversight.

5

Stakeholder engagement is essential:

- **There is a need to involve** all relevant partners and other stakeholders at every stage of the risk assessment and exploration of potential measures to reduce the impact of marine plastic litter;
- **Partnerships** are particularly useful for communities or nations that may have common concerns but be geographically isolated, such as SIDS;

6

Sources of marine plastics are poorly quantified:

- **'Leakage' of plastics** into the environment occurs at all stages of the production-use-waste management cycle;
- **The principal land- and sea-based sources** and the main entry points into the ocean have been described, but the absolute quantities entering the ocean, and regional differences in the relative importance of different sources, remain largely unknown.

7

- **Impacts of marine plastics** have been demonstrated for the social, economic and ecological dimensions
- **Marine macroplastics** can lead to injury and death, to loss of income and to loss of intrinsic social values;
- **Marine macroplastics** can cause significant economic impacts in the fisheries, aquaculture, shipping and tourism sectors;
- **Marine macroplastics** can cause significant ecological impacts to sensitive habitats, commercially-

valuable seafood species, and to the welfare and conservation of vulnerable or endangered species;

- **Abandoned, lost and discarded** fishing gear (ALDFG) causes substantial and wide range of economic problems and these problems have received increasing international attention in the past decade. Economic costs associated with marine safety, ghost fishing mortality, compliance, control, rescue, recovery and research activities due to ALDFG are complex and have not been estimated systematically yet;
- **Microplastics are widespread** in the ocean but the impact on individuals or populations is not yet understood;
- **From the available** limited evidence, it is concluded that microplastics in seafood do not currently represent a human health risk, although many uncertainties remain.

8

Social attitudes are important

- **Social attitudes** have a significant effect on littering behaviour and the acceptance of reduction measures, and need to be taken into account when designing litter reduction strategies.

9

Reduction measures are essential

- **Reduction measures** should be guided by a risk-based approach to target appropriate intervention points and design cost-effective measures;
- **Reduction measures** can be based on BATs, BEPs, education, awareness raising, voluntary agreements and legislation;
- **The selection** of the most appropriate measures must take into account the social and economic circumstances of the community or region to which the measures are being directed;
- **Inadequate solid waste management** in developing countries appear to be a major source of ocean plastics;
- **There are many additional benefits** from improving waste minimisation and management, including reducing the health impacts from poorly managed waste treatment processes;
- **There is a case for extending** corporate responsibility and encouraging public-private partnerships.

10

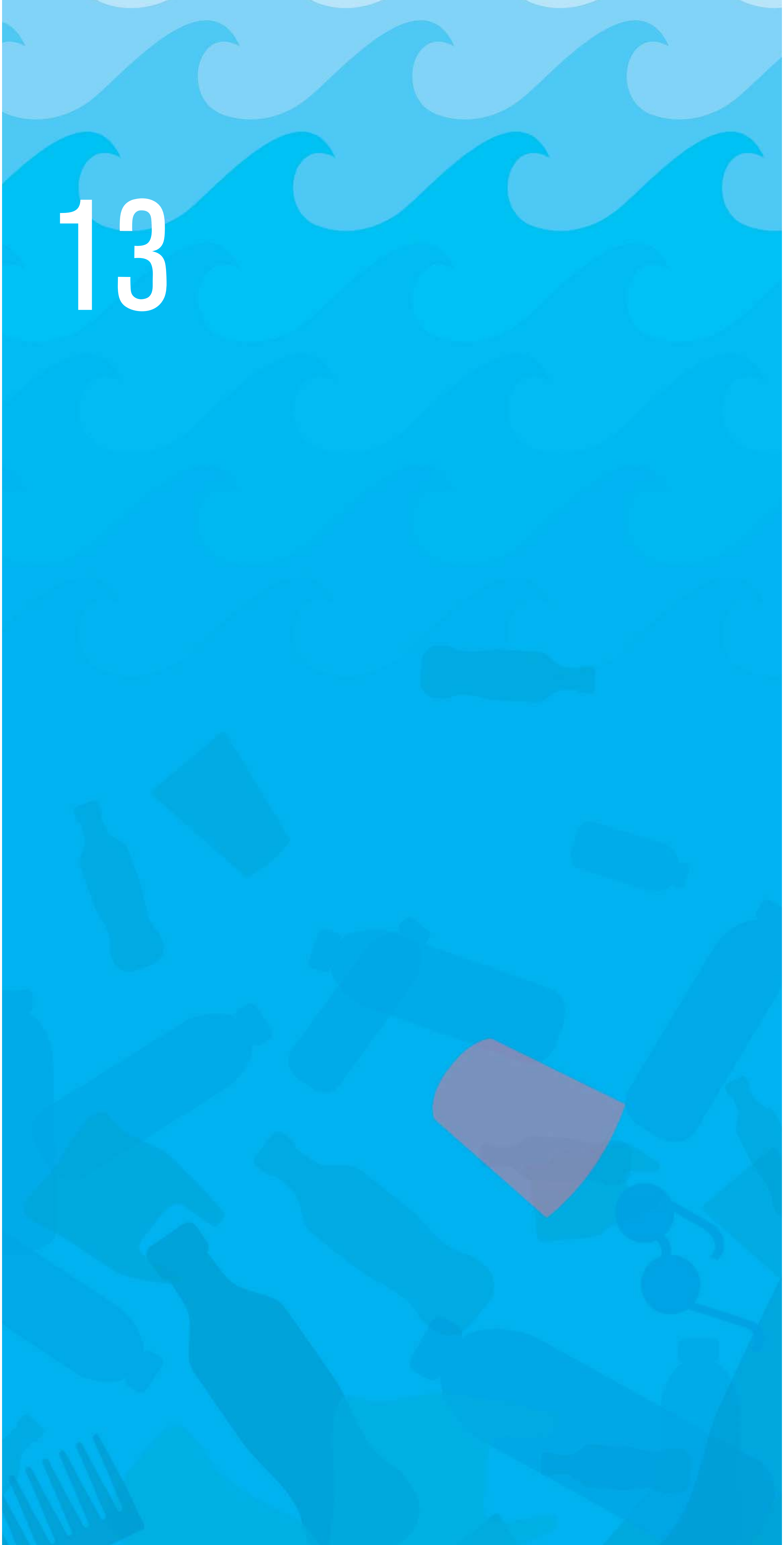
Recovery and restoration may be justified, provided that the measures adopted are environmentally sound

- **Recovery measures** can be justified where there is clear, unacceptable damage or loss of an ecosystem service, such as the damage caused by ALDFG to coral habitats or injury to a rare or endangered species;
- **Recovery measures** can be justified where there is a significant loss of commercial species due to ghost fishing;
- **Recovery measure** can be justified to prevent harm or injury to maritime users

11

- **There is a need** to strengthen and harmonise monitoring and assessment effects
- **To meet global** commitments under the UN SDG targets, and
- **To target and gauge** the effectiveness of marine litter reduction measures.

13



13. SUMMARY OF KEY RESEARCH NEEDS

13.1

GOVERNANCE

To improve the coverage and effectiveness of governance mechanisms, research is required to:

- **Explore potential** multi-governance mechanisms;
- **Examine the legal** *marge de manoeuvre* of states with regard to implementing MBIs;
- Examine **the effectiveness** of current governance arrangements and the reasons for any lack of implementation; and
- **Identify gaps** in current governance arrangements.

13.2

PROPERTIES OF PLASTICS

An area of particular concern is the release of chemicals that are added to plastics to achieve a range of desirable properties, such as UV resistance, increased plasticity and flame retardation. Some of these chemicals can have profound effects on biological systems, in particular on the endocrine system (e.g. brominated flame retardants). Research is required:

- **To minimise the use** of additive chemicals known to have an environmental impact;
- **To identify additive chemicals** that have a lower impact on the environment;
- **To identify polymer-additive combinations** in which the additives are less likely to desorb once ingested; and
- **To adopt a precautionary approach** in the formulation of new plastics with regard to their behavior in the environment.

13.3

SOURCES AND PATHWAYS OF PLASTICS AND MICROPLASTICS

Sources and pathways of macro-plastics

The quantities and relative importance of different land- and sea-based sources of macro-plastics and their entry points to the ocean need to investigated in greater detail, in particular taking account of regional differences. Research is required:

- **To quantify inputs** from the fisheries sector, including ALDFG, and the factors contributing to such losses;
- **To quantify inputs** from the aquaculture sector and the factors contributing to such losses;
- **To quantify inputs** from the shipping and offshore sectors and the factors contributing to such losses;
- **To quantify inputs** from the tourism sector and the factors contributing to such losses;
- **To quantify inputs** from the waste management sector and the factors contributing to such losses, including stormwater run-off and overflows;
- **To investigate** the relative importance of atmospheric transport; and
- **To quantify inputs** due to catastrophic events (e.g. storms, tsunamis, river basin and coastal flooding) and the factors contributing to such losses, including the identification of vulnerable coastlines and communities.

Sources and pathways of microplastics

- **The quantities and relative importance** of different sources of primary and secondary microplastics and their entry points to the ocean need to investigated in greater detail, in particular taking account of regional differences. Research should consider the relative importance of the main sources, and is required to assess:
- **The relative contribution** of synthetic fibers;
- **The relative contribution** of vehicle tire fragments;
- **The size, shape and composition** (polymer and additives) of microplastics from different sources;
- **The input of resin** pellets from the plastics production and plastic manufacturers sectors, including at transhipment points;
- **River inputs;**
- **Atmospheric inputs;** and
- **The relative contribution** of wastewater as a pathway of microplastics.

13.4

DISTRIBUTION AND FATE

Factors controlling degradation

- **Expertise from polymer** and materials science is essential to gain a better understanding of the behavior of the main types of plastics in the marine environment, including conditions controlling the rates of weathering, fragmentation and biodegradation. Research is required:
- **To better understand** the extent and rate of weathering and fragmentation of plastic according to polymer type, size and shape, and environmental setting (shoreline, buried, seabed, floating on the sea surface);
- **To examine the role** of microbial action in promoting degradation; and
- **To establish the behavior** of 'biodegradable' plastics in the ocean according to polymer type, size and shape, and environmental setting (shoreline, buried, seabed, floating on the sea surface).

Presence, transport and fate of plastics in the marine environment

At present, surface circulation models provide a reasonable representation of the transport of floating plastics on a global scale, on the basis of observed distributions (Ericksen et al. 2015). However, many plastics are denser than water and will therefore be expected to sink, either near the source or whenever buoyancy is removed. Currently there is a lack of data on both sub-surface distribution of plastics in the water column and seabed, and on the rate and nature of vertical transport processes. From a management perspective there is a need to improve the provision of data and improve data quality to better support reduction measures. Research is needed to:

- **Encourage the development** and use of harmonised monitoring techniques to facilitate data collation and comparison;
- **Coordinate monitoring** and assessment on a regional scale, incorporating and extending Regional Seas Action Plans;
- **Develop cost-effective** and, where practical, automated sampling and analysis techniques, including for fibers;
- **Develop a method** to measure nano-plastics in the aquatic environment;
- **Encourage the uptake** of citizen science;
- **Collate existing data** on plastic distribution in all environmental compartments;
- **Investigate vertical and horizontal** transport of non-buoyant plastics, taking account of the substantial scientific literature on organic and inorganic particle fluxes and sediment transport;
- **Improve the 3D representation** of plastic particle transport;
- **Improve the representation** of particle fragmentation and biodegradation in model simulations, including the rate of formation of microplastics from macro-plastics;
- **Utilize other modeling applications,** such as fish egg/larvae studies, as appropriate for transforming particle properties;
- **Include investigations** of long-term fate including 'sinks', deep ocean basins and canyons; and
- **Examine the importance** of shoreline deposits, including buried plastics, as a time-dependent source and sink.

13.5

IMPACTS

Quantifying impacts on biota

Concerning macro-plastics, research is required to:

- **Quantify the impacts** of entanglement and ingestion in support of management objectives;
- **Extend the range** of taxa investigated, including invertebrates;
- **Look for population-level** and food chain effects, including for commercial species;
- **Investigate the importance** of plastics for rafting organisms, including non-indigenous species; and
- **Further investigate effective prevention,** rescue and recovery techniques to minimize impacts for entangled species or those with ingested plastics.

Concerning microplastics, research is required to:

- **Determine if microplastics** in fisheries and aquaculture resources present a risk for food security, including food safety and impacts on human health;
- **Determine at what concentrations** microplastics will have an impact on populations, assemblages and species;
- **Understand the impacts** of nano-sized plastics on marine organisms;
- **Understand the extent** to which microplastics are transferred through foodwebs;

- **Clarify the fate** of contaminants to and from microplastic debris (both sorbed chemicals and additive ingredients);
- **Measure the impact** of chemicals associated with microplastics under environmentally-relevant exposure scenarios;
- **Measure the impact** of the mixture of microplastics and chemicals under environmentally-relevant exposure scenarios;
- **Better understand** the role microbes have in facilitating the fouling of microplastics by organisms, the ingestion of microplastic by organisms, and potentially the transformation of toxins;
- **Better understand** the relationship between pathogens and microplastics;
- **Perform risk assessments** that help clarify the various ecological impacts that may be a consequence of the widespread contamination of microplastics in the marine environment;
- **Establish threshold** levels for impact in various habitats and species; and
- **Identify microplastic** 'hotspots' for risk, and identify priority species.

Social impacts

There are a number of knowledge gaps that hinder taking better account of the social dimension of the discussion about reducing the impact of marine plastic litter. Research is required to:

- **Measure consumer perception** of plastic in seafood, i.e. how they consumers would react to awareness about plastic levels in their food and related health risks;
- **Study the differences** between public perception and established science regarding the impacts of marine debris;
- **Understand why many people** do not take responsibility for their waste and what motivates those that do take responsibility;
- **Gain a greater understanding** of different stakeholders' (especially consumers') perceptions of the issues and risks surrounding microplastics in order to take appropriate action;
- **Measure the effectiveness** of citizen-science campaigns;
- **Understand** what would drive behavior change away from single-use plastic;
- **Test the most effective messaging** to encourage responsible use; and
- **Study how media campaigns** cover risk and actions on marine debris and how to develop more effective campaigns.

Economic impacts

- **To improve the assessment** of economic impacts, research is required to:

- **Improve understanding** of the cost of action and non-action and the benefits of action to highlight cost-effective solutions; and

- **Apply this understanding** based on sector, product, type of marine litter and the macro-scale to develop a new evidence base for different decision-making frameworks and governance processes.

13.6

FISHERIES AND AQUACULTURE

The research needs concerning the fisheries and aquaculture sectors have been combined, covering sources, impacts and potential solutions. For macro-plastics, research is required to:

- **Assess the quantities** of fishing- and aquaculture-related debris released by these sectors;
- **Assess the influence** of the type of practice on debris generation (gear type, gear design, materials, means of deployment, use of ground lines, area deployed and fishing practices);
- **Experiment with gear types** and deployment practices to reduce losses;
- **Investigate, develop and implement** gear-marking schemes;
- **Assess the impact** of ghost fishing on commercial stocks; and
- **Employ risk assessment** in decision support for siting or re-siting aquaculture and developments.

For microplastics, research is required to:

- **Assess levels** of microplastic contamination in commercial species, seafood products (e.g. fishmeal and fish oil) and in fish prey (e.g. zooplankton);
- **Determine** if there is transfer of microplastics from one trophic level to the next;
- **Assess chemical** contaminant transfer from microplastics to seafood;
- **Assess microbial** pathogen load on microplastics in different areas of the ocean (open ocean, areas impacted by human sewage, aquaculture and fisheries areas);

- **Determine if seafood** microplastic concentration is higher in cultured versus wild-caught organisms;
- **Determine if microplastic** in seafood is a risk for human health in regards to food security and safety;
- **Determine how microplastics** affect different life stages (e.g. if earlier life stages are more sensitive);
- **Determine if microplastics** impact the quality and palatability of food;
- **Conduct a risk assessment** to assess the hazards of microplastics in fish and shellfish; and
- **Increase awareness** and investigate public perceptions about microplastics in seafood.

13.7

RISK ASSESSMENT

Research is required to:

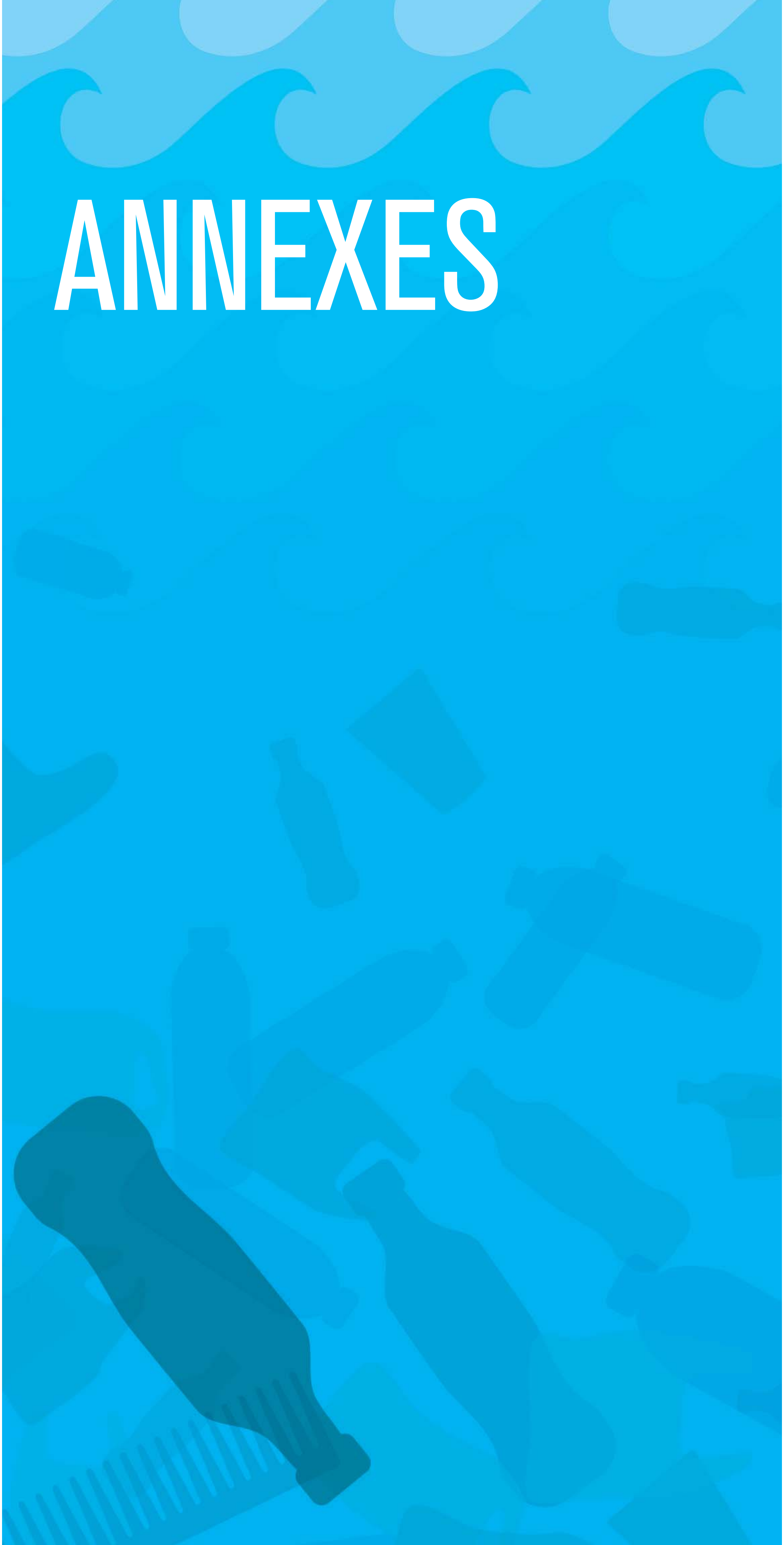
- **Develop improved methodologies** for measuring the loss of ecosystem services for non-monetized components, recognizing that regional differences in the social, cultural and economic context will limit some types of benefit transfer techniques;
- **Perform more detailed risk assessments** and cost-benefit analyses in the areas of food security, food safety, biodiversity, social impacts (including human health), and economic impacts;
- **Take account** of uncertainties of outcome when interpreting the results of risk assessments, including the influence of adopting a more precautionary approach; and
- **Explore methods** for more effective risk communication between specialists and non-specialists.

13.8

ECONOMIC DIMENSIONS

- **To improve the assessment** of economic impacts, research is required to:
- **Improve understanding** of the cost of action and the benefits of action to highlight cost-effective solutions;
- **Determine the value** of plastics (cost and benefit) to help underline the potential benefits of circular economic activities and the economic inefficiencies of letting plastic become waste;
- **Estimate the economic** value of reducing the use of plastic;
- **Estimate the likely elasticity** of demand for plastic products, i.e. how is demand likely to change with price (e.g. for plastic bottles, plastic bags); and
- **Explore the economics** of recycling for plastic waste, i.e. the value of recycling waste before it becomes marine litter, and the value of different plastic types that have become marine litter, hence incentives for recycling.

ANNEXES



ANNEX I.

UNEA RESOLUTION 1/6 MARINE PLASTIC DEBRIS AND MICROPLASTICS

The United Nations Environment Assembly,

Recalling the concern reflected in the outcome document of the United Nations Conference on Sustainable Development, entitled: "The Future We Want", that the health of oceans and marine biodiversity are negatively affected by marine pollution, including marine debris, especially plastic, persistent organic pollutants, heavy metals and nitrogen-based compounds, from numerous marine and land-based sources, and the commitment to take action to significantly reduce the incidence and impacts of such pollution on marine ecosystems,

Noting the international action being taken to promote the sound management of chemicals throughout their life cycle and waste in ways that lead to the prevention and minimization of significant adverse effects on human health and the environment,

Recalling the Manila Declaration on Furthering the Implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities adopted by the Third Intergovernmental Review Meeting on the Implementation of the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities, which highlighted the relevance of the Honolulu Strategy and the Honolulu Commitment and recommended the establishment of a global partnership on marine litter,

Taking note of the decisions adopted by the eleventh Conference of the Parties to the Convention on Biological Diversity on addressing the impacts of marine debris on marine and coastal biodiversity,

Recalling that the General Assembly declared 2014 the International Year of Small Island Developing States and that such States have identified waste management among their priorities for action,

Noting with concern the serious impact which marine litter, including plastics stemming from land and sea-based sources, can have on the marine environment, marine ecosystem services, marine natural resources, fisheries, tourism and the economy, as well as the potential risks to human health;

1. **Stresses** the importance of the precautionary approach, according to which lack of full scientific certainty should not be used for postponing cost-effective measures to prevent environmental degradation, where there are threats of serious or irreversible damage;

2. **Recognizes** the significant risks arising from the inadequate management and disposal of plastic and the need to take action;

3. **Encourages** governments, intergovernmental organizations, non-governmental organizations, industry and other relevant actors to cooperate with the Global Partnership on Marine Litter in its implementation of the Honolulu Strategy and to facilitate information exchange through the online marine litter network;

4. **Recognizes** that plastics, including microplastics, in the marine environment are a rapidly increasing problem due to their large and still increasing use combined with the inadequate management and disposal of plastic waste, and because plastic debris in the marine environment is steadily fragmenting into secondary microplastics;

5. **Also recognizes** the need for more knowledge and research on the source and fate of microplastics and their impact on biodiversity, marine ecosystems and human health, noting recent knowledge that such particles can be ingested by biota and could be transferred to higher levels in the marine food chain, causing adverse effects;

6. **Notes** that microplastics may also contribute to the transfer in the marine ecosystems of persistent organic pollutants, other persistent, bioaccumulative and toxic substances and other contaminants which are in or adhere to the particles;

7. **Recognizes** that microplastics in the marine environment originate from a wide range of sources, including the breakdown of plastic debris in the oceans, industrial emissions and sewage and run-off from the use of products containing microplastics;

8. **Emphasizes** that further urgent action is needed to address the challenges posed by marine plastic debris and microplastics, by addressing such materials at source, by reducing pollution through improved waste management practices and by cleaning up existing debris and litter;

9. **Welcomes** the establishment of the Global Partnership on Marine Litter launched in Rio de Janeiro, Brazil, in June 2012 and the convening of the first Partnership Forum in 2013;

10. **Also welcomes** the adoption by the contracting parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (Barcelona Convention) at its eighteenth ordinary meeting, held in Istanbul, Turkey, from 3 to 6 December 2013, of the Regional Action Plan on Marine Litter Management, the world's first such action plan, and welcomes the draft Action Plan on Marine Litter for the North-East Atlantic region awaiting adoption by the Commission of the Convention for the Protection of the Marine Environment of the North-East Atlantic at its meeting in Cascais, Portugal, and encourages governments to collaborate through relevant regional seas conventions and river commissions with a view to adopting such action plans in their regions;

11. **Requests** the Executive Director to support countries, upon their request, in the development and implementation of national or regional action plans to reduce marine litter;

12. **Welcomes** the initiative by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection to produce an assessment report on microplastics, which is scheduled to be launched in November 2014;

13. **Also welcomes** the work undertaken by the International Whaling Commission on assessing the impacts of marine debris on cetaceans and the endorsement by the Conference of the Parties to the Convention on the Conservation of Migratory Species of Wild Animals at its tenth meeting of resolution 10.4, addressing the impacts of marine debris on migratory species;

14. **Requests** the Executive Director, in consultation with other relevant institutions and stakeholders, to undertake a study on marine plastic debris and marine microplastics, building on existing work and taking into account the most up-to-date studies and data, focusing on:

    (a) **Identification** of the key sources of marine plastic debris and microplastics;
    (b) **Identification** of possible measures and best available techniques and environmental;

practices to prevent the accumulation and minimize the level of microplastics in the marine environment;

(c) **Recommendations** for the most urgent actions;

(d) **Specification** of areas especially in need of more research, including key impacts on the environment and on human health;

(e) **Any other relevant priority areas identified** in the assessment of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection;

15. **Invites** the secretariats of the Stockholm Convention on Persistent Organic Pollutants, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal and relevant organizations involved in pollution control and chemicals and waste management and the secretariats of the Convention on Biological Diversity, the Convention on Migratory Species and the regional seas conventions and action plans to contribute to the study described in paragraph 14 of the present resolution;

16. **Encourages** governments and the private sector to promote the more resource-efficient use and sound management of plastics and microplastics;

17. **Also encourages** governments to take comprehensive action to address the marine plastic debris and microplastic issue through, where appropriate, legislation, enforcement of international agreements, provision of adequate reception facilities for ship-generated wastes, improvement of waste management practices and support for beach clean-up activities, as well as information, education and public awareness programmes;

18. **Invites governments,** intergovernmental organizations, the scientific community, non-governmental organizations, the private sector and other stakeholders to share relevant information with the Executive Director pertinent to the study described in paragraph 14;

19. **Invites those** in a position to do so to provide financial and other support to conduct the study identified in paragraph 14;

20. **Requests** the Executive Director to present the study on microplastics for the consideration of the United Nations Environment Assembly at its second session.

ANNEX II.

A) COMMON CHEMICAL ADDITIVES IN PLASTICS;

B) COMMON ORGANIC CONTAMINANTS ABSORBED BY PLASTICS

a) Common chemical additives in plastics

Table II a

Short form	Full name	Examples of function
BPA	Bisphenol A	A monomer used in the manufacture of polycarbonates and epoxy resins
DBP	Dibutyl Phthalate	Anti-cracking agents in nail varnish
DEP	Diethyl Phthalate	Skin softeners, colour and fragrance fixers
DEHP	Di-(2-ethylhexyl)phthalate	Plasticizer in PVC
HBCD	Hexabromocyclododecane	Flame retardant
PBDEs	Polybrominated Diphenyl Ethers (penta, octa & deca forms)	Flame retardants
	Nonylphenol	Stabilizer in PP, PS
phthalates	Phthalate esters	Improve flexibility and durability

b) Common organic contaminants absorbed by plastics

Table II b

Short form	Full name	Origin
DDT	Dichlorodiphenyltrichloroethane	Insecticide
PAHs	Polycyclic Aromatic Hydrocarbons	Combustion products
PCBs	Polychlorinated Biphenyls	Cooling and insulating fluids, e.g. in transformers

ANNEX III.

EXAMPLES OF CONCENTRATIONS OF PLASTICS IN RIVERS FLOWING TO THE OCEAN

Examples of concentrations of plastics in rivers flowing to the ocean (adapted from GESAMP 2016)

Table III

Location	Compartment	Sampling	Abundance (densities)	References
Europe				
Danube river, Austria, Europe	Surface water	Sizes classes: <2mm, 2-20mm Sampling mesh: 500mm	Max: 141 647.7 items /1000m^{-3} Mean: 316.8 (±4664.6) items/ 1000 m^{3} 73.9% represent spherules (~3mm)	Lechner 2014
Elbe, Mosel, Neckar and Rhine rivers, Germany, Europe	Sediment	Size classes: <5mm	Max: 64 items kg^{-1} dry weight, Mean: not indicated	Wagner 2014
Po river/Adriatic Sea	Surface water	Neuston net (330µm), Monthly,	1 (Spring) to 12.2 items m^{-3} (winter)	Vianello 2013
Seine river/ English Channel	Surface water	A plankton net (80mm mesh), and (ii) a manta trawl (330mm mesh)	(i) Plankton net: 3-108 particles/m3. (ii) Manta trawl: 0.28–0.47particles m^{-3}	Dris 2015
Rhine, Main Rivers, Germany	Sediment	63–5000µm Three size clases: 630–5000, 200–630, and 63–200µm	Range: 228–3763 particles kg^{-1}	Klein 2015
Solent: Hamble, Itchen and Test as tributaries to Southampton Water in Hampshire, UK	Surface water	1235 (total of 4 samples) sampled in each estuary. 0.3mm mesh	Itchen 1.55mp m^{-2} Test 5.86m^{-2} Hamble 0.4mp m^{-2} Total all estuaries: 3.72m^{-2} (Southampton water 1.29m^{-2})	Gallagher 2015
Tamar estuary, UK, Europe	Surface water	Size classes: <1mm, 1e3mm, 3e5mm, >5mm Sampling mesh: 300mm	Max: 204 pieces of suspected plastic Mean: 0.028 items m^{-3} Abundances include all plastic particles, of which 82% represents size <5mm	Sadri 2014

Table III

Location	Compartment	Sampling	Abundance (densities)	References
North America				
North Shore Channel (Chicago, USA)	Surface water	Two neuston nets (0.92 × 0.42m and 0.36 × 0.41m) of 333-µm mesh	Upstream waters : 1.94 (0.81) particles m^{-3} Downstream waters : 17.93 (11.05) particles m^{-3}	McCormick 2014
St. Lawrence River, Canada/USA,	Sediment	Size classes: not indicated. Items size range: 0.4-2.16mm	Mean: 13 759 (±13 685) items m^{-2} max at 136 926 (±83947) items m^{-2}	Castañeda 2014
Los Angeles River, San Gabriel River, Coyote Creek, USA, North America	Surface, mid and near-bottom water	Size classes: >1.0 and <4.75mm, >4.75mm Sampling mesh: 333, 500, and 800µm	Max: 12 932 items m^{-3} Mean 24-h particle counts on date of greatest abundance: Coyote creek: 5000 items m^{-3} San Gabriel river: 51 603 items m^{-3} Los Angeles River: 1 146 418 items m^{-3} Item size class: 1.0-4.75mm	Moore 2011
South America				
Elqui, Maipo, Maule and BioBio rivers, northern-central (29° S) to southern central Chile (37° S)	Surface water	Neuston net with a mesh size of 1mm and an opening area of 27 * 10.5cm2. 6 2 counts by scientists + 2-6 counts by students	Elqui Mouth: 0.12875m^{-3} Maipo: 0.647m^{-3} Maule: 0.74m^{-3} BioBio: 0.05m^{-3}	Rech 2015
Asia				
Nakdong River (187.1 m3/s)/ Jinhae Bay, southern Korea.	Surface water	Trapping of surface water, 2mm mesh screen, 100 times, 3.14m2 /2.2-2.8l. samples/ station	120 particles l^{-1} (10% paints) , 187±207 particles l^{-1} after heavy rain	Song 2015
Yangtze Estuary, China	Surface	Pumping/filtration (32-µm steel sieve)	4137 ± 2462m^{-3}	Zhao 2014

ANNEX IV.

ABUNDANCE OF MICROPLASTICS IN SUBTIDAL SEDIMENTS WORLDWIDE

Abundance of microplastics in subtidal sediments worldwide. Location and location specification (Modified from Van Cauwenberghe et al. 2015).

Table IV

Continent	Location	Location Specification	Depth	Particle Size	Measured Abundance	Reference
Americas	US	Maine Subtidal		0.250mm-4mm	105 items/L	Graham & Thompson 2009
	US	Florida Subtidal		0.250mm-4mm	116-215 items/L	Graham & Thompson 2009
	Brazil	Tidal Plain		1mm-10cm	6.36-15.89 items/m^2	Costa et al. 2011
Asia	India	Shipbreaking Yard		1.6mm-5mm	81.4mg/kg	Reddy et al. 2006
	Singapore	Mangrove		1.6mm-5mm	36.8 items/kg dry	Nor & Obbard 2014
Europe	UK	Estuary			2.4-5,6 fibres/50ml	Thompson et al. 2004
	Sweden	Subtidal		2mm-5mm	2-332 items/100ml	Noren 2007
	Belgium	Harbour		0.38mm-1mm	166.7 items/kg dry	Claessens et al. 2011
		Continental Shelf	0-200m		97.2 items/kg dry	
	Italy	Subtidal		0.7mm-1mm	672-2175 items/kg dry	Vianello et al. 2013
	Slovenia	Shelf	Infralittoral (<50m)		30-800 items/kg dry	Bajt et al. 2015

Continent	Location	Location Specification	Depth	Particle Size	Measured Abundance	Reference
Oceanic Sediments	Polar Ocean, Mediterranean, North Atlantic, Gulf of Guinea	Deep Sea	1176-4848	5 mm-1mm	0.5 items/cm^2	Van Cauwenberghe et al. 2013
	NW Pacific	Deep Sea Trench	4869-5766	0.300mm-5 mm	60-2020 items/m^2	Fisher et al. 2015
	Subpolar/ North Atlantic	Deep Sea Mount Slope	1000-2000	0.032-5mm	10-15 pieces per 50ml	Woodall et al. 2015
	North East Atlantic	Canyons/Slope	1400-2200	0.032-5mm	6-40 pieces per 50ml	Woodall et al. 2015
	Mediterranean	Canyons/Slope/Basin	300-3500	0.032-5mm	10-35 pieces per 50ml	Woodall et al. 2015
	SW Indian	Seamount	500-1000	0.032-5mm	Up to 4 pieces per 50ml	Woodall et al. 2015

ANNEX V.

ENTANGLEMENT OF CETACEANS AND PINNIPEDS

Overview of literature containing data on entanglement of cetaceans (from Butterworth et al. 2012)

Table V.1

Species / Subspecies	Region (FAO statistical areas [FAO 2012])	Entanglement rate (% entangled each year)	Entanglement rate (by animal or by % of population with scars)	Fishing pot gear debris (%)	Net (derelict) debris (%)	Mortality estimate (%)*	Source
Humpback whale	Western Central Atlantic			41	50	10	Johnson et al. 2005
Humpback whale	North West Atlantic	2.4	17 whales become entangled each year			26	Cole et al. 2006
Humpback whale	North West Atlantic	8-10.4	48-57				Robbins & Mattila 2004
Humpback whale	North East Pacific	8	52-78				Neilson et al. 2007
Western grey whale	North West Pacific		18.7				Bradford et al. 2009
Minke whale	North East Atlantic		5-22				Northridge et al. 2010
Minke whale	North West Pacific			31	69	0.9	Song et al. 2010
Minke whale	North West Atlantic	2.6	7 whales per year			37	Cole et al. 2006
North Atlantic right whale	North West Atlantic		57	25	67	12	Kraus 1990
North Atlantic right whale	North & Central West Atlantic	1.6	6 whales per year			27	Cole et al. 2006
North Atlantic right whale	North & Central West Atlantic	1.15		71	14	29	Johnson et al. 2005
Fin whale	North East Atlantic		5				Sadove & Morreale 1990

Species / Subspecies	Region (FAO statistical areas [FAO 2012])	Entanglement rate (% en-tangled each year)	Entangle-ment rate (by animal or by % of population with scars)	Fishing pot gear debris (%)	Net (derelict) debris (%)	Mortality estimate (%)*	Source
Fin whale	North West Atlantic	0.8	2 whales per year			44	Cole et al. 2006
Blue whale	North West Atlantic		<1 whale per year				Cole et al. 2006
Bryde's whale	North West Atlantic	0.2	<1 whale per year				Cole et al. 2006

Overview of literature containing data on the entanglement of pinnipeds (from Butterworth et al. 2012).

Table V.2

Species / Subspecies	Region (FAO statistical areas [FAO 2012])	Entanglement rate (% incidence in population)	Plastic debris (%)	Net debris (%)	Fishing Line debris (%)	Mortality estimate (%)*	Source
Kalikoura fur seal	South West Pacific	0.6-2.8	31	42			Boren et al. 2006
Australian fur seal	Eastern Indian Ocean	1.9	30	40		73	Pemberton et al. 1992
New Zealand fur seal	Eastern Indian Ocean	0.9	30	29	3	57	Page et al. 2004
Australian sea lion	Eastern Indian Ocean	1.3	11	66	6	44	Page et al. 2004
Antarctic & Sub – Antarctic fur seal	Western Indian Ocean	0.24	41	17	c. 10		Hofmeyr et al. 2002
Antarctic fur seal	South East Atlantic	0.024-0.059	18	48		50	Hofmeyr et al. 2006
Antarctic fur seal	South West Atlantic	0.4	46-52			80	Arnould and Croxhall 1995
Cape fur seal	South East Atlantic	0.1-0.6	50				Shaughnessy 1980
Californian sea lion	Eastern Central Pacific	3.9-7.9		50	33		Harcourt et al. 1994
Hawaiian monk seal	Eastern Central Pacific	0.7	8	32	28	16	Henderson 2001
Stellar sea lion	North East Pacific	0.26	54	7	2		Raum-Sayuran et al. 2009
Californian sea lion	Eastern Central Pacific	0.08-0.22	25	19	14		Stewart & Yochem 1987
Northern ele-phant seal	Eastern Central Pacific	0.15	36	19	33		Stewart & Yochem 1987
Harbour seal	Eastern Central Pacific	0.09	33				Stewart & Yochem 1987
Northern fur seal	North East Pacific	0.24		50			Stewart & Yochem 1987

ANNEX VI.

INGESTION OF MICROPLASTICS BY MARINE ORAGANISMS

Laboratory studies exposing organisms to microplastics. Organisms which have a commercial interest have a * after the species name. Table includes all published studies until 11th November 2015. (Rochman et al highlighted as it is a freshwater study)

Table VI.1

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Dinoflagellata								
Oxyrrhis Marina		7.3µm	PS	3000 per ml	1 hr	Digestive tract	Ingestion	Cole et al. 2013
Phylum Chlorophyta								
Tetraselmis Chuii		1 – 5µm	PE	0.000046 - 0.0015 per ml	96 hrs	Cellular	No significant effect on growth, did not interact with toxicity of copper	Davarpanah & Guilhermino 2015
Scenedesmus Spp.		20nm	PS	1.6-40mg per ml	2 hrs	Cellular	Absorption, ROS increased, photosynthe-sis affected	Bhattacha-rya et al. 2010
Phylum Haptophyta								
Isochrysis Galbana		2µm	PS	9 x 104 per ml	6 hrs	External	Microspheres attached to algae, no negative effect observed	Long et al. 2014
Phylum Dinophyta								
Heterocapsa Triquetra		2µm	PS	9 x 104 per ml	6 hrs	External	Microspheres attached to algae, no negative effect observed	Long et al. 2014

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Cryptophyta								
Rhodomonas Salina		2µm	PS	9 x 104 per ml	6 hrs	External	Microspheres attached to algae, no negative effect observed	Long et al. 2014
Phylum Ochrophyta								
Chaetoceros Neogracilis		2µm	PS	9 x 104 per ml	6 hrs	External	Microspheres attached to algae, no negative effect observed	Long et al. 2014
Phylum Ciliophora								
Strombidium Sulcatum		0.41 -10µm	-	5-10% ambient bacteria concentra-tion	1 hr	Digestive tract	Ingestion	Christaki et al. 1998
Tintinnopsis Lobiancoi		10µm	PS	1000, 2000, 10000 per ml	3 hrs	Digestive tract	Ingestion	Setälä et al. 2014
Phylum Cnideria								
Obelia Sp.		20.6	PS	2240 per ml	1 hr	Digestive tract	Partial inges-tion	Cole et al. 2013
Dipsastrea Pallida	Coral	10µm-2mm	PP	0.395mg per ml	48 hrs	Mouth and mesen-teries of polyps	Ingestion	Hall et al. 2015
Phylum Rotifera								
Synchaeta Spp.		10µm	PS	2000 per ml	3 hrs	Digestive tract	Ingestion	Setälä et al. 2014
Phylum Annelida								
Arenicola Marina	Lugworm	20-2000µm	-	1.5mg per ml	Several days	Digestive tract	Ingestion	Thompson et al. 2004
Arenicola Marina	Lugworm	130µm	U-PVC	0-5% by weight	48 hour, 4 weeks	Digestive tract	Ingestion, reduced feeding, increased phagocytic activity, reduced available energy reserves, lower lipid reserves	Wright et al. 2013
Arenicola Marina	Lugworm	230µm	PVC	1500g of sediment	10 days	Digestive tract	Ingestion, oxidative stress	Browne et al. 2013

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Annelida								
Arenicola Marina	Lugworm	< 5mm	HDPE, PVA, PA	0.02, 0.2 2% of sediment	31 days	Digestive tract	Concentration in sediment had significant effects on the metabolic rate of lugworms (increase mp = increase metabolic rate)	Green et al. 2015
Arenicola Marina	Lugworm	400-1300µm	PS	0, 1, 10, 100 mg per ml	28 days	Faeces	Ingestion, reduced feed-ing, weight loss	Besseling et al. 2013
Galeolaria Caespitosa	Fan worm	3 – 10µm	-	5000 per ml	20 mins	Digestive tract	Ingestion	Bolton & Havenhand 1998
Marenzelleria Spp.		10µm	PS	2000 per ml	3 hrs	Digestive tract	Ingestion	Setälä et al. 2014
Phylum Mollusca								
Bivalvia (larvae)		7.3µm	PS	3000 per ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
*Mytilus Edulis**	Blue mussel	30nm	PS	0, 0.1, 0.2, 0.3mg per ml	8 hrs	Digestive tract	Ingestion, pseudofae-ces, reduced filtering	Wegner et al. 2012.
*Mytilus Edulis**	Blue mussel	0 – 80µm	HDPE	2.5mg per ml	< 96 hrs	Digestive tract, Lymph system	Ingestion, retention in digestive tract, transfer to lymph system, immune response	Von Moos et al. 2012 & Köhler 2010
*Mytilus Edulis**	Blue mussel	0.5µm	PS	50µL per 400 ml seawater	1 hr	Digestive tract	Ingestion, trophic trans-fer to *Carcinus maenas*	Farrell & Nelson 2013
*Mytilus Edulis**	Blue mussel	3, 9.6µm	PS	0.51mg per ml	12 hrs	Digestive tract, Lymph system	Ingestion, retention in digestive tract, transferred to lymph system	Browne et al. 2008
*Mytilus Edulis**	Blue mussel	10µm	PS	2×10^4 per ml	45 mins	Faeces	Ingestion, egestion	Ward & Tagart 1989
*Mytilus Edulis**	Blue mussel	10µm	PS	1000 per ml	45 mins	Faeces	Ingestion, egestion	Ward & Kach 2009
*Mytilus Galloprovincialis**	Mediter-ranean mussel	< 100µm	PS, PE	1.5mg per ml	7 days	Gills, digestive tract and lymph system	presence in haemolymph, gills and digestive gland	Avio et al. 2015
*Mytilus Galloprovincialis**	Mediter-ranean mussel	50nm	PS	1, 5, 50 µg per ml	-	Haemo-cytes	Only the haemocytes were exposed, signs of cyto-toxicity	Canesi et al. 2015

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Mollusca								
*Mytilus Trossulus**	Bay mussel	10µm	PS	/	0.5 - 1.5 hr	Digestive tract	Ingestion	Ward et al. 2003
*Placopecten Magellanicus**	Atlantic Sea scallop	15, 10, 16, 18, 20µm	PS	1.05 per ml	1 hr	Faeces	Ingestion, retention, egestion	Brilliant & MacDonald 2000
*Placopecten Magellanicus**	Atlantic Sea scallop	15, 10, 16, 18, 20µm	PS	1.05 per ml	1 hr	Faeces	Ingestion, retention, egestion	Brilliant & MacDonald 2002
*Crassostrea Virginica**	Eastern oyster	10µm	PS	1000 per ml	45 mins	Faeces	Ingestion, egestion	Ward & Kach 2009
*Crassostrea Gigas**	Pacific oyster	2, 6µm	PS	1800 per ml for the 2µm size; 200 per ml for the 6µm size	2 months	Digestive tract	Increased filtration and assimilation, reduced gamete quality, slower larval rearing for larvae from MP exposed parents	Sussarellu et al. 2014
Phylum Echinodermata								
Apostichopus Californicus	Giant Californian sea cucumber	10, 20µm	PS	2.4 per µL	-	Digestive tract	Ingestion, retention	Hart 1991
Thyonella Gemmate	Striped sea cucumber	0.25-15mm	PVC, PA	11g PVC shavings, 60g resin pellets, 2g nylon line, to 600ml of silica sand	20-25 hrs	Digestive tract	Selective ingestion	Graham & Thompson 2009
Holothuria (Halodeima) Grisea	Grey sea cucumber	0.25-15mm	PVC, PA	As above	20-25 hrs	Digestive tract	Selective ingestion	Graham & Thompson 2009
Holothuria Foridana	Florida sea cucumber	0.25-15mm	PVC, PA	As above	20-25 hrs	Digestive tract	Selective ingestion	Graham & Thompson 2009
*Cucumaria Frondosa **	Orange footed sea cucumber	0.25-15mm	PVC, PA	As above	20-25 hrs	Digestive tract	Selective ingestion	Graham & Thompson 2009
*Paracentrotus Lividus**	Sea urchin	40nm	PS	<25µg per ml	48 hr	Digestive tract	Accumulation and embryo toxicity	Della Torre et al. 2014
Lytechinus Variegatus	Green sea urchin	3-5mm	PE	2ml per 8ml	24 hr	External	Toxic effects, inc. anomalous embryonic development	Nombre et al. 2015
*Tripneustes Gratilla**	Collector urchin	32-35µm	PE	1, 10, 100, 300 per ml	1-6hrs, 9 days	Faeces	Ingestion, egestion	Kaposi et al. 2014
Dendraster Excentricus	Eccentric sand dollar	10, 20 µm	PS	2.4 per µL	-	Digestive tract	Ingestion, retention	Hart 1991

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Echinodermata								
Ophiopholis Aculeate	Crevice brittle star	10, 20 µm	PS	2.4 per µL	-	Digestive tract	Ingestion, retention	Hart 1991
Dermasterias Imbricate	Leather star	10, 20 µm	PS	2.4 per µL	-	Digestive tract	Ingestion, retention	Hart 1991
Phylum Arthropoda								
Semibalanus Balanoides	Barnacle	20-2000 µm	-	1mg per ml	Several days	Digestive tract	Ingestion	Thompson et al. 2004
Tigriopus Japonicas	Copepod	0.05µm	PS	9.1×10^{11} per ml	24 hrs	Faeces	Ingestion, egestion, mortality, decreased fecundity	Lee et al. 2013
Tigriopus Japonicas	Copepod	0.5µm	PS	9.1×10^{8} per ml	24 hrs	Faeces	Ingestion, egestion, mortality, decreased fecundity	Lee et al. 2013
Tigriopus Japonicas	Copepod	6µm	PS	5.25×10^{5} per ml	24 hrs	Faeces	Ingestion, egestion, mortality, decreased fecundity	Lee et al. 2013
Acartia (Acanthacartia) Tonsa	Copepod	7-70 µm	-	3000-4000 beads per ml	15 mins	Digestive tract	Ingestion, size selection	Wilson 1973
Acartia Spp.	Copepod	10µm	PS	2000 per ml	3 hrs	Faeces	Ingestion	Setälä et al. 2014
Acartia Clausi	Copepod	7.3, 20.6, 30.6 µm	PS	635, 2240, 3000 beads per ml	24 hrs	Digestive tract	Size based selection: Ingestion at 7.3 µm , no ingestion at 20.6 µm, partial ingestion at 30.6 µm	Cole et al. 2013
Eurytemora Affinis	Copepod	10µm	PS	1000, 2000, 10,000 per ml	3 hrs	Faeces	Ingestion, egestion	Setälä et al. 2014
Limnocalanus Macrurus	Copepod	10µm	PS	1000, 2000, 10, 000 per ml	3 hrs	Digestive tract	Ingestion	Setälä et al. 2014
Temora Longicornis	Copepod	1.7, 3.8, 7.3, 20.6, 30.6 µm	PS	635, 2240, 3000 beads per ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
Temora Longicornis	Copepod	20µm	PS	100 per ml	over-night	Digestive tract	Ingestion 10.7 ± 2.5 beads per individual	Cole et al. 2014
Calanus Helgolandicus	Copepod	20µm	PS	75 per ml	23 hrs	Faeces	Egestion, ingestion	Cole et al. 2015

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Arthropoda								
Calanus Helgolandicus	Copepod	7.3, 20.6, 30.6 µm	PS	635, 2240, 3000 beads per ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
Centropages Typicus	Copepod	7.3, 20.6, 30.6 µm	PS	635, 2240, 3000 beads per ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
Idotea Emarginata	Isopod	10µm	PS	0.3-120 mg/g	3 days	Faeces	Ingestion, presence in stomach, faeces, no evidence of assimilation, no absorb-ance, no adverse effect on life history	Hamer et al. 2014
Orchestia Gammarellus	Amphipod	20 – 2000µm	-	1g per individual (n = 150)	several days	Digestive tract	Ingestion	Thompson et al. 2004
Talitrus Saltator	Amphipod	10 – 45µm	PE	10% weight (0.06-0.09 p/g dry food	24 hrs	Faeces	Ingestion, egestion after 2 hours	Ugolini et al. 2013
Allorchestes Compressa	Amphipod	11 - 700µm	PE	0.1 per g	72 hrs	Faeces	Ingestion, egestion within 36 hours	Chua et al. 2014
Neomysis Integer	Shrimp	10µm	PS	2000 spheres per ml	3 hrs	Digestive tract	Ingestion	Setälä et al. 2014
Mysis Relicta		10µm	PS	2000 spheres per ml	3 hrs	Faeces	Ingestion, egestion	Setälä et al. 2014
*Carcinus Maenas**	Shore crab	8 - 10µm	PS	4.0 x 10^4 per l ventilation 1.0 x 106 per g	16 hrs, 24 hrs, 21 days	Faeces	Ingestion through gills and gut, retention and excretion, no biological effects meas-ured	Watts et al. 2014
*Carcinus Maenas**	Shore crab	250-500µm	-	180mg per 9 cubes of feed	3 weeks	Digestive tract	Ingestion, MP presence did not affect PAH uptake	Msc thesis: Zoeter Vanpoucke Mechtild

Species	Common Name	Size of Ingested Material	Poly-mer	Exposure Concen-tration	Length of ex-posure	Particle end-point	Effect	Source
Phylum Arthropoda								
Uca Repax	Fiddler crab	180-250µm	PS	108-1000mg/kg	2 months	Gills, Digestive tract, Lymph system	2 month exposure, 100% with MP found in gills, stomach, hepatopan-creus. More MP exposure, more MP in crab. Not sure of effect	Brennecke et al. 2015
*Nephrops Norvegicus**	Norway lobster	5mm	PP	10 fibres per cm³ fish	24 hrs	Digestive tract	Ingestion	Murray and Cowie 2011
Porcellanidae (zoea)	Decopoda	30.6µm	PS	635 beads p/ml	24 hrs	Digestive tract	Partial Inges-tion	Cole et al. 2013
Paguridae (zoea)	Decopoda	20.6µm	PS	2240 beads p/ml	24 hrs	Digestive tract	Partial Inges-tion	Cole et al. 2013
Caridea (larvae)	Decopoda	20.6µm	PS	2240 beads p/ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
Barchyura (megalopa)	Decopoda	20.6µm	PS	2240 beads p/ml	24 hrs	Digestive tract	Ingestion	Cole et al. 2013
Artemia Franciscana	Brine shrimp	40 & 50 nm	PS	5-100 µg p/ml	48 hrs	Digestive tract	Ingestion, no mortality, pos-sible effect on motility, some excretion	Bergami et al. 2015
*Nephrops Norvegicus**	Norway lobster	500 - 600 µm loaded with 10 µg of PCBs	PE	150mg microplas-tics in gelatine food	3 weeks	Faeces	Ingestion, 100% eges-tion. Increase of PCB level in the tissues. Same increase for positive control. No direct effect of microplastics.	Devriese et al. in prep
Phylum Chordata								
Doliolidae	Tunicata	7.3µm	PS	3000 beads ml	1 hr	Digestive tract	Ingestion	Cole et al. 2013
Pomatoschistus Microps	Common goby	1 - 5 µm	PE	18.4 & 184 µg p/l	96 hrs	External	Abnormal swimming behaviour and lethargy, ACHe activity affected	Oliveria et al. 2013
Pomatoschistus Microps	Common goby	420 - 500 µm	PE	< 30 per fish	3 mins	Digestive tracts	Ingestion, significant decrease in predatory performance	De Sa et al. 2015

Phylum Chordata								
Species	**Common Name**	**Size of Ingested Material**	**Poly-mer**	**Exposure Concen-tration**	**Length of ex-posure**	**Particle end-point**	**Effect**	**Source**
Pomatoschistus Microps	Common goby	1 - 5 µm	PE	0.216 mg p/l	/	Digestive tracts	The toxicolog-ical interaction between MP and Cr(VI) at conc >3.9 mg/l decreased predatory performance (67%) and caused significant inhibition of AChE activity (<31%)	Luis et al. 2015
*Gadus Morhua**	Atlantic cod	2, 5 mm	PE	/	/	Faeces	Ingestion, egestion, 5mm held for prolonged periods, emp-tying of plas-tics improved by food consumption additional meals.	Dos Santos & Jobling 1991
*Oryzias Latipes**	Japanese medaka	<0.5mm	LDPE	Ground up as 10% of diet	1-2 months	Digestive tracts	Liver toxicity, pathology, hepatic stress	Rochman et al. 2013
*Oryzias Latipes**	Japanese medaka	<0.5mm	LDPE	Ground up as 10% of diet	1-2 months	Digestive tracts	Altered gene expression, decreased choriogenin regulation in males and decreased vitellogenin and choriogenin in females	Rochman et al. 2014
*Dicentrarchus Labrax**	Seabass (larvae)	10 - 45 µm	PE	0-105 per g incorpo-rated with food	8dph - 26dph	Digestive tract	Ingestion, no significant increase in growth, effect on survival of larvae. Possible gastric obstruction.	Mazurais et al. 2014
Halichoerus Grypus	Grey seal	3mm	PE	2818 beads (99% recovery)	96 hours	Faeces	Used as a tracer for diet study	Grellier and Hammond 2006
Calonectris leucomelas	Streaked shearwater	3-5 mm	PE	1g of beads exposed to PCBs ~ 97ng per g	1st day exposed, studied for 42 days	Chem-icals in preen oil	Ingestion, chemical transfer	Teuten et al. 2009

Table VI.2

Evidence of microplastic ingestion by field studies organisms. If mean not available, range is reported. Standard deviation is reported where possible.* represents percentage ingestion by total number of individuals, not separated by species. * species which are commercially important

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Mollusca										
Dosidicus gigas	Humboldt squid	30	26.7	/	0-11	/	Nurdles	3-5mm	British Columbia, Canada	Braid et al. 2012
Mytilus galloprovincialis*	Mediterranean mussel	17	/	Total: 0.08 (0.09)-0.34 (0.22sd) p/g	/	/	Fibres, particles	<5mm	Tagus Estuary, Portugal	Vandermeersch et al. 2015
Mytilus galloprovincialis*	Mediterranean mussel	17	/	Mean: 0.11 (0.12)-0.15 (sd0.33) p/g	/	/	Fibres, particles	<5mm	Ebro Delta Coastal Embayment, Spain	Vandermeersch et al. 2015
Mytilus galloprovincialis*	Mediterranean mussel	5	/	Mean: 0.25 (0.26sd) p/g	/	/	Fibres, particles	<5mm	Goro, Italy	Vandermeersch et al. 2015
Mytilus galloprovincialis*	Mediterranean mussel	5	/	Mean: 0.04 (0.09sd) p/g	/	/	Fibres, particles	<5mm	Amposta, Ebro Delta, Spain	Vandermeersch et al. 2015
Mytilus galloprovincialis*	Mediterranean mussel	18	100	4.33 (2.62)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Mytilus galloprovincialis*	Mediterranean mussel	17	/	Mean 0.05 (0.11)-0.16 (0.11 sd) p/g	/	/	Fibres, particles	<5mm	Po estuary, Italy	Vandermeersch et al. 2015
Mytilus edulis*	Blue mussel	5	/	Mean 0.06 (±0.13) particles p/g	/	/	Fibres	<5mm	Baie de Saint Brieux, France	Vandermeersch et al. 2015
Mytilus edulis*	Blue mussel	5	/	Mean 0.32 (±0.22) p/g	/	/	Fibres, particles	<5mm	Inschot, The Netherlands	Vandermeersch et al. 2015
Mytilus edulis*	Blue mussel	45	/	3.5 per 10g		/	Fibres	300-1000 µm	Belgium, The Netherlands	De Witte et al. 2014

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Mollusca										
Mytilus edulis*	Blue mussel	36	/	0.36 (±0 .07) p/g		/	/	5-25 µm	North Sea, Germany	Van Cauwenberghe & Janssen 2014
Mytilus edulis*	Blue mussel	20	/	170-375 particles per 5 mussels		/	Fibres	/	Nova Scotia, Canada	Mathlon & Hill 2014
Scapharca subcrenata*	Ark shell	6	100	45 (± 14.98)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Tegillarca granosa*	Blood cockle	18	100	5.33 (± 2.21)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Patinopecten yessoensis*	Yesso Scallop	6	100	57.17 (± 17.34)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Alectryonella plicatula*	Fingerprint oyster	18	100	10.78 (± 4.07)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Sinonovacula constricta*	Chinese razor clam	6	100	14.33 (± 5.35)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Ruditapes philippinarum*	Carpet shell	24	100	5.72 (± 2.86)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Meretrix lusoria*	Orient clam	18	100	9.22(± 0.46)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Cyclina sinensis*		30	100	4.82 (± 2.17)	/	PET, PA, PE	Fibres, fragments, pellets	<5mm	Fish market, China	Li et al. 2015
Crassostrea gigas*	Pacific oyster	12	30	0.6±0.9	0-2	/	Fibres		USA	Rochman et al. 2015
Crassostrea gigas*	Pacific oyster	11	/	0.47(± 0.16) per g		/	/	5-25 µm	Atlantic Ocean	Van Cauwenberghe & Janssen 2014

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Arthrapoda										
Lepas spp. *	Gooseneck barnacle	385	33.5	/	01/30/16		/	<5mm	North Pacific	Goldstein & Goodwin 2013
Neocalanus cristatus	Calanoid copepod	960	/	1 particle per 34 zoop			Fibre, fragment	556 (149) µm	North Pacific	Desforges et al. 2015
Euphausia pacifica	Euphausid	413	/	1 particle per 7 euph			Fibre, fragment	816 (108) µm	North Pacific	Desforges et al. 2015
*Nephrops norvegicus**	Norway lobster	120	83	/			/		Clyde, UK	Murray and Cowie 2011
*Crangon crangon**	Brown shrimp	110	/	11.5 fibres per 10 g			95% fibres, 5% films	300-1000 µm	Belgium	Devriese et al. 2015
Phylum Annelida										
Arenicola marina	Lugworm			1.2 +- 2.8 g/w.w				>5µm	Belgium, NL, France	Van Cauwenberge et al. in Devriese et al. 2015
Phylum Chaetognatha										
Parasagitta elegans	Arrow worm	1	100	/		PS	Spheres	0.1-3mm	New England, USA	Carpenter et al. 1972
Phylum Chordata										
Phoca vitulina	Harbour seal	100 stomachs 107 intestines	S:11.2 , I:1	Max: 8 items (s), 7 items (i)			Fragments	>0.1	The Netherlands	Bravo Rebolledo et al. 2013
Mesoplodon mirus	True's beaked whale	1	100	88			Fibres, fragment	mean 2.16 mm	Connemara, Ireland	Lusher et al. 2015
Megaptera novaeangliae	Humpback whale	1	100	45 items			Fragments	1-17 cm	The Netherlands	Besseling et al. 2015
Arctocephalus spp.	Fur seal	145	100	1-4 per scat			Fragments, beads	4.1mm	Macquarie Island, Australia	Eriksson & Burton 2003

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
*Chelonia mydas**	Green turtle	24	/	Total: 11 pellets			Pellets	<5mm	Rio Grande do Sul, Brazil	Tourinho et al. 2010
Menidia menidia	Atlantic silversides	9	33	/			PS	0.1-3mm	New England, USA	Carpenter et al 1972
*Atherinopsis californiensis**	Jacksmelt	7	28.57142857	1.6+-3.7			Fibres, fragments	0-10	USA	Rochman et al. 2015
Alepisaurus ferox	Longnosed lancetfish	144	24	2.7 (± 2.0)			Fragments	68.3 (±91.1)	North Pacific	Choy and Drazen 2013
Cololabis saira	Pacific saury	52	*35	3.2 (± 3.05)			Fragments	0--2	North Pacific	Boerger et al. 2010
*Clupea harengus**	Atlantic herring	2	100	1		PS	PS	0.1 -3mm	New England, USA	Carpenter et al 1972
*Clupea harengus**	Atlantic herring	566	2		1 to 4		Fragments	0.5-3	North Sea	Foekema et al. 2013
*Clupea harengus**	Atlantic herring	3	100	/			/	/	North Sea	Collard et al. 2015
*Sprattus sprattus **	European sprat	111	38.74%	0.88 (0.88)			Fibres, granual, film	0.1-4.9mm	Belgium, North Sea	Msc thesis: Zoeter Vanpoucke Mechtild
*Spratelloides gracilis**	Silverstripe round herring	4	40	1.1 +-1.7	0-5		0-5 fragments		Indonesia	Rochman et al. 2015
*Alosa fallax **	Twait shad	1	100	1			Fragment	<5mm	North Eastern Atlantic	Neves et al., 2015
*Sardina pilchardus**	European pilchard	3	100%	/			/	/	North Sea	Collard et al. 2015
*Sardina pilchardus**	European pilchard	99	19%	1.78 ± 0.7				<1mm	Adriatic sea	Avio et al. 2015
*Sadinella longicxeps**	Oil sardine	10	60%	/			Fibres	0.5-3mm	Mangalore	Sulochanan et al. 2014

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
*Stolephorus commersonnii**	Anchovy	16	37.5	/			Fragments	1.14-2.5	Alappuzha, India	Kripa et al. 2014
*Engraulis encrasiscolus**	Anchovy	3	100%	/			/	/	North Sea	Collard et al. 2015
*Engraulis mordax**	Pacific anchovy	10	30	0.3 +- 0.5	0-1		Fibres and film		USA	Rochman et al. 2015
*Pollachius virens**	Saithe	1	100	1		PS	PS	0.1-3mm PS	New England, USA	Carpenter et al 1972
Ciliata mustela	Five-bearded rocklings	113	0-10	/		PS	PS	2mm	Severn Estuary, UK	Kartar 1976
*Merlangius merlangus**	Whiting	105	6	01/03/16				1.7 (±1.5)	North Sea	Foekema et al. 2013
*Merlangius merlangus**	Whiting	50	32	1.75 (± 1.4)			Fragment, fibres, beads	2.2 (±2.3)	English Channel	Lusher et al. 2013
*Melanogrammus aeglefinus**	Haddock	97	6	1			Fragments	0.7 (±0.3)	North Sea	Foekema et al. 2013
*Gadus morhua**	Cod	80	13	01/02/16			Fragments	1.2 (±1.2)	North Sea	Foekema et al. 2013
*Micromesistius poutassou**	Blue whiting	27	51.9	2.07 (± 0.9)			Fragment, fibres, beads	2.0 (±2.4)	English Channel	Lusher et al. 2013
*Trisopterus minutus**	Poor cod	50	40	1.95 (± 1.2)			Fragment, fibres, beads	2.2 (±2.2)	English Channel	Lusher et al. 2013
*Merlucius merlucius**	Hake	3	100%	1.33 ± 0.57				<1mm	Adriatic sea	Avio et al. 2015
*Merlucius merlucius**	Hake	12	25%	0.33 ±0.65			4 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
Lampris sp. (big eye)		115	29	2.3 (± 1.6)			Fragments	49.1 (±71.1)	North Pacific	Choy & Drazen 2013

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
Lampris sp. (small eye)		24	5	5.8 (± 3.9)			Fragments	48.8 (±34.5)	North Pacific	Choy & Drazen 2013
*Lophius piscatorius**	Monkfish	2	50	0.5			1 fibre	<5mm	North Eastern Atlantic	Neves et al. 2015
Hygophum reinhardtii		45	*35	1.3 (± 0.71)			Fragments	1 – 2.79	North Pacific	Boerger et al. 2010
Loweina interrupta		28	*35	1			Fragments	1 – 2.79	North Pacific	Boerger et al. 2010
Myctophum aurolaternatum		460	*35	6.0 (± 8.99)			Fragments	1 – 2.79	North Pacific	Boerger et al. 2010
Symbolophorus californiensis		78	*35	7.2 (± 8.39)			Fragments	1 – 2.79	North Pacific	Boerger et al. 2010
Diaphus anderseni	Anderson's lanternfish	13	15.4	1			Fragments		North Pacific	Davison & Asch 2011
Diaphus fulgens		7	28.6	1			Fragments		North Pacific	Davison & Asch 2011
Diaphus phillipsi	Boluin's lanternfish	1	100	1			Fragments	0.5	North Pacific	Davison & Asch 2011
Lobianchia gemellarii	Coco's lanternfish	3	33.3	1			Fragments		North Pacific	Davison & Asch 2011
Myctophum nitidulum	Pearly lanternfish	25	16	1.5			Fragments	5.46	North Pacific	Davison & Asch 2011
Morone americana	White perch	12	33	/		PS	PS	0.1-3mm	New England, USA	Carpenter et al. 1972
Tautogolabrus adspersus	Bergall	6	< 83	/		PS	PS	0.1-3mm	New England, USA	Carpenter et al. 1972

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
Pomatoschistus minutus (As Gobius minutus)	Goby	200	0 – 25	/		PS	PS	2mm	Severn Estuary, UK	Kartar 1976
*Argyrosomus regius**	Meagre	5	60	0.80 (±0.8)			2 fragments, 2 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
Stellifer brasiliensis		330	9.2	0.33 – 0.83			Fragments	<1	Goiana Estuary, Brazil	Dantas et al. 2012
Stellifer stellifer		239	6.9	0.33 – 0.83			Fragments	<1	Goiana Estuary, Brazil	Dantas et al. 2012
Eugerres brasilianus		240	16.3	1–5			Fragments	1 – 5	Goiana Estuary, Brazil	Ramos et al. 2012
Eucinostomus melanopterus		141	9.2	1–5			Fragments	1 – 5	Goiana Estuary, Brazil	Ramos et al. 2012
Diapterus rhombeus		45	11.1	1–5			Fragments	1 – 5	Goiana Estuary, Brazil	Ramos et al. 2012
		7	71	5.+-5.2	0-24				Indonesia	Rochman et al. 2015
*Trachurus trachurus**	Horse mackerel	100	1	1			Fragments	2.52	North Sea	Foekema et al. 2013
*Trachurus trachurus**	Horse mackerel	44	7	0.07 ±0.25			2 fragments; 1 fibre	<5mm	North Eastern Atlantic	Neves et al. 2015
*Trachurus trachurus**	Horse mackerel	56	28.6	1.5 (± 0.7)			Fragment, fibres, beads	2.2 (±2.2)	English Channel	Lusher et al. 2013
*Trachurus picturatus**	Blue jack mackerel	29	3.00%	0.03 ±0.18			1 fibre	<5mm	North Eastern Atlantic	Neves et al. 2015
*Seriola lalandi**	Yellowtail amberjack	19	10.5	1			Fragments	0.5 – 11	North Pacific	Gassel et al. 2013

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
Decapyerus macrosoma	Shortfin scad	17	29	2.5 +- 6.3	0-21		Fragments and PS		Indonesia	Rochman et al. 2015
Callionymus lyra	Dragonette	50	38	1.79 (± 0.9)			Fragment, fibres, beads	2.2 (±2.2)	English Channel	Lusher et al. 2013
Cepola macrophthalma	Red band fish	62	32.3	2.15 (± 2.0)			Fragment, fibres, beads	2.0 (±1.9)	English Channel	Lusher et al. 2013
Morone saxatilis	Striped bass	7	28.57142857	0.9+- 1.2	0-3		Bibre, film, foam		USA	Rochman et al. 2015
*Mullus barbatus**	Red mullets	11	64%	1.57 ± 0.78				<1mm	Adriatic sea	Avio et al. 2015
*Mullus surmulletus**	Striped red mullet	4	100%	1.75±0.5			7 fiberes	<5mm	North Eastern Atlantic	Neves et al. 2015
*Boops boops**	Bogue	32	9	0.09 (±0.3)			1 fragment, 2 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
*Dentex macrophthalmus**	Large-eye dentex	1	100	1			1 fibre	<5mm	North Eastern Atlantic	Neves et al. 2015
*Brama brama**	Atlantic pomfret	3	33	0.67±1.2			2 fibres	< 5mm	North Eastern Atlantic	Neves et al. 2015
*Thunnus thynnus**	Bluefin tuna	34	32.40%	/				> 0.63 mm	Mediterranean	Romeo et al.2015
*Thunnus alalunga**	Albacore tuna	2	50.00%			PE		<3cm	Arabian Sea	Sajikumar et al. 2013
*Thunnus alalunga**	Albacore tuna	131	12.90%	/				> 3.60 mm	Mediterranean	Romeo et al.2015
*Rastrelliger kanagurta**	Indian Mackerel	10	50.00%	/			Fibres	0.5 -3mm	Mangalore	Sulochanan et al. 2014

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
*Rastrelliger kanagurta**	Indian Mackerel	9	56	1 (+- 1.1)	0-3		Fragments, pellets		Indonesia	Rochman et al. 2015
*Scomber japonicas**	Chub mackerel	35	31	0.57 ±1.04			14 fragments; 6 fibres	< 9.42 mm	North Eastern Atlantic	Neves et al. 2015
*Scomber scombrus**	Atlantic mackerel	13	31	0.46 ±0.78			3 fragments; 3 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
siganus argenteus	Streamlined spinefoot	2	50	0.5+-0.7			0-1 fragments		Indonesia	Rochman et al. 2015
Siganus canaliculatus	Rabbitfish	3	29	0.3-0.6			0-1 fragments		Indonesia	Rochman et al. 2015
*Xiphias gladius**	Swordfish	56	12.50%	/				> 3.69 mm	Mediterranean	Romeo et al.2015
*Pagellus acarne**	Axillary seabream	1	100	1			1 fiber	<5mm	North Eastern Atlantic	Neves et al., 2015
*Citharichthys sordidus**	Pacific sandab	5	60	1+-1.2	0-3		Fibre and dilm		USA	Rochman et al. 2015
*Pseudopleuronectes americanus**	Winter Flounder	95	2.1	/		PS	PS	0.1-3mm	New England, USA	Carpenter et al 1972
*Platichthys flesus**	Flounder	/	/	/		PS	PS	1mm	Severn Estuary, UK	Kartar 1973
*Platichthys flesus**	Flounder	1090	0 – 20.7	/		PS	PS	1mm	Severn Estuary, UK	Kartar 1976
Buglossidium luteum	Solenette	50	26	1.23 (± 0.4)			Fragment, fibres, beads	1.9 (±1.8)	English Channel	Lusher et al. 2013
Microchirus variegatus	Thickback sole	51	23.5	1.58 (± 0.8)			Fragment, fibres, beads	2.2 (±2.2)	English Channel	Lusher et al. 2013

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
*Oncorhynchus tshawytscha**	Chinook salmon	4	25	0.25+-0.5	0-1		Fibre		USA	Rochman et al. 2015
Myoxocephalus aenaeus	Grubby	47	4.2	/		PS	PS	0.1-3mm	New England, USA	Carpenter et al 1972
*Ophiodon elongates**	Ling cod	11	9.090909091	0.1+- 0.3	0-1		0-1 film		USA	Rochman et al. 2015
Liparis liparis liparis	Sea snails	220	0 – 25	/		PS	PS	1mm	Severn Estuary, UK	Kartar 1976
*sebastes flavidus**	Yellowtail rockfish	1	33	0.3+-0.6	0-1		Fibres		USA	Rochman et al. 2015
*Sebastes mystinus**	Blue rockfish	10	20	0.2+-0.4	0-1		Fibres		USA	Rochman et al. 2015
*Chelidonichthys cuculus**	Red gurnard	66	51.5	1.94 (± 1.3)			Fragments	2.1 (±2.1)	English Channel	Lusher et al. 2013
*Chelidonichthys lucernus**	Tub gurnard	3	0.67	1 ± 0				<1mm	Adriatic Sea	Avio et al. 2015
*Trigla lyra**	Piper gurnard	31	19	0.26 ±0.57			1 fragment; 7 fibers	<5mm	North Eastern Atlantic	Neves et al., 2015
Prionotus evolans	Striped searobin	1	100	1		PS	PS	0.1-3mm	New England, USA	Carpenter et al 1972
Cathorops spixii	Madamago sea catfish	60	18.3	0.47	1 – 4				Goiana Estuary, Brazil	Possatto et al. 2011
Cathorops spp		60	33.3	0.55	1 – 4				Goiana Estuary, Brazil	Possatto et al. 2011
Sciades herzbergii	Pemecoe catfish	62	17.7	0.25	1 – 4				Goiana Estuary, Brazil	Possatto et al. 2011
Astronesthes indopacificus		7	*35	1			Fragments	1 – 2.79	North Pacific	Boerger et al. 2010

Scientific name	Common name	Number of individuals	% with microplastic	Mean particles per individual (SD)	Range	Polymer	Type of microplastic	Size ingested (mm)	Study location	Source
Phylum Chordata										
Sternoptyx diaphana	Hatchetfish	4	25	1			Fragments	1.58 mm	North Pacific	Davison & Asch 2011
Sternoptyx pseudobscura	Highlight hatchetfish	6	16.7	1			Fragments	4.75 mm	North Pacific	Davison & Asch 2011
Idiacanthus antrostomus	Pacific black dragon	4	25	1			Fragments	0.5 mm	North Pacific	Davison & Asch 2011
*Zeus faber**	John Dory	46	47.6	2.65 (± 2.5)			Fragment, fibres, beads	2.2 (±2.2) mm	English Channel	Lusher et al. 2013
*Zeus faber**	John Dory	1	100	1			Fibre	<5mm	North Eastern Atlantic	Neves et al. 2015
*Scyliorhinus canicula**	Lesser-spotted catshark	20	20	0.27 (±0.55)			1 fragment; 5 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
*Raja asterias**	Starry ray	7	43	0.57 (±0.79)			4 fibres	<5mm	North Eastern Atlantic	Neves et al. 2015
*Squalus acanthias**	Spiny dogfish	9	44	1.25 (± 0.5)				<1mm	Adriatic sea	Avio et al. 2015

Evidence of microplastic ingestion by seabirds mean (±SD unless * = SE).

Table VI.3

Species	Common name	n	Percentage with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
(Aphrodroma brevirostris) (as Pterodroma brevirostris)	Kerguelen petrel	26	3.8	1		Pellets	North Island, New Zealand	Reed 1981
(Aphrodroma brevirostris) (as Pterodroma brevirostris)	Kerguelen petrel	13	8	0.2	Mass <0.0083g	Pellets	Gough Island, South Atlantic	Furness 1985a
Aphrodroma brevirostris (as Pterodroma brevirostris)	Kerguelen petrel	63	22.2	/	-	Pellets	Southern Ocean	Ryan 1987
Aphrodroma brevirostris	Kerguelen petrel	28	7	/	3-6mm	Fragments, pellets	Antarctica	Ainley et al. 1990
Calonectris diomedea	Cory's shearwater	7	42.8	/		Pellets	Southern Ocean	Ryan 1987
Calonectris diomedea	Cory's shearwater	147	24.5	Stomach= 2 Gizzard= 3.1		Beads	North Carolina, USA	Moser & Lee 1992
Calonectris diomedea	Cory's shearwater	5	100	/	<10		Rio Grande do Sul, Brazil	Colabuno et al 2009
Calonectris diomedea	Cory's shearwater	85	83	8 (± 7.9)	3.9 ± 3.5		Canary Islands, Spain	Rodríguez et al. 2012
Calonectris diomedea	Cory's shearwater	49	96	14.6 (± 24.0)	2.5 ± 6.0 A		Catalan coast, Mediterranean	Codina-García et al. 2013
Daption capense	Cape petrel	18	83.3	/		Pellets	Southern Ocean	Ryan 1987
Daption capense	Cape petrel	30	33	1	5		Ardery Island, Antarctica	Van Franeker & Bell 1988
Daption capense	Cape petrel	105	14	/	3-6mm	Fragments, pellets	Antarctica	Ainley et al. 1990
Fulmarus glacialis	Northern fulmar	3	100	7.6	1-4mm	Pellets	California, USA	Baltz & Morejohn 1976
Fulmarus glacialis	Northern fulmar	79	92	11.9		Pellets	Netherland and Arctic colonies	Van Franeker 1985
Fulmarus glacialis	Northern fulmar	8	50	3.9		Pellets	St. Kilda, UK	Furness 1985
Fulmarus glacialis	Northern fulmar	13	92.3	10.6		Pellets	Foula, UK	Furness 1985b

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Fulmarus glacialis	Northern fulmar	1	100	1	4mm	Pellets	Oregon, USA	Bayer & Olson 1988
Fulmarus glacialis	Northern fulmar	44	86.4	Stomach = 3 Gizzard = 14	-	Beads	North Carolina, USA	Moser & Lee 1992
Fulmarus glacialis	Northern fulmar	19	84.2	Max: 26	-	Pellets	Alaska, USA	Robards et al. 1995
Fulmarus glacialis	Northern fulmar	3	100	7.7	-	Pellets	Eastern North Pacific	Blight & Burger 1997
Fulmarus glacialis	Northern fulmar	15	36	3.6 (± 2.7)	7 (± 4.0)		Davis Strait, Canadian Arctic	Mallory et al. 2006
Fulmarus glacialis	Northern fulmar	1295	95	14.6 (± 2.0*) –33.2(± 3.3*)	>1.0		North Sea	Van Franeker et al. 2011
Fulmarus glacialis	Northern fulmar	67	92.5	36.8 (± 9.8*)	>0.5		Eastern North Pacific	Avery-Gomm et al. 2012
Fulmarus glacialis	Northern fulmar	58	79	6.0 (± 0.9*)	>1.0		West-fjords, Iceland	Kühn & van Franeker 2012
Fulmarus glacialis	Northern fulmar	176	93	26.6 (± 37.5)		Frag-ments, pellets	Nova Scotia, Canada	Bond et al. 2014
Fulmarus glacialoides	Antarctic fulmar	84	2	/	2-6mm	Frag-ments, pellets	Antarctica	Ainley et al. 1990
Fulmarus glacialoides	Antarctic fulmar	9	79	/	<10		Rio Grande do Sul, Brazil	Colabuno et al 2009
Halobaena caerulea	Blue petrel	27	100	/		Pellets	New Zealand	Reed 1981
Halobaena caerulea	Blue petrel	74	85.1	/		Pellets	Southern Ocean	Ryan 1987
Halobaena caerulea	Blue petrel	62	56	/	3-6mm	Frag-ments, pellets	Antarctica	Ainley et al. 1990
Pachyptila spp.	Prions	/	/	/		Pellets	Gough Island, South Atlantic	Bourne & Imber 1982
(Pachyptila salvini)	Salvin's prion	663	20	/	2.5-3.5mm	Pellets	Welling-ton, New Zealand	Harper & Fowler 1987
Pachyptila salvini		31	51.6	/		Pellets	Southern Ocean	Ryan 1987

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Pachyptila belcheri)	Thin-billed prion	152	6.6	/	2.5-3.5mm	Pellets	Welling-ton, New Zealand	Harper & Fowler 1987
Pachyptila belcheri	Thin-billed prion	32	68.7	/		Pellets	Southern Ocean	Ryan 1987
Pachyptila vittata	Broad-billed prion	31	39	0.6	Max mass: 0.066g	Pellets	Gough Island, South Atlantic	Furness 1985a
Pachyptila vittata	Broad-billed prion	310	16.5	/	2.5-3.5mm	Pellets	Welling-ton, New Zealand	Harper and Fowler 1987
Pachyptila vittata	Broad-billed prion	137	20.4	/		Pellets	Southern Ocean	Ryan 1987
Pachyptila vittata	Broad-billed prion	69	10	/	3-6mm	Frag-ments, pellets	Antarctica	Ainley et al. 1990
Pachyptila vittata	Broad-billed prion	149	/	1987-89 B1.73 ± 3.58		Pellets	Southern Ocean	Ryan 2008
Pachyptila vittata	Broad-billed prion	86	/	1999 B2.93 ± 3.80		Pellets	Southern Ocean	Ryan 2008
Pachyptila vittata	Broad-billed prion	95	/	2004 B2.66 ± 5.34		Pellets	Southern Ocean	Ryan 2008
Pachyptila desolata	Antarctic prion	35	14.3	/	2.5-3.5mm	Pellets	Welling-ton, New Zealand	Harper and Fowler 1987
Pachyptila desolata	Antarctic prion	88	47.7	/		Pellets	Southern Ocean	Ryan 1987
Pachyptila desolata	Antarctic prion	2	100	1	6-8.1mm		Heard Island, Australia	Auman et al. 2004
Pachyptila turtur	Fairy prion	105	96.2	/	2.5-3.5mm	Pellets	Welling-ton, New Zealand	Harper and Fowler 1987
Pagodroma nivea	Snow petrel	363	1	/	3-6mm	Frag-ments, pellets	Antarctica	Ainley et al. 1990
Procellaria aequinoctialis	White-chinned petrel	193	/	1983-1985 B1.66 (± 3.04)		Pellets	Southern Ocean	Ryan 1987, 2008
Procellaria aequinoctialis	White-chinned petrel	526	/	2005-2006 B1.39 (± 3.25)		Pellets	Southern Ocean	Ryan 2008
Procellaria aequi-noctialis	White-chinned petrel	41	/	/	<10		Rio Grande do Sul, Brazil	Colabuno et al. 2009

Species	Common name	n	Percentage with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Procellaria aequinoctialis	White-chinned petrel	34	44	/	<10		Rio Grande do Sul, Brazil	Colabuno et al. 2010
Procellaria conspicillata	Spectacled petrel	3	33	/	<10		Rio Grande do Sul, Brazil	Colabuno et al. 2010
Procellaria conspicillata	Spectacled petrel	9	/	/	<10		Rio Grande do Sul, Brazil	Colabuno et al. 2009
Pseudobulweria rostrata	Tahiti petrel	121	<1	1		Fragments	Tropical, North Pacific	Spear et al. 1995
Pterodroma incerta	Atlantic petrel	13	8	0.1	Max mass: 0.0053g	Pellets	Gough Island, South Atlantic	Furness 1985a
Pterodroma incerta	Atlantic petrel	20	5	/		Pellets	Southern Ocean	Ryan 1987
Pterodroma macroptera	Great-winged petrel	13	7.6	/		Pellets	Southern Ocean	Ryan 1987
Pterodroma mollis	Soft-plumaged petrel	29	20.6	/		Pellets	Southern Ocean	Ryan 1987
Pterodroma mollis	Soft-plumaged petrel	18	6	0.1	0.014g	Pellets	Gough Island, South Atlantic	Furness 1985a
Pterodroma externa	Juan Fernández petrel	183	< 1	1	3-5mm	Pellets	Offshore, North Pacific	Spear et al. 1995
Pterodroma cervicalis	White-necked petrel	12	8.3	5	3-4mm	Fragments	Offshore, North Pacific	Spear et al. 1995
Pterodroma pycrofti	Pycroft's petrel	5	40	2.5 (± 0.7)	3-5mm	Fragments and pellets	Offshore, North Pacific	Spear et al. 1995
Pterodroma leucoptera	White-winged petrel	110	11.8	2.2 (± 3.0)	2-5mm	Fragments	Offshore, North Pacific	Spear et al. 1995
Pterodroma brevipes	Collared petrel	3	66.7	1	2-5mm		Offshore, North Pacific	Spear et al. 1995
Pterodroma nigripenni	Black-winged petrel	66	4.5	3.0 (± 3.5)	3-5mm	Fragments	Offshore, North Pacific	Spear et al. 1995

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Pterodroma longirostris	Stejneger's petrel	46	73.9	6.8 (± 8.6)	2-5mm	Frag-ments and pellets	Offshore, North Pacific	Spear et al. 1995
Puffinus Ilherminieri	Audubon's shearwater	119	5	Stomach = 1 Gizzard = 4.4		Beads	North Carolina, USA	Moser & Lee 1992
Puffinus assimilis	Little shearwater	13	8	0.8	Max mass: 0.12g	Pellets	Gough Island, South Atlantic	Furness 1985a
Puffinus bulleri	Buller's shearwater	3	100	8.5 (± 8.6)	2-8mm	Frag-ments and pellets	Tropical, North Pacific	Spear et al. 1995
Puffinus creatopus	Pink-footed shearwater	5	20	2.2	1-4mm	Pellets	California, USA	Baltz and Morejohn 1976
Puffinus gravis	Great shearwater	24	100	/		Beads	Briar Island, Nova Scotia	Brown et al. 1981
Puffinus gravis	Great shearwater	13	85	12.2	Max mass: 1.13g	Pellets	Gough Island, South Atlantic	Furness 1985a
Puffinus gravis	Great shearwater	55	63.6	Stomach = 1 Gizzard = 13		Beads	North Carolina, USA	Moser and Lee 1992
Puffinus gravis	Great shearwater	50	66	1983-1985 [B]16.5(± 19.0)		Pellets	Southern Ocean	Ryan 1987, 2008
Puffinus gravis	Great shearwater	53	/	2005-2006 [B]11.8 (± 18.9)		Pellets	Southern Ocean	Ryan 2008
Puffinus gravis	Great shearwater	19	89	/	<10 mm		Rio Grande do Sul, Brazil	Colabuno et al. 2009
Puffinus gravis	Great shearwater	6	100	/	<3.2-5.3mm	Pellets	Rio Grande do Sul, Brazil	Colabuno et al. 2010
Puffinus gravis	Great shearwater	84	88	11.8 (± 16.9)		Frag-ments and pellets	Nova Scotia, Canada	Bond et al. 2014
Puffinus griseus	Sooty shearwater	21	43	5.05	1-4mm	Pellets	California, USA	Baltz and Morejohn 1976

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Puffinus griseus	Sooty shearwater	5	100	/	Beads	Beads	Briar Island, Nova Scotia, Canada	Brown et al. 1981
Puffinus griseus	Sooty shearwater	36	58.3	11.4 (± 12.2)	3-20mm	Frag-ments and pellets	Tropical, North Pacific	Spear et al. 1995
Puffinus griseus	Sooty shearwater	218	88.5	/		Pellets	Offshore, North Pacific	Ogi et al. 1990
Puffinus griseus	Sooty shearwater	20	75	3.4		Pellets	Offshore eastern North Pacific	Blight and Burger 1997
Puffinus griseus	Sooty shearwater	50	72	2.48 (± 2.7)		Frag-ments and pellets	Nova Scotia, Canada	Bond et al. 2014
Puffinus mauretanicus	balaric shearwa-ter?	46	70	2.5 (± 2.9)	3.5 (± 10.5A)		Catalan coast, Mediterra-nean	Codi-na-García et al. 2013
Puffinus nativitatis	Christmas shearwater	5	40	1	3-5mm	Frag-ments and pellets	Tropical, North Pacific	Spear et al. 1995
Puffinus pacificus	Wedge-tailed shearwater	23	4	2.5 (± 2.1)		Frag-ments and pellets	Tropical, North Pacific	Spear et al. 1995
Puffinus pacificus dark phase	Wedge-tailed shearwater	62	24.2	3.5 (± 2.7)		Frag-ments and pellets	Tropical, North Pacific	Spear et al. 1995
Puffinus pacificus	Wedge-tailed shearwater	20	60	max: 11	Pellets 2-4mm	Pellets	Hawaii	Fry et al. 1987
Puffinus puffinus	Manx shearwater	10	30	0.4		Pellets	Rhum, UK	Furness 1985b
Puffinus puffinus	Manx shearwater	25	60	/	<10 mm		Rio Grande do Sul, Brazil	Colabuno et al. 2009
Puffinus puffinus	Manx shearwater	6	17	/		Frag-ments	Rio Grande do Sul, Brazil	Colabuno et al. 2010
Puffinus tenuirostris	Short-tailed shearwater	6	100	19.8	1-4mm	Pellets	California, USA	Baltz and Morejohn 1976

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Procellariidae								
Puffinus tenuirostris	Short-tailed shearwater	324	81.8	/		Pellets	Offshore, North Pacific	Ogi et al. 1990
Puffinus tenuirostris	Short-tailed shearwater	330	83.9	5.8 (± 0.4*)	2-5mm	Pellets	Bering Sea, North Pacific	Vlietstra and Parga 2002
Puffinus tenuirostris	Short-tailed shearwater	5	80	/		Frag-ments and pellets	Alaska, USA	Robards et al. 1995
Puffinus tenuirostris	Short-tailed shearwater	99	100	15.1 (± 13.2)	>2mm		Offshore, North Pacific	Yamashita et al. 2011
Puffinus tenuirostris	Short-tailed shearwater	129	67	Adults: 4.5 Juvenile: 7.1	0.97-80.8mm	Frag-ments	North Strad-broke Island, Australia	Acampora et al. 2013
Puffinus tenuirostris	Short-tailed shearwater	12	100	27	>2mm		Offshore, North Pacific	Tanaka et al. 2013
Puffinus yelkouan	Yelkouan shearwater	31	71	4.9 (± 7.3)	4.0 (± 13.0 A)		Catalan coast, Mediterra-nean	Codi-na-García et al. 2013
Antarctic petrel (Thalassoica antarctica)		184	< 1	/	Fragments, pellets 3-6mm		Antarctica	Ainley et al. 1990
Family Hydrobatidae								
Fregetta grallaria	White-bel-lied storm petrel	13	38	1.2	Pellets Max mass: 0.042g		Gough Island, UK South Atlantic	Furness 1985a
Fregetta grallaria	White-bel-lied storm petrel	296	< 1	1	Fragment		Offshore, North Pacific	Spear et al. 1995
Fregetta grallaria	White-bel-lied storm petrel	318	/	1987-89 [B]0.63 ± 1.13	Pellets 33.3%		Southern Ocean	Ryan 2008
Fregetta grallaria	White-bel-lied storm petrel	137	/	1999 [B]0.63 ± 1.37	Pellets 20.9%		Southern Ocean	Ryan 2008
Fregetta grallaria	White-bel-lied storm petrel	95	/	2004 [B]0.72 ± 1.87	Pellets 16.2%		Southern Ocean	Ryan 2008

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Hydrobatidae								
Garrodia nereis	Grey-backed storm petrel	11	27	0.3	Pellets: Max mass: 0.010g		Gough Island, UK South Atlantic	Furness 1985a
Garrodia nereis	Grey-backed storm petrel	12	8.3	/	Pellets		Southern Ocean	Ryan 1987
Oceanodroma furcata	Fork-tailed storm petrel	/	/	/	<5mm		Aleutian Islands, USA	Ohlendorf et al. 1978
Oceanodroma furcata	Fork-tailed storm petrel	21	85.7	Max: 12	Pellets 22%		Alaska, USA	Robards et al. 1995
Oceanodroma furcata	Fork-tailed storm petrel	7	100	20.1	Pellets 16%		Eastern North Pacific	Blight and Burger 1997
Oceanodroma leucorhoa	Leach's storm petrel	15	40	1.66 (± 1.2)	2-5mm		New-foundland, Canada	Rothstein 1973
Oceanodroma leucorhoa	Leach's storm petrel	17	58.8	2.9	Pellets		St. Kilda, Scotland, UK	Furness 1985b
Oceanodroma leucorhoa	Leach's storm petrel	354	19.8	3.5 (± 2.6)	Fragments, pellets 2-5mm		Offshore, North Pacific	Spear et al. 1995
Oceanodroma leucorhoa	Leach's storm petrel	64	48.4	Max: 13	Monofila-ment line, fragments, pellets		Alaska, USA	Robards et al. 1995
Oceanites ocean-icus	Wilson's storm petrel	20	75	4.4	2.9mm		Ardery Island, Antarctica	van Franeker and Bell 1988
Oceanites ocean-icus	Wilson's storm petrel	91	19	/	Fragments, pellets 3-6mm		Antarctica	Ainley et al. 1990
Oceanites ocean-icus	Wilson's storm petrel	133	38.3	Stomach = 1.4 Gizzard = 5.4	26% beads		North Carolina, USA	Moser and Lee 1992
Pelagodroma marina	White-faced storm petrel	19	84	11.7	Pellets Max mass: 0.34g		Gough Island, UK South Atlantic	Furness 1985a
Pelagodroma marina	White-faced storm petrel	15	73.3	13.2 ± 9.5	Pellets 2-5mm		Offshore, North Pacific	Spear et al. 1985

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Hydrobatidae								
Pelagodroma marina	White-faced storm petrel	24	20.8	/	Pellets 41%		Southern Hemi-sphere	Ryan 1987
Pelagodroma marina	White-faced storm petrel	253		1987-89 B3.98 ± 5.45	Pellets 69.6%		Southern Ocean	Ryan 2008
Pelagodroma marina	White-faced storm petrel	86	/	1999 B4.06 ± 5.93	Pellets 37.5%		Southern Ocean	Ryan 2008
Pelagodroma marina	White-faced storm petrel	5	/	2004 B2.52 ± 4.43	Pellets 13.5%		Southern Ocean	Ryan 2008
Family Diomedeidae								
Phoebetria fusca	Sooty albatross	73	42.7	/	Pellets 34%		Southern Ocean	Ryan 1987
Phoebastria immutabilis	Laysan albatross	/	52	/	Pellets 2-5mm		Hawaiian Islands, USA	Sileo et al. 1990
Phoebastria nigripes	Black-footed albatross	/	12	/	Pellets 2-5mm		Hawaiian Islands, USA	Sileo et al. 1990
Phoebastria nigripes (As Diomedea nigripes)	Black-footed albatross	3	100	5.3	Pellets 50%		Offshore, eastern North Pacific	Blight and Burger 1997
Thalassarche melanophri	Black-browed albatross	2	100	3	Pellets 50%		Rio Grande do Sul, Brazil	Tourinho et al. 2010
Order Charadriiformes Family Laridae								
Larus audouinii	Audouin's gull	15	13	49.3 (± 77.7)	2.5 (± 5.0*)		Catalan coast, Mediterra-nean	Codina-García et al. 2013
Larus glaucescens	Glaucous-winged gull	589 bo-luses	12.2	/	<10mm		Protection Island, USA	Lindborg et al. 2012
Larus heermanni	Heer-mann's Gull	15	7	1	Pellets 1-4mm		California, USA	Baltz and Morejohn 1976
Larus melanocephalus	Mediterra-nean gull	4	25	3.7 (± 7.5)	3.0 (± 5.0*)		Catalan coast, Mediterra-nean	Codina-García et al. 2013

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Laridae								
Larus michahellis	Yellow-legged gull	12	33	0.9 (± 1.5)	2.0 (± 8.0*)		Catalan coast, Mediterra-nean	Codi-na-García et al. 2013
Rissa brevirostris	Red-legged kittiwake	15	26.7	/	Pellets: Mean 5.87mm		Alaska, USA	Robards et al. 1995
Rissa tridactyla	Black-legged kittiwake	8	8	4	Pellets 1-4mm		California, USA	Baltz and Morejohn 1976
Rissa tridactyla	Black-legged kittiwake	256	7.8	Max: 15	Pellets		Alaska, USA	Robards et al. 1995
Rissa tridactyla	Black-legged kittiwake	4	50	1.2 (± 1.9)	3.0 (± 5.0*)		Catalan coast, Mediterra-nean	Codi-na-García et al. 2013
Family Alcidae								
Aethia psittacula	Parakeet auklet	/	/	/	<5mm		Aleutians Islands, USA	Ohlendorf et al. 1978
Aethia psittacula	Parakeet auklet	208	93.8	17.1	Pellets 4.08mm		Alaska, USA	Robards et al. 1995
Fratercula cirrhata	Tufted puffin	489	24.5	Max: 51	Pellets 4.10mm		Alaska, USA	Robards et al. 1995
Fratercula cirrhata	Tufted puffin	9	89	3.3	Pellets		Offshore, North Pacific	Blight & Burger 1997
Fratercula corniculata	Horned puffin	/	/	/	<5mm		Aleutian Islands, USA	Ohlendorf et al. 1978
Fratercula corniculata	Horned puffin	120	36.7	Max: 14	Pellets 5.03mm		Alaska, USA	Robards et al. 1995
Fratercula corniculata	Horned puffin	2	50	1.5	Pellets		Offshore, North Pacific	Blight and Burger 1997
Uria aalge	Common murre	1	100	2011 – 2012 1	6.6 (± 2.2)		New-foundland, Canada	Bond et al. 2013
Uria lomvia	Thick-billed murre	186	11	0.2 (± 0.8)	4.5 (± 3.8)		Canadian Arctic	Provencher et al. 2010
Uria lomvia	Thick-billed murre	3	100	2011 – 2012 1	6.6 (± 2.2)		New-foundland, Canada	Bond et al. 2013
Uria lomvia	Thick-billed murre	1249	7.7	1985 – 1986 0.14 (± 0.7*)	10.1 (± 7.4)		New-foundland, Canada	Bond et al. 2013

Species	Common name	n	Percent-age with plastic (%)	Mean number of particles p/ individual	Mean size ingested ± SD (min-max) (mm)	Type of plastic	Location	Source
Family Stercorariidae								
Stercorarius antarcticus) (as Catharacta antarcticu)	Brown skua	494	22.7	/	Pellets 67%		Southern Ocean	Ryan 1987
Stercorarius ham-iltoni (as Catharacta hamiltoni)	Tristan skua	11	9	0.3 Max: 3	Pellets Max mass: 0.064g		Gough Island, UK South Atlantic	Furness 1985a
Stercorarius longi-caudus	Long-tailed skua	2	50	5	Fragments, pellets		Eastern North Pacific	Spear et al. 1995
Stercorarius parasiticu)	Arctic skua	2	50	/	Pellets 50%		Southern Ocean	Ryan 1987
Family Scolopacidae								
Phalaropus fuli-carius	Grey phal-arope	20	100	Max: 36	Beads 1.7-4.4mm		California, USA	Bond 1971
Phalaropus fuli-carius	Grey phal-arope	7	85.7	5.7	Pellets		California, USA	Connors and Smith 1982
Phalaropus fuli-carius	Grey phal-arope	2	50	/	Pellets		Southern Ocean	Ryan 1987
Phalaropus fuli-carius	Grey phalarope	55	69.1	Stomach = 1 Gizzard = 6.7	Beads 16.7%		North Carolina, USA	Moser and Lee 1992
Phalaropus lobatus)	Red-necked phalarope	36	19.4	Stomach = 0 Gizzard = 3.7	Beads 16.7%		North Carolina, USA	Moser and Lee 1992
Family Sternidae								
Onychoprion fuscatus	Sooty tern	64	1.6	2	Pellets 4mm		Offshore, eastern North Pacific	Spear et al. 1995
Gygis alba	White tern	8	12.5	5	Fragments 3-4mm		Offshore, eastern North Pacific	Spear et al. 1995
Order Suliformes Family Phalacrocoracidae								
Phalacrocorax atri-ceps purpurascens	Macquarie shag	C64	7.8	1 per bolus	Polystyrene spheres		Mac-quarie Island, Australia	Slip et al. 1990

ANNEX VII.

ESTIMATED COST OF MARINE LITTER FOR THE EU FISHERY SECTOR

Estimated cost of marine litter for the EU fishery sector (based on Mouat et al. 2010 in Arcadis 2014)

Table VII

Type of cost	Cost per vessel (€)	Estimated cost for the EU (M€)	Calculation method
Reduced catch revenues (contamination forces fishermen to use more time for the selection of their catches and to discard part of them)	2,340	28.64	The cost estimated by Mouat et al. (2010) for Scottish vessels (€2,200 per vessel per year), actualised in 2013 prices, was multiplied by the number of EU trawlers (EU vessels that use seafloor fishing gear), i.e. 12,238.
Removing litter from fishing gear	959	11.74	The time needed to remove litter from fishing gear, as estimated by Mouat et al (2010) for Scottish vessels (41 hours per vessel per year), was multiplied by the average EU27 labour cost (€23.4 per hour) and then by the number of EU trawlers (EU vessels that use seafloor fishing gear), i.e. 12,238.
Broken gear, fouled propellers	191	16.79	The cost related to broken fear and fouled propellers, as estimated by Mouat et al. (2010) for Scottish vessels (€180 per vessel per year), actualised in 2013 prices was multiplied by the total number of fishing vessels in the EU (87,667 according to Eurostat).
Cost of rescue services	52	4.54	The average cost of incidents around the British Isles attended by the Royal National Lifeboat Institution (RNLI) in 1998 (£4,000 per vessel) was multiplied by the number of incidents (200), and divided by the number of UK fishing boats (7,800), as indicated by Fanshawe (2002). The estimated yearly cost per boat resulting by this calculation was then multiplied by 31.1%, i.e. the share of rescue operation dedicated to fishing vessels, as indicated for the UK by Mouat et al (2010) (year 2008). The result (£32 per vessel) was then actualised in 2013 prices and converted to € and multiplied by the total number of fishing vessels in the EU (87,667 according to Eurostat).
Total		61.71	

ANNEX VIII.

ESTIMATED CLEAN-UP AND MANAGEMENT COSTS OF MARINE LITTER

Estimated clean-up and management costs of marine litter – some examples

Table VIII

Country / Region	Estimated cost at national and municipality level	Source
Belgium and The Netherlands	USD 13.8 million (EUR 10.4 million) for all municipalities in Belgium and The Netherlands (ave. USD 264 885/municipality/year (EUR 200 000/ municipality/ year; EUR 629 – 97 346 per km)) Costs are higher for areas with high visitor numbers; for example the Den Haag Municipality spends USD 1.43 million/year (EUR 1.27 million/ year) with costs for processing litter (including transport) about USD 229/tonne (EUR 165/tonne).	Mouat et al, 2010 OSPAR 2009
Peru	USD 2.5 million in labour costs (ave. USD 400 000/year in municipality of Ventanillas)	Alfaro, 2006 cited in UNEP, 2009
UK	USD 24 million (EUR 18 million) (ave. USD 193 365/municipality/year (EUR 146,000/municipality/ year) (per km cleaning costs range from USD 226-108 600/km/year (EUR 171-82 000/km/year)). Specific municipality costs: • Suffolk: approx. USD 93 500/year (GBP 60 000/year) on 40km of beaches • Carrick District Council (Devon): approx. USD 56 000/year (GBP 32 000/year) on 5km of beaches. • Studland (Dorset): USD 54 000/year (GBP 36,000/year) to collect 12-13 tonnes of litter each week in the summer along 6km of beaches. • Kent coastline: direct and indirect cost of litter estimated at over USD 17 million/year (GBP 11 million/year). • Annual expenditure on beach cleaning in 56 local authorities ranged from USD 23/km (GBP 15/km) in West Dunbartonshire to USD 78,000/km (GBP 50 000/km) in Wyre.	Mouat et al, 2010 Fanshawe and Everard, 2002 OSPAR 2009
Bay of Biscay and Iberian coast	A Spanish council with 30 beaches (5 Blue Flags) spends around USD 111 000/year (EUR 80 000/year) on beach cleaning A French council with 30 beaches (5 Blue Flags) spends around USD 556 000/year (EUR 400 000/year) on 'beach caring' (including beach clearing, monitoring of buoys, coastguards etc.), of which around 20% (USD 111 000 (EUR 80 000)) relates to beach clearing. In Landes, the cost of cleaning up 108km of sandy beaches was USD 11 million (EUR 8 million) between 1998 and 2005 Cost of beach cleaning between USD 6 250-69 460/year/council (EUR 4 500-50 000/year/council) corresponding to average cost of USD 9 000/km (EUR 6 500/km) of cleaned beach/year.	OSPAR, 2009

Country / Region	Estimated cost at national and municipality level	Source
Poland	Beach cleaning and removing litter from harbour waters cost USD 792 000 (EUR 570 000) in 2006 (same amount also spent in five communes and two ports)	(UNEP, 2009)
Oregon, California, Washington (USA)	Annual combined expenditure of USD 520 million (USD 13/resident/year) to combat litter and curtail potential marine litter	Stickel et al., 2012
APEC region	USD 1 500/tonne of marine litter in 2007 terms	(McIlgorm, 2009)

ANNEX IX.

COMPILATION OF ELEVEN BEST PRACTICES IN EUROPEAN SEAS (EVALUATED USING THE DECYDE-4-MARLISCO TOOL)

Table XI

	Title	Implementation area	Implementation scale	Duration (y)	Theme(s)	Type of initiative[1]
1	Operation clean coasts 'Calanques Propres'	France	Sub-national	>5	Mitigation Awareness	Campaign P-A-A
2	Responsible snack bar project	Spain	National	0-1	Prevention	Econ./Market instrument
3	Sea surface marine litter cleaning operation	Turkey	Sub-national	>5	Mitigation	P-A-A
4	Integrated action plan for the cleaning of the Channel coast	France	Sub-national	>5	Prevention Mitigation Awareness	P-A-A campaign
5	The plastic bag levy	Ireland	National	>5	Prevention	Policy/Reg. Impl. Econ./ Market instrument
6	Coastwatch Portugal campaign	Portugal	National	>5	Mitigation Awareness	Campaign
7	Fishing for litter	Netherlands	Sub-national	2-5	Mitigation Awareness	P-A-A
8	Blue lid campaign	Turkey	National	1-2	Awareness	P-A-A campaign
9	Separation and recycling of materials from fishing nets and trawls	Denmark	National	>5	Prevention Mitigation	P-A-A other
10	BREF – best available techniques reference document – in common wastewater and waste gas treatment/management systems in the chemical sector	Europe	European	>5	Prevention	Policy/Reg. Impl.
11	Dive against debris, project AWARE	Global	Global	>5	Mitigation	P-A-A campaign

ANNEX X.

SAMPLING AND ANALYSIS TECHNIQUES FOR MICROPLASTICS

Microplastics in Sediments

A wide range of sampling techniques are used for monitoring microplastics in sediments reviewed in Hidalgo-Ruz et al. (2012), van Cauwenberghe et al. (2013) and Rocha-Santos and Duarte (2015). These methods include density separation, filtration and/or sieving (Hidalgo-Ruz et al. 2012, Rocha-Santos and Duarte 2015). Also, to facilitate the plastic extraction among organics components such as organic debris (shell fragments, small organisms, algae or sea grasses, etc.) and other items such as pieces of tar, other methods can be applied, such as enzymatic, CCL_4 or H_2O_2 digestion of organic materials have been proposed (Galgani et al. 2011, Hidalgo-Ruz et al. 2012, Cole et al. 2014) such as for water samples.

The most common approach is to extract plastic particles from the sediment using a density separation based on the differences in density between plastic and sediment particles. Typically, this is achieved by agitating the sediment sample in concentrated sodium chloride (NaCl) solution. However, as the density of the NaCl solution is only 1.2 g cm^3, only low density plastics will float to the surface and can hence be extracted. Different authors have addressed this issue by using different salt solutions to obtain higher densities. Corcoran et al. (2009)) used a 1.4 g cm^{-3} polytungstate solution, Imhof et al. (2013) extracted microplastics from sediments using zinc chloride ($ZnCl_2$, 1.5-1.7 g cm^3), while others (Dekiff et al. 2014, Van Cauwenberghe et al. 2013a, Van Cauwenberghe et al. 2013b) used a sodium iodide (NaI, 1.6 -1.8 g cm^3) solution. These modifications result in an increased extraction efficiency for high density microplastics such as polyvinylchloride (PVC, density 1.14 - 1.56 g cm^3) or polyethylene terephthalate (PET, density 1.32-1.41 g cm^3). As these high-density plastics make up over 17% of the global plastic demand (PlasticsEurope 2013), not including these types of microplastics can result in a considerable underestimation of microplastic abundances in sediments. Especially as these high-density plastics are the first to settle and incorporate into marine sediments.

Sieves used in separation of particles usually have mesh sizes ranging from 38µm to 5 mm and often include 330µm, 1mm and 2mm. To avoid degradation, plastics separated from the sample have been dried and kept in the dark, however this step is probably unnecessary if samples are examined within a few months of collection.

Visual examination is the most common method to assess size and quantities of microplastics. Various imaging approaches, such as zooscan™ (Gilfillan 2009) or semi-automated methods (flow/cytometer, cell sorter, coulter counters) may be practical for the visualization or counting of microplastic particles, with the potential to enable a large number of samples to be analysed. For a better identification of plastics, specific criteria can be applied, such as the presence of cellular or organic structures, the constant thickness of fragments or fibres, homogeneous colours and plastic brightness. However, the reliability of such approaches has not been evaluated. Other analyses based on visual examination with light, polarised or not, or electron microscopy, may provide higher resolution but cannot be used to determine polymer type.

The choice of sampling strategy and sampling approach (reviewed by (Hidalgo-Ruz et al. 2012) will eventually determine the unit in which observed abundances will be reported. While a simple conversion can sometimes be made to compare among studies (Lusher et al. 2015), comparison is often impossible or requires assumptions that lead to biased results. Studies sampling an area (using quadrants) will often report abundances per unit of surface ($m^{-2)}$; e.g. (Martins and Sobral 2011). If real bulk samples up to a specific depth are taken the reporting unit is m^3 (e.g. (Turra,et al. 2014)). Conversion between these types of abundances is possible, if sufficient information is available on sampling depth. Yet, for 20% of the studies this is not the case as reported sampling depths can range from 0 to 50 cm. Other widely used reporting units are volume (mL to L; e.g. Noren 2007) or weight (g to kg; e.g. Claessens et al., 2011, Ng and Obbard 2006). Conversion between these two types of units is not straight forward. Detailed information on the density of the sediment is required. As this is never (as far as we could establish) reported in microplastic studies, assumptions have to be made. For example, the conversion of microplastic abundances in sediment (Claessens et al. 2011). Additionally, within studies reporting weight, a distinction can be made among those reporting wet (sediment) weight and those reporting dry weight. This adds to the constraints of converting from weight to volume units, or vice versa. Sediment samples from different locations or even different zones on one beach have different water content. Therefore, a (limited) number of authors choose to express microplastic abundance per sediment as dry weight to eliminate this variable (Claessens et al. 2013, Dekiff et al. 2014, Ng and Obbard 2006, Van Cauwenberghe et al. 2013); (Vianello et al. 2013).

Microplastics in Biota

In terms of monitoring and with regards to "in situ" experiments, one of the most important aspects is the choice of target species. It is important to consider (i) the exposure to plastics, especially for the species that are living at the surface or in the sediments, (ii) the ingestion rate, especially for filter feeders such as bivalves, (iii) the significance of results which vary depending on whether environmental impact or human health is considered, (iv) the biological sensitivity of certain species, such as the high retention rate in birds of the procellariform family, and (v) a large distribution and easy sampling of the target species.

Biological sampling that involves the examination and characterisation of plastic fragments consumed by marine organisms has been used for fishes (Lusher et al. 2013, Choy and Drazen 2013, Avio, Gorbi et al. 2015), invertebrates (Browne et al. 2008, Murray and Cowie 2011, Desforges et al. 2015, Van Cauwenberghe et al.,2015) and birds ((van Franeker et al. 2011). In general, the research question addressed will greatly influence which sampling and extraction technique to use. For example, size range of microplastics can be related to the micro- and macro-plankton highlighting the potential for microplastic ingestion by a wide variety of organisms (Hidalgo-Ruz et al. 2012). Thus, the sampling scale and methodology will depend on the size of the particle or the size group of the studied organisms. However, harmonisation of sampling and extraction techniques should be adopted for monitoring purposes.

The methodological difficulties in isolation protocols partly explain why only a few studies specifically addressed the occurrence of microplastics in marine organisms. Even though suitable methods have been identified for sediment and water samples, the extraction and quantification of microplastics from organisms may be masked within biological material and tissues. Protocols on the extraction of microplastics from marine invertebrates after a pre-digestion of organic matter have been proposed (Claessens, Van Cauwenberghe et al. 2013), indicating the importance of solvent properties and pH for sample treatment, affecting both the estimation and the characterization of the polymers by FT-IR. The enzymatic digestion of organic matter with proteinase k is a reliable method to extract microplastics from planktons samples (Cole et al. 2014), but at higher costs when considering large scale field sampling and monitoring.

ANNEX XI.

REVISED GPML INDICATORS AND TARGETS INDICATORS AND TARGETS - GPML IMPLEMENTATION & RELATED PROCESSES

Generic Indicators – Goals A, B and C

Table 1

Intended Outcome	Indicator of GPML Implementation	Target (by December2016)[2]	Monitoring/Verification
Operational partnership with a wide range of partners facilitated through an online forum promoting the Honolulu Commitment and Strategy	Number of Governments, organisations, agencies and institutions joining the GPML.	>100	Number of submitted forms to join the GPML
	An effective and functional international steering committee (SC)	SC established according to Terms of Reference and meeting at least once per year	SC meeting report, containing clear guidance to develop the GPML
	An effective and functional set of Regional Nodes	Four Regional Nodes established according to Terms of Reference with developed networks operational	Regional Nodes report to GPML Secretariat and Focal Areas A, B and C
	Meeting of the global partnership to review implementation of the Honolulu Strategy	Partnership meeting	Meeting report with recommendations for improving implementation of the GPML and associated management measures
Development of regional and national policy instruments aligned with the 'Honolulu Strategy'	Number of regional[3] and national policy instruments aligned with the Honolulu Strategy discussions for decision-making at respective levels.	5 regional policy instruments 10 national policy instruments	Policy instruments

Indicators and Targets - GPML Outputs

Table 2

Intended outcome	Indicator of GPML outputs	Target (by December 2016)	Monitoring/verification
Operational partnership promoting the GPML Honolulu Strategy by the production of reports, articles, videos, training materials and related products and activities	Number of activities	1 per Region	Report uploaded to MLN
	Production of Steering Committee reports	1 per year from each	Reports approved by GPML Secretariat
	Production of GPML Newsletter/webinar	At least annual	Newsletter produced by GPML Secretariat
	Demonstration Project progress reports	1 annual progress report per project	Reports approved by GPML Secretariat

Indicators and Targets - Demonstration Projects

Specific Land-Based Indicators based on Demonstration Projects – Goals A and C

Table 3

Intended outcome	Indicator description	Target (by 2020)[4]	Monitoring/verification
Reduction of influx of solid waste to the marine environment through the demonstration of good policy and on-the- ground practices and technologies, including the introduction of new instruments and market-based policies	Reduction in the direct entry of plastic to the marine environment by improved waste management	20% reduction in marine input in 5 demonstration projects[5]	Self-reporting & project reports Independent assessment of degree of reduction of inputs and cost-benefit analysis.
	Increase in recycling rates of specified wastes	50% increase in recycling rates in 5 demonstration projects	Self-reporting & project reports Independent assessment of degree of increase of recycling
	Reduction in demand for 'single-use' plastic shopping bags[6]	25% reduction in demand in 5 countries	National reporting
	Agreement to adopt new good practises resulting from demonstration projects	10 Governments or private sector organisations agree to make use of good practises[7]	Self-reporting of proposed actions
	Number of illegal waste dumps on coast	Significant reduction[8]	National reporting

Specific Sea-based Indicators based on Demonstration Projects – Goals B and C

Table 4

Intended Outcome	Indicator Description	Target (2020)[9]	Monitoring/Verification
Reduction of influx of solid waste to the marine environment through the demonstration of good policy and on-the- ground practices and technologies, including the introduction of new instruments and market-based policies	Reduction in the direct entry of plastic to the marine environment by improved waste management	20% reduction in marine input in 5 demonstration projects[10]	Self-reporting & project reports Independent assessment of degree of reduction of inputs and cost-benefit analysis.
	Increase in recycling rates of specified wastes	50% increase in recycling rates in 5 demonstration projects	Self-reporting & project reports Independent assessment of degree of increase of recycling
	Agreement to adopt new good practices resulting from demonstration projects	10 Governments or private sector organisations agree to make use of good practices[11]	Self-reporting of proposed actions

Indicators and Potential Targets - Environmental State[12] - Goals A, B and C

Generic Indicators – Goal C

Table 5

Intended outcome	Indicator description	Target (2020-25)	Monitoring/verification
Reduce the quantities and impact on the environment of marine litter entering from all sources	Number of cetaceans injured or killed	Significant reduction[13]	IWC, Regional Seas Bodies, national government, municipalities and NGO reporting
	Number of turtles killed by entanglement	Significant reduction	Regional Seas Bodies, national government, municipalities and NGO reporting
	Quantity of plastic (number and mass of items) in guts of indicator species from necropsies (e.g. fish, birds, reptiles, cetaceans)	Significant reduction	Regional Seas Bodies, national government, municipalities and NGO reporting
	Number and mass of items of floating macro-litter (items km^{-2})	Significant reduction	Regional Seas Bodies, national government and NGO reporting
	Number of items of floating micro-litter, especially microplastics (items km^{-2})	Significant reduction	Regional Seas Bodies, national government and NGO reporting
	Number and mass of items of litter on shorelines - km-1 shoreline		Regional Seas Bodies, national government and NGO reporting

Specific Land-based Indicators – Goals A and C

Table 6

Intended Outcome	Indicator description	Target (2020-25)	Monitoring/verification
Reduce the quantities and impact on the environment of marine litter introduced on land and entering the sea	Quantity of litter on tourist beaches - km^{-1} shoreline	Significant reduction[14]	Regional Seas Bodies, national government, municipalities and NGO reporting

– Goals B and C

Table 7

Intended Outcome	Indicator Description	Target (2020-25)	Monitoring/Verification
Reduce the quantities and impact on the environment of marine litter introduced directly at sea	Quantity (volume m^3 and length km) of capture fisheries gear abandoned, lost or otherwise discarded (ALDFG) (e.g. nets, lines, pots, FADs)	Significant reduction[15]	FAO reporting (LC/LP), Regional Seas Bodies, national governments, municipalities, fisheries industry
	Quantity of other capture fisheries-related items in the environment – items km^{-2} sea surface, km^{-2} water column, km^{-2} seabed, km^{-1} shoreline (e.g. strapping bands, boxes, rope)	Significant reduction	Reporting by NGOs, Regional Seas Bodies, national governments, municipalities, fisheries industry
	Quantity (volume m^3 and length km) of aquaculture gear abandoned, lost or otherwise discarded (ALDFG) - items km^{-2} sea surface, km^{-2} water column, km^{-2} seabed, km^{-1} shoreline (e.g. floats, rope, nets, cages, poles)	Significant reduction	FAO reporting; regional reporting e.g. Network of Aquaculture Centres in Asia-Pacific (NACA), NGOs, Regional Seas Bodies, national governments, municipalities
	Quantity of litter derived from commercial shipping	Significant reduction	National governments, NGOs, Regional Seas Bodies & municipalities reporting
	Quantity of litter derived from cruise industry	Significant reduction	National reporting
	Number of turtles killed by ALDFG	Significant reduction	CBD, Regional Seas Bodies, national and NGO reporting
	Number of cetaceans injured by ALDFG	Significant reduction	FAO, IWC, CBD, Regional Seas Bodies, national and NGO reporting
	Number of fish killed by ALDFG	Significant reduction	FAO, CBD, Regional Seas Bodies, national and NGO reporting
	Number of birds killed by ALDFG	Significant reduction	CBD, Regional Seas Bodies, national and NGO reporting
	Number of containers and other cargo lost by commercial shipping	Significant reduction	National and shipping industry reporting

Indicators of Social and Economic Impacts – Goal C

Table 8

Intended Outcome	Indicator Description	Target (2020-25)	Monitoring/Verification
Reduce the social and economic impact on the environment of marine litter entering from all sources	Number of vessels damaged or lost due to collisions or entanglement (e.g. fouled propellers or blocked cooling water intake)	Significant reduction[16]	Operators, national governments
	Loss of energy generation capacity (and income) and risk of accidental damage due to blocked cooling water intakes in coastal power stations, including nuclear power stations; loss of functioning of desalination plants.	Significant reduction	Operators, national governments
	Cost of beach cleaning	Significant reduction	Municipalities
	Number of injuries to public caused by marine litter	Significant reduction	National governments, municipalities, health authorities
	Number of call-outs of emergency services by stricken vessels	Significant reduction	National governments, emergency services, municipalities

ENDNOTES

1 Key to type of initiative: P-A-A – Practice/Activity/Action; Policy/Reg. Impl. – policy/regulation implementation; Econ./Market Instrument – economic and market-based instruments.

2 December 2016 is initial target date. Further targets to be agreed as the GPML develops.

3 Regional in this context refers to multi-national bodies, agreements and other arrangements, such as Regional Seas Organisations. In some countries, regional is used to indicate sub-national levels of governance or organisation.

4 Dependent on: i) the timescale for introduction of demonstration projects and other measures; ii) the scale and complexity of the socio-ecological system; iii) the willingness of all relevant stakeholders to play an active role; iv) the availability of technical know-how and funding as required; and, v) any in-built hysteresis in the social, economic, physical or ecological elements of the system (Oosterhuis et al. 2014).

5 To include representative sectors, for example: illegal waste dumps, coastal tourism, waste management in urban areas, retail sector and Small Island Developing States (SIDS).

6 For example, by introducing a charge per bag and encouraging more durable multiple-use replacements

7 To include representative sectors, for example: illegal waste dumps, coastal tourism, waste management in urban areas, retail sector and SIDS.

8 Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

9 Dependent on: i) the timescale for introduction of demonstration projects and other measures; ii) the scale and complexity of the socio-ecological system; iii) the willingness of all relevant stakeholders to play an active role; iv) the availability of technical know-how and funding as required; and v) any in-built hysteresis in the social, economic, physical or ecological elements of the system.

10 To include representative sectors, for example: aquaculture, fisheries, shipping, cruise industry and recreational boating.

11 To include representative sectors, for example: aquaculture, fisheries, shipping, cruise industry and recreational boating

12 'Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

13 'Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

14 Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

15 'Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

16 'Significant reduction' – this will be dependent on a number of factors including the chain of responsibility, context, identifying manageable sources and the cost-benefit of introducing reduction measures

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