MARINE PLASTIC DEBRIS & MICROPLASTICS

GLOBAL LESSONS AND RESEARCH TO INSPIRE ACTION AND GUIDE POLICY CHANGE

UNEP

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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

TABLE OF CONTENTS

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.

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 multi-disciplined 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

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. 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
7 AFFORDABLE AND CLEAN ENERGY
Goal 6 – ensure availability and sustainable management of water and sanitation for all
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
Goal 11 – make cities and human settlements inclusive, safe, resilient and sustainable
Goal 12 – ensure sustainable consumption and production patterns
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS
Goal 14 – conserve and sustainably use the oceans, seas and marine resources for sustainable development

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.

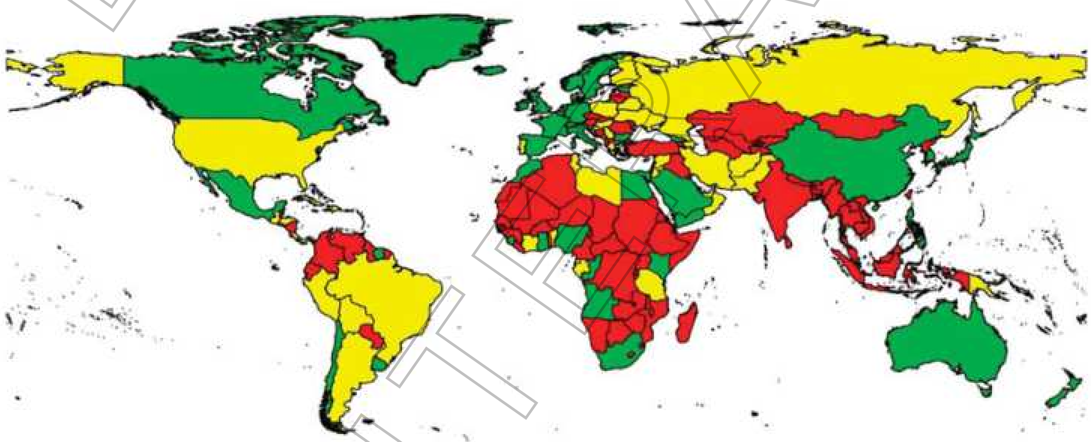
London Convention and Protocol

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.

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

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

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/

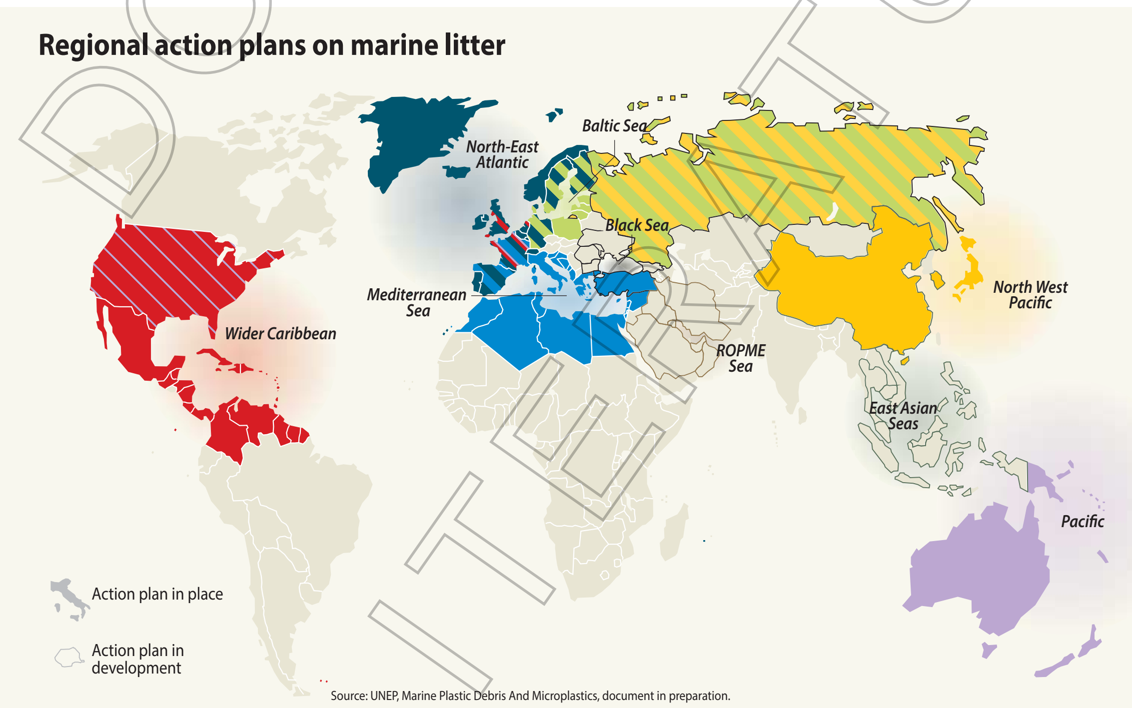
2.3

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. 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. 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).

Box 4.1

DEFINITION OF POLYMERS AND MONOMERS

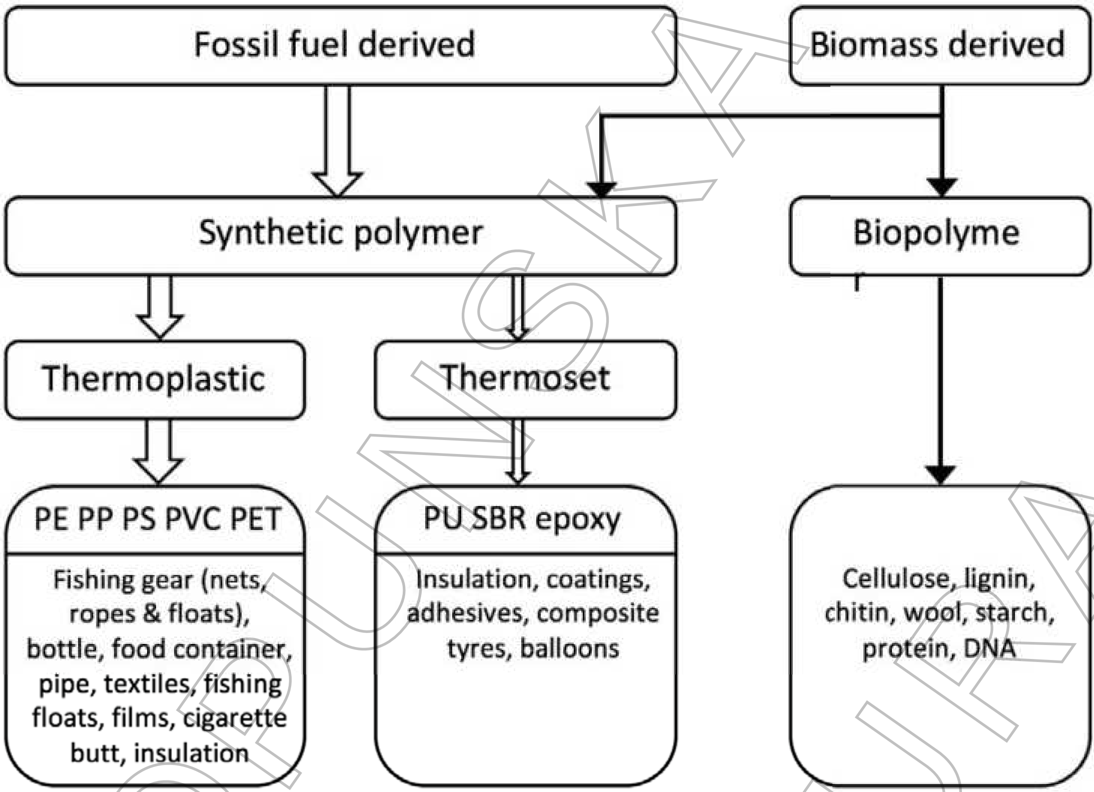
Polymers are large organic molecules composed of repeating carbon-based units or chains that occur naturally and can be synthesised. Common natural polymers include chiton (insect and crustacean exoskeleton), lignin (cell walls of plants), cellulose (cell walls of plants), polyester (cutin) and protein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

Bio-derived plastics

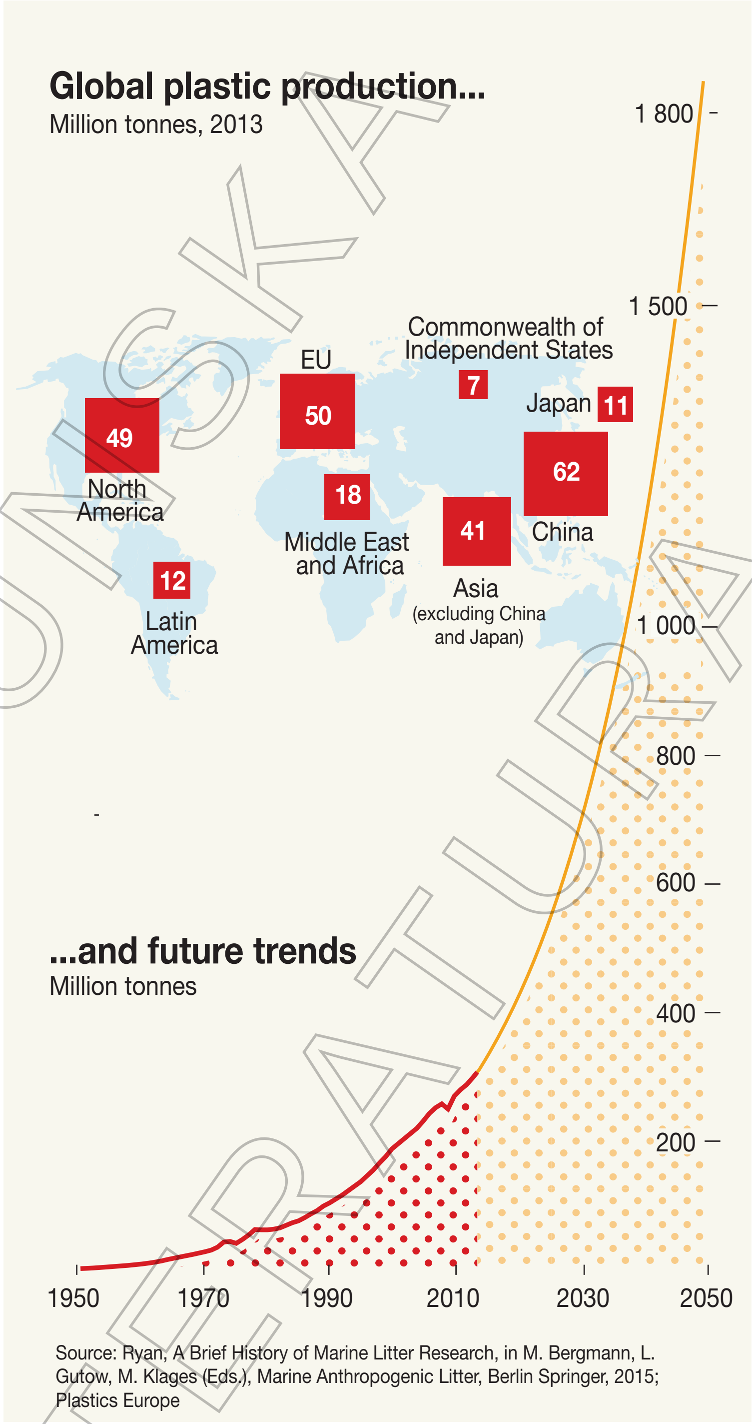
These plastics are derived from biomass such as organic waste material or crops grown specifically for the purpose. Utilising waste material can be seen as fitting into the model of the circular economy, closing a loop in the resource-manufacture-use-waste stream. The latter source could be considered 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).

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



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).

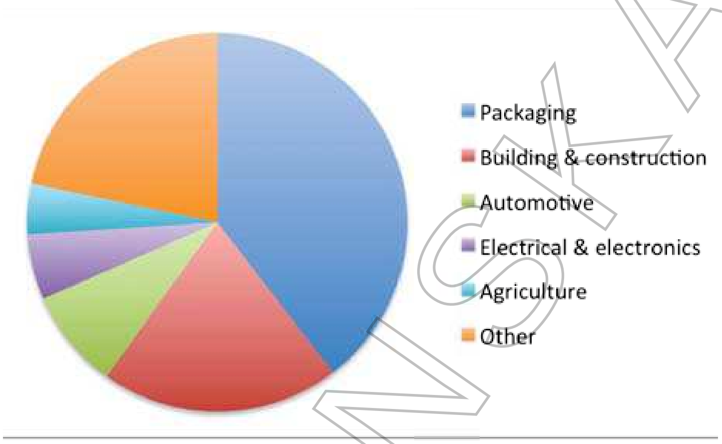
An additional important category of primary microplastics comprises plastic resin beads. These are spherical or cylindrical, a few mm in diameter, and are the form 'raw' plastics are produced in, for transport to production facilities for further processing. The influence of particles on the potential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

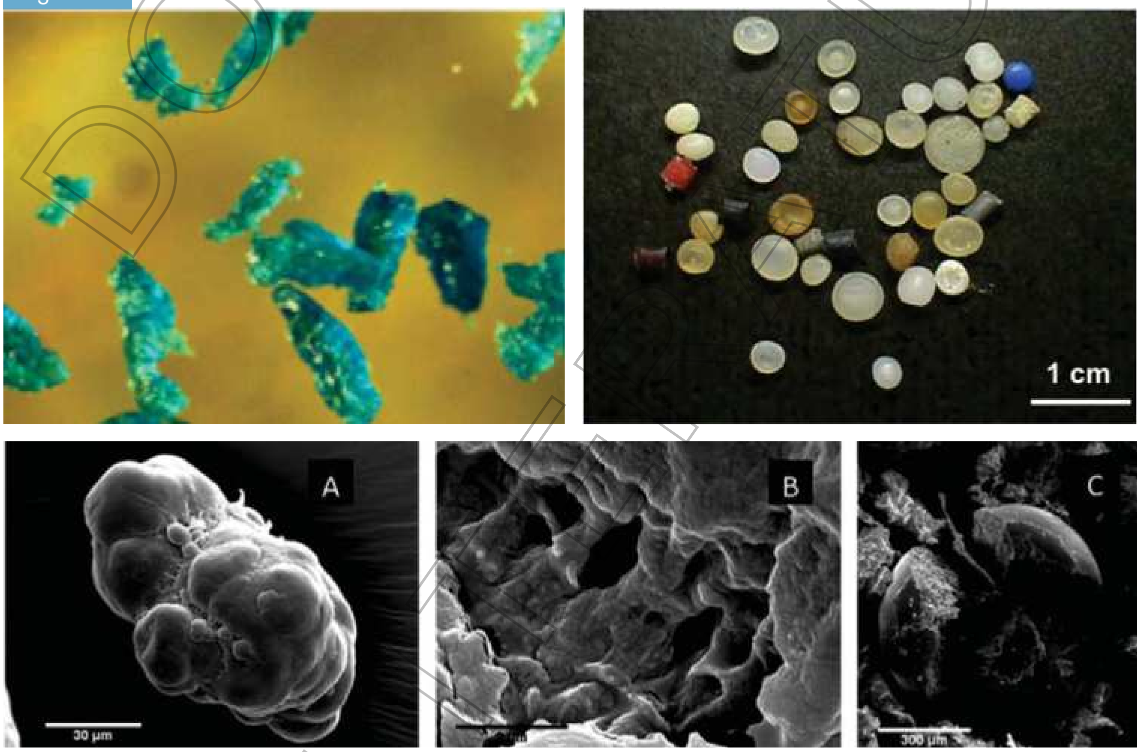
22 http://www.plasticsrecycling.org/images/pdf/resources/Position_Statements/APR_Position_Degradable_Additives.pdf

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).

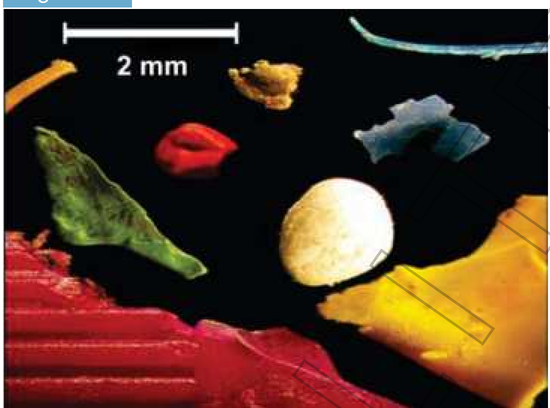
Photo: © Heidi Savelli / UNEP

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, CO_2/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 CO_2, 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

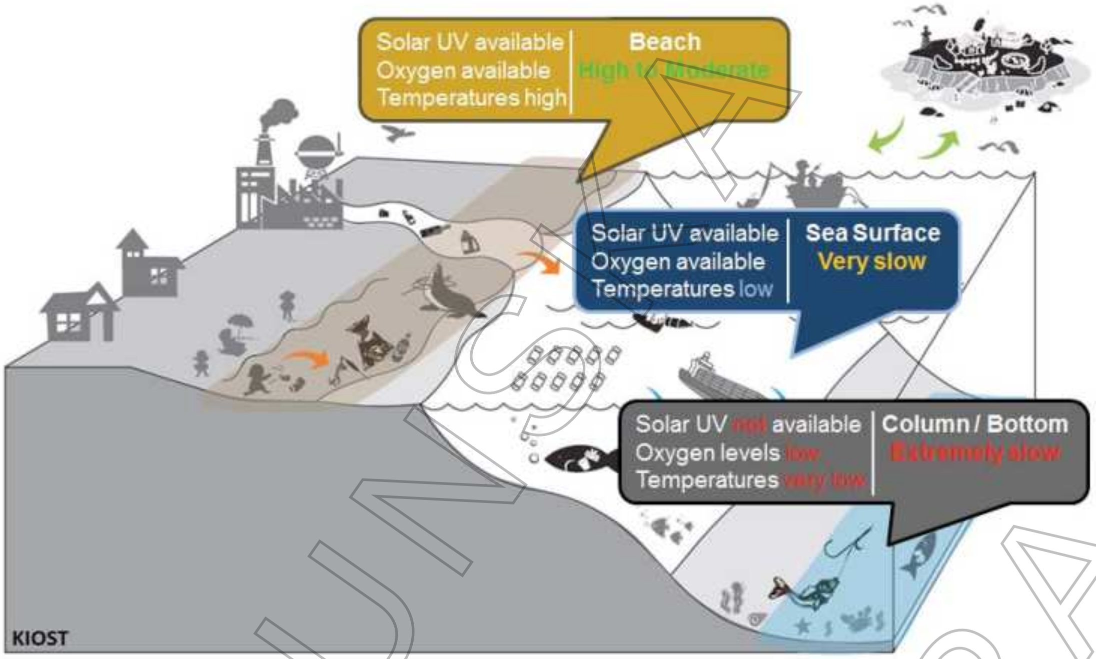


Figure 4.6 Factors affecting the degradation and fragmentation of plastic in different ocean compartments (GESAMP 2015)

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. 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

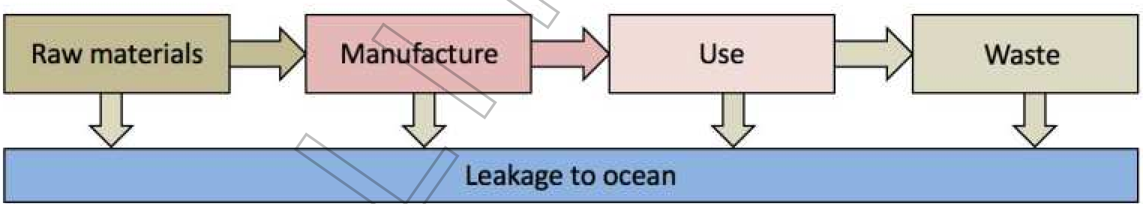
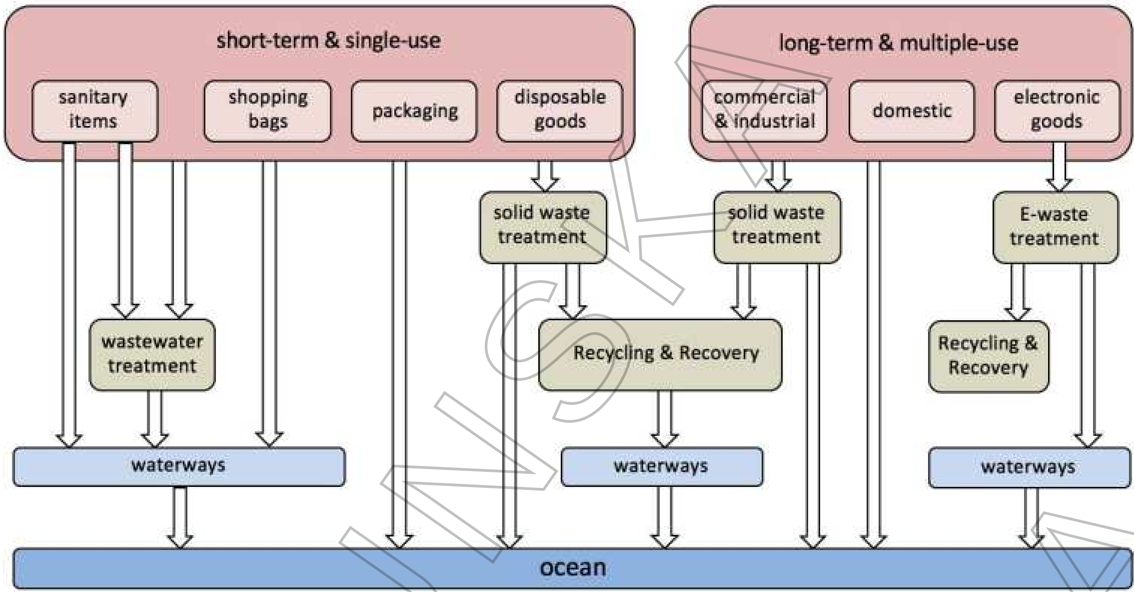


Figure 5.1 Simplified representation of a linear approach to plastics production and use, indicating potential leakage points to the ocean (original by P. J. Kershaw).

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

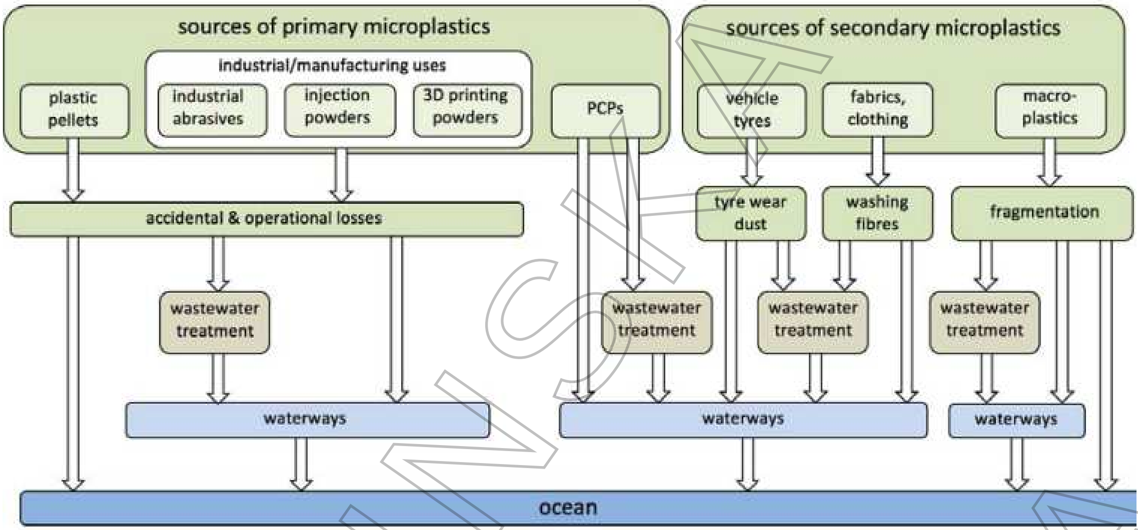
Sources in brief

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 microplastics	Secondary microplastics	Entry points	Relative importance*
Tourism industry		Fragmented packaging, household goods, consumer goods,	Wastewater, rivers, coastal, atmosphere	High
Food and drink		Fragmented single-use packaging	Wastewater, rivers, coastal, atmosphere	High
Plastic producers	Plastic resin pellets		Wastewater, rivers, coastal	Medium
Retail		Fragmented packaging, household goods, consumer goods	Wastewater, rivers, coastal	Medium
Households		Fragmented packaging, household goods, consumer 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, consumer goods	Wastewater, rivers	Low
Construction		Fragmented EPS, packaging,	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.

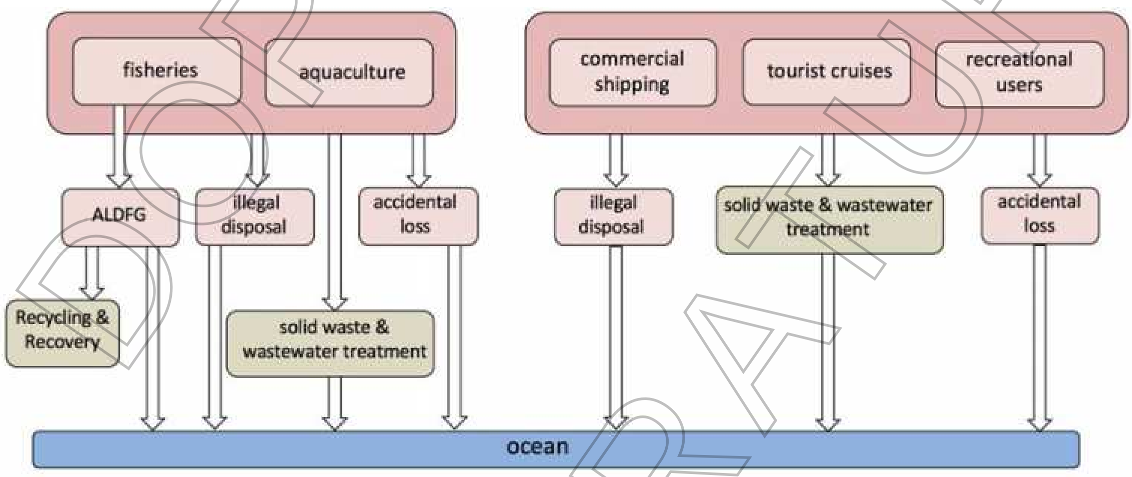
Table 5.3

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

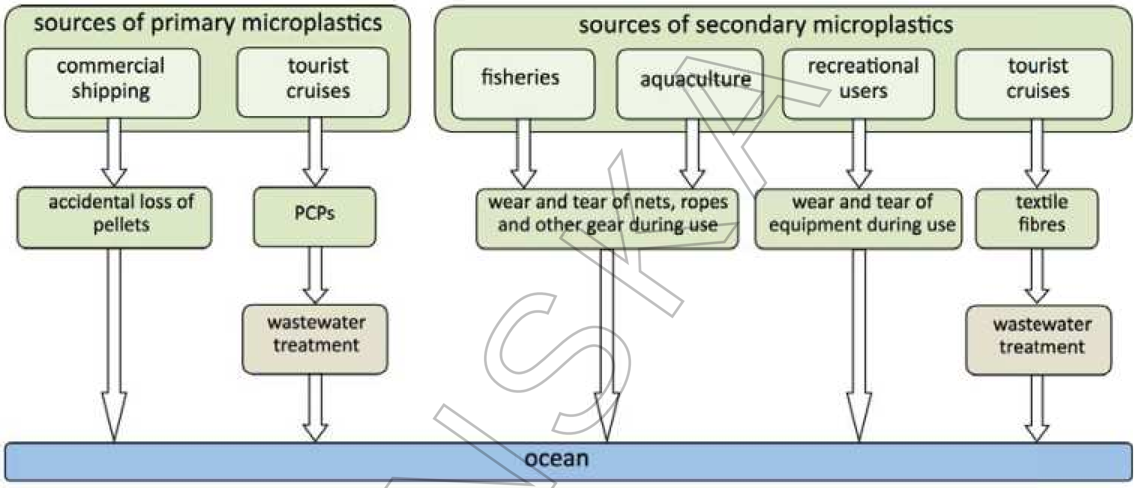
The main source of primary microplastics at sea is due to the introduction of plastic resin beads as a result of accidental loss of cargo. A more minor source is represented by the use of PCCPs, most notably by passengers on cruise ships.

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

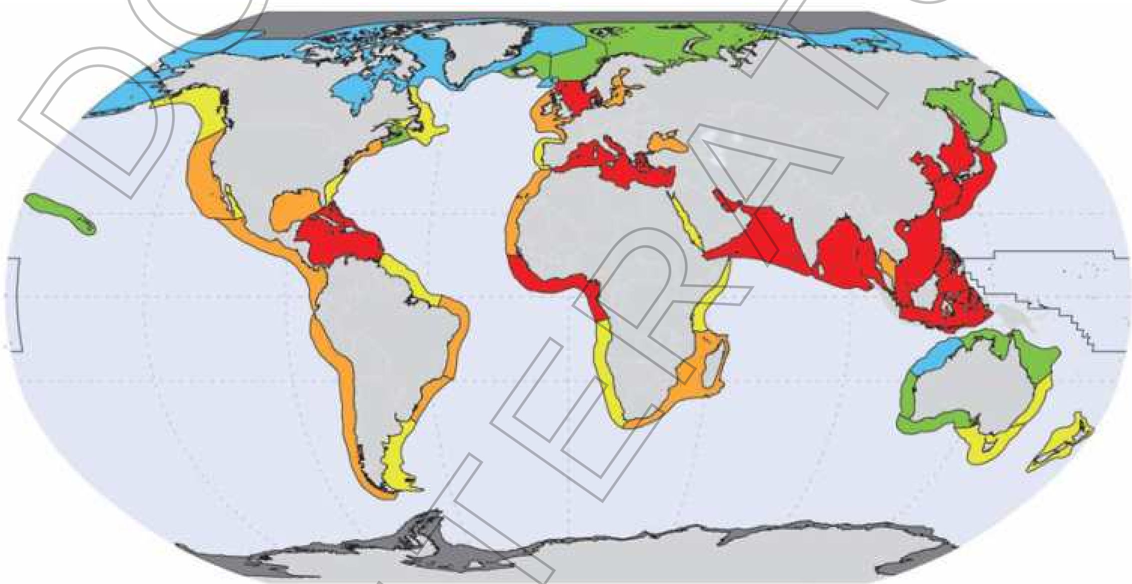


Figure 5.7 Coastal population within 100 km of the coast (2010 millions), displayed on an outline of Large Marine Ecosystems (taken from TWAP 2016)

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

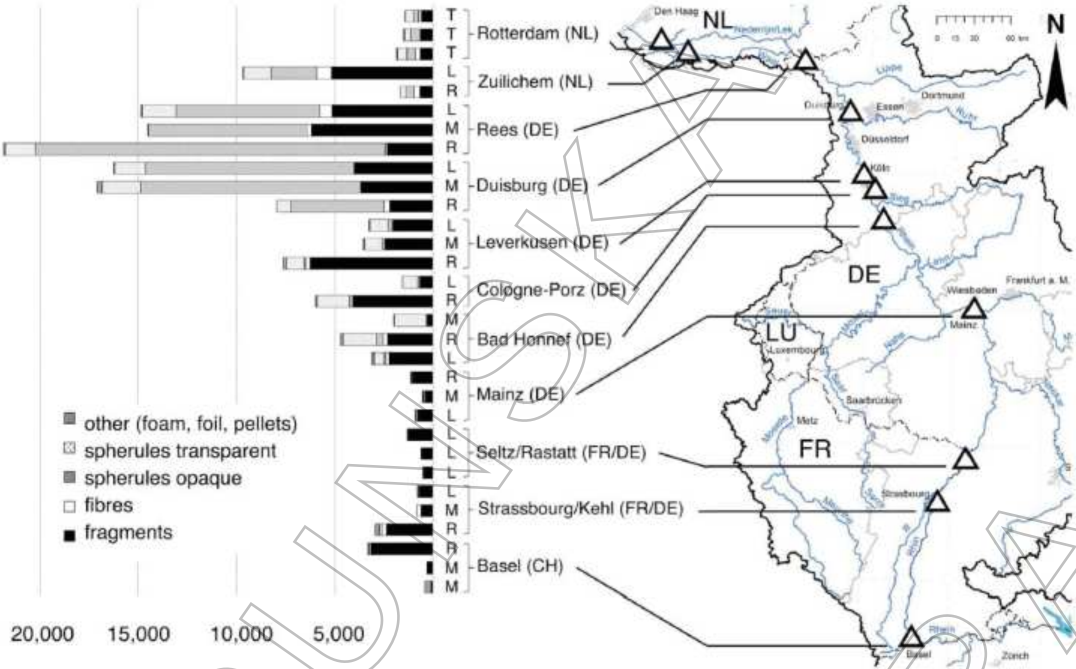
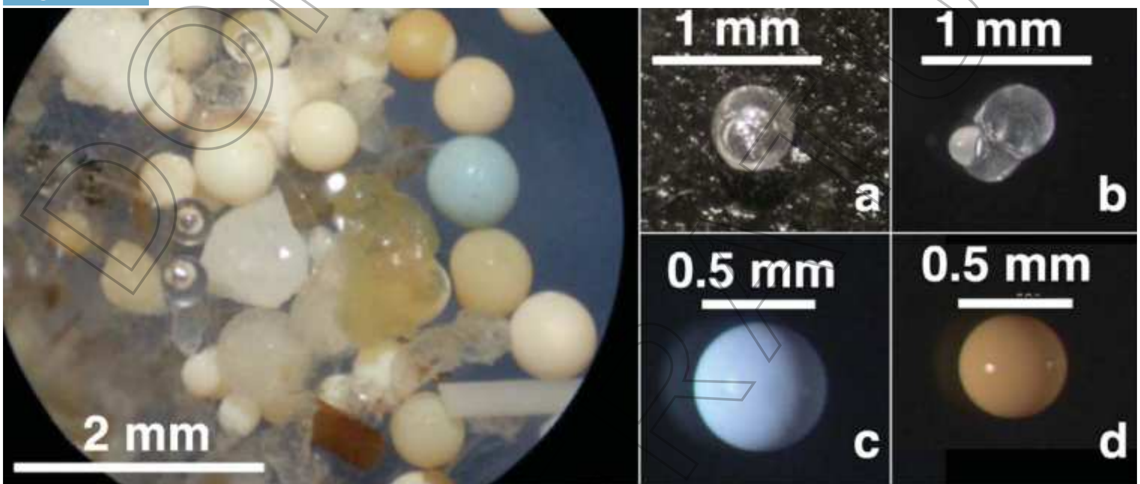


Figure 5.9a



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.

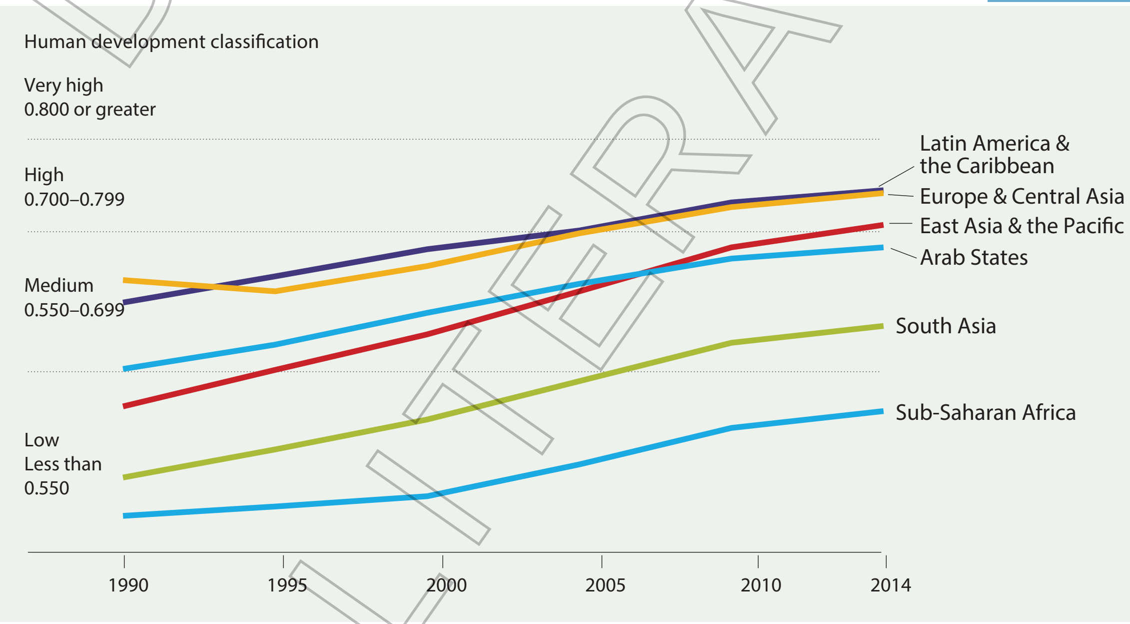
The quantities of waste produced by each country depend on the per capita waste generation and the population. There is a general pattern for richer countries to have higher per capita waste generation, which may be offset by larger populations in some poorer countries (Hoornweg and Bhada-Tata 2012)[29]. 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.

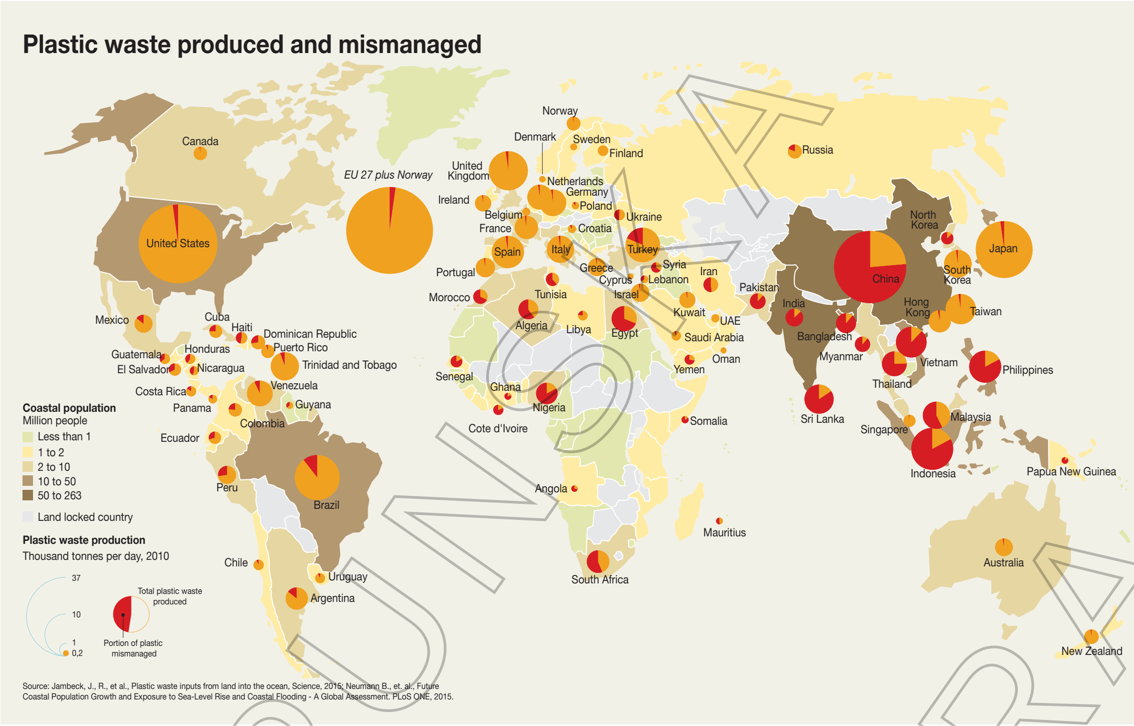
Jambeck et al. (2015) estimated that 16 of the top 20 contributors to plastic marine litter were from middle-income countries, where economic growth is rapidly occurring (Chapter 5.4). The top five countries (China, Indonesia, Philippines, Sri Lanka and Vietnam) accounted for more than 50% of 'mismanaged'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

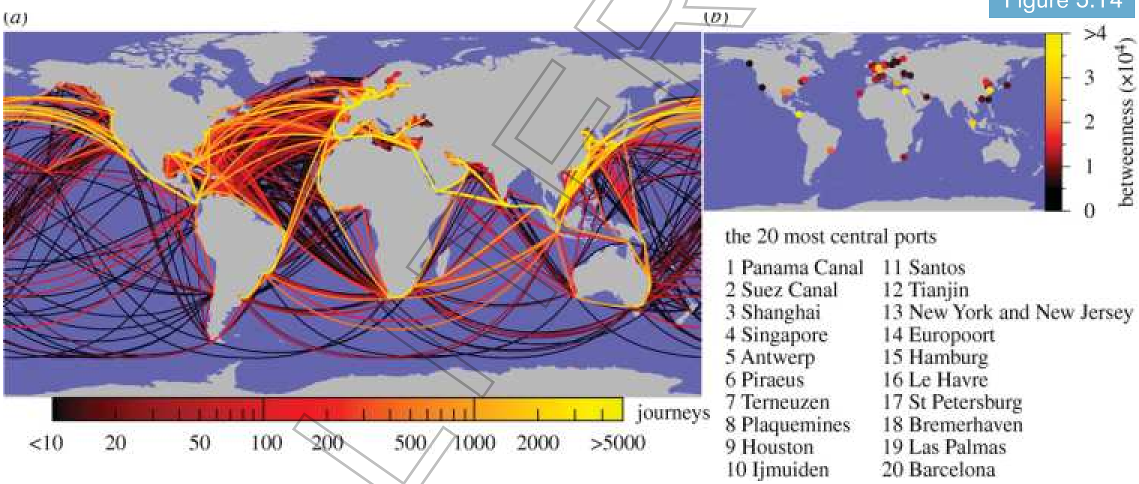
The number of containers lost each year is disputed, but was reported by the World Shipping Council (2014)[31] to be approximately 550 per annum on average, not counting catastrophic losses (regarded as losses of > 50 containers in one incident). In 2011 there was the grounding of the M/V Rena off New 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.

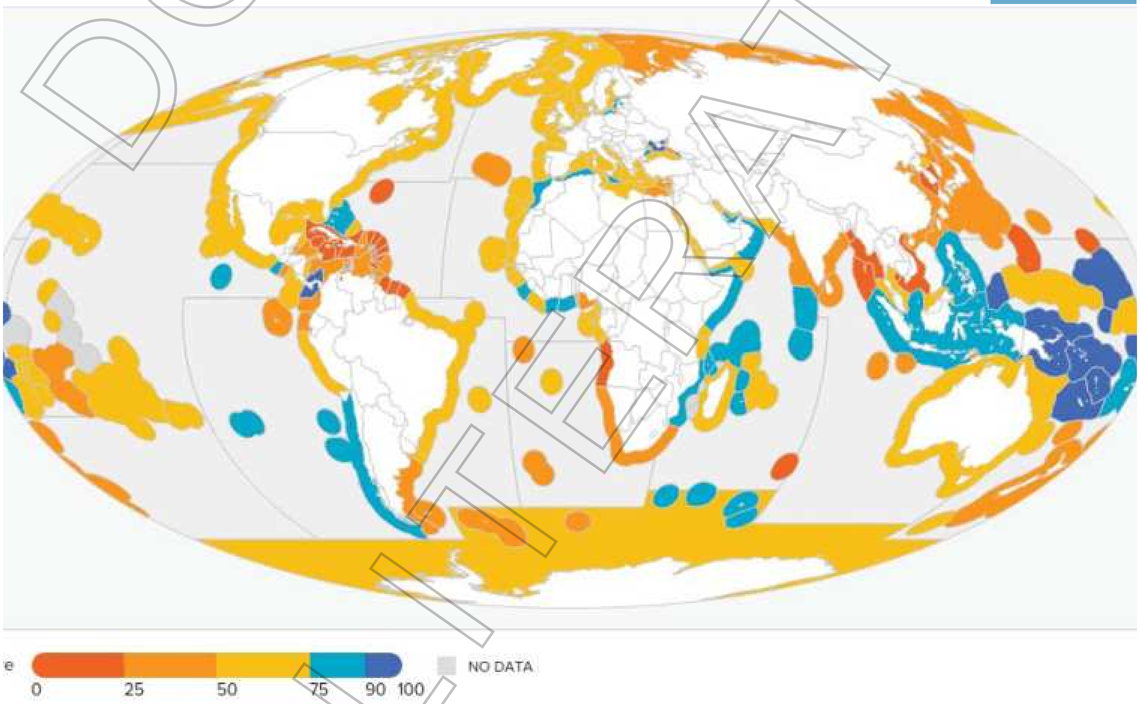
Fisheries

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.

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

(Eriksen et al. 2014)

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).

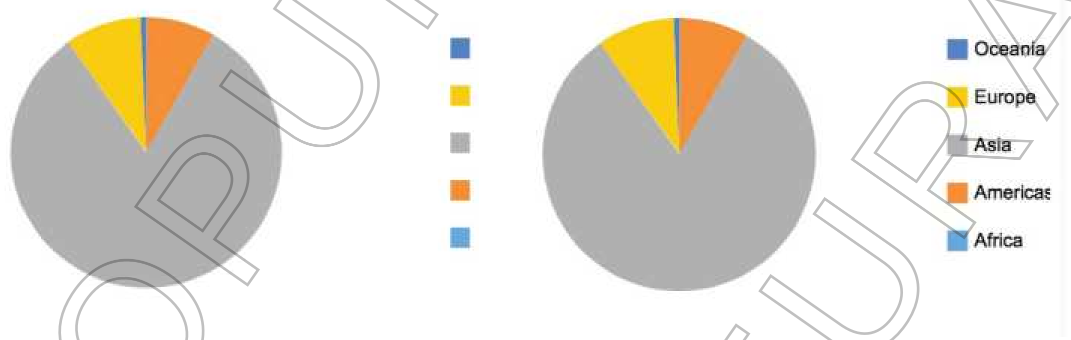
Photo: © Sustainable Coastlines

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).

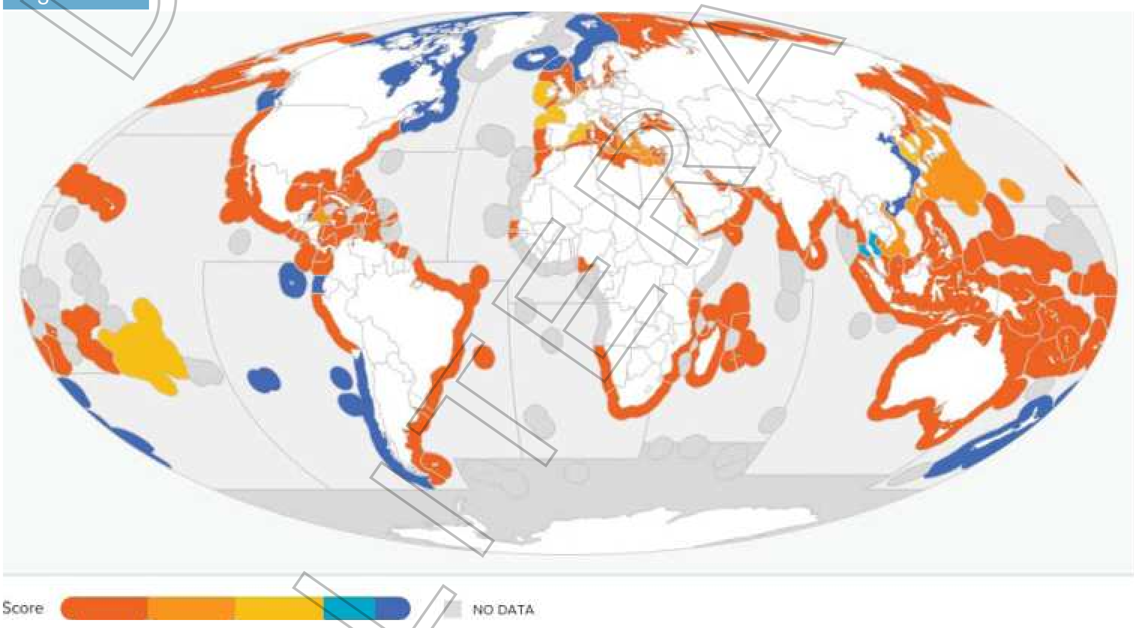
The quantities of equipment lost generally have not been quantified. Regional differences may be expected due to the type of culture, the selection of designs and materials, and exposure to adverse conditions. For example, EPS buoys are used extensively in some regions of Asia for the hanging culture 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)

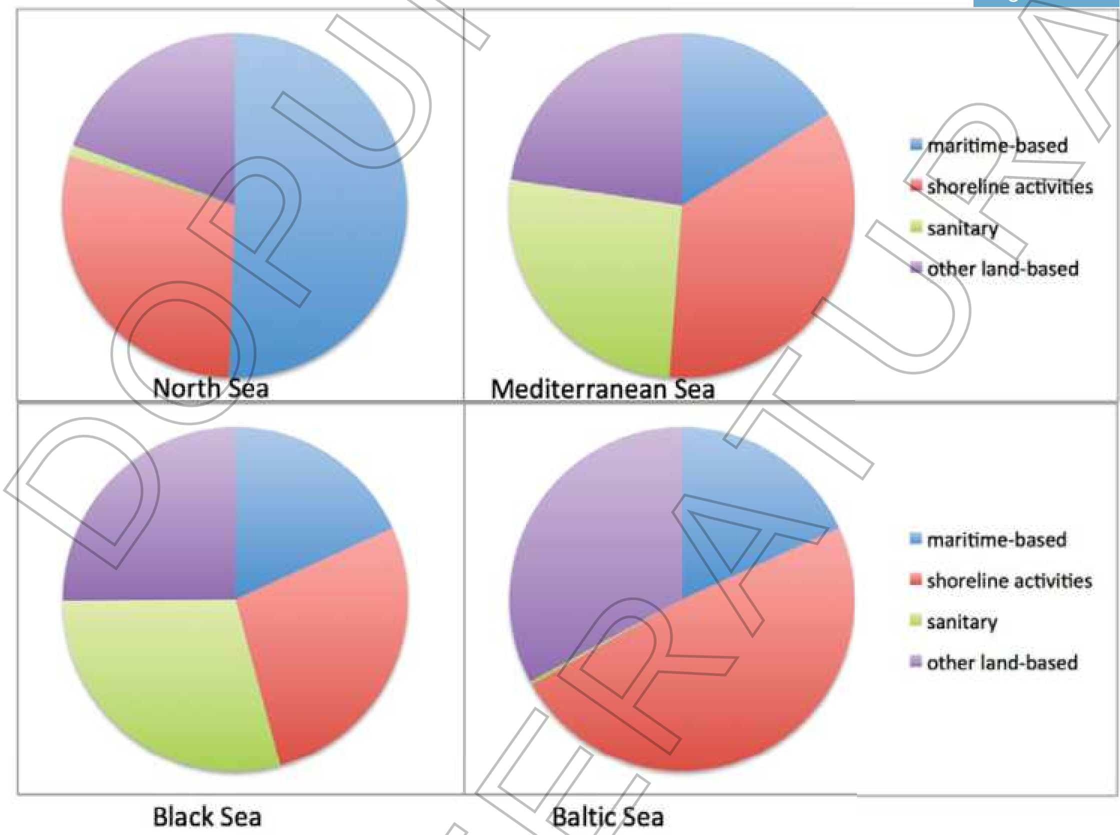
5.9

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. 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

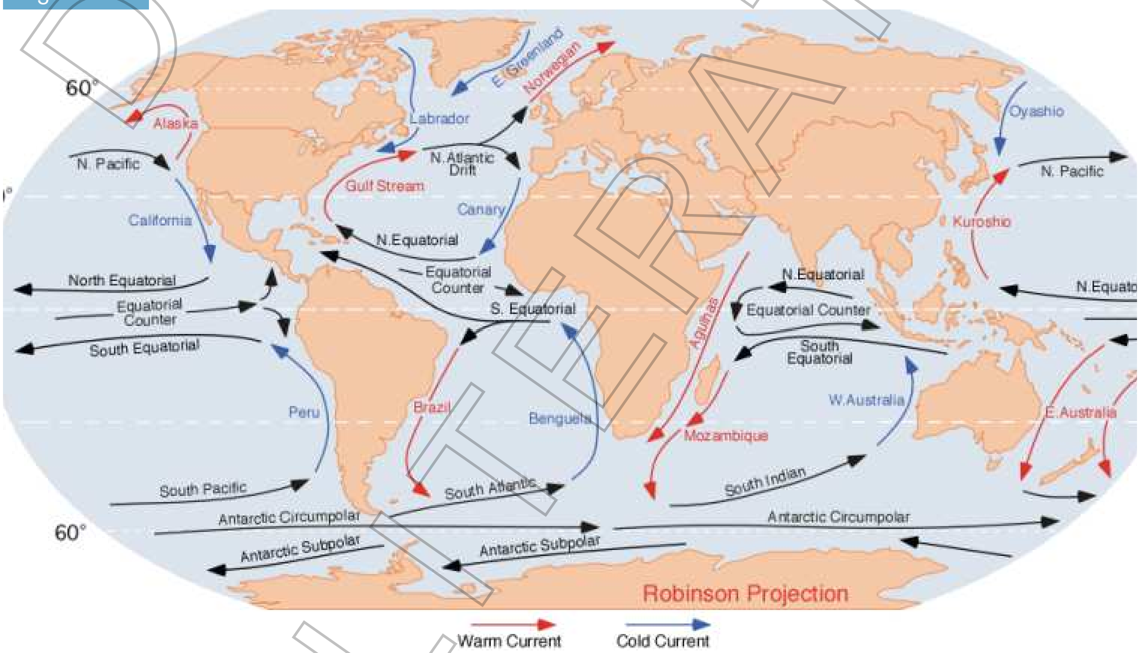


Figure 6.1 Surface ocean circulation, showing main currents and the location of the sub-tropical gyres in the North and South Pacific, Indian, and North and South Atlantic Oceans, and the Norwegian Current transporting material from the NE Atlantic to the Arctic (image courtesy of Dr. Michael Pidwirny (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

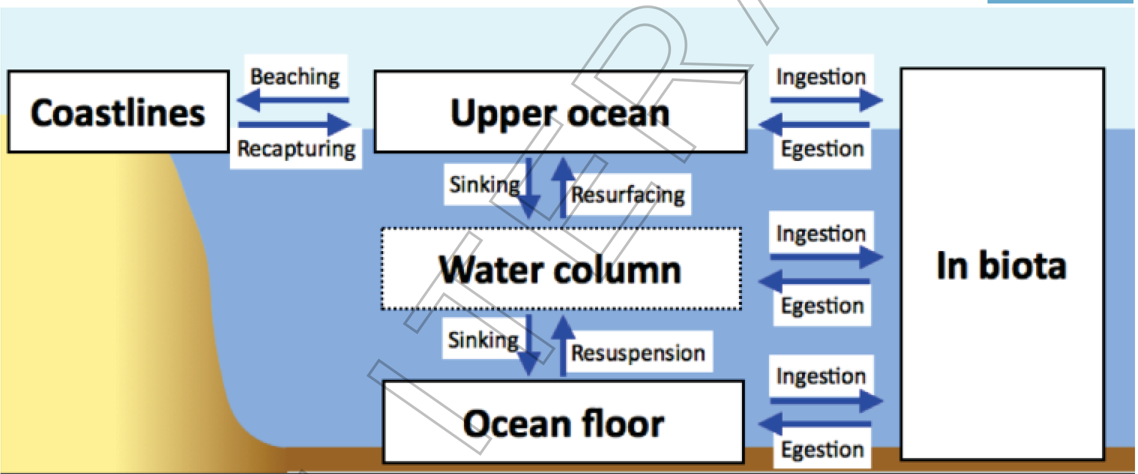


Figure 6.3 Overview of compartments and fluxes of marine plastics (figure based on a version by Erik van Sebille, taken from GESAMP 2016).

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).

Figure 6.4

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

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).

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.

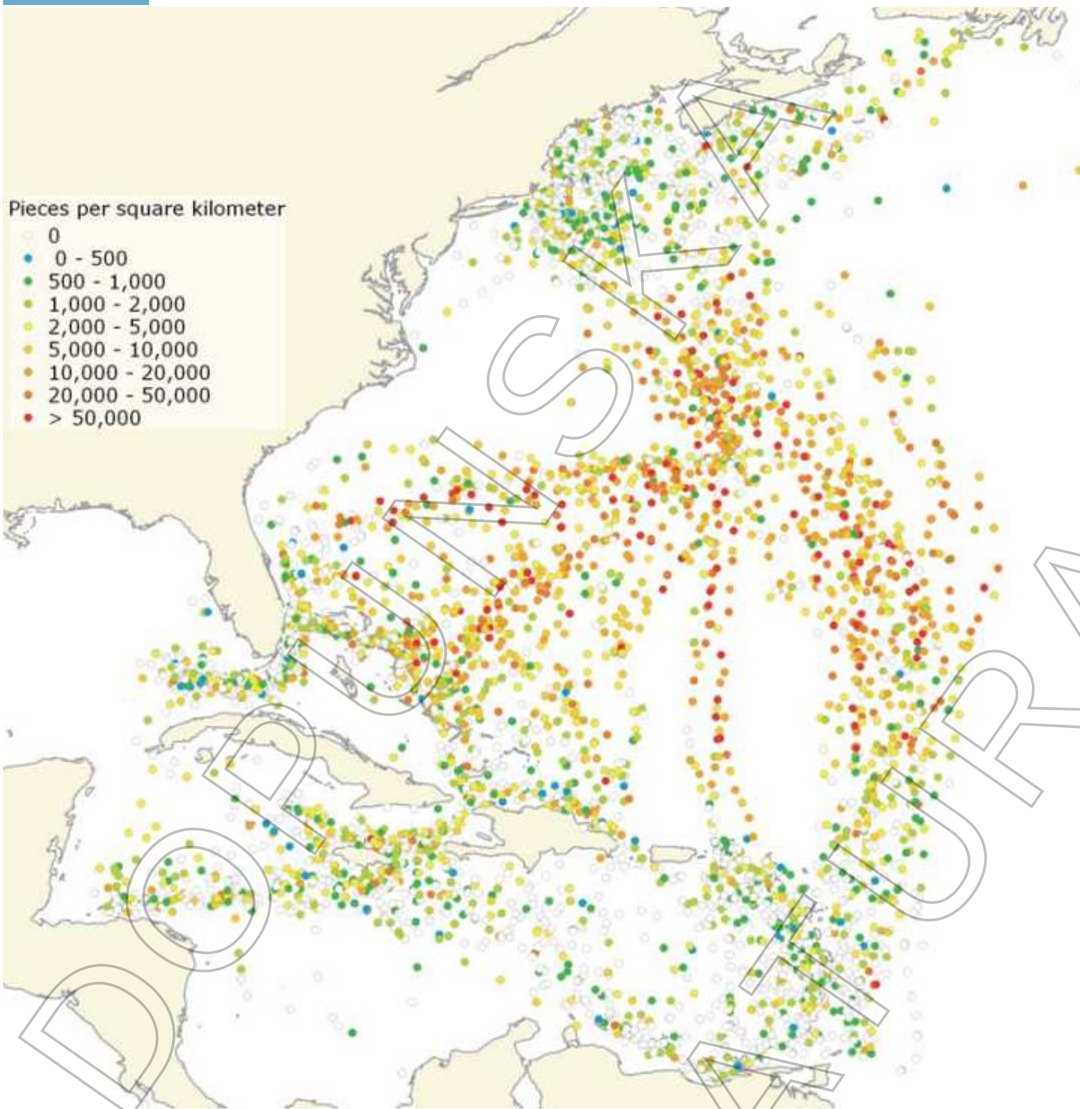
Box 6.1

'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



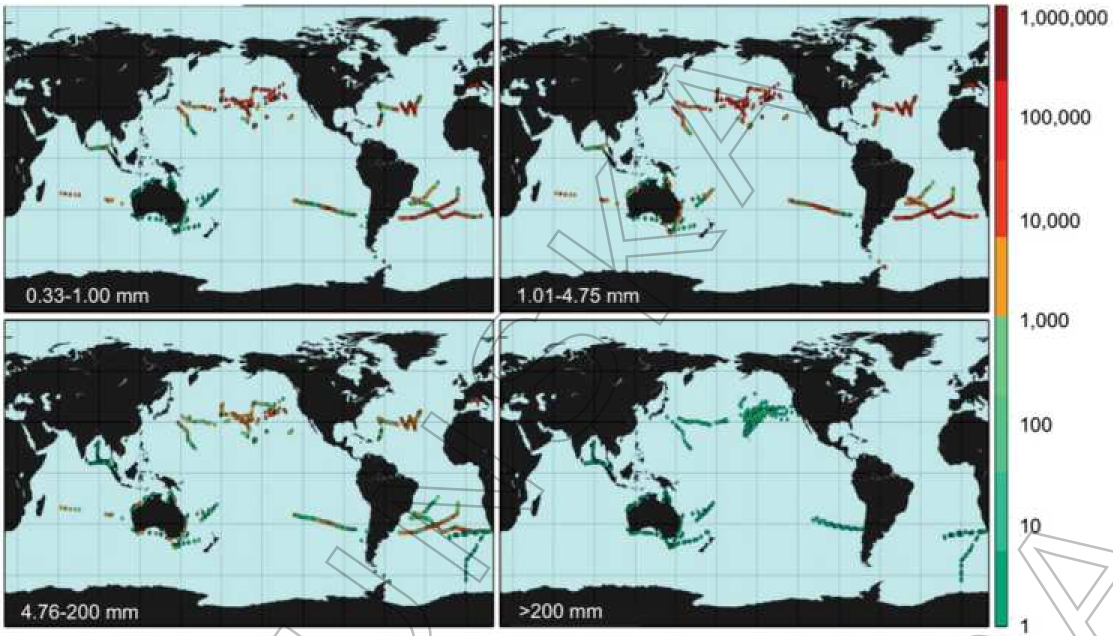
Western North Atlantic sub-tropical gyre showing elevated concentrations of microplastics (pieces km-2) at each sampling site from a 20-year data set; described by Law et al. 2010 and re-plotted by IOC-UNESCO.

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

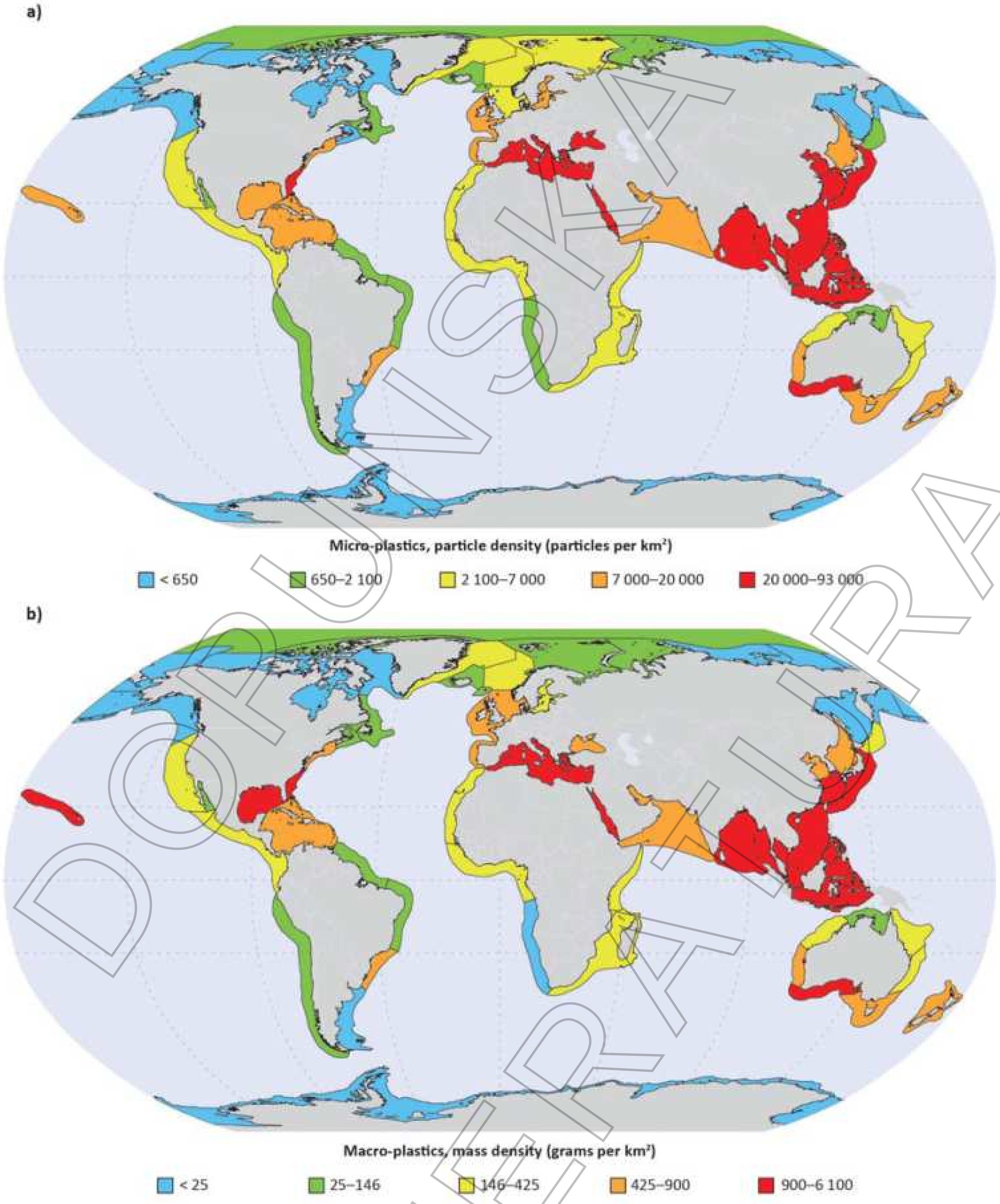
Such weaknesses do not invalidate the usefulness of the modelling approach, but do introduce large uncertainties into the results, something which is readily admitted by the modelling community (e.g. van Sebille et al. 2015).

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).

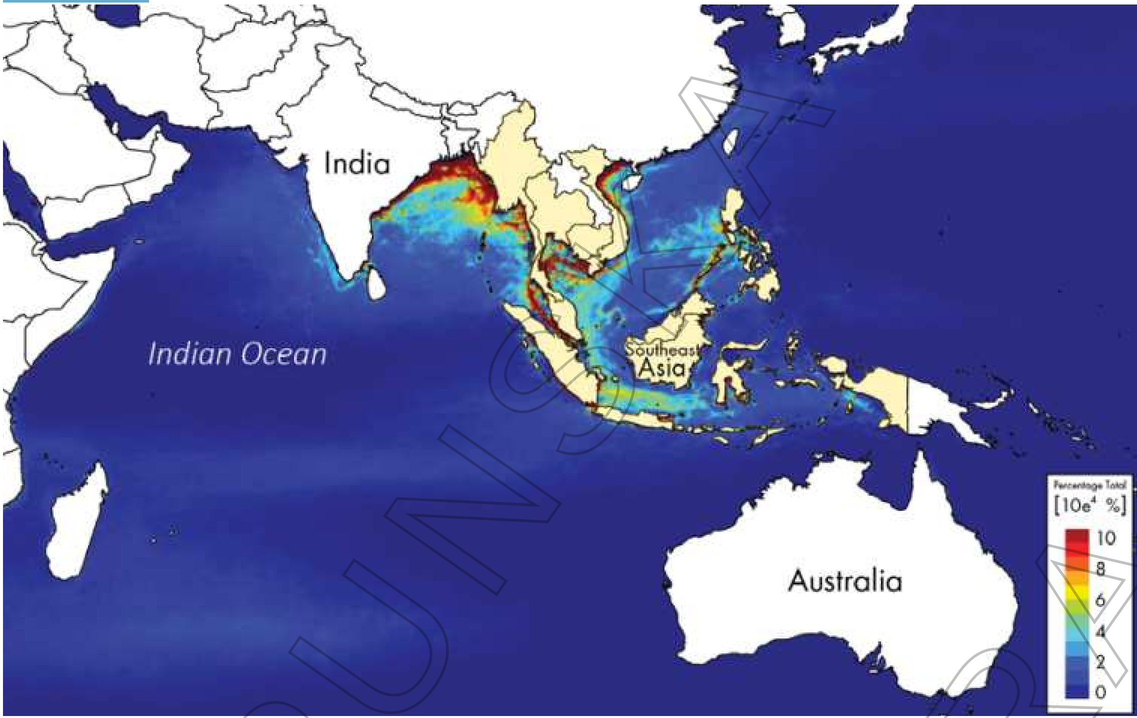
Figure 6.10



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



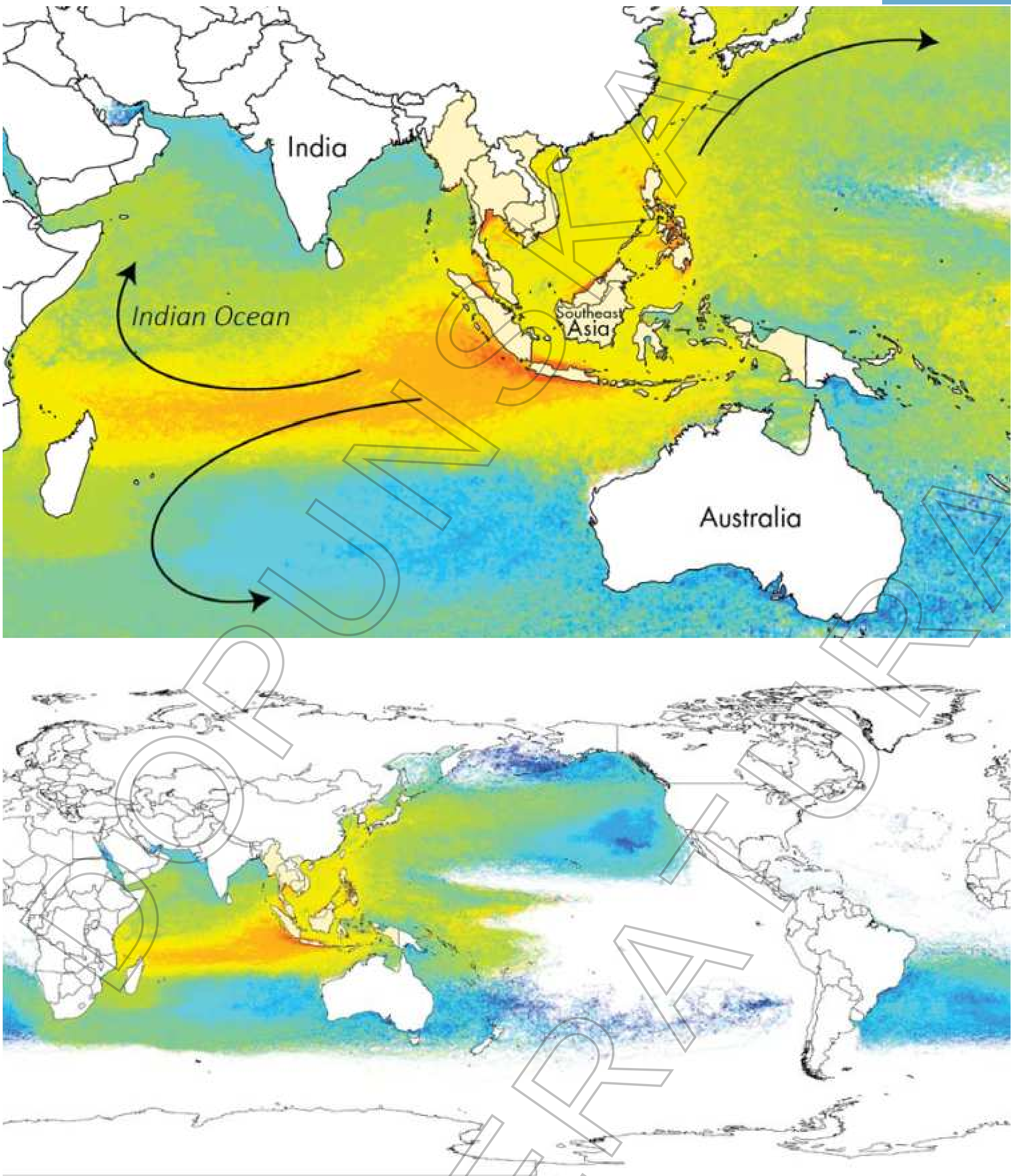
Simulated distribution of floating plastic. Showing high concentrations in coastal waters, using as the source term the estimated influx of plastics from SE Asia due to 'mismanaged waste' (based on Jambeck et al. 2015), from 2004-2014 (from UNEP 2016b)

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

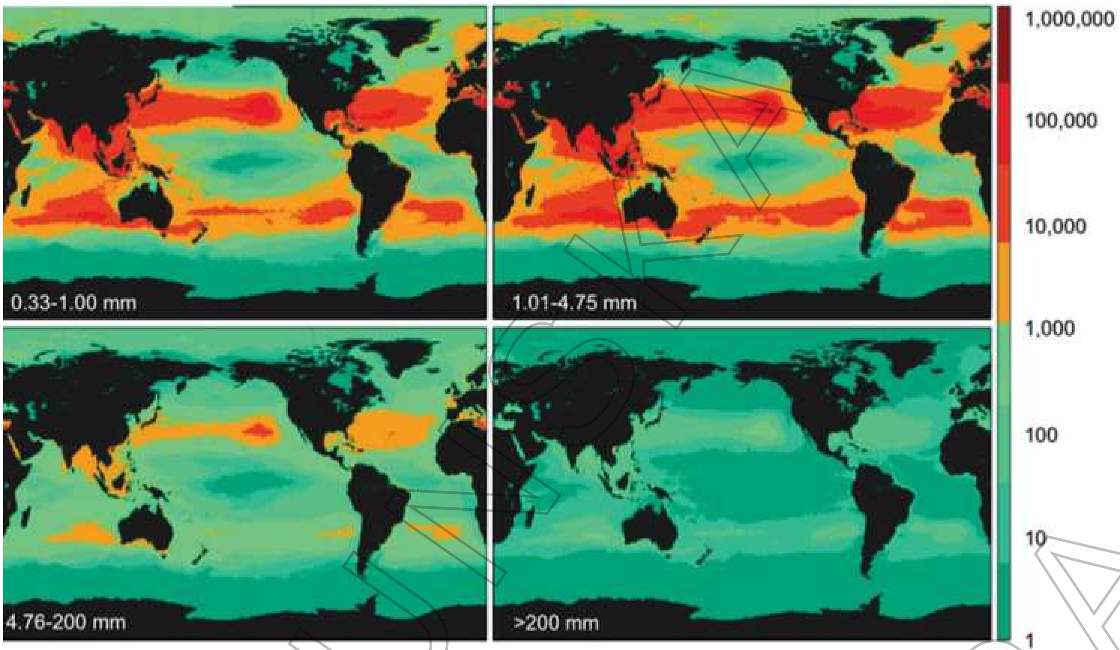


Figure 6.13 Model prediction of the distribution by global count (pieces km-2, see colour scale bar) of particles/items for each of four size classes: 0.33 – 1.00 mm, 1.01 – 4.75 mm, 4.75 – 200 mm, and >200 mm (Eriksen et al. 2014)

Figure 6.14

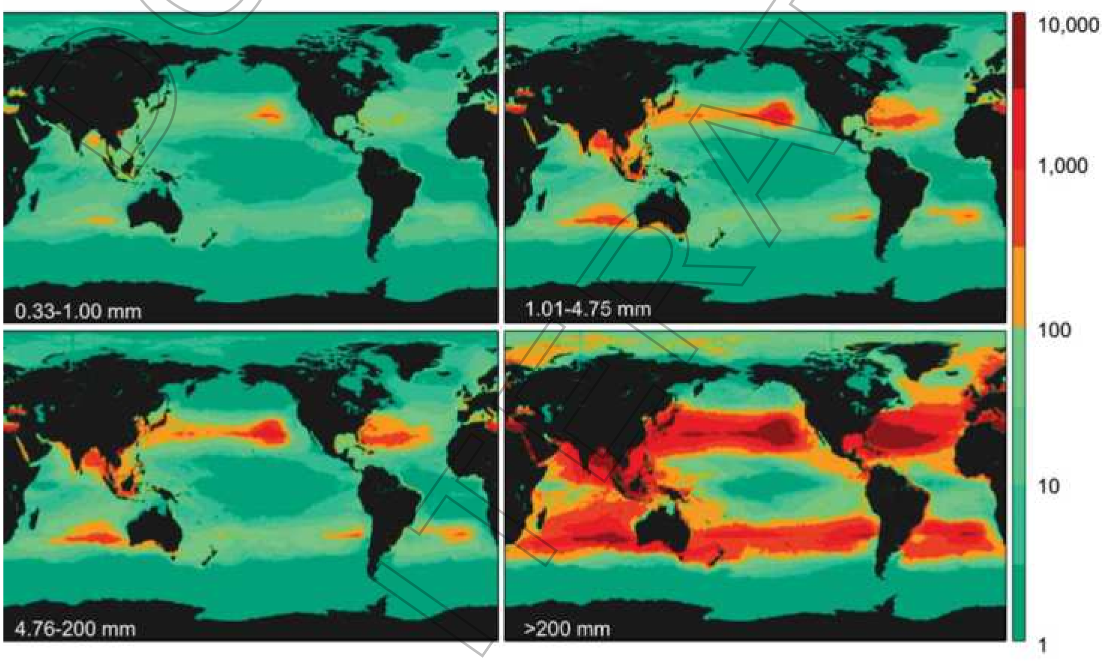
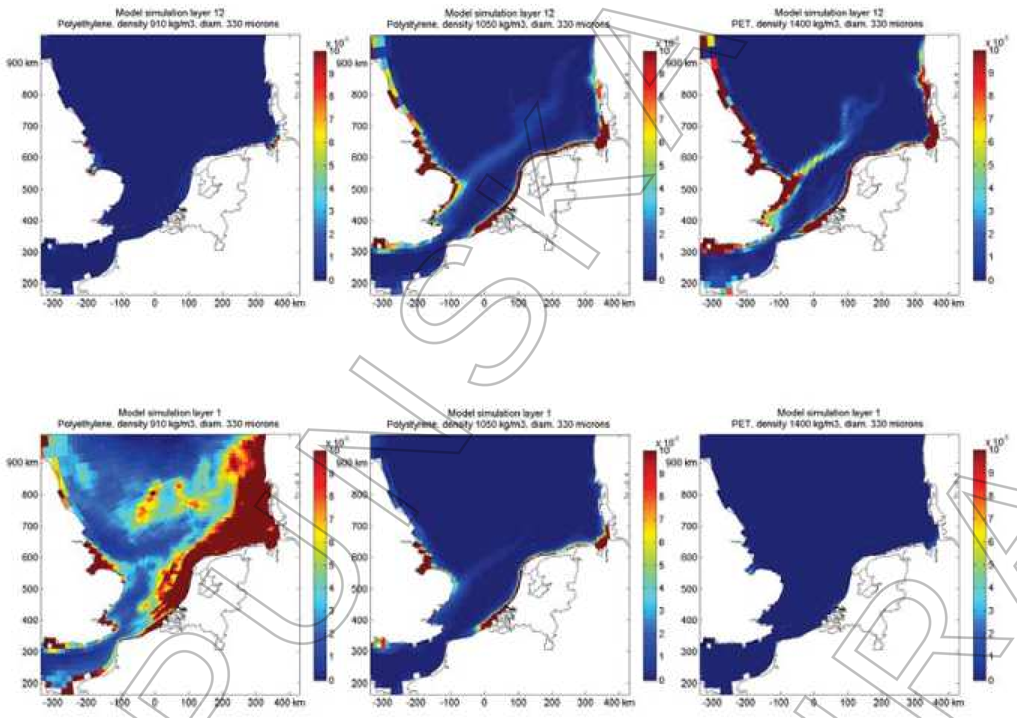


Figure 6.14 Model prediction of the distribution by weight density (g kg-1, see colour scale bar) of particles/items for each of four size classes: 0.33 – 1.00 mm, 1.01 – 4.75 mm, 4.75 – 200 mm, and >200 mm (Eriksen et al. 2014)

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

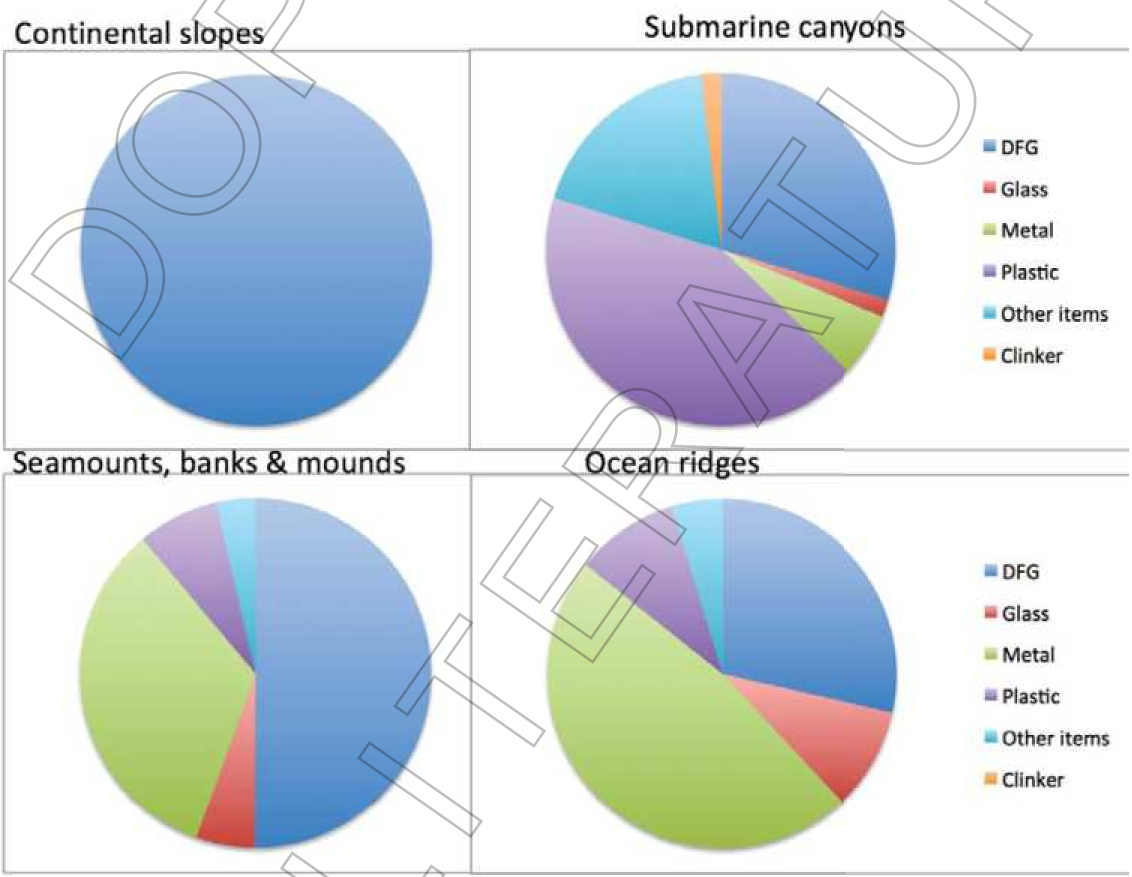
Plastic accumulation on mid-ocean islands in the North Pacific: a)Hawaiian monk seal hauled out on derelict fishing gear on Lisianski Island in the Northwestern Hawaiian Islands. (image: NOAA Marine Debris Program); b) Miscellaneous debris washed ashore on Laysan Island in the Hawaiian Islands National 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

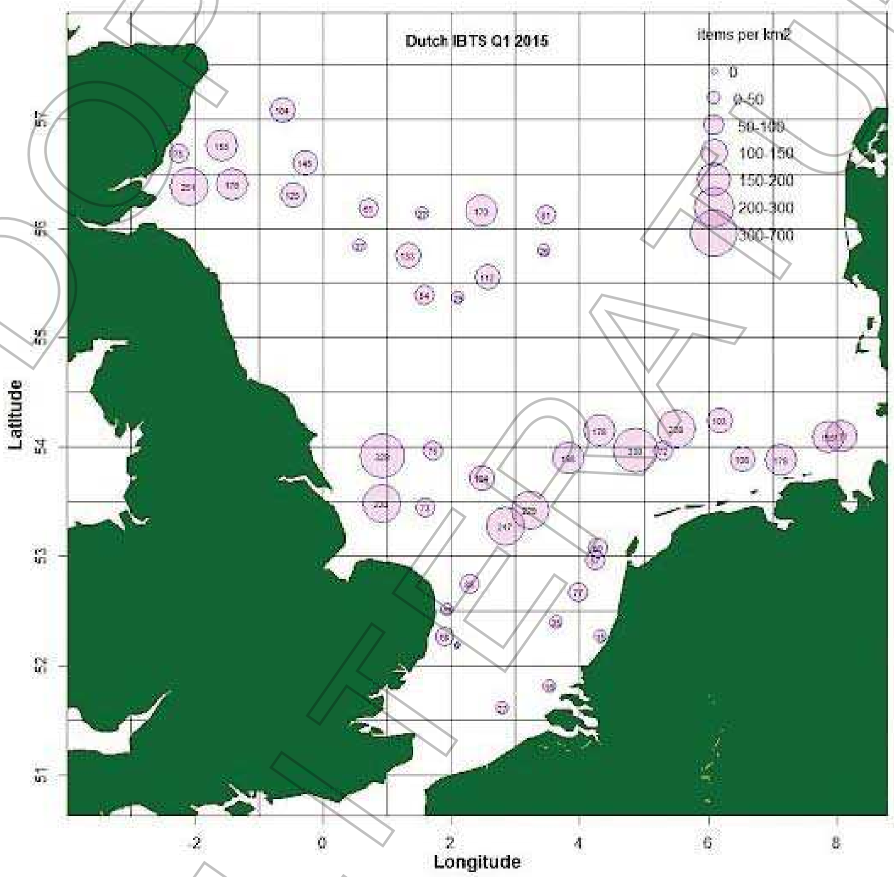


Figure 6.19 Seabed distribution of marine debris in the greater North Sea collected during a routine ground-fish survey by the Netherlands, for fisheries management purposes. Much of the debris found in this region can be attributed to fisheries (IMARES).

7. 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

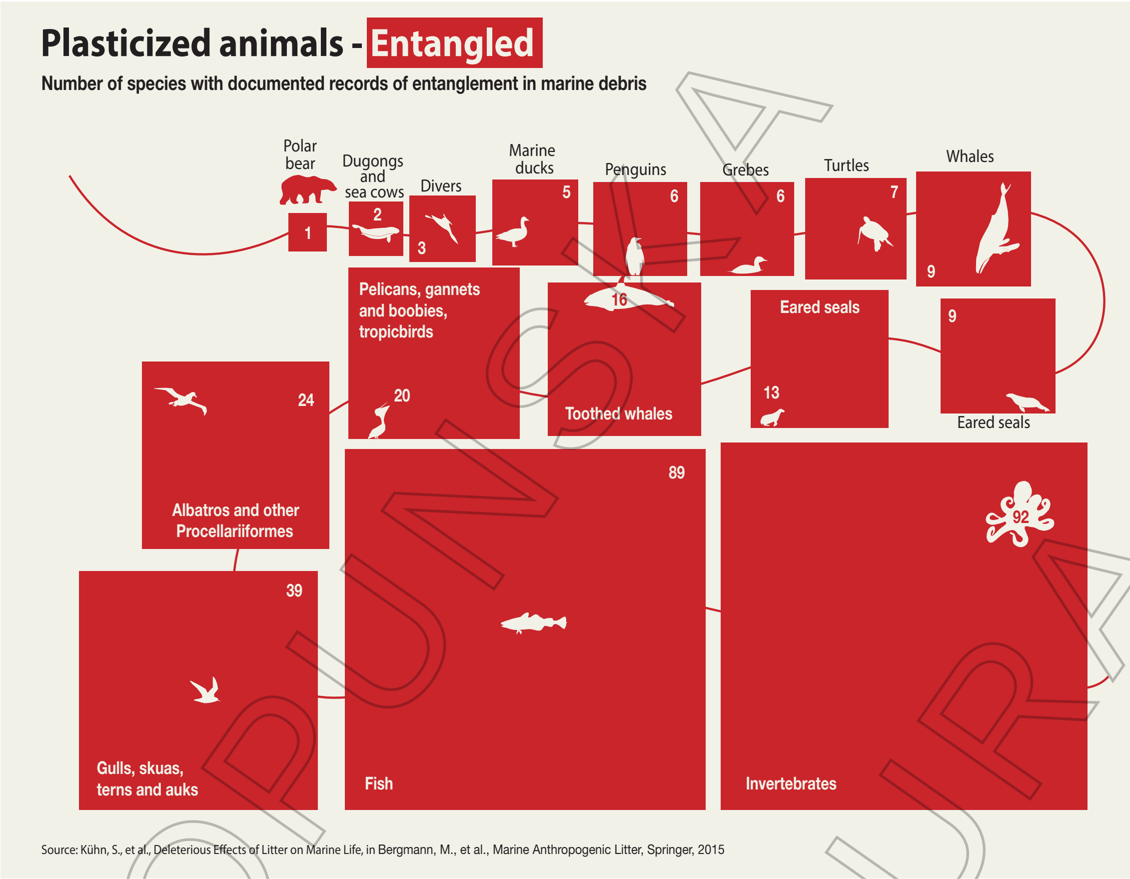
Figure 7.1b

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

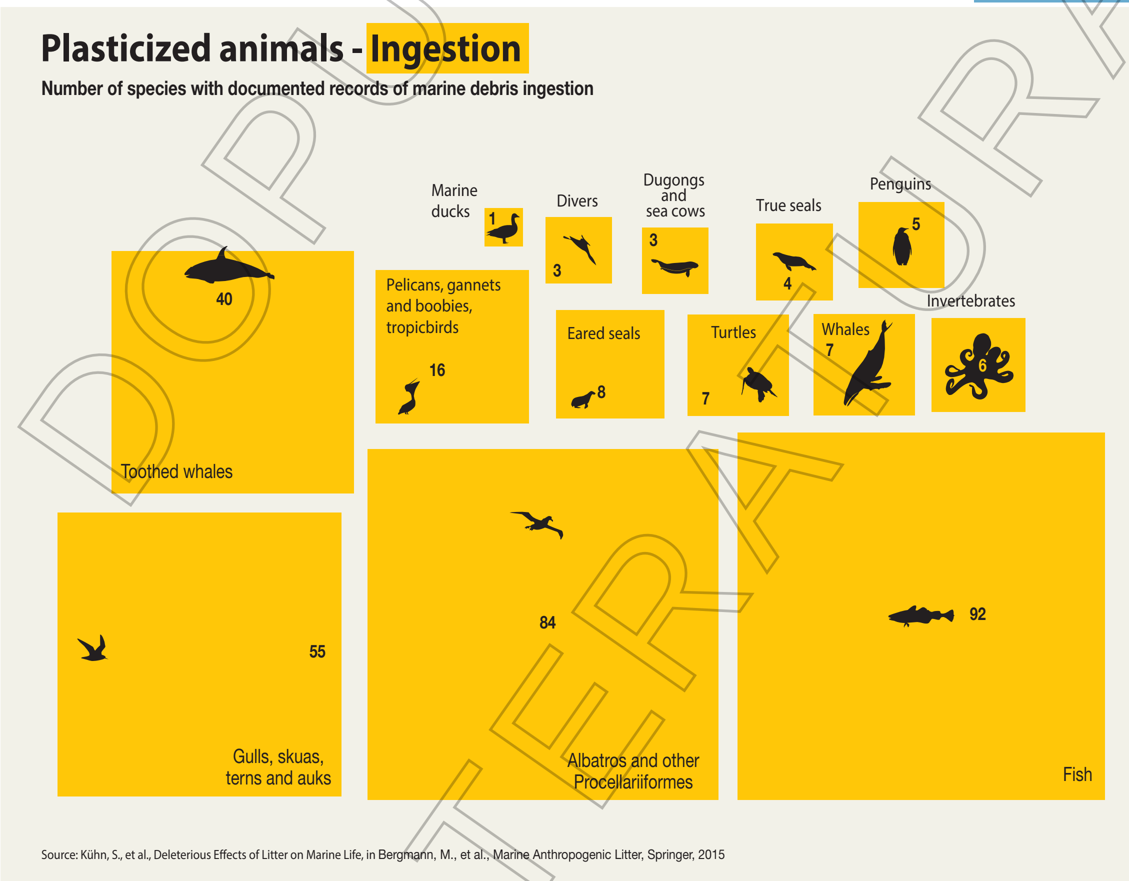
Item	Rank of expected impact			
	Mean	Bird	Turtle	Mammal
Buoys/traps/pots	1	1	1	1
Monofilament line	2.3	3	2	2
Fishing nets	2.7	2	3	3
Plastic bags	5.7	4	9	4
Plastic utensils	5.7	7	4	6
Balloons	6.7	8	5	7
Cigarette butts	7.3	5	12	5
Caps	7.7	9	6	8
Food packaging	8.7	10	7	9
Other EPS packaging	9.7	11	8	10
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).

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)

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).

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).

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

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

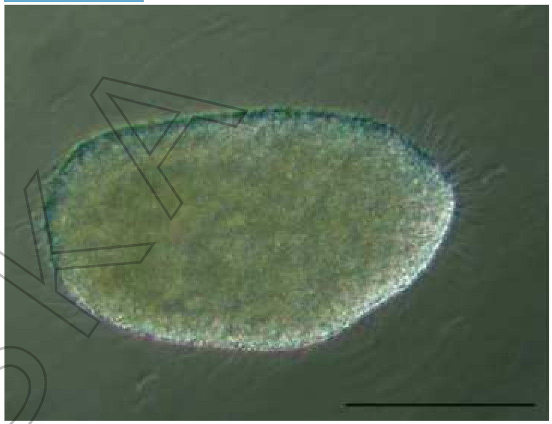


Figure 7.8b

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.

***http://www.rachelcarsoncouncil.org**

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 – Sonnensche in 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).

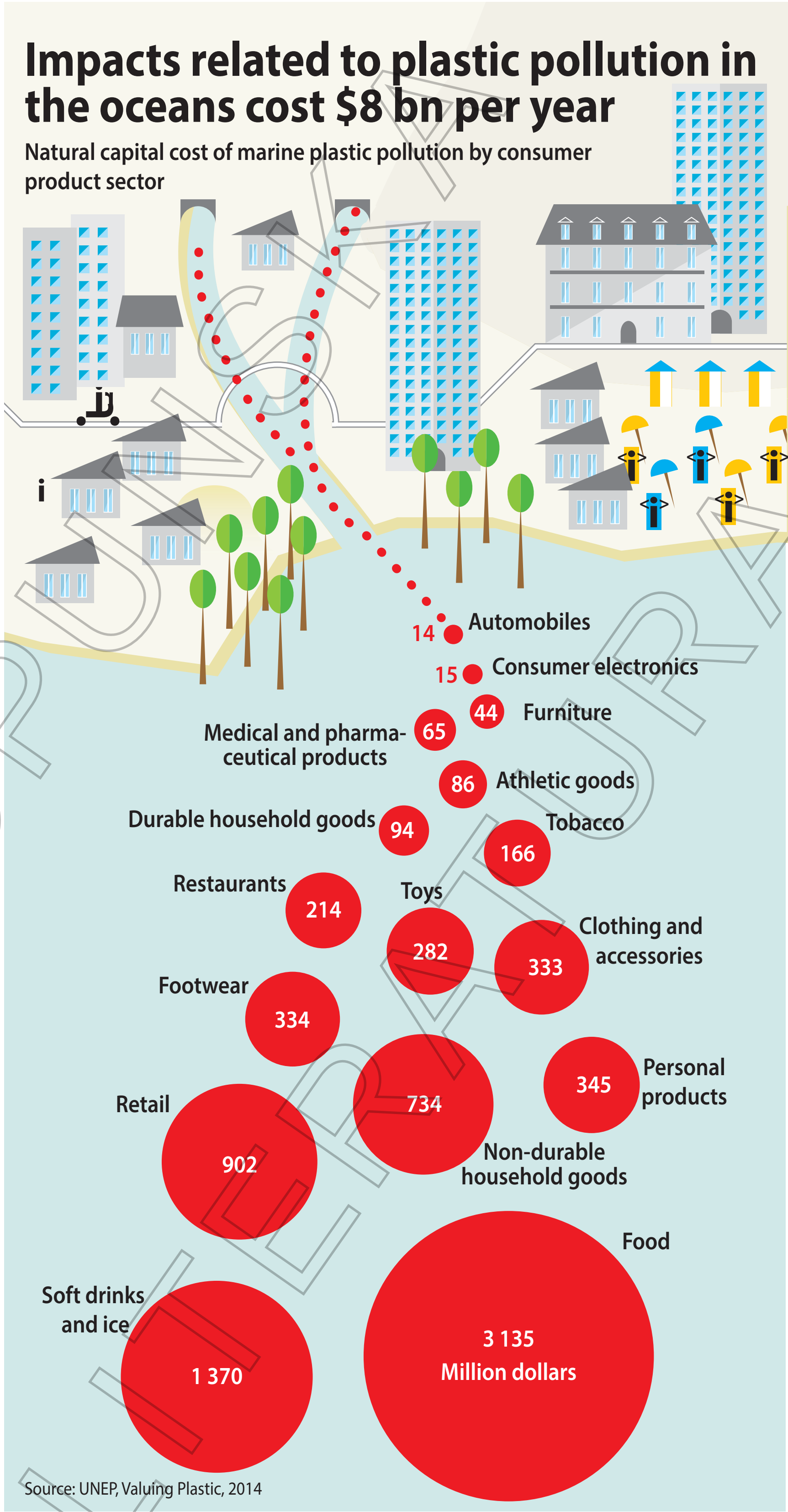
The tourism sector is both significantly affected by marine litter and a major contributor to the problem. The presence of marine litter can discourage visitors from going to certain beaches, thus reducing visitor numbers, which in turn leads to lost revenues and jobs in the tourism industry (see UNEP 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

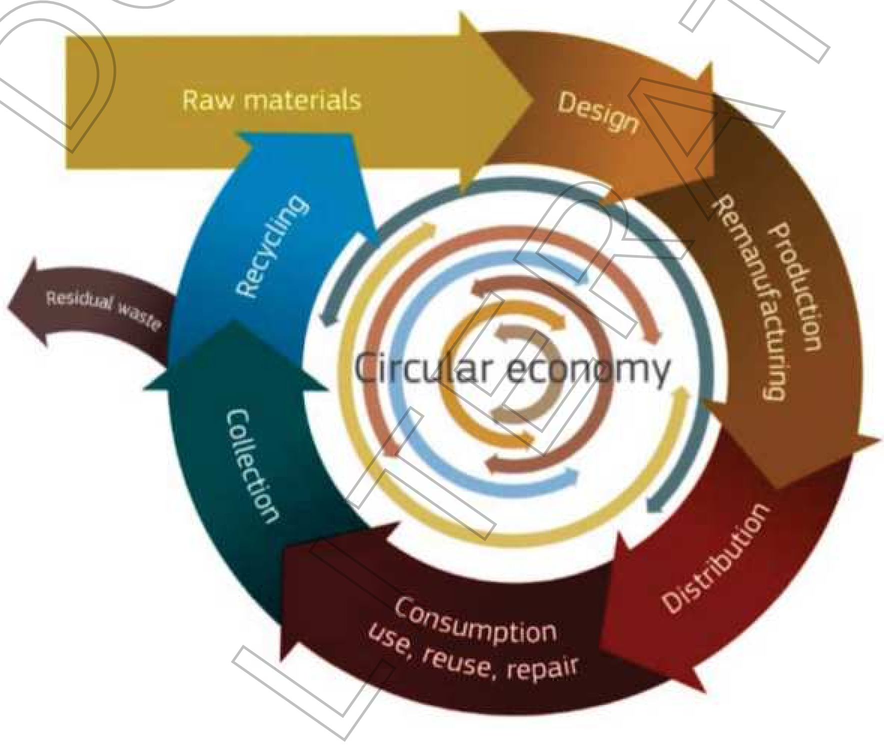
TOWARDS A CIRCULAR ECONOMY

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

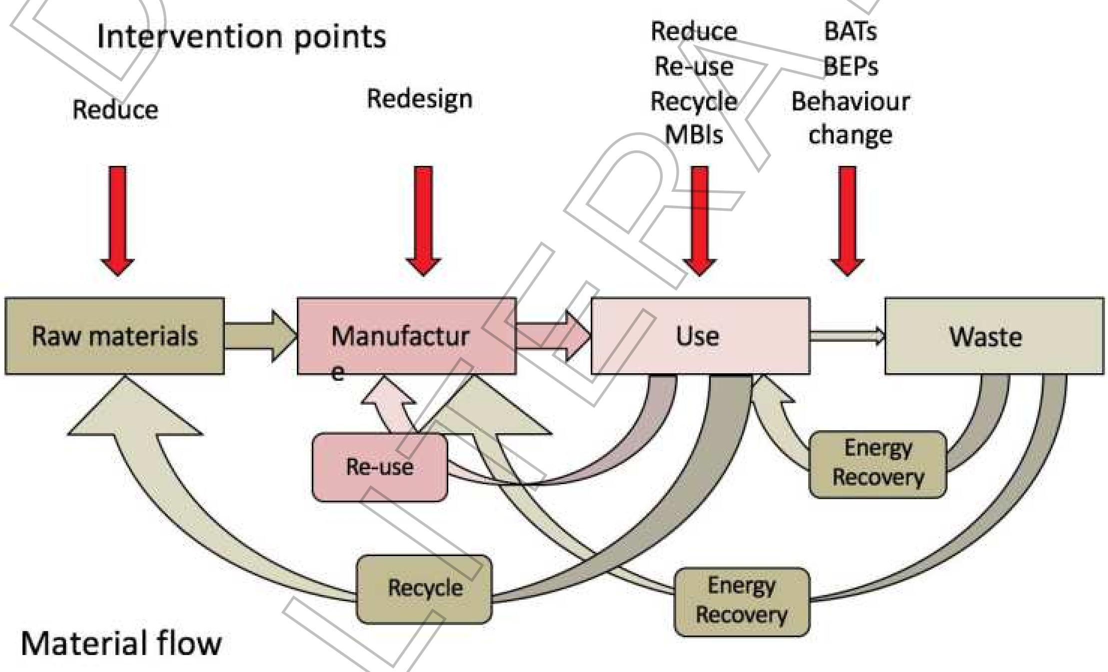
life value and hence provide an incentive to prevent leakage, especially for those working in the informal waste sector (WEF/EMF/MCKINSEY 2016).

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'

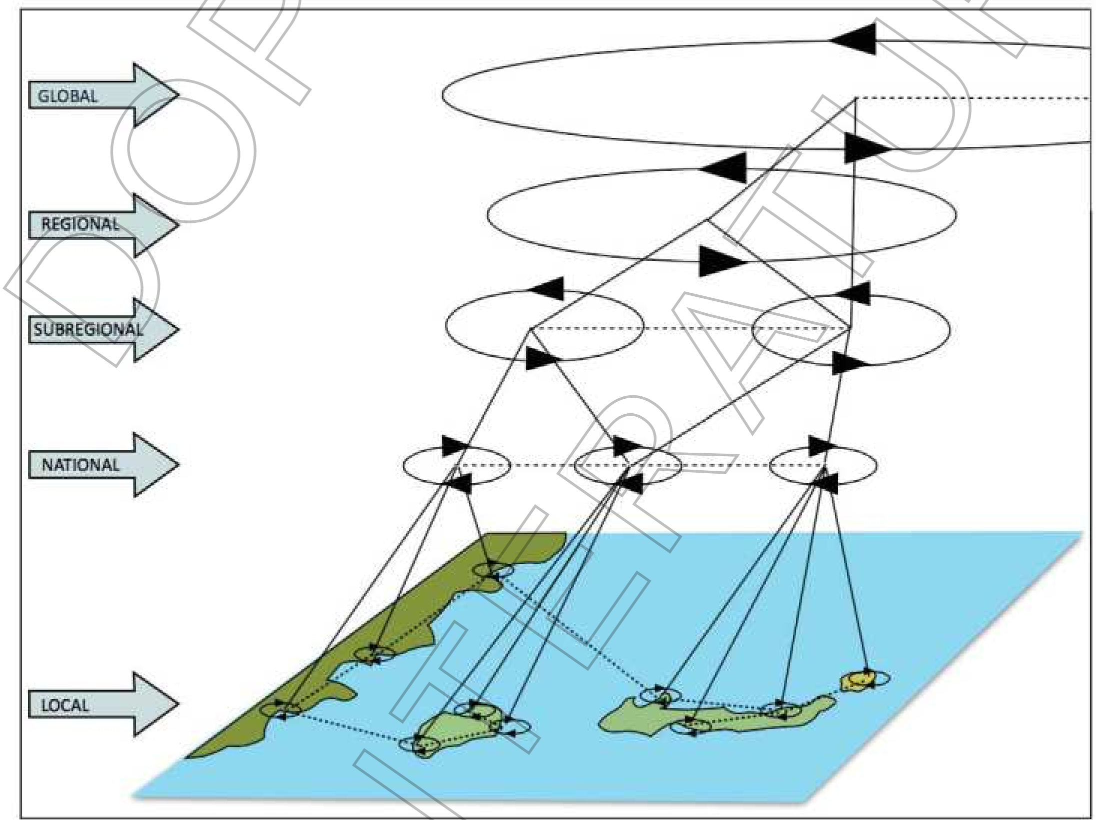
Regulation can be difficult to enforce in some maritime sectors. For example, MARPOL Annex V prohibits the discharge of plastics from ships and other offshore platforms anywhere in the ocean. This prohibition has been supported by the need to maintain a garbage record book on the ship and for ports to 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:

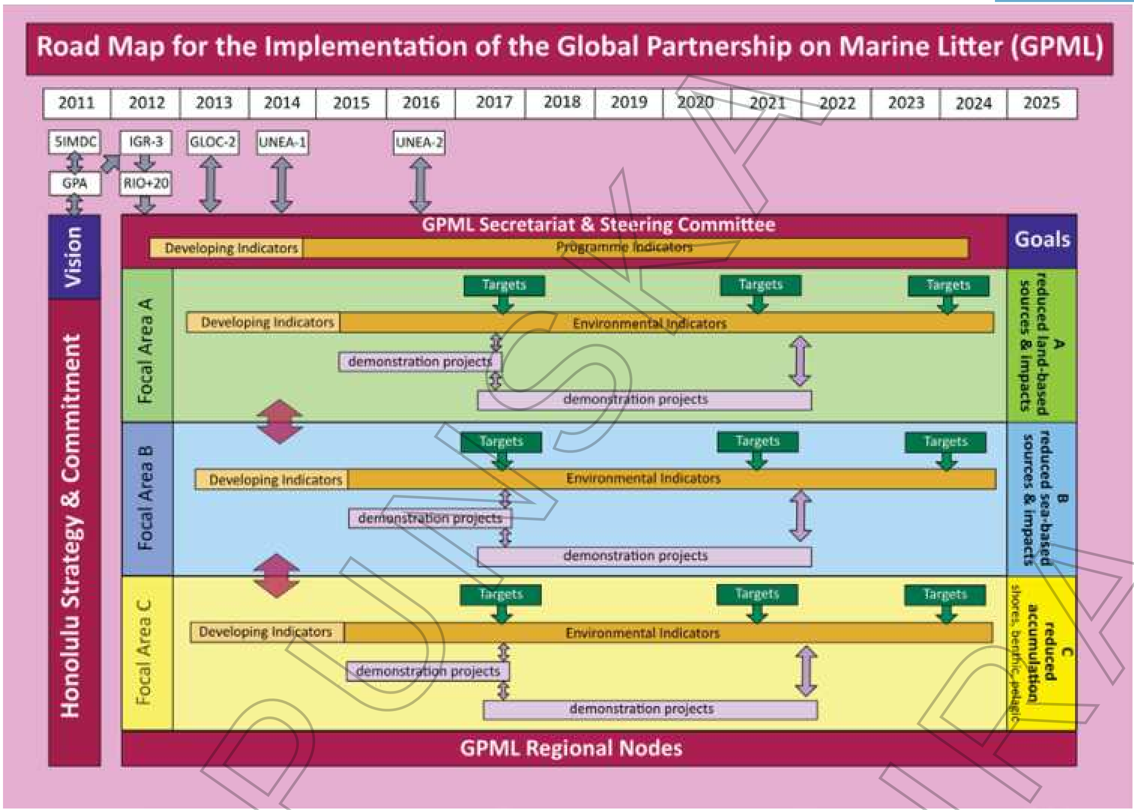
1. **To reduce** the impacts of marine litter worldwide on economies, ecosystem, animal welfare and human health.
2. **To enhance** international cooperation and coordination through the promotion and implementation of the Honolulu Strategy - a global framework for the prevention and management of marine 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

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. 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.