103

GESAMP

Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection

REPORTS AND STUDIES

PROCEEDINGS OF THE GESAMP INTERNATIONAL WORKSHOP ON ASSESSING THE RISKS ASSOCIATED WITH PLASTICS AND MICROPLASTICS IN THE MARINE ENVIRONMENT

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The report contains views expressed or endorsed by participants at the workshop, including invited experts acting in an individual capacity; their views may not necessarily correspond with those of the Sponsoring Agencies.

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CONTENTS

TABLES

FIGURES

Workshop participants

PREFACE

The scope of shared services provided by United Nations agencies and programmes is broad and includes technical assistance and capacity-development, research and data management, support of intergovernmental processes, financial assistance, methodologies and outreach. It is essential that these services are based on sound science.

All major marine environmental issues are complex and transdisciplinary. Strategic frameworks such as the Sustainable Development Goals, in particular SDG 14 (life below water) and the UN Decade for Ocean Science for Sustainable Development (2021-2030) call for cross sectoral thinking and more than ever require UN agencies and programmes to join forces. Alignment of their individual and joint interventions is also based on science.

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) is co-sponsored by the International Maritime Organisation (IMO), Food and Agriculture Organization (FAO), Intergovernmental Oceanographic Commission of the United Nations Educational Scientific and Cultural Organisation (IOC-UNESCO), United Nations Industrial Development Organisation (UNIDO), World Meteorological Organisation (WMO), International Atomic Energy Agency (IAEA), United Nations Secretariat (UN), United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP) and the International Seabed Authority (ISA). This interagency mechanism ensures impartial and independent scientific advice to the sponsors on the state of the marine environment, minimizes duplication, reduces costs, and most importantly, makes it possible to provide to Member States, governments and society at large a very consistent message.

This report represents the proceedings of a three-day GESAMP workshop on the current risk assessment approaches for plastics and microplastics in the marine environment. The workshop was an opportunity to work with multiple entities in the UN system (e.g. FAO, IMO, UNIDO, WHO) and share interests and expertise with representatives of academia, industry, intergovernmental organizations (IGOs) and non-governmental organizations (NGOs).

The lead UN partners behind the workshop, UNEP and IOC-UNESCO, have a common agenda in the issues of plastics and microplastics in the marine environment. The IOC-UNESCO is interested in the underlying science and building the evidence base for sustainability. The UN Environment Programme strives to assess the overall impact and effect of human activities on the marine environment and its sustainable management. Both organizations have the need to describe and quantify ocean processes re-distributing plastics and microplastics, evaluate societal, environmental and economic consequences of widespread plastics in the ocean (ranging in size from nano-sized particles to objects measuring several metres, including Abandoned Lost or otherwise Discarded Fishing Gear ALDFG), and to identify proportionate and cost-effective corrective measures.

This report is a first step to address the environmental and human health risks associated with plastic litter and microplastics in the marine environment, from a biological, physical and chemical perspective. It provides a state-of-the-art overview of risks and exposure pathways due to plastics and microplastics, including particles in the nano size range, and an overview of existing or planned initiatives to identify synergies and avoid overlap. It critically examines current methods of risk assessment and makes some recommendations for improving risk assessment methods, including the potential for developing a risk assessment framework that can capture the complexity of the exposure pathways identified. Finally, it provides guidance to GESAMP on its future work programme with respect to assessing the risks from plastics and microplastics and to addressing some of the related concerns of the United Nations Environmental Assembly (UNEA).

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© Jason Hall-Spencer. Crab on fishing net in deep sea seafloor.

1 INTRODUCTION

1.1 Background

The Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) established a Working Group (WG40) in 2012, in response to a request to provide a more in-depth, comprehensive, independent and global assessment of the sources, fate and effects of microplastics in the environment. The need was highlighted in the conclusions of a GESAMP International Workshop on microplastics in 2010 (GESAMP 2010), which examined microplastic particles as a vector in transporting persistent, bioaccumulating, and toxic substances in the ocean. At that stage, the potential for microplastics to act as vectors for pathogens (e.g. Arias-Andres *et al.* 2018) was not recognised. Initially WG40 was led by the Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) and received additional financial support from Plastics Europe and the American Chemistry Council, and the first assessment was published in 2015 (GESAMP 2015). The second phase was co-led by IOC-UNESCO and the United Nations Environment Programme (UNEP), to include receiving financial support mainly from UNEP and IOC-UNESCO. The remit of WG40 (GESAMP 2016) was expanded in 2017 to include all size categories of plastic marine litter. The third phase resulted in the production of a set of Guidelines for the monitoring and assessment of plastic litter, including microplastics. This was launched at the 4th UN Environment Assembly in March 2019 (GESAMP 2019).

The Current Terms of Reference of GESAMP WG40 (as of September 2018, Annex I) are to provide an assessment of:

1. The impact of plastics and microplastics on food security – environmental impacts of plastics and microplastics on species at a population level, including physical and chemical effects

2. The impact of plastics and microplastics on food safety - chemical contaminants and pathogens in seafood associated with ingested microplastics

3. Transfer of biota – the social, economic and environmental effects of plastics and microplastics on the distribution of biota, including indigenous and non-indigenous species and pathogens

1.2 Purpose and Rationale for the workshop

There is sufficient scientific evidence to conclude that plastic marine litter can cause significant adverse social, economic and environmental effects. These are most clearly demonstrated for larger items (i.e. macro-plastics > 25 mm) and certain categories of litter (e.g. Abandoned Lost or otherwise Discarded Fishing Gear, ALDFG). It follows that management options may need to be considered for reducing these effects, but these need to be based on a clear understanding of the nature and magnitude of the risks. Regulators need to be able to respond to legitimate questions from the public on matters such as food safety, human health and environmental status, and mitigation measures need to be targeted and proportionate. Plastics and microplastics may cause adverse effects due to a wide variety of mechanisms and exposure pathways. For microplastics the adverse effects may relate to the physical (e.g. size, shape), chemical (e.g. polymer, monomers, additives, absorbed contaminants) or biological (e.g. microbial coatings) characteristics of the particles. It can be argued that the risk can be best assessed by considering whether an exposure level exceeds a threshold effect concentration, rather like a risk assessment of chemical toxicity. For macro-sized plastics the adverse effects may be more readily observed but the balance of social, economic and environmental risks may differ. A variety of public and private organisations have started to address this issue. However, it seems unlikely that any one existing approach to risk assessment will be appropriate to address all types of plastic and exposure pathways. The workshop was designed to allow informed discussion of possible ways forward, including the practicality and efficacy of developing an overarching risk assessment framework.

The overall objective of the workshop was to address the environmental and human health risks associated with plastic litter and microplastics in the marine environment, from a biological, physical and chemical perspective. This was to be achieved by undertaking a number of specific objectives:

1. Provide a state-of-the-art overview of risks and exposure pathways due to plastics and microplastics, including particles in the nano size range

2. Provide an overview of existing or planned international or other initiatives, to identify synergies and avoid overlap

3. Critically examine current methods of risk assessment

4. Make recommendations for improving risk assessment methods, including the potential for developing a risk assessment framework that can capture the complex risks and exposure pathways identified

5. Provide guidance to GESAMP on its future work programme with respect to assessing the risks from plastics and microplastics

The use of the terms 'risk' and 'impact' implies the probability of a negative consequence. However, the presence of macro-plastic and micro-plastic litter may have positive, neutral or adverse effects on different aspects of the socio-ecological system. There may be 'winners' and 'losers' from the same phenomenon.

Thirty-five people attended the workshop (Annex II), representing UN agencies, other international and regional bodies, industry and NGOs, and experts from academia taking part in an independent capacity. The workshop was hosted by the Secretariat of the Basel, Rotterdam and Stockholm (BRS) Conventions. The participants were welcomed by representatives of the Secretariat, the UN Environment Programme (UNEP) and GESAMP, who explained how the workshop related to the wider context of existing or planned international activities. The format comprised a number of plenary sessions interspersed with breakout groups (Annex III).

2 AN OVERVIEW OF ENVIRONMENTAL AND HUMAN HEALTH RISKS (SESSION 1)

The following sections provide brief summaries of plenary presentations that were given to provide an overview of the state-of-the-science as it relates to environmental and human health risks.

2.1 An overview of risks associated with marine plastic litter

Professor Alexander Turra provided an initial overview of the risks associated with marine plastic litter and microplastics. The definition of risk was first based on the review by Besseling *et al.* (2019) on ingestion of micro- and nanoplastics and then was broadened to incorporate other hazards related to plastics and microplastics. The risk assessment is associated with three basic components: exposure, threat or hazard, and effects (Figure 2.1). Exposure refers to the environmental concentrations of different types and sizes of plastics and microplastics, which may vary considerably at a range of spatial and temporal scales. In other words, exposure indicates the probability of encounter of a given type or size of particle. The threats or hazards refer to the understanding of the overall pathways or processes impacted by marine litter, considering the environmental compartment and/or the socio-economic activity affected. In general, these pathways are dependent on the relative size of the plastic particles, and may be summarized as (GESAMP 2015; GESAMP 2016):

(i) ingestion by the biota,

(ii) entanglement/collision, and

(iii) rafting/substrate.

Finally, the effects indicate how the interaction with the particles will affect the environmental compartment or a socio-economic activity. The effects will be strongly dependent on the characteristics of the particles/objects as well as the vulnerability of the environmental compartment or socio-economic activity.

Overall there is a lack of information on exposure. This is unsurprising given the wide range of sizes (nano- to mega-plastics), shapes and chemical compositions involved, the complex relationship between sources and fates, the nature and rate of processes governing degradation of plastics, absorption and desorption of chemicals, interactions with biota and accumulation zones. A combination of field sampling and modelling techniques (e.g. Eriksen *et al.* 2014) can be used to reduce some of these uncertainties but this is insufficient to provide a reliable estimate of risk. Improved and harmonised monitoring and assessment of plastics and microplastics in the marine environment are thus an essential step to better understanding exposure pathways (GESAMP 2019). Examples of risks associated with the different pathways of plastics and microplastics to different environmental compartments and socio-economic activities, were described, citing the work by Keswani *et al.* (2016).

Ingestion

Ingestion of particles by biota is highly dependent on the relative sizes of organisms and plastics; the smaller the particles, the larger the variety of organisms that are able to ingest them. For large-sized organisms, small-sized particles may be ingested incidentally, such as by ingestion of sediment (e.g. deposit-feeders) or water (e.g. filter-feeder). Small-sized organisms, on the other hand, are not able to ingest large particles. In addition, smaller particles will tend to have a higher potential for translocation from gut to the circulatory system and become assimilated into tissues (GESAMP 2016). Although there are several factors affecting intake of particles by the biota, a wide variety of effects has been observed at different levels of biological organization, from sub-organismal to ecosystem (Santana and Turra 2020). However, substantive gaps in scientific knowledge still exist related to the effects on organisms at higher levels of organization and about the combined effects of the different characteristics of microplastics, such as type, size, colour and presence of additives and environmental pollutants. It is important to attempt to understand the independent effects of the physical toxicity of plastic particles and the chemical toxicity related to additives or other pollutants absorbed from the environment.

Particle ingestion by biota may lead to potential effects on food security, food safety and human health (Vethaak and Leslie 2016; Barboza *et al.* 2018). Although particles can be transferred along the food chain (Farrel and Nelson 2013), there is no evidence of bioaccumulation and biomagnification of particles to date (Santana *et al.* 2017). The Food and Agricultural Organisation of the United Nations (FAO) commissioned a study of microplastics in fisheries and aquaculture, by a group of independent experts. Their conclusion was that the current risk to humans from the ingestion microplastics in seafood is very low (Lusher *et al.* 2017).

Entanglement/Collision

Entanglement and collision are common hazards caused by certain types of litter, such as nets, lines and ropes. One major category is litter related to fishing and aquaculture activities. These items are classified as Abandoned Lost or otherwise Discarded Fishing Gear (ALDFG). ALDFG can cause direct damage to sensitive habitats (e.g. coral reefs and seagrass beds), as well as increased morbidity or mortality to a wide variety of fish, birds, reptiles and mammals (GESAMP 2016). Of particular concern is the phenomenon of 'ghost fishing', where ALDFG continues to entrap both target and non-

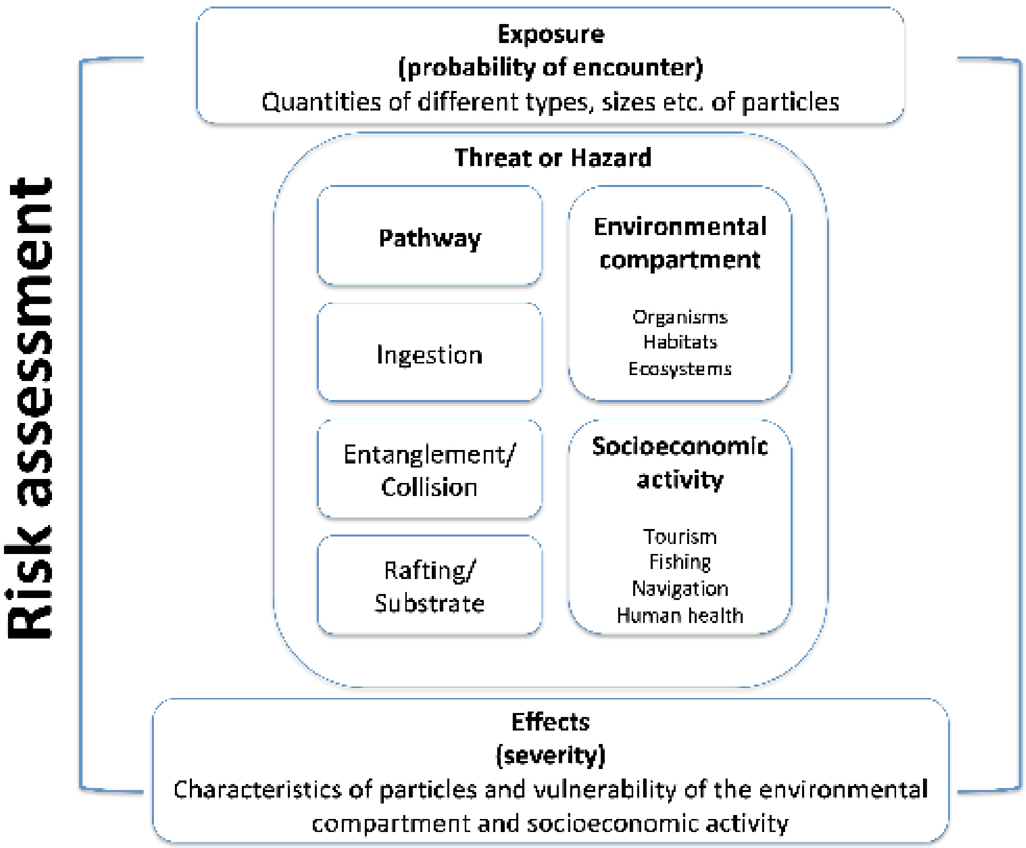

Figure 2.1 Risk assessment framework of plastics and microplastics, drawn by A. Turra to summarise the workshop discussions.

target species. This can have a significant impact on biodiversity and food security, with a social and economic impact on the communities dependent on the fishery.

Entanglement and collision are pathways that present risks to human activities such as navigation and tourism. Litter threatens navigation (commercial and recreational) due to entanglement of propellers and rudders, blocked water intakes and collisions with floating objects (Hong, Lee and Lim 2017). ALDFG may also cause drowning of beach goers and divers.

Rafting/Substrate
Plastic litter may be used as substrate by a wide variety of species, with the potential for environmental and socio-economic impacts. The increased availability of hard substrates may result in an increase in the population of indigenous species. For example, marine insects of the genus *Halobates* (Majer et al. 2012) use floating litter as oviposition sites. Rafting of organisms attached to litter by ocean currents represents a risk to both biodiversity and human health. Biodiversity may be affected by changes in the species composition, especially if non-indigenous species are relatively more successful and become invasive (GESAMP 2016; Tutman et al. 2017). This can also have social and economic consequences. Plastic surfaces are also known to harbour pathogens (GESAMP 2016; Keswani et al. 2016). Transportation of pathogens can spread diseases and reduce environmental quality of areas that accumulate litter.

Other social and economic risks
Floating litter can affect a number of maritime and coastal industries. For example, floating macro-litter can block cooling water intakes on ships and coastal power stations, with significant social and economic impacts. The presence of litter can have a negative impact on the attractiveness of locations for coastal tourism. For example, Krelling *et al.* (2017) estimated the potential economic loss to tourism to be up to US$ 8.5 million due to increases in stranded litter at a number of a tourist destinations in Southern Brazil. Preventing such losses may incur increased direct costs from beach cleaning. Increased costs are experienced in the fisheries sector due to contamination of the catch, damage and the time taken to clean the nets.

The examples above reveal a strong link between environmental and socio-economic aspects of the marine litter issue, which need to be integrated in risk assessments. One additional challenge is the integration of all these caveats into a broader and holistic understanding of the risks and impacts caused by marine litter, but it is necessary to assess the risks adequately. For example, there are different and highly complex aspects of microplastics that need to be understood in terms of risk assessment related to ingestion (e.g. size, morphology, colour, composition).

Challenges to addressing risk assessment
There are several challenges that need to be addressed in order to improve the risk assessment of marine plastic litter and microplastics. These include:

(i) understanding the pathways of plastics and microplastics in the environment and their interaction with biota (ingestion, entanglement, rafting, smothering);

(ii) quantifying the ingestion, gut transfer and elimination of particles as well as their physical, chemical and biological impacts;

(iii) developing methods to assess exposure to nanoplastics;

(iv) developing technologies to enable more comprehensive and reliable monitoring of the whole size range of plastics in the ocean, including in-situ and remote earth observation;

(v) upscaling sub-organismal effects to individual, population, community and ecosystem levels;

(vi) quantifying and communicating the uncertainties and limitations of the risk assessment to all stakeholder groups; and

(vii) integrating risk assessment with policy-relevant concerns to adequately inform decision makers.

Finally, there is a significant need to fill the different scientific gaps that currently prevent the scientific community from having a more consistent view of risk assessment of marine plastics and microplastics.

2.2 Environmental risk from nano- and microplastics

Dr Bart Koelmans provided an overview of environmental risks from nano- and micro-plastics and introduced a major study that was published in early 2019, at the request of the Group of Chief Scientific Advisors of the European Commission, entitled: *A scientific perspective on microplastics in nature and society*. (Science Advice for Policy by European Academies [SAPEA] 2019). The study consisted of a review of the evidence base with respect to what is known about nano- and microplastic particles (referred to as NMPs) in nature, in society and in policy terms (Figure 2.2).

Dr Koelmans focussed his presentation on the natural science aspects of the study, stressing the complex nature of the problem and the need to prioritise research, given the limited funding available. NMPs have been found in virtually all environmental compartments, including biota. Impacts of NMPs can be measured using a number of biological endpoints at different levels of biological organisation (Figure 2.3). The study reviewed the current state of

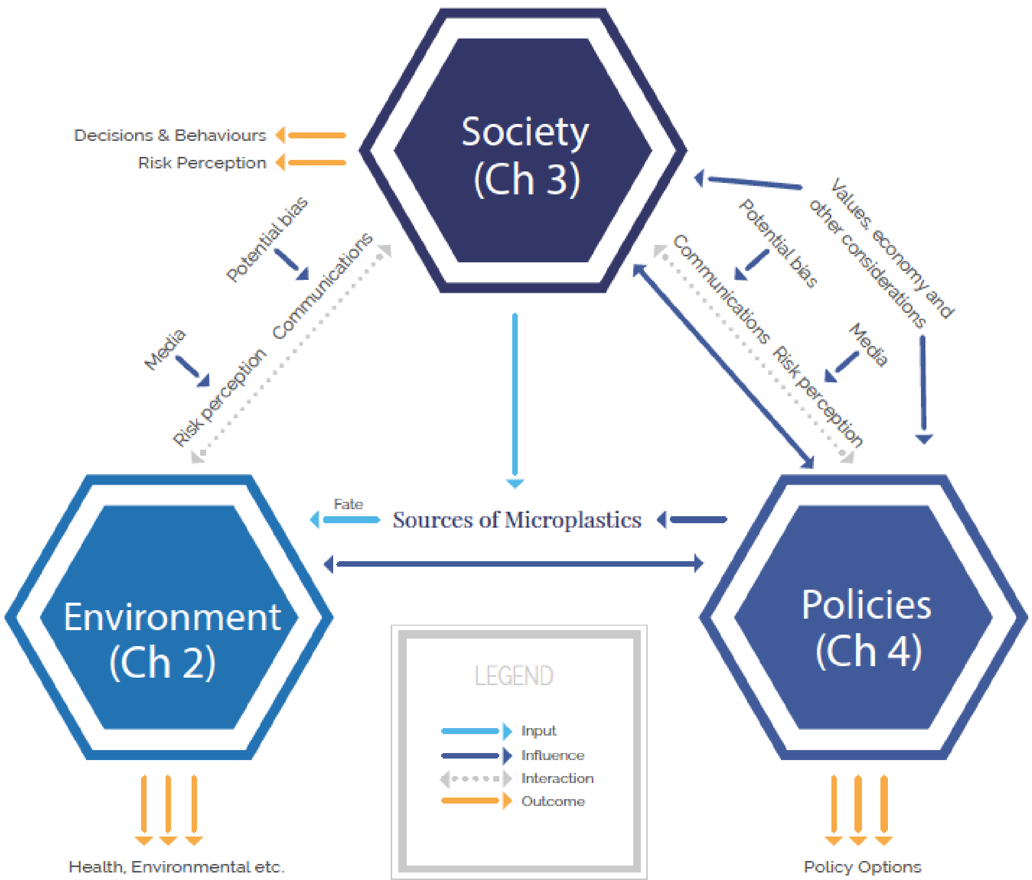

Figure 2.2 Scope of the SAPEA study *A scientific perspective on microplastics in nature and society*, reviewing the evidence base for what is known about nano- and microplastics in nature (Chapter 2), society (Chapter 3) and in policies (Chapter 4), taken from SAPEA 2019

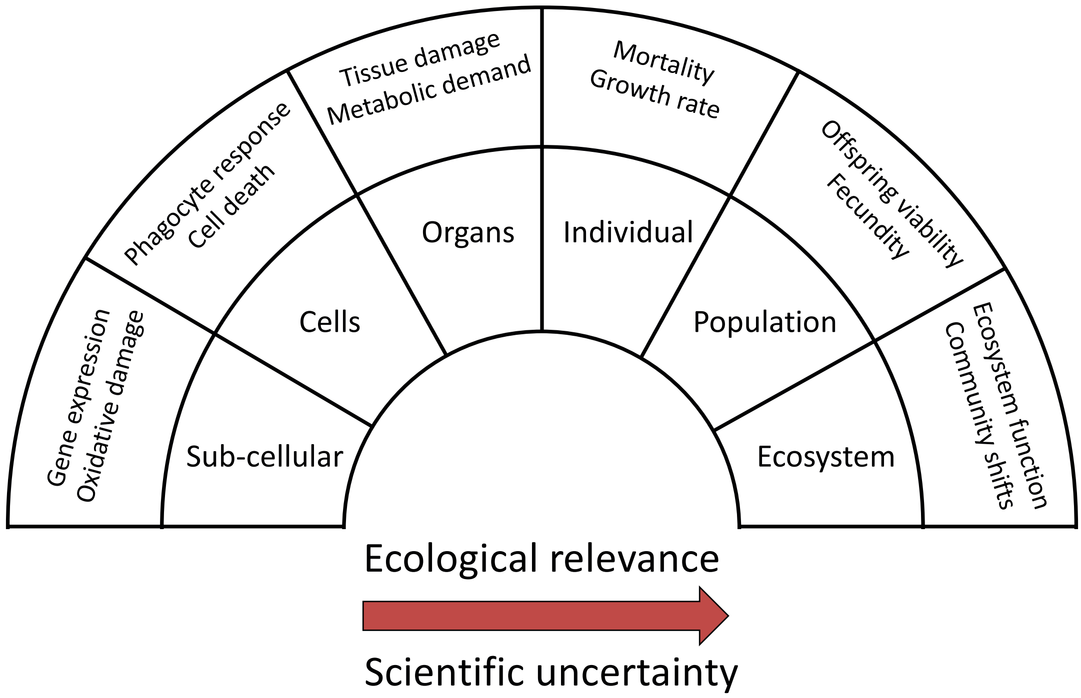

Figure 2.3 Impacts of nano- and micro-plastic particles on biota reported at various levels of biological organisation; note: uncertainty in predicted effects increases substantially with increasing biological organisation, due to a lack of data (adapted from SAPEA 2019).

knowledge and identified a number of key research needs, to:

1. develop methods to assess the relationships between polymer structural characteristics and the formation of smaller plastic particles (NMP) in nature, due to embrittlement, fragmentation or degradation - in order to be able to understand the fate of NMP and to build models for prospective risk assessment;

2. develop markers and/or approaches to causally link plastic that one can find in nature to its origin, source or manufacturer;

3. increase knowledge of the presence and fate of NMP in air and soil compartments, freshwater systems and sub-surface ocean waters;

4. develop improved methods to measure the presence of nanoplastics and describe their fate, effects and associated risks;

5. improve NMP measurement methods, to standardise and internationally harmonise them, to obtain agreement on them internationally, such that they can be applied on a comparable routine basis in a regulatory context;

6. develop adequate NMP risk assessment methods, including those involving NMP interactions with other stressors (e.g. chemicals, climate change, eutrophication, acidification) to standardise and internationally harmonise them and to obtain agreement on them internationally, such that they can be applied on a routine basis in a regulatory context;

7. improve and validate the limited number of promising theoretical models that simulate the fate and transport of NMP in environmental compartments, including food web transfer, that are potentially relevant for prospective risk assessment and associated risks with respect to nano- and microplastics;

8. understand fate, exposure and risk for those NMPs that are most relevant to sensitive receptors across all environmental compartments, based on specific protection goals set (risk assessment always has a different protection goal in different contexts);

9. understand the abundances of NMP in the human diet, drinking water and air, specifically down to sizes <10 µm, in order to be able to start assessing risks for human health; and

10. understand the potential modes of toxicity for different sizes, shapes and types of NMP in human models.

> *'…… even though 'high quality' risk assessment is not yet feasible, action to reduce, prevent and mitigate pollution with NMP [nano- and microplastic particles] is suggested ……… ……. it is important to develop and use risk assessment approaches for NMP to be able to prioritise these actions, and to plan where and when to apply them.'*
>
> SAPEA (2019)

Crucially, the SAPEA study reached three important conclusions about potential impacts:

1. There may at present be at least some locations where the predicted or measured environmental concentration exceeds the predicted no-effect level (PEC/PNEC>1).

2. Given the current generally large differences between known measured environmental concentrations (MEC) and predicted no-effect levels (PNEC), it is more likely than not that ecological risks of microplastics are rare (no widespread occurrences of locations where PEC/PNEC>1).

3. If microplastic emissions to the environment remain the same, the ecological risks of microplastics may be widespread within a century (widespread occurrence of locations where PEC/PNEC>1).

Furthermore, Dr. Koelmans presented a new approach to characterise environmental (micro-) plastic, an approach meant to simplify exposure and risk assessment of this complex material (Kooi and Koelmans 2019). Because of their diverse densities, shapes and sizes, environmental plastics are often perceived as complex. Studies struggle with this complexity and either present data where characteristics are translated into discrete classifications (Hartmann *et al.* 2019) or address only a part of the diversity. Classifications will never be fully satisfactory, as any definition using classes does not capture the essentially continuous nature of environmental plastics. Therefore, it has been proposed to simplify (micro-)plastics by fully defining them through probability distributions, for instance with size, shape, and density as dimensions. Probability distributions can be fitted to empirical data, which results in a realistic representation of "true" environmental plastics. This approach to simplifying microplastic provides opportunities to address variability and uncertainty in effect assessment, e.g. by normalising Species Sensitivity Distributions (SSDs), and for the development of probabilistic fate and risk assessment models.

2.3 Human health risks associated with nano- and micro-plastics

Dr Stephanie Wright provided an overview of the human health implications of microplastic and nanoplastics particles, in part based on material presented in the SAPEA report (SAPEA 2019). Microplastics are ubiquitous in the environment and have been documented in marine (Yang *et al.* 2015) and freshwater (Oßmann *et al.* 2018) dietary sources. Exposure via ingestion of atmospheric deposition represents a substantial exposure pathway (e.g. about 68,000 microplastics/person/yr (Catarino *et al.* 2018). Microplastics have also been reported in indoor (Dris *et al.* 2017) and outdoor air (Dris *et al.* 2016, Cai *et al.* 2017) in major population centres; total atmospheric deposition is two orders of magnitude greater indoors at 11,000 microplastics/m²/d (Dris *et al.* 2017). Reports of relatively high numbers of particles in the environment have prompted public health concerns. However, our current understanding of human exposure, while limited, suggests that the risk of adverse health effects is low.

Aside from environmental concentration, exposure is also influenced by particle kinetics and biodistribution in vivo. Exposure via inhalation is dictated by aerodynamic equivalent diameter (<10 μm aerodynamic diameter deposit in the central and distal airway) (Carvalho *et al.* 2011). In the gut, particle uptake (<10 μm) can occur via endocytosis and phagocytosis (Eldridge *et al.* 1989) in the Peyer's patches of the ileum, or via persorption at the microvilli for larger particles (up to 130 μm) (Volkheimer 1993). These mechanisms of uptake are rate-dependent and hence probability of uptake depends on the scale of exposure. However, this all remains unknown for environmentally-representative microplastics.

Since microplastics are considered bio-persistent (Law *et al.* 1990), they could cause physical effects by inducing or enhancing inflammation. In vivo laboratory studies have found inhalation exposure to high levels of plastic dusts triggers inflammation. This is also mirrored *in situ*; occupational exposure to microplastic fibres leads to granulomatous lesions, postulated to contain acrylic, polyester, and/or nylon dust (Pimentel *et al.* 1975). This causes a higher prevalence of respiratory irritation (Warheit *et al.* 2001). Flock worker's lung is a rare interstitial lung disease which establishes in nylon textile workers exposed to respirable-sized fibre dust (Boag *et al.* 1999; Eschenbacher *et al.* 1999, Kremer *et al.*, 1994). Workers also present chronic respiratory symptoms and restrictive pulmonary function abnormalities.

Physical effects will be influenced by particle parameters including surface chemistry and charge, hydrophobicity, size, shape and composition, which will likely change in the environment. Subsequently, unique biofilms may colonise the surface, potentially leading to immune effects, yet this remains to be determined. Moreover, plastic is a complex, heavily modified material, often containing harmful additives (Lithner *et al.* 2011, Fromme *et al.* 2014; Linares *et al.* 2015), a proportion of which could transfer to biological fluids and tissues. This is dependent on the burden remaining in microplastics and the relative importance of this is unclear but likely negligible in relation to other exposure pathways. Whilst there are plausible adverse outcomes, our understanding of our aggregate exposure is sparse but necessary in order to determine whether microplastics should be considered a human health risk.

2.4 Societal aspects of microplastics

Dr Sabine Pahl gave a keynote presentation on societal aspects of microplastics, partly based on the outcome of the SAPEA study (SAPEA 2019).

Plastics as a system

Plastic pollution from macro- to micro-levels results from a system of interlinked economic, technical and societal processes (Figure 2.4). Convenience, price and durability are drivers for the current abundant use of the material in society that spills over into the environment, because end-of-life plastic is insufficiently captured. The quantities lost mean that global aesthetic and wildlife impacts are now widely visible and frequently reported in the media. This is associated with a high level of public awareness and demand for action. However, the actual impacts of *microplastics* in particular are still somewhat uncertain (SAPEA 2019), and it has been questioned if plastic is receiving 'too much' attention in comparison with other environmental hazards such as other forms of chemical pollution or climate change. Thus, to successfully address the issue, it is crucial to consider the decisions and behaviours that underlie plastic use and loss in a range of actors, and apply the large existing literature on risk perception and communication. Understanding and integrating this human dimension systematically will improve the success of actions taken, by combining top-down approaches such as bans and communication campaigns with bottom-up approaches such as voluntary agreements and community / grassroots activities. There are some firm indications that public awareness is growing. Media coverage of microplastics has increased from near zero to over a thousand items a month between January 2017 and October 2018, and participant numbers for beach cleans have doubled. This is probably linked to a similar trend in scientific publications between 2011 and 2018 for microplastics research in general and microplastics in food in particular (SAPEA 2019).

Risk perception and risk judgement principles

In the risk perception literature, risk is defined as a "situation, event, or activity, which may lead to uncertain adverse outcomes affecting something that humans value" (Boehm and Tanner 2018, p. 16), and environmental risks are seen as a special category (as opposed to personal risks such as those related to health or money). Environmental risks are typically high in complexity and uncertainty; they comprise risks for and from the environment; they are due to the aggregated behaviour of many individuals (with the exception of purely natural disasters); they may be temporally and geographically distant; and, finally, ethics and fairness considerations play a key role: do the risks arise to the same people or groups that cause them, or is the burden unfairly distributed (Boehm and Tanner 2018)? Risk perception is the subjective interpretation of a risk. Slovic observed: "Danger is real, but risk is socially constructed" (1999, p. 689, in Boehm and Tanner 2018). Risk perception can be in line with technical assessments of risk but is often different, because experts and non-experts differ in the way they make these judgements. Slovic (1987) originally established two key factors that were associated with higher risk perception in non-experts: 'unknown' and 'dread'. The first factor includes perceived lack of knowledge, novelty and delay; the second factor includes perceptions of catastrophic, uncontrollable, increasing and involuntary risk and the emotional aspect of dread. Both of these factors are based on subjective assessments that are not directly linked to the actual scientific evidence base. Subjective perceptions drive action and acceptance (or not) of measures, and while the original approach has since been further refined (see Boehm and Tanner 2018 for overview), even this early work found that unknown and dreaded risks were associated with desire for regulation. Moreover, sometimes the public is more worried about a risk than experts are (social amplification), whereas at times the public is less worried than experts are (social attenuation). Capturing these perceptions through social science methods is important and provides a different kind of evidence base that helps manage the system (see e.g. Pahl and Wyles 2016, for an overview of social and behavioural science approaches).

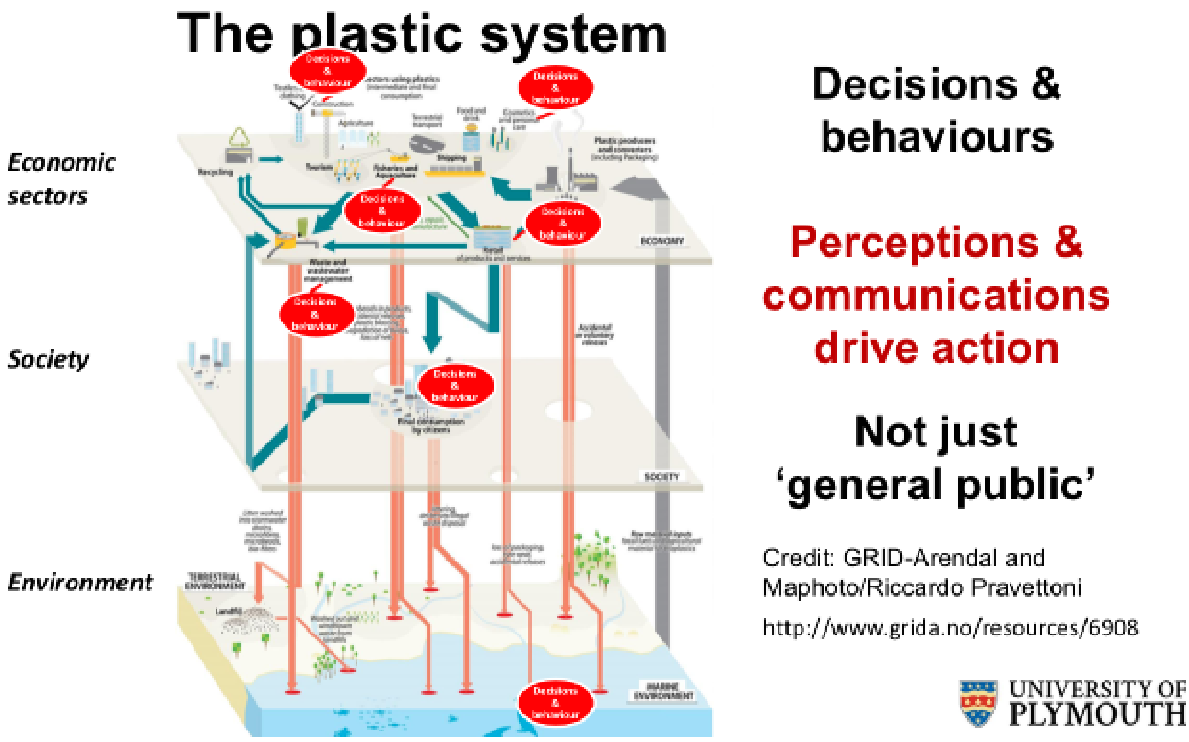

Figure 2.4 The 'plastic system' of interlinked economic, technical and societal processes (adapted from UNEP and GRID-Arendal 2016)

There is also a large literature that describes heuristics and biases that affect the formation of risk judgements. These are mental shortcuts that people use to make sense of information such as the availability heuristic (what's easy to imagine is perceived as high risk), anchoring-and-adjustment (an initial value will influence the final judgement even if irrelevant to the issue) and the affect heuristic (affective and emotional states influence judgement; see Boehm and Tanner 2018, for overview). Additional influences on risk perception are values. People with higher altruistic and biospheric values (relatively to egoistic and hedonic values) have higher environmental risk perception. Finally, there are individual differences in what people use as the basis for their risk judgements, with some people relying on cost-benefit trade-offs more, and others relying on moralistic considerations more, i.e. the inherent rightness or wrongness of an issue (SAPEA 2019).

Risk perception of marine litter, macro- and microplastics

In terms of the wider context, there is data on marine litter perceptions broadly (the vast majority of marine litter is plastic). We know people are concerned about this issue; there is no evidence of plastic pollution denial currently (e.g. in a Europe-wide study of general public and other stakeholder perceptions by Hartley *et al.* 2018; in a UK-based study on fishermen, Wyles *et al.* 2019). This is quite different from the public response to other environmental threats such as climate change, where we have seen denial and huge polarisation along political lines. Hartley *et al.* (2018) also showed that psychological factors such as values and social norms were associated with marine litter concern, as was the frequency of noticing litter (see availability heuristic above). The only socio-demographic variable that had a similar size association was education level, with more educated respondents being more concerned (although there is some evidence from other research that females are more concerned about environmental threats than males). Hartley *et al.* (2018) also undertook an analysis of the image held by the public about different actors in the system. While government and industry were seen as highly responsible for marine litter, they were perceived as moderate in competence and low in motivation to deal with the issue. On the other hand, environmental groups and independent scientists were seen as moderate in responsibility but high in competence and motivation. These discrepancies help formulate communications and identify starting points for change.

In terms of microplastics specifically, we are currently lacking a good body of social data (SAPEA 2019). Initial studies focused on microplastics in cosmetics and evidence is mixed. Data from 2015 and 2016 suggests a lack of awareness in UK and US samples, but when asked to handle a sample of microplastics extracted from exfoliant products, UK participants were shocked and intended to change their behaviour (SAPEA 2019). Lack of visibility, particularly for very small particles could be an important feature, because if a risk cannot be observed and assessed directly, public risk perception is more reliant on trust in experts. This could be more of an issue for microplastic than macro-plastic pollution, which is easier to see. Applying a 'mental models' approach here would be useful because it would show a 'non-experts' understanding of the issue that could then be used for tailored communications and behaviour change approaches.

Since the (SAPEA 2019) report, Dilkes-Hoffman *et al.* (in press) have presented data from an Australian representative sample showing that the three environmental threats rated as most serious are all plastic and waste related, with number one being "plastic in the ocean", whereas air pollution, water shortages and climate change are further down the list (although still rated as serious). Similar data on prioritisation of different environmental threats in particular with a view to human health and wellbeing, including data on desire for regulation, are currently being collected by the European SOPHIE project (Seas and Oceans for Public Health in Europe, https://sophie2020.eu). Finally, Heidbreder *et al.* (2019) have published a review of perceptions, behaviours and interventions regarding plastic pollution which includes data on problem awareness, the link between plastic pollution and human health and wellbeing as well as consumer perceptions of products and materials. This is a very useful overview that summarises a range of different studies albeit varying in size and quality. In addition to these perception studies, Beaumont *et al.* (2019) have recently provided estimates for the global ecological, social and economic impacts of marine plastic litter. In terms of cost per tonne of marine plastic, the researchers estimate between $3,300 and $33,000 reduction in environmental value.

Risk communication

This is defined as "an interactive process of exchange of information and opinion between individuals, groups and institutions" (United States National Research Council 1989, in Bostrom *et al.* 2018). While experts or governments may wish to control the flow of risk *information* to the public, many different sources voice opinions and may be trusted by the public (or ' publics', as there are different public groupings rather than one homogenous public), even if these sources do not have access to the scientific facts. Risk *communication* can have different goals, from raising awareness to passing on specific knowledge, changing hearts and minds as well as behaviour, and it may include advocacy from certain groups such as industry or NGOs. Risk communication also happens at different levels: between individuals, communities, groups, societies, for example, or between one trusted communicator and a large audience (e.g. David Attenborough and the BBC audience). It is better to have a transparent strategy for risk communication and to understand when risk communication is effective. This requires a clearly defined goal, or set of goals, and systematic evaluation to identify miscommunication and misunderstandings between sender and receiver.

Factors that influence this process include repeated exposure, a history of false and/or missed alarms, risk-benefit trade-offs and competing risks that influence perception (Bostrom *et al.* 2018). Breaking down the steps in the communication process, first the message needs to reach the audience, and reach their attention, second the audience needs to understand the message, third the audience reacts to and evaluates the message in the context of their prior perceptions and concerns, and finally there may be a behavioural response (cf. Bostrom, *et al*. 2018). There are potential barriers at each step, from lack of attention right at the start to a mismatch with existing perceptions that may lead the audience to reject the message. Even if the message is understood and accepted, there is a well-known gap between perception and behaviour if the goal is behaviour change. Fischhoff already described in 1995 how 'getting the numbers right' and 'explaining the numbers' is not enough, even 'treating the audience nice' is not sufficient. There is now considerable research on engaging publics and co-creating science agendas and decision-making processes.

In the context of micro-plastics specifically, there are examples for communications by the media and some NGOs that have covered risks, not necessarily strictly based on facts or published literature, e.g. microplastics in sushi (Surfrider campaign), microplastic in human stool (very small sample and, at that point, unpublished research), health effects of plastics (2019 Plastic Soup Foundation campaign). While there is little research specifically on the uptake of these messages in the public and on motivations by the communicator, the quantity of existing coverage makes communicating about this issue a challenging task. It can also be observed that these existing messages are at the more extreme, negative end of the spectrum. Psychological research has shown that 'bad is stronger than good', meaning that negative content leaves stronger memory traces and is harder to 'undo'.

Final thoughts

While the literature on risk perception and communication in general is vast, very little research to date has focused on micro- and even macro-plastics specifically. Currently there does not seem to be evidence for plastic pollution denial as we have seen for climate change, which provides a good starting point – society appears to be ready for change. However, we need to understand better how perceptions of this ubiquitous useful material most people use every day is potentially changing, as the negative news stories accumulate. We need to understand better how to work with society while we design better production and usage systems, and avoid kneejerk reactions with undesired side effects. We can do this by focusing on societal processes of change from the individual to the larger group level in order to address this problem, not just in terms of how information gets passed on but also in terms of how social identity and social norms shape responses. Focusing only on the information processing aspects will fall short of key motives of human behaviour, of who we are and what we care about most.

2.5 Panel discussion

The panel discussion was facilitated by Ms Jennifer de France.

- ❑ The Chair thanked the presenters for providing an excellent overview of the issues. She stated that although many people understand the problem in general, we all suffer a lack of sufficient data. The Panellists were asked to address the key problems that we should be focussing on, given the overview that had been presented, and the responses are summarised below:
- ❑ Scientists have to focus on a multi-level approach (i.e. to account for biological and societal complexity) in order to be able to tackle this complex problem of plastic wastes and microplastics;
- ❑ Scientists must be clear about the questions they are addressing;
- ❑ The results of specific studies need to be 'translated' and communicated effectively to policy makers and the general public to allow participation in complex discussions;
- ❑ Identifying "representative particles" of plastics is key to understanding the general influence of plastic on human health; this would simplify then the research and discussions about the risk;
- ❑ It is important to understand the advantages and limitations of the methodologies we are applying;
- ❑ It is important to include societal aspects in the research of marine litter and microplastics as they essentially belong to the same system; different groups in society may have different perceptions of the risk that plastics and microplastics represent;
- ❑ Current chemical risk assessments are established and we should learn from them (e.g. SAICM, Stockholm Convention and OECD). However, in addressing 21st century risk assessment needs, traditional approaches may be insufficient, as these approaches typically address the risks of one chemical in isolation of other chemicals. There is thus a need to consider chemical mixture and non-chemical stressors within the risk assessment paradigm; for example, the combined risks associated with exposure to mixtures of particulates (such as micro- and nanoplastic particles), chemical mixtures, population effects, climate effects and pathogens. Established environmental principles should be taken into account (e.g. Precautionary Principle); and
- ❑ There is a need for more research because the influence of microplastics (and chemicals) on animals and humans is not well established.

3 AN OVERVIEW OF THE INTERNATIONAL RESPONSE (SESSION 2)

The following summarizes brief overviews that were presented related to activities by various international agencies and industry associations. The session provided an opportunity to raise awareness of the breadth of activities occurring at various levels of governance and to enable consideration for how future activities might be complementarily aligned to address many of the research needs in the future.

3.1 United Nations agencies

3.1.1 World Health Organisation (WHO)

Ms Jennifer de France of the WHO presented the organisation's recent work on microplastics. The areas of environment and climate change have been prioritised in the current General Programme of Work (GPW13, 2019-2023), and plastics are identified as an important emerging issue in the health and environment department. WHO has prepared a report on 'Microplastics and drinking water', due for publication in the summer of 2019. As a contribution to this study, WHO commissioned a systematic review of data quality, involving an analysis of 50 published studies (Koelmans *et al*. 2019). The review comprised a quantitative quality assessment of sampling, extraction and detection methods, including studies of bottled, tap, surface, ground and wastewater, using nine quality criteria. The authors concluded that microplastics are present frequently in freshwater and drinking water, but only four out of fifty studies received positive scores for all nine criteria. This illustrates the need for improvements in sampling, extraction and analysis methods, including consideration of adopting standard methods. The target audience for the microplastics in drinking water report includes drinking water regulators, policy makers and water suppliers.

The drinking water study represents the initial phase of a broader effort to assess human health risks due to microplastics, covering additional environmental exposure routes (e.g. air, food).

3.1.2 Intergovernmental Oceanographic Commission (IOC)

Mr Henrik Oksfeldt Enevoldsen of the IOC-UNESCO introduced the mandate from the IOC Assembly for the IOC to continue to engage actively in the microplastic issue through GESAMP Working Group 40. IOC-UNESCO has co-led GESAMP Working Group 40 since its inception in 2012. It is within the mandate of the IOC to be particularly concerned about ecological impacts of microplastics in the marine environment, but as this potentially may impact human health the multidisciplinary approach begun is considered both needed and very valuable. Mr Enevoldsen highlighted IOC's role in preparing the "UN Decade of Ocean Science for Sustainable Development" and the opportunities and potential herein for the IOC - in cooperation with other UN agencies and organisations - to ensure that the microplastic issue is integrated in the science plan for the Decade. The Decade is also an opportunity for GESAMP to focus its efforts on microplastics in a 10 year plan and thereby concretely contribute to the objectives of the Decade as well as benefit from the awareness possibilities provided by the Decade.

3.1.3 Secretariat of the Basel, Rotterdam and Stockholm Conventions

Ms Kei Ohno-Woodhall from the Secretariat of the Basel, Rotterdam and Stockholm Conventions presented the Basel and Stockholm Conventions and explained how plastics and microplastics are covered by both Conventions. New annexes to the Basel Convention were adopted at the Conference of the Parties in May 2019 (Basel Convention CoP-14), covering Plastic Wastes, including the different treatment of plastic wastes under the annexes II, VII and IX of the Convention. It was agreed at the COP-14 to initiate a working group under the newly established Basel Convention *Partnership on Plastic Waste* (Basel Convention 2019).

The Partnership has the following working principles:

1. To promote action and dialogue among governments, regional and local authorities, Regional Seas Programmes, intergovernmental organizations, private sector, non-governmental organizations and academia on initiatives that could be carried out in different regions;

2. To foster best practice solutions showing concrete and practical results consistent with the Basel Convention;

3. To coordinate and cooperate as appropriate, in relation to the goal referred to above, with other activities under the Convention, including the Partnership on Household Waste and the updating of the technical guidelines on plastic waste, as well as with bodies and activities outside the Convention such as the Global Partnership on Marine Litter and other initiatives, and build on the existing body of knowledge on best practices, successes and challenges, realized at the local, regional and global levels.

3.1.4 Food and Agriculture Organisation of the United Nations (FAO)

The FAO was unable to send a member of staff but had prepared a presentation that was given by Mr Peter Kershaw. Key areas of importance to FAO regarding plastics and microplastics are:

(i) Abandoned Lost or otherwise Discarded Fishing Gear (ALDFG);

(ii) Seafood safety implications of microplastics; and

(iii) Ecological impacts of microplastics

ALDFG
A number of approaches have been adopted or are under development:

- Conducting a global quantitative assessment of ALDFG;
- Promotion of good practices to avoid gear loss;
- Offering assistance on the implementation of the Gear Marking Guidelines, including reporting, recovery and disposal of ALDFG or unwanted fishing gear and commercial traceability of fishing gear;
- Co-leading, with IMO, a new GESAMP Working Group on sea-based sources of marine litter, to include:
  - Relative contribution of different sources, analysis of plastic use and management within the fisheries (and shipping) sectors;
  - Range and extent of impacts from sea-based sources; and
  - Comprehensive understanding of specific types of marine litter and guidance for interventions on those sources based on identified priorities.

Microplastics and seafood safety
FAO has a number of priorities regarding microplastics and seafood safety, working in collaboration with WHO:

- Data on toxicity of the most common plastic monomers and polymers detected in fish products (capture fisheries and aquaculture);
- Data on toxicity of some plastic additives;
- Information on local effects and dynamics of micro and nanoplastics in the human gastro-intestinal tract;
- Information on impacts of cooking and/or processing of fish products on microplastics toxicity;
- Inclusion of pathogens in risk profiling on microplastics exposure through fish products consumption;
- Analytical method for detection and quantification of nanoplastics; and
- Data on presence of nanoplastics in fish products.

Ecological impacts on microplastics
FAO has a number of concerns regarding the possible ecological implications of microplastics:

- Data/information on microplastics contamination and impacts in developing countries;
- Global estimate of microplastics presence in the various compartments of the aquatic environment;
- Impacts of microplastics on ecological structures and processes and implications for fish populations and species assemblages (in particular commercial species);
- Method for detection and quantification of nanoplastics; and
- Information on nanoplastics dynamics and impacts.

Risk assessment priorities
FAO has identified several priorities to be taking into account in the development of risk assessment methods:

- Identification of criteria such as robustness, practical viability, needs of methodological development, data sources/gaps, capacity development constraints, opportunities for exchange and collaboration across specific themes (e.g. ecological risk assessment (RA), public health/food safety RA, etc);
- Case studies on experiences made with applying partial or full risk assessments in seafood safety as well as in fisheries resources & ecology;
- Advisory or policy recommendations on application of RA approaches and methodologies targeting different stakeholders including public administrations, academia, civil society organisations, consumers, (environmental resource management, public health, food safety ….); and
- Capacity development assistance in Application of Codex Alimentarius [FAO/WHO] Risk Analysis framework (risk assessment, risk management, risk communication) for micro- and nanoplastics in seafood.

3.1.5 United Nations Industrial Development Organization (UNIDO)

Mr Yunrui Zhou of UNIDO presented the organisation's recent work onm microplastic and marine litter, especially in specific projects in target countries (e.g. China) and through a paper for the G20 senior officers meeting on energy and environment.

The United Nations Industrial Development Organization (UNIDO) is mandated by its Member States to promote Inclusive and Sustainable Industrial Development (ISID). Three pillars of ISID work together to accelerate the creation of prosperity, advance economic competitiveness, while safeguarding the environment.

Reduction and eventual elimination of marine litter and microplastics is considered by UNIDO as part of its efforts related to:

(i) prevention and reduction of land-based waste through resource efficiency and circular approaches and business practices;

(ii) extraction of resources from and safe disposal of land-based waste that could not be prevented; and

(iii) conservation and sustainable use of ecosystem services.

UNIDO is a member of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) and collaborates with FAO, UN Environment, IOC-UNESCO and other relevant UN Agencies and Programmes, NGOs and academic institutions in addressing these priority areas. UNIDO also implements interventions on large marine ecosystems and facilitates water stewardship initiatives by private firms through public-private partnerships.

In April 2019, UNIDO issued a working paper for the G20 Second Senior Officers Meeting on Energy and Environment in Japan, namely "Addressing the challenge of Marine Plastic Litter using Circular Economy methods - relevant considerations". The paper focuses on adopting circular economy practices in the whole life cycle of plastic including design, manufacturing, use, end of first life and final disposal to reduce marine plastic.

Recently, as requested by the Ministry of Ecology and Environment of China, UNIDO is developing a pipeline project aimed at building capacity for marine plastic waste management and control in China.

3.1.6 UNEP Chemicals & Health

Ms Jacqueline Alvarez of UNEP Chemicals & Health presented their recent work, especially about the Global Chemicals Outlook, published in 2019, which includes a chapter about plastics. The rapid increase in plastics production and use has not been matched by end-of-life management, resulting in a large proportion of 'waste' plastics leaking into the environment. Chemicals in plastics (e.g. additives) pose challenges for adopting a circular economy. For example, one study of plastics collected from the shores of Lake Geneva revealed high levels of heavy metals due to their former widespread use as pigments (Filella and Turner 2018). As plastics are persistent in the environment such legacy issues should not be unexpected. Furthermore, Ms Alvarez underlined UNEP's own concept of risk, presented the current regulatory actions in different parts of the world and presented UNEP's next steps, including reports on life-cycle and policy dialogue beyond 2020.

Global Chemicals Outlook II

A key development in 2019 has been the publication of the 2nd edition of the Global Chemicals Outlook (GCO-II) (UNEP 2019). The request to update the original 2013 report was enshrined in Resolution 2/7, adopted by the United Nations Environment Assembly (UNEA) in 2016. A synopsis report (Jackson 2019) and summary for policy makers were prepared in addition. One section of the synthesis report discusses the potential for refining chemical risk assessment methods to accelerate progress (Figure 3.1). In several countries, including the European Union, the burden of proof to show that an industrial chemical is safe has shifted from government to industry. Approaches are being explored to reduce the complexity of chemical risk assessments and make them more efficient. Guidance tools have been developed for human health by WHO and environmental health by the OECD.

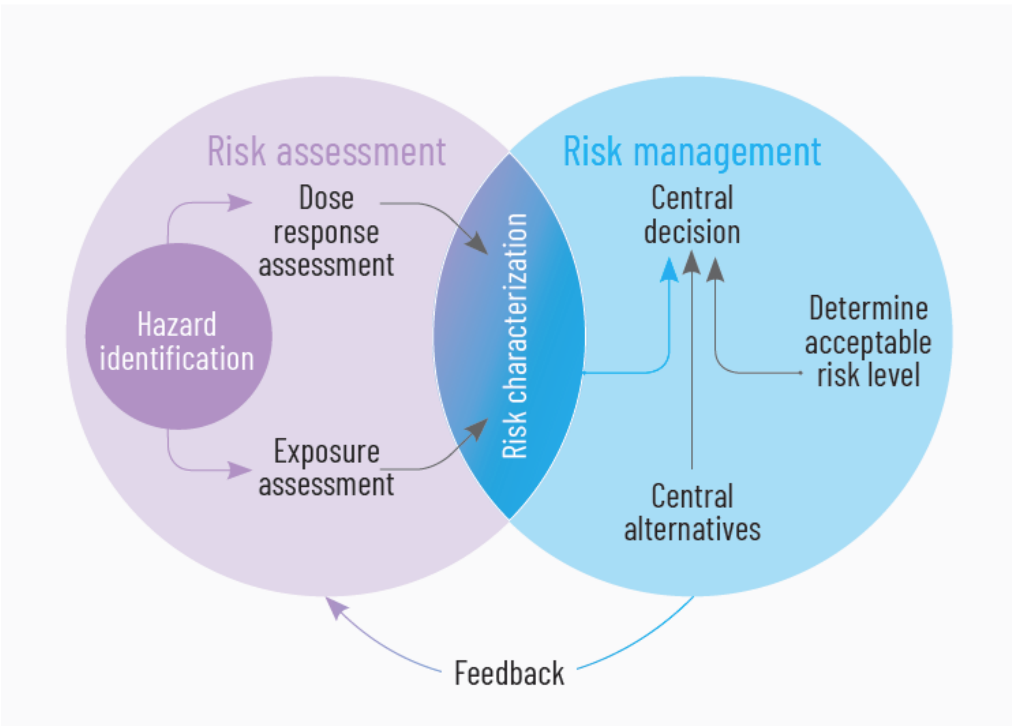

Figure 3.1 Risk assessment and risk management decision process (adapted from US Library of Medicine 2018 and presented in Global Chemicals Outlook Synthesis report, UNEP 2019).

The Inter-Organisation Programme for the Sound Management of Chemicals (IOMC) has produced an internet-based Toolbox for decision-making in chemicals management. There are nine partner organisations, including FAO, UNEP, UNIDO, UNDP, GESAMP, WHO and OECD. Additional components in a more effective risk assessment approach include:

- Considering weight of evidence and undertaking systematic reviews;
- Defining clearly specific human and environmental protection goals;
- Improving risk assessment for chemical mixtures and cumulative exposures;
- Strengthening the integration of human health and environmental aspects in risk assessment;
- Better linking of risk assessment and risk management;
- Strengthening risk communication; and
- Advancing solution-orientated approaches in risk assessment.

3.2 Related international and regional initiatives

3.2.1 OECD

The OECD could not be represented due to a clash of commitments, but a presentation had been prepared which was given by the Chair of the GESAMP working group 40. The OECD has been working for several years in the chemicals and waste area, including avoiding toxic substances in plastics and case studies about the lack of alignment between chemicals and waste legislation. OECD published a background paper on '*Considerations and criteria for sustainable plastics from a chemicals perspective*' for the OECD Global Forum on Environment: Plastics in a circular economy, which took place in Copenhagen in May 2018 (OECD 2019). The approach being proposed is illustrated in Figure 3.2. Their future work within the plastic area will focus on policy guidance, including wastewater and drinking water, textiles, tyre sector and the circular economy.

OECD work on microplastics in the period 2019-2020 will focus on providing policy guidance for mitigation of microplastics in fresh and coastal waters, at least cost to society. The scope will include:

- Secondary microplastics from the use phase of the textile and tyre sectors;

Figure 3.2 OECD approach to promoting sustainable plastics from the chemicals perspective, taken from OECD 2019.

❑ Freshwater (surface and groundwater) and marine, including wastewater, drinking water and sludge;

❑ OECD + BRIICS countries (Brazil, Russian Federation, India, Indonesia, China and South Africa); and

❑ OECD Workshop on microplastics and textiles scheduled for 10 Feb 2020, Paris.

3.2.2 International Council of Chemical Associations (ICCA)

The International Council of Chemical Associations is an organization comprising trade associations from around the world that represent companies in the business of chemistry. Mr Brett Howard represented ICCA and described their recent work regarding their newly developed environmental risk assessment framework and gave an overview of the latest development from the standards development in the USA. Through voluntary initiatives, like Responsible Care® and the Global Product Strategy, ICCA is committed to improving the safe management of chemicals and improving sustainability. The ICCA also supports efforts to prevent plastic marine debris and industry efforts towards this end, including the Alliance to End Plastic Waste (2019). Further, member association representatives have created a framework to assess risk from microplastics through stakeholder engagement, outlining challenges and data gaps that need to be rectified to inform both policy makers and the public about risks from microplastic in the environment. The most recent framework was published recently (Gouin *et al.* 2019).

3.2.3 European Chemicals Agency (ECHA)

At the request of the European Commission, the European Chemicals Agency (ECHA) has recently made a proposal to restrict the placing on the market of intentionally added 'microplastic'. For the purposes of the proposal, microplastics are defined as solid-polymer-containing particles, to which additives or other substances may have been added, and where ≥ 1% w/w of particles have:

(i) all dimensions 1nm ≤ x ≤ 5mm, or

(ii) for fibres, a length of 3nm ≤ x ≤ 15mm and length to diameter ratio of >3.

Microplastics have diverse applications, including in agriculture, horticulture, cosmetic products, paints, coatings, detergents, maintenance products, medical and pharmaceutical applications. In European countries with adequate wastewater treatment, they are predominantly released to the environment through the application of sewage sludge to agricultural land. The risks posed by microplastics were considered in a weight-of-evidence approach considering PEC/PNEC, non-threshold and 'case-by-case' approaches, that concluded that uses of intentionally added microplastics that inevitably resulted in a release to the environment were not adequately controlled. Derogations are proposed for polymers that occur in nature, polymers that meet criteria for minimum (bio)degradability, uses of microplastics at industrial sites as well as certain uses by consumers or professionals that would not inevitably lead to a release of microplastics to the environment. Certain derogated uses are accompanied with requirements to provide additional information on packaging or

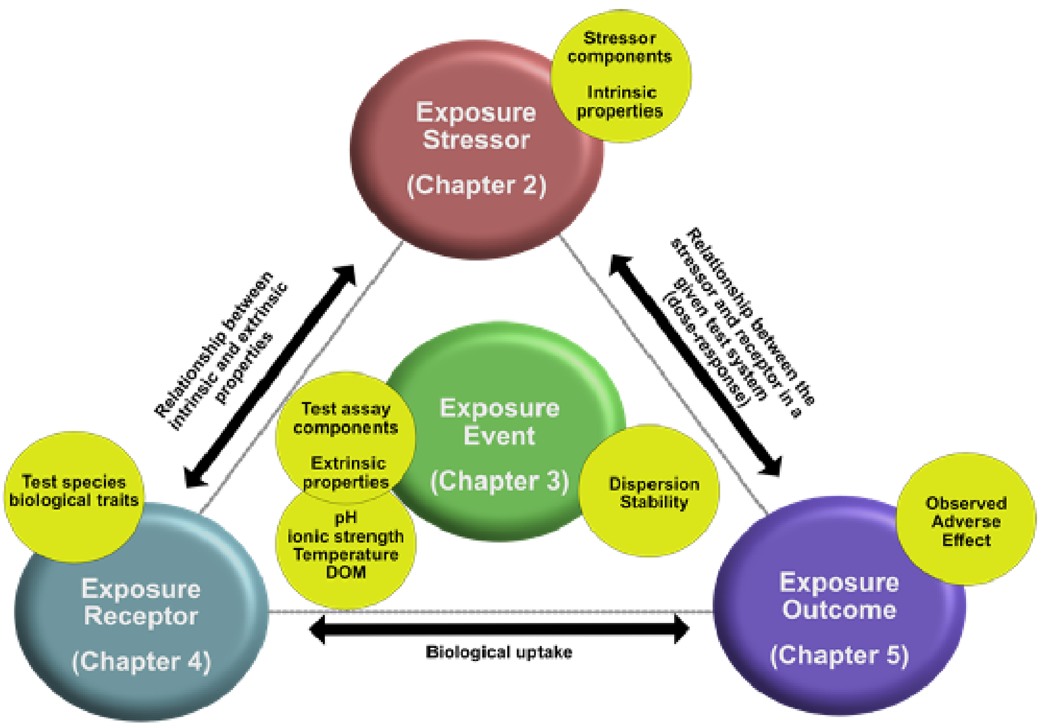

Figure 3.3 Schematic of the approach developed by an ECETOC Task Force to evaluate the challenges and limitations associated with toxicity and bioaccumulation studies for sparingly soluble and manufactured particulate substances; the chapter numbers refer to the appropriate chapters in ECETOC 2018.

safety datasheets and to report certain information annually to ECHA. The proposal includes transitional arrangements for specific applications, such that the restriction enters into effect progressively over a period of six years after entry into force. Uses of 'microbeads' (microplastics used as an abrasive) would be prohibited immediately after the entry into force of the restriction.

3.2.4 European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC)

A Task Force set up by the European Centre for Ecotoxicology and Toxicology of Chemicals (ECETOC) has provided new insights into scientific testing for the impact of undissolved particles in the aquatic environment (Figure 3.3). The Task Force reviewed the literature relating to aquatic toxicity testing of particulates such as nanomaterials (NMs), microplastic particles (MPs) and poorly soluble liquids, and identified the key challenges in how currently available toxicity tests can be interpreted (ECETOC 2018). A key observation is that there is limited guidance available to enable differentiation of observed adverse effects (OAEs) associated with a physical interaction from those due to intrinsic toxicity. To advance the scientific understanding of the potential impacts of particles and poorly soluble liquids, the Task Force recommends that there should be multi-stakeholder discussions to identify and prioritise key research needs and to develop a consensus on how best to assess the risks associated with the exposure to particles originating from commercial activities. The considerations and recommendations set out in the Task Force report can be used as a basis for these discussions.

4 'BRAINSTORMING' - SCOPING THE ISSUES (SESSION 3)

4.1 Introduction

For the Scoping the Issues session (Session 3) the workshop participants were divided into three breakout groups (A, B and C), with an attempt made to balance the types of organisations and expertise represented in each. The aim was to encourage everyone to become involved, provide an opportunity to present a wide range of opinions, capture the broadest range of views on what constituted 'risk', and form the basis of subsequent in-depth discussions. Each group was asked to address the same set of issues and their responses were then discussed during a reporting-back session in plenary.

Tasks:

(i) What are the key [*potential*] environmental risks due to macro-plastic marine litter?

(ii) What are the key [*potential*] societal risks due to macro-plastic marine litter?

(iii) What are the key [*potential*] environmental risks due to microplastics?

(iv) What are the key [*potential*] societal risks due to microplastics?

(v) Conduct a Strengths-Weaknesses-Opportunities-Threats (SWOT) analysis.

It is important to note that the outputs of the groups, reported below, are the result of a wide-ranging 'brainstorming exercise'. They have not been subject to a critical review. In many cases they are not supported by scientific evidence and should not be considered as a conclusion of the workshop that 35 participants have discussed and agreed on. They are included to give an indication of the breadth of ideas and discussion raised by the participants, in preparation for more detailed and nuanced discussions in the later sessions.

The outputs in Chapter 4 are the results of a 'brainstorming exercise'; they have not been critically reviewed and should not be taken as a considered, consensus view of the workshop participants. In many cases there is no scientific evidence to support the listing of a phenomenon as having a potential effect.

Some evidence of effects of nano- and microplastic particles at a cellular and sub-cellular level have been observed under laboratory conditions, usually using high particle concentrations, but these responses are non-specific and, under natural conditions, difficult to sort out from those caused by other stressors.

4.2 Breakout group A

This group considered environmental and societal aspects together. The group's overview of potential adverse effects is summarised in Tables 4.1 and 4.2.

Table 4.1 Summary of key potential environmental and societal risks due to macro-plastics – outcome of Break-out Group A

What are the potential key environmental and societal risks due to macro-plastic marine litter?	
Mechanical issues: ▪ Maritime transport/navigation/safety ▪ Leisure / Aesthetics degradation / loss of amenities ▪ Production of microplastics ▪ Destruction of Habitat / Mechanical damage to ecosystems ▪ Change of habitat (e.g. 7% plastic)	Pathogens and invasive species ▪ Increase of habitat ▪ Aquaculture - Potential infectious agent/disease ▪ Biofouling – invasive species / transportation of species ▪ Increase of habitat - e.g. jellyfish habitat
Loss (economic, biodiversity, protein): ▪ Entanglement & Ghost fishing (protein – species of commercial interests), loss if income and biodiversity ▪ Food chain - ecosystem food web - direct effects on organisms and indirect effects on ecosystems ▪ (algae – photosynthesis decreases, fish-navigational reduction) ▪ Endocrine disruption ▪ Ecological damage – biodiversity	Others: ▪ Flooding ▪ Fossil fuel demand & greenhouse gas emissions (/ climate change / ocean acidification) ▪ Air and other environment pollution to communities who live close to plastic production facilities and plastic mismanagement (e.g. open burning) sites ▪ Industrial plants – cooling water, desalination plants ▪ Political issues – trans-boundary ▪ Cost aspects to deal with issue ▪ Food chain
Hygienic aspects: ▪ Pathogens – swimming water ▪ Impact on recreational water and beaches ▪ Environmental health risk ▪ Vector for fish disease ▪ Vector – coral disease? ▪ Leaching of chemicals	Chemical issues: Hazardous chemicals (e.g. POPs) used in manufacture of plastics and leached/released throughout the life cycle of macro-plastics

Table 4.2 Summary of key potential environmental and societal risks due to microplastics – outcome of Break-out Group A

What are the key potential environmental and societal risks due to marine microplastics?
▪ POPs + microplastics increased impact than only exposure to a single stressor ▪ Permanent pollution stock ▪ Reduced quality of food ▪ Ecotoxicity risk in hotspots ▪ Community effects ▪ Probability of gut-absorption – (phthalates – in blood) – nanoplastics ▪ Societal fear – reduce certain food ▪ Persistence of microplastics ▪ Ingestion and inhalation ▪ Misdirecting societal resources based on misinformation - unwarranted concern has a cost ▪ Underestimation of risk and/or miscommunication/misinterpretation of lack of evidence for risk to lack of risk – missed opportunity to protect environment and/or human health (lack of evidence for risk in the marine environment does not prove the lack of risk)

Table 4.3 SWOT analysis – breakout group A

Strengths:	Weaknesses:
▪ Lots of interest from IGOs/Government ▪ Societal concerns high ▪ Range of risk methods potentially available ▪ Lots of committed people ▪ Good practice at local scale	▪ Constraints of mandates ▪ Insufficient evidence to convince industry/decision makers vs. precautionary principle ▪ Epidemiological evidence not available ▪ Cannot establish exposure levels ▪ Science-policy 2-way communication is weak ▪ Lack of multi-disciplinary approach ▪ Lack of harmonized methodology ▪ Limitations of existing risk assessment methods ▪ Lack of awareness to address the issue (+ the resulted lack of risk assessment and risk management options) from a more holistic point of view covering the whole life cycle of plastics and microplastics ▪ (Trying to impose chemical risk assessment to an issue which does not only have chemical risk)
Opportunities:	**Threats:**
▪ Engage and channel concern ▪ Multi-disciplinary and multi-sectoral approach ▪ Better integrate different risk assessment approaches ▪ Set priorities (comparative risk) ▪ To reconsider use of materials / social models to incentivize ▪ Better governance and management options are under discussion and consideration by governments, IGOs, civil societies and business, e.g. UNEA	▪ Over-complicate (Paralysis by analysis) ▪ Over-simplify ▪ Unwarranted concerns (ignore other stressors) ▪ Ineffective communication ▪ Ignoring regional differences in social and economic development, culture etc.) ▪ Unanticipated consequences of proposed solutions ▪ Expected exponentially increasing production of plastics which outpace the potential increase in the already insufficient sound waste treatment capacity ▪ Bio-based plastics be promoted as an alternative – it will lead to high-intensity agriculture ▪ Bio-degradable plastics be promoted as an alternative – not truly biodegradable in nature environment particularly the marine environment, the fragmentation – not the degradation - exacerbating the problem

4.3 Breakout group B

The group's overview of potential adverse effects is summarised in Tables 4.4 – 4.7.

Table 4.4 Summary of key potential environmental risks due to macro-plastics – outcome of Break-out Group B

What are the key potential environmental risks due to macro-plastic marine litter?	
Themes are consistent [with other Break-out Groups] ▪ Entanglement and suffocation. Entanglement of animals and coral reefs. Fishing aggregative devices. ▪ Ingestion: turtles, birds, death ▪ Rafting and invasive species ▪ Human social contact, as aesthetic having an impact and emotional side. ▪ Egg deposition on hard surfaces of plastic which are everywhere [*leading to increase in invasive species, for example*] ▪ Shadow: below the accumulation of plastic → ▪ Biofilms, they act as source of pathogens in many places → eutrophication, algal bloom ▪ Large sheets of plastic used in aquaculture, ▪ Ships: ▪ Macro doesn't remain macro, but breakdown into micro → food chain	*Is there a way of making a prioritization?* ▪ Checking first species and systems that are already in sensitive and vulnerable
How do you measure negative externalities? ▪ Differing perceptions of the value of a marine species, or ecosystem services, for example: someone who likes turtles would pay for straws for be removed vs. someone that doesn't care who would not be willing to pay ▪ What kind of indicator we should be looking at it? The interconnectedness of the plastic-system ▪ Indicator 14.1 density of floating litter, based on drivers → we need to bring risks into the development of the sub-indicators.	*What are the synergic effects?* We could make a categorization according to: ▪ Concerns ▪ Interactions ▪ Risk ▪ Charismatic species vs. unknown but important species ▪ Chronic vs. acute effects ▪ Operating in different times ▪ What macro-plastic could say about microplastics in terms of exposure? ▪ Knock on effects ▪ Theory of intermediate disturbance: pristine environment that comes to point where it [the effect] becomes negative regime shifts

Table 4.5 Summary of key potential societal risks due to macro-plastics – outcome of Break-out Group B

What are the key potential societal risks due to marine macro-plastic litter?
▪ Human injuries ▪ Human activities ▪ Navigation ▪ Lower tourism ▪ Pathogens, bathing water, insect population proliferation. ▪ Entanglement/drowning for divers ▪ Lower recreational value ▪ Lower wellbeing benefits ▪ Cows/goats ingest plastic and die ▪ Cultural disruption to certain communities. ▪ Waste management – by burning plastic human health risk.

Table 4.6 Summary of key potential environmental and societal risks due to microplastics – outcome of Break-out Group B

What are the key potential environmental and societal risks due to microplastics?	
▪ Ingestion and accumulation of plastic in the stomach may give the feeling of satiation for birds and fish. ▪ Concerns that ingestion of microplastic has a possibility to negatively affect health. ▪ Assimilation ▪ Possibly toxicological transfer (including absorbed pollutants) ▪ Possibly crossing blood- brain barrier ▪ Passive carriers of biodiversity and alien species, and antibiotics → carriers of pathogens since the surface areas of the plastic. ▪ Adsorption of pollutants. ▪ Algae bloom and collapsing ▪ Bio-magnification → there is no evidence for the bio-magnification of particles, but it might be bio-magnification of pollutants	▪ Potential for translocation ▪ Nanoplastics ▪ Role of microplastics in inflammatory disease to ED. ▪ There is mixture of events. ▪ Microbeads in cosmetics. ▪ Effect on Fisheries. ▪ Microplastics in drinking water and drinks ▪ Intake of microplastic through food and raising food concerns for food safety ▪ Lack of information on how plastic might have an effect while being fish/meat is cooked. ▪ Possibly inhaled.

Table 4.7 SWOT analysis – breakout group B

Strengths:	**Weaknesses:**
▪ There is existing risk assessment (RA) framework. We already have a backbone, ▪ We understand the processes and have concrete info. ▪ We have some methods for sampling Data on exposure. ▪ Enthusiasm, motivation and high willingness	▪ We have data gaps and fragmented information ▪ Data quality is questionable in some cases and there are discrepancies in reporting standards. ▪ Existing methods are not standardized. ▪ Methods should be simplified.
Opportunities:	**Threats:**
▪ Harmonization of methods. ▪ Collaboration among stakeholders. ▪ Development of simple methods ▪ Innovation and capacity building	▪ No indication of when to stop ▪ Lack of transparency in RA

4.4 Breakout group C

In this group macro-plastic was defined as objects >5mm. The group's overview of potential adverse effects is summarised in Tables 4.8 – 4.12.

Table 4.8 Summary of key potential environmental risks due to macro-plastics – outcome of Break-out Group C.

What are the key environmental risks due to macro-plastic marine litter?
▪ Ingestion by marine biota leading to reduced nutrient uptake ▪ Entanglement of marine biota ▪ Impaired ecosystem services ▪ Habitat destruction → biodiversity impact ▪ Vector for undesired transfer of hazardous chemicals and organisms, including (antimicrobial resistant) pathogens

Table 4.9 Summary of key potential societal risks due to macro-plastics – outcome of Break-out Group C.

What are the key potential societal risks due to marine macro-plastic litter?
▪ Economic impact due to littered coastlines and reduction of tourism ▪ Potential co-exposure to pathogens such as E. coli ▪ Leaching of chemicals ▪ Shipping safety due to engine entanglement / navigation ▪ Damage to fishing gear – economic burden ▪ Flooding disease outbreaks ▪ Psychological value of clean coastlines (sense of place) ▪ Reduction of the quality of catch

Table 4.10 Summary of key potential environmental and societal risks due to microplastics – outcome of Break-out Group C.

What are the potential key environmental risks due to microplastics?
▪ Ingestion / uptake ▪ Impact on carbon and nutrient cycling (e.g. via influence on the density of sinking aggregates) ▪ Entanglement of microorganisms ▪ Species transfer / antimicrobial resistance (AMR) ▪ Possible pathogen transfer in commercially important species and impact on pathogen dynamics ▪ Influence on the density of sinking aggregates

Table 4.11 Summary of key societal risks due to microplastics – outcome of Break-out Group C.

What are the potential key societal risks due to microplastics?
▪ Possible pathogen transfer and impact on pathogen dynamics ▪ Inhalation ▪ To date, assessments could not identify a risk to human health via ingestion of MP ▪ Concern on possible health impacts could pose an economic burden

Table 4.12 SWOT analysis – breakout group C.

Strengths: ▪ Broad global awareness and interest, enabling policy action ▪ Visibility of the macro-plastic issue	**Weaknesses:** ▪ Little data available / knowledge gaps ▪ Data quality ▪ Complexity - confusion of population ▪ End-of-use-cost is not priced into plastic products (e.g. medical products)
Opportunities: ▪ Opportunity to also address other environmental issues such as climate change, with broad involvement of the general public ▪ Collaboration of different stakeholders ▪ Circular economy (but strongly based on recyclability) ▪ Rising number of available studies on impact of microplastic ▪ Novel chemical recycling methods – e.g. via supercritical water	**Threats:** ▪ Unwillingness to replace plastics, especially in private sector / commercial interests ▪ focus on visible plastic only but those that sink/are not visible (e.g. PVC and microplastics) do not necessarily get appropriate attention ▪ Involvement of different stakeholders with different agenda and biases disperse focus


© F Galgani. Microplastics on a sandy shoreline

5 ASSESSING RISK AND IMPACT (SESSIONS 4 AND 5)

5.1 Introduction

Having completed the scoping exercise, three sub-groups were formed to consider exposure pathways and risks in one of three areas of concern:

(i) marine environmental risks due to macro-plastics;

(ii) marine environmental risks due to nano- and microplastics; and

(iii) human health risks due to plastics and nano- and microplastics.

The composition of the sub-groups reflected the expertise of the participants.

Table 5.1 Examples of policy concerns related to the impact of macro-plastic litter on shipping and coastal industries, fisheries and aquaculture and biodiversity.

Sector	Policy concern
Shipping and coastal industries	Maritime transport/navigation hazard (entanglement of propellers/steering gear, blockage of cooling water systems, safety)
	Provision of rescue services
	Industrial plant – blockage of power station cooling water intakes and desalination plants
Fisheries and aquaculture	Depletion of commercial species by ghost fishing and entanglement ▪ Loss of income ▪ Impact on food security
	Damage to fishing nets, contamination of nets by litter, loss of income
Biodiversity including habitat damage and animal welfare	Destruction of habitat/mechanical damage e.g. coral reefs
	Alteration of habitat ▪ reduction in light penetration by shading ▪ additional surfaces for colonisation e.g. jelly fish polyps
	Entanglement and ghost fishing – loss of biodiversity
	Ingestion leading to morbidity or mortality – loss of biodiversity
	Ecological impacts of transportation of organisms
	Economic impacts of transportation of organisms

Table 5.2 Summary of information required to carry out a risk assessment of the impact of macro-plastic litter, relevant to key sectors and policy concerns.

Summary of information requirement to carry out risk assessment	
Description of hazard ▪ Environmental, Human health/Social/economic	▪ Chronic/acute ▪ Scale
Occurrence & severity of hazard ▪ What do we know? ▪ What do we need to know?	▪ Indicator – link to SDG14.1 ▪ Challenges/opportunities
Occurrence and vulnerability of organisms/activities/economies/sectors that could be affected by the hazard ▪ What we know? ▪ What do we need to know? ▪ Indicator – link to SDG 14.1	▪ Challenges/opportunities ▪ Risk ▪ Target/reference
Costs/benefit ▪ Economic costs?	▪ Risk perception and societal response?
Assessment methodology	

5.2 Marine environmental and societal risks due to macro-plastics

Risks due to macro-plastics may have a wide variety of environmental and/or societal consequences that cannot be quantified using the same methods employed for chemical risk assessment. The group decided to start by listing the principal types of potential hazard represented by macro-litter, based around policy concerns. These are summarised in Table 5.1. They then considered the information required to characterise the potential hazard and perform a risk assessment (Table 5.2). This formed the basis of producing a matrix (Annex IV) to include information of the current state of knowledge for each of the sectors and policy concerns listed in Table 5.1.

5.3 Marine environmental risks due to nano- and microplastics

This group took as its starting point the high-level risk assessment of micro- and nanoplastics in the marine environment by Besseling *et al.* (2019) (Figure 5.1). Definitions and targets for protection used by the group are shown in Table 5.3. A summary of exposure

Table 5.3 Definitions and targets for protection considered by the group.

Definitions and targets for protection
Definitions: ▪ microplastic < 5 mm, solid particles ▪ nanoplastic < 1 μm ▪ plastic/polymer – synthetic or semisynthetic non-soluble polymeric material plus monomers, non-intentionally added substances contaminants, breakdown products, etc.) and intentionally added substances; monomers, plasticizers, flame-retardants, pigments, UV stabilizers, bioactive compounds, etc.)
Target for protection: ▪ ecosystem services protection? ▪ Single species/groups of organisms? Or choose representative seafood species (algae, filter-feeders, top predators)? ▪ Food safety ▪ Genetic material – biodiversity, eDNA ▪ Erosion control, Storm protection, Habitat protection ▪ (Cultural – religious, heritage, value, future generations)

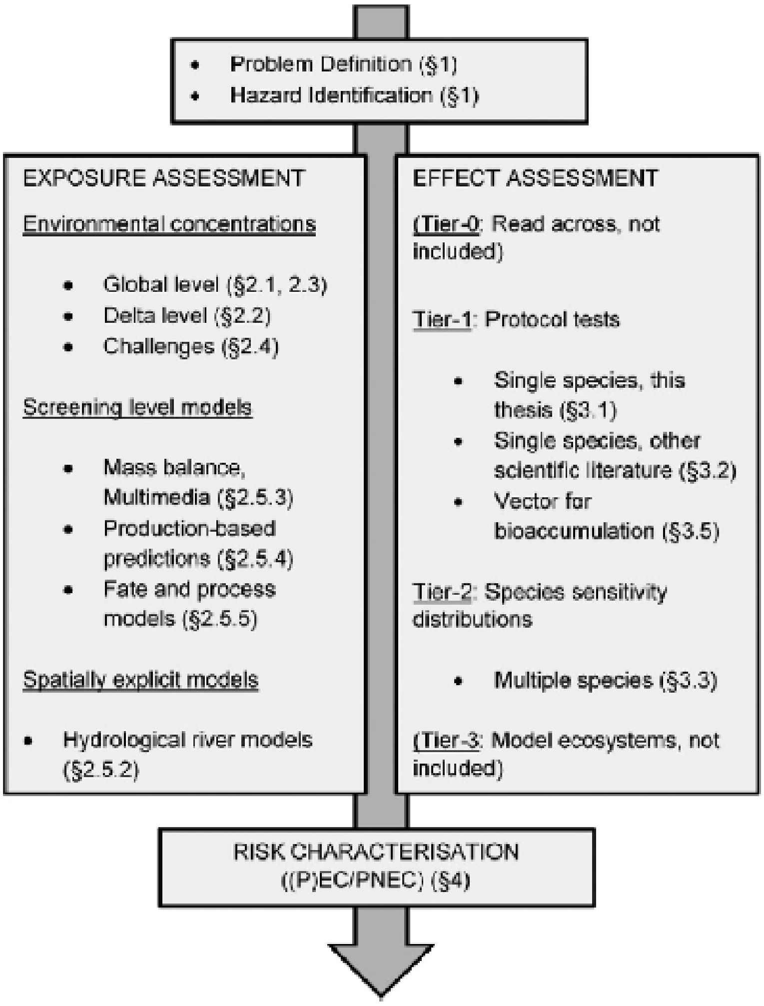

Figure 5.1 Tools for exposure and effect assessment as part of the general environmental risk assessment framework for micro- and nanoplastic, based on Koelmans *et al.* (2017). The symbol § marks the section in which each tool is discussed. Reproduced from Besseling *et al.* (2019) under Creative Commons Attribution-NonCommercial-NoDerivativesLicense (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Table 5.4 Summary of assessments of exposure and effect approaches, based on a tiered approach agreed by the group.

Exposure assessment	Effect Assessment
Environmental concentrations ▪ Global level, delta levels ▪ Coastal regions, point sources, accumulation zones ▪ Identification of hotspots ▪ Surface water ▪ Water column (transition zone, not accumulation) ▪ Sediment **Screening level models** ▪ Mass balance (too unbalanced? uncertainty too great?), surface layer vs sedimentation vs beaches – drives hypotheses ▪ Production based predictions – quantity produced, where does it go? Material flows ▪ Fate and process models – empirical data is important for verification/validation ▪ Integrate knowledge/models from oil/fish eggs	**Tier 0 - read across** ▪ Early ecological work on particles - clay particles, turbidity, etc. ▪ Pharmaceutical research ▪ Immunological research ▪ Prediction of sensitive species based on knowledge of the organisms ecology/physiology ▪ Probability of effects **Tier 1 - protocol tests** ▪ Dose effect relationship (homogeneous exposure matrices versus uneven particle distribution) ▪ Single species - (sensitive species identified in tier 1) ▪ Mode of action, ecological effect mechanism ▪ Physical blockage, food dilution ▪ Identification of appropriate mechanisms ▪ Immunological effects, epithelial tissue damage ▪ Vectors for bioaccumulation? Chemical vector effect **Tier 2** ▪ Species sensitivity distributions **Tier 3** ▪ model ecosystem experiments ▪ Predator prey interactions (kairomones, olfactory cues) could be important for toxicity testing ▪ Food chain studies ▪ Population effects, disease ecology
Measurements /monitoring	**Particles**
▪ Woods Hole Oceanographic Inst. – floaters, plans to develop technologies to measure MPs in situ ▪ NIVA- real-time microplastic monitoring in Arctic ▪ Need for harmonization – GESAMP ▪ Lack of standardized methodologies (sampling methods, filter sizes, matrices, sample handling, identification, reporting (number of particles/mass/volume/surface area of particles per volume/surface area/wt in water/sediment/biota)	▪ Realism of particles used in effect studies – polymer, size, shape ▪ Chemical composition of microplastics ▪ Additives ▪ Sorbed compounds ▪ Organisms are exposed to these chemicals, there is evidence for this ▪ Biofilms
▪ Fate modelling/ research on degradation and fragmentation of plastics to nanoplastics could be helpful ▪ Costs for monitoring nanoplastics in the marine environment are prohibitive ▪ Funding (World Bank?) ▪ Technological advancements are needed ▪ Capacity building needed	Effects of nano – ▪ Read across from pharmaceutical industries, particle physics
▪ Exposure to pathogens on microplastics/plastics, – hotspots v global levels	▪ Pathogens, plastic vector v water exposure? ▪ Population level effects – fish kills? (lack of knowledge) ▪ Human infections – population density, temperature, litter?

assessments and different methods of assessing effects, using the tiered approach, is presented in Table 5.4. In addition, the group completed an information needs matrix (Annex V).

Risk assessment of chemicals in plastics

There are tools and regulations in place covering chemical exposure, but the question arises as to whether a more specific framework is needed to cover chemicals associated with plastics. We do have knowledge concerning:

i) gradients that drive chemical transport;

ii) mechanisms that drive effects; and

iii) case-dependent effects of chemicals.

Risk assessment of chemicals in plastics, from a regulatory perspective, is based on assumptions of human exposure during use (e.g. food-contact packaging), but the chemicals also have to be assessed for environmental risk. In the latter case this is based on the total tonnage of chemical used in commerce being released into the environment. This represents a conservative, worst-case scenario.

Plastics can act as vectors for sorbed or additive chemicals in the marine environment, although the quantity associated with plastic, in terms of mass balance, has previously been considered relatively small (GESAMP 2010). While microplastic may not be a major exposure route for chemical exposure, they may represent an additional non-chemical stressor. Potentially this might contribute towards a tipping point for organisms/environments already under stress (e.g. raised temperature, low oxygen, food scarcity, disease), especially for vulnerable species, but the scope for this is largely unknown. For environmental risk assessment we could assume a worst case scenario – everything leaches out of the particles regardless of particle size, surface area, surface structure, mass and polymer composition, and regardless of gut retention time and gut fluid characteristics (temperature, pH, surfactants, presence of food). This would be applied to the total intake of plastic in the diet, which will vary in proportion depending on location and species.

One approach would be to extrapolate results from effects measurements (thresholds derived from dose-response relationships) and deduce an exposure vs. effect relationship, expressed as PEC/PNEC (Predicted Effects Concentration/Predicted No Effects Concentration). The PEC/PNEC approach is aimed at protecting a proportion of a population. The lack of evidence for adverse effects in the marine environment should not be interpreted as there as there being 'no risk' – there will always be a risk (i.e. probability of an effect) even if the risk is very low. The consensus from the SAPEA study was that the chance that PNEC is exceeded might be low but there may be some 'hot spots' that currently exceed thresholds – the evidence base is insufficient to know how extensive or significant these may be at present, and to predict their occurrence in the future with any certainty. Therefore, the rate of plastic production and pollution/littering will be relevant, together with information about the transport routes (vertical and horizontal) and transit times.

It can be argued that we should use the precautionary principle taking account of our present level of knowledge (with possible risks in hot spots and for vulnerable species), together with projected continued release and persistence of materials. However, the precautionary principle has to be applied carefully and proportionately, with due regard to the cost and impact of mitigation measures to reduce a poorly quantified risk. Risk management of plastics is intrinsically linked to improvements in waste management and other measures to reduce leakage of plastics into the ocean.

With regards to nanoplastics, there are no environmental data making it problematic to identify exposure pathways. However, it is possible to characterize PNEC values for nano-sized plastic particles of varying composition and shape. Estimates of exposure could then be derived using environmental fate model. This approach is typical of how environmental risk assessments are currently performed. The approach proposed would thus be entirely consistent with approaches described under the EU Technical Guidance Document for chemical risk assessment. It would be possible to conduct an environmental risk assessment based on current estimates of environmental concentrations then estimate how far away we are away from the risk (i.e. environmental concentration in orders of magnitude) and predict the time it will take (years – decades) before the adverse effect is realised.

Where do we need new technologies/knowledge/ approaches?

There is a need to harmonise risk assessment strategies/methods for monitoring and assessing exposure and hazard. Technological development is required in some areas, such as regarding pathogenicity of microbes and nano-detection, especially considering the presence of microplastics and pathogens in high concentrations in wastewater effluents.

It is problematic to treat 'microplastics' as one contaminant, but impractical and unnecessary to be comprehensive in describing the characteristics of large numbers of microplastics. One option is to treat the different features of microplastics (e.g. size, shape, surface properties) as probability distributions (Kooi and Koelmans 2019). A second option would be to create a limited number of representative groups of most commonly found microplastics based on their characteristics (shape/size, polymer, additives); i.e. defining functional groups of microplastics for testing/risk assessment, an approach that could be described as using a 'pragmatic proxy'.

From epidemiological studies we do have single species tests that could be used to conduct a meta analysis. From toxicological testing (PEC/PNEC) there is a need to understand what drives the hazard (particle, polymer, chemical). It is also important to consider what kinds of effects should we be looking at and which ecologically relevant endpoints. The protection goals could be survival, reproduction, growth or behaviour. It was suggested that apical studies paired with the use of appropriate sensible biomarker would be a useful approach.

5.4 Human health risks due to plastics and nano- and microplastics

Inhalation exposure and dietary exposure.

Exposure to microplastics has been recognised as being of potential human health concern (Vethaak and Leslie 2016; Wright and Kelly, 2017, Barboza *et al.*, 2018) raising a number of questions regarding which type of information is needed on hazards, vectors, exposure, toxicity and risk:

- ❑ Should we try and assess exposure to 100% of the population or to restrict our efforts to that portion of the population considered likely to be at greatest risk?
- ❑ How should we prioritise our actions and/or formulate the key questions needed to address human health risk?

The physicochemical properties of the ingested or inhaled particles will be critical, particularly the size and shape but also the surface characteristics, such as the presence of a microbial film that may harbour pathogens.

One strategy would be to focus on that portion of the population considered to experience higher exposure or to be susceptible to exposure, for example:

- ❑ Individuals who have a pre-disposition to be more at risk; for example, an abnormal gut physiology may lead to increased translocation across the gut wall;
- ❑ Individuals/populations who are high consumers of seafood;
- ❑ Individuals/populations who experience higher airborne occupational exposure (e.g. manufacture of clothing, recycling);
- ❑ Individuals/populations who experience higher airborne recreational exposure (e.g. house dust); and
- ❑ Individuals/populations who live near 'hot-spots' (e.g. urban dwellers, living close to an incinerator, open-burning sites and/or plastic manufacturing facilities.

In addition, it may be possible to identify opportunities to utilize the wealth of information obtained from studies of occupational exposure to asbestos and other airborne dusts in the mining, construction and manufacturing industries. These data could act as proxy indicators until more data on microplastics become available.

Translocation of plastic particles to tissue and membranes

The extent to which plastic particles cross gut and lung membranes and are translocated to internal tissues is an important mechanism in helping to identify specific toxicological modes-of-action and in helping to inform the quantification of risk. We are aware that particle size strongly influences the translocation of particles. For instance, the inhalation of fine mineral dusts is a significant health problem, but we don't know the extent to which fine particles of plastic pose the same threat. Inhalation of ultrafine particles of vehicular emissions, with particle sizes <2.5 microns, have been linked to certain diseases and mechanisms, such as inflammation of lung tissues. This is because ultrafine particles (< 2.5 microns) are capable of reaching deeper parts of the lungs (pleurae), where they can be deposited beyond the ciliated airways and are slowly cleared via a macrophage-mediated clearance mechanism. The relatively long residence times in the lungs can then result in proliferation of granuloma/inflammation. Observations from occupational studies of workers and lab-based studies of rats exposed to polyester, acrylic and nylon report similar fate of plastic particles within the lung. It is unknown, however, to what extent plastic particles represent the composition of fine particles under ambient conditions. Given the propensity of ultrafine particles (<100 nm) for translocation, it would be important to characterize their fate within internal tissues, such as their potential to penetrate the membranes of the blood brain barrier as well as the placenta.

One example of a critical question is the extent to which plastic particles contribute to ultrafine particles in ambient air that can penetrate into the lung and become systemically available?

Experimental studies can be useful in this regard. For instance, polystyrene, due to its inherent inert properties, has been used in many experimental research studies in assessing mechanisms of translocation and systemic circulation of particles (Brown *et al.* 2001). It is one of the most common types of plastic, and polystyrene spheres of precise dimensions for scientific research purposes are relatively easy to acquire. However, the shape and size of particles within the ambient environment are highly variable, with these properties potentially having an intrinsic toxicity that differs from that of inert polystyrene spheres. For example, asbestos is similar to plastic in the sense of being persistent and durable, but chronic exposure to asbestos fibres is known to result in their deposition in organs other than lung, such as the liver and heart, and fibres can penetrate membranes more readily than spherical particles. However, the extent to which microplastic fibres also behave in a similar manner represents an area of ongoing research (Ferin *et al.* 1992; Hesterberg, 1992; Oberdörster *et al.*, 2005; Pauly *et al.* 1998; Warheit *et al.* 2003). Lastly, the body's response to 'clean/virgin' plastic may differ to the response to plastic containing additive chemicals, contaminants or covered in surface coatings (e.g. pathogens, allergens, proteins) or other co-occurring chemical and non-chemical stressors.

Risks associated with pathogens

The microbial communities that form readily on the surfaces of plastics and microplastics have been referred to as the "Plastisphere" (Zettler *et al.* 2013;

Van der Meulen *et al.* 2014, Amaral-Zettler *et al.* 2015). Pathogens may form part of that assemblage, often attaching to surfaces with the aid of adaptive features. Many bacteria possess fimbriae, which are short appendages that are used by bacteria to adhere to one another and organic and inorganic substrates. Plastic particles increase the area of substrate available for pathogens to grow on, acting as 'islands' and as potential vectors. Furthermore, microplastic particles provide a unique platform for the colonization of bacterial community growth (i.e. microplastic biofilm), which has the potential to enhance the spread of genes resistant to antibiotics (Arias Andres *et al.* 2018). This has been observed even under extreme weather conditions such as in the Antarctic (Lagana *et al.* 2019). Under these conditions, these bacterial communities enrich the substrate being able to boost the pathogen´s movement between species and make the communities more virulent.

Recent research has observed that plastic pieces are capable of transporting multiple types of pathogens simultaneously in aqueous environments, which in turn may affect a particular species of cultured seafood (for example, an oyster). Evidence shows that mussels and other cultured seafood for human consumption, boost its virulence, and are responsible for a great economic loss of aquaculture activities in India. This might be a relevant connection to further explore the links between marine plastic and microplastics and health and food safety. Many questions were raised about this connection, for example:

- ❑ what is the potential influence of pathogens on the microbiome for the gut of an affected organism?
- ❑ are there risks of these pathogens being transferred along the coastlines where aquaculture activities operate? and;
- ❑ could these pathogens trigger other changes at higher ecosystems level over time?

Lastly, water-borne plastic debris could potentially intensify disease impacts in local coastal communities in the event of natural disasters, such as flooding.

Key areas of uncertainty

The group considered a wide range of issues that were believed to be potentially important, although in many cases there is a lack of evidence to support the hypotheses. These are summarised in Table 5.5. It may be possible to explore and utilise scenarios, but the key would be prioritisation of problem formulation. A recurring theme was how to communicate the current status of knowledge and present evidence in an accurate and understandable manner while simultaneously preventing the spread of misinformation that might lead to overreaction or knee-jerk responses to risks with low probabilities.

Table 5.5 Summary of key concerns related to assessing human health impacts of microplastics.

Key concern	Comment
Chronic vs. acute exposure, e.g. flooding events	
Immune suppression leading to infectious and non-infectious disease occurrence	May be linked to gut disease or other organs if particles translocated. E.g. Crohn's disease
Potential to learn from pharmaco-kinetics	Transparency of research/knowledge in industry
Circumstances and location of internal translocation and accumulation	
Size and shape effects	
Burden and effects of chemicals associated with plastics -	
Quantification and characterisation of particles from different sources	Particles from different uses/sectors may exhibit different exposure pathways and have different effects –e.g. textiles, tyre dust
Concentration dose-response effects	Particle and chemical concentration
Relative importance of effects from ingested/inhaled microplastics vs. other plastic-related toxicity, e.g. endocrine-disrupting chemicals leached from food packaging	It seems likely that much of the ingested larger plastic particles will be excreted in faeces
Degradation of particles in the body	Potential release of smaller particles and associated chemicals
Transfer of pathogens	May cause a spread of potential pathogens and increased risk of infections
Does the presence of plastic particles increase disease burden, e.g. for coastal populations and/or population near plastic production sites and/or plastic waste disposal/ mismanaged sites	Causality may be difficult to establish, causation may be easier to demonstrate

6 IDENTIFYING ASSESSMENT NEEDS AND RESEARCH GAPS (SESSION 6)

6.1 Introduction

Each of the three groups was requested to identify assessment needs and research gaps, based on their discussions. Each group approached this task in a manner chosen by the membership, and the structure and content of the outcomes reflected this.

6.2 Marine environmental and societal risks due to macro-plastics

The group decided to group risks by major policy concern, and then created a matrix in which various factors such as scale and vulnerability could be recorded (Table 6.1, Annex IV). The three main groups were sub-divided into specific areas of concern:

❑ Navigational and industrial hazards

- Maritime transport (e.g. fouled propellers, blocked cooling water intakes, crew safety);
- Entanglement of divers (commercial and leisure, rescue operations); and
- Coastal industrial plants (blockage of cooling water intakes and desalination plants).

❑ Fisheries and aquaculture

- Entanglement and ghost fishing of commercial species (loss of income, reduction in food security especially protein);
- Direct cost to operations (contaminated catch, damage to gear, cleaning nets).

❑ Biodiversity, ecosystems and animal welfare

- Destruction of habitat (mechanical damage, smothering);
- Alteration of habitat - reduction in light penetration;
- Alteration of habitat - increased area of substrate for attachment (e.g. sessile organisms, jellyfish resting stage);
- Entanglement and ghost fishing – loss of biodiversity, animal welfare;
- Vector for indigenous and non-indigenous organisms, including pathogens – potential increase in disease (human and non-human); and
- Vector for indigenous and non-indigenous organisms – environmental and socio-economic impacts of invasive species.

The group concluded that there were large knowledge gaps and therefore a degree of speculation/ hypothesis was inherent in the interpretation of this exercise.

6.3 Marine environmental risks due to nano- and microplastics

This group posed a series of questions and considered what had been covered to date by WG40 and compared that with what they considered to be key assessment needs. WG40 had noted the potential role in rafting of organisms, including the presence

Table 6.1 (a and b) Sub-set of headers used to form a matrix describing the nature of risks due to marine litter in key areas of policy concern (b) expands the headers in (a). (see Annex IV for more detail.)

(a)

Policy concern	Impact – socio-economic, &/or environmental	Chronic/acute	Scale (space & time)	Occurrence & severity of hazard – state of knowledge	Indicator (SDGs)
Shipping					
Fisheries & aquaculture					
Biodiversity					

(b)

Policy concern	Challenges/ opportunities	Nature of risk	Target/ Reference	Cost-benefit	Actions
Shipping					
Fisheries & aquaculture					
Biodiversity					

of pathogens and invasive species, but this had not been extended into a risk assessment. Nanoplastics had not been considered on the basis of a lack of reported environmental data.

It was agreed that the following elements should be considered in an assessment:

- Effects of nano- and microplastics – endpoints that capture sensitive species, mode of action (MOA), associated chemicals;
- Fate of nano- and microplastics including exposure pathways;
- Focus on specific systems? Food chains, human food sources, areas of high value (biodiversity, etc), hot spots, sinks, impact on abiotic structures and processes (sedimentation rates, sediment composition, etc.);
- Long-term trends, future risks; and
- Risk perception and communication to the wider community, including the 'general public'.

This led to the identification of the following knowledge gaps:

Microplastics

- Methodologies for monitoring, harmonization, standardization in terms of sampling, separation, characterization, analytics, technologies;
- Fate (where do they go?), degradation, mineralization, timescales;
- Representative 'microplastics' for testing;
- Intentionally and non-intentionally added substances;
- Mesocosm scale testing/ ecological relevance / complex systems / chronic exposures; and
- Food security.
    - Immune system effects;
    - Trophic transfer.

Nanoplastics

- Environmental levels – exposure;
- Methodologies for monitoring, harmonization, standardization in terms of sampling, separation, characterization, analytics, technologies;
- Mesocosm scale testing/ ecological relevance / complex systems / chronic exposures; and
- Food security.
    - Immune system effects;
    - Trophic transfer; and
    - Uptake via epithelial tissues.

In order to fill these knowledge gaps the following research initiatives were proposed:

Harmonization of monitoring techniques

- Standardization of reporting – mass, number, etc. – ensure relevance to risk assessment and enable comparison with toxicological studies (risk characterisation);
- Global monitoring over appropriate spatial and temporal scales;
- New and improved fate and transport models, taking regional differences into account;
- Uptake mechanisms (from environment/gut to the organisms) via epithelial tissues – is it happening, when and where and how?;
- Pathogens – selection, the role of plastics in exacerbating this problem – do plastics increase the rate of genetic selection/recombination, increased virulence, will this increase/facilitate infection, effects on organism health, aquaculture (e.g. Viršek *et al.* 2017), food safety/security;
- Organism health;
- Epidemiology studies, proof of effects – risks;
- Degradation of polymers in the environment(s);
- Role of plastics as a vector for transporting chemicals in the marine environment;
- Role of plastics as new habitats in all environments;
- Impact of plastics on ecosystem processes (e.g. ecosystem productivity);
- Large scale biogeochemical impacts – e.g. nitrogen and carbon cycling, marine snow, carbon sequestering, deep sea food and nutrient chains;
- Formation/melting of sea ice, impacts on temperature in different environments;
- Immunological biomarkers; and
- Impacts in specific/sensitive habitats e.g. mangroves, rocky shores, areas of high biodiversity.

6.4 Human health risks

This group articulated their discussions around three main themes: human exposure, public perception and concerns and key research needs.

Human exposure

Humans are exposed to micro- and nanoplastics from ingestion and inhalation (Vethaak and Leslie 2016; Wright and Kelly 2017). The current level of evidence suggests that the risk is relatively low, but that assessing exposure and hazard would benefit from greater mechanistic understanding of dose-response relationships. These could be explored by developing a series of scenarios aimed at assessing the influence of various factors/descriptors/effects/impacts that we might take into consideration. The situation is dynamic, as humans are exposed to varying concentrations of particles, both via inhalation and ingestion. Unfortunately, there is a fundamental lack of data, particularly with respect to exposure, which results in a high level of uncertainty.

It is widely recognized that that microplastics do not represent a single entity with a specific set of physicochemical properties, but in fact represent a continuum of particles with varying size, shape, and density that greatly influence exposure and effects. In addition to difference in size and shape, particles may have different compositions (polymer and additive chemicals) and surface properties that can also affect exposure and toxicity. For example, shellfish may retain relatively low number of particles, but these can carry pathogens, especially if harvesting in coastal waters near major urban centre. A small number of particles coated with high virulence pathogens could have much higher toxicity than many more 'clean' particles with a lower pathogen load. In this case the concern would be about load of pathogens being carried on each particle rather than simply the number of particles and how the shellfish have been processed prior to consuming (for instance, cooking at elevated temperature should be sufficient to eliminate the risk of exposure to pathogens). A supplementary question is the role plastic particles play in increasing the prevalence or virulence of pathogens, such as amoebas, legionella bacteria. What would be the role of plastic particles in the virulence of these organisms?

A number of assessment priorities were identified (Table 6.2)

Public perception and concerns
It is very important to consider human health from the perspective of public perception and concern (Section 2.5). There may be significant differences in understanding of risk and its consequence depending on whether the audience is a group of health professionals or a group of fish-eating members of the public, for example. In addition, the discussion within the group had been steered from the perspective of people living in more developed countries. It is important to recognise that socio-economic and environmental realities, and health priorities, may differ in less developed economies.

Key research needs
Given the concerns with respect to quantifying exposure, all activities aimed at refining the exposure estimate are given high priority, and include:

- ❑ Harmonization of exposure metric: The group agreed that the ideal scenario for exposure metric is to have access to information that reports both the particle count and the mass of particles/kg for a specific size category. These data are needed to better harmonize between exposure and effect threshold levels (i.e. dose-response);
- ❑ Improved analytical methods are needed to quantify exposures of particles, air monitoring data, human bio-monitoring data/biomarkers; and
- ❑ Mechanistic toxico-kinetic modelling tools to support greater understanding of the overall fate of particles that may enter the human system, including processes influencing adsorption, distribution, and elimination, which should also include an assessment of immune response to exposure and potential for immunological responses.

Through a better appreciation of exposure characterisation it will then be possible to guide characterization of adverse effects as they may be associated with physical responses, chemical and pathogenic particle-facilitated transport.

Table 6.2 Priorities for assessing the human health impacts on micro- and nanoplastics.

Assessment priorities	
▪ Chronic inflammation (micro and nano particles): which could lead to an on set for cancer neurological, Crohns (this is regarding size, and taking into consideration any other fine particle with similar size) ▪ Inhalation – Respiratory (micro and nano) Make a difference between chronic and acute, and target specific organs as markers such as the lungs for nanoplastics. ▪ Chemical transport? this would be the dependant on the level of exposure (micro- and macro-plastics): • Trophic magnification • Open burning • Chemical leaching hazards • Manufacturing	▪ Pathogenic transport (micro- and nano-): invasive species and pathogens ▪ Physical hazards (macro-plastics) ▪ Psychological/emotional effects ▪ Trophic magnification ▪ Mismanaged waste and indirect effluents. ▪ Ingestion of seafood

© Sebastien Herve. Microplastics prepared for analysis

7 DEVELOPING AN ASSESSMENT LANDSCAPE FOR IMPROVING RISK ASSESSMENT OF MARINE PLASTICS AND MICROPLASTICS (SESSION 7)

7.1 Introduction

Several approaches to conducting risk assessments were raised and critically addressed during the workshop. It is clear that there is no one approach that is suitable for assessing the wide range of potential hazards and exposure routes associated with marine plastic litter and microplastics, taking into account all of the possible social, economic and environmental consequences. These may range from the possible health consequences of ingestion of microplastics in seafood to societal concerns for animal welfare and biodiversity in the case of entanglement of endangered species. Instead it may be more appropriate to set out a 'risk assessment landscape'. It is essential to clarify the scope and purpose of the risk assessment and assess our level of knowledge, and important to consider a tiered approach.

Refining the scope of the risk assessment:

- ❑ What do we want to know?
- ❑ What is the problem?
- ❑ Why we are interested?
- ❑ What is the policy concern?
- ❑ How do we fill knowledge gaps?
- ❑ How do we deal with uncertainty?
- ❑ How do we communicate the risk?

Tiered approaches to risk assessment

The objective of frameworks for tiered approaches to hazard, exposure and risk characterization is to increase transparency and defensibility in the selection of methodological approaches (including envisaged tier of assessment and associated tools) based on a priori consideration of specified aspects in problem formulation (Figure 7.1). The construct reflects increasing experience in the development of tools for the assessment of hazard and risk in a wide range of applications, for which relevant factors for consideration vary, including resources and existing knowledge and urgency, taking into account social considerations and potential pubic or environmental health risk. The objective of tiered approaches is "fit for purpose" assessment, to ensure that no more resources than necessary are invested to set aside non-priorities for further consideration or to inform risk management. Approaches to assessment range from less labour intensive and expeditious qualitative approaches requiring limited data to increasingly complex, assumed more accurate and mechanistically based, normally more data intensive and quantitative approaches. In addition to conserving resources in assessment, the approach is helpful in focusing research in critical areas (Koelmans *et al.* 2017).

The WHO IPCS (International Programme on Chemical Safety) framework for the risk assessment of combined exposure to multiple chemicals provides an example of a tiered assessment strategy developed to aid risk assessors in identifying priorities for risk management for a wide range of scenarios where co-exposures to multiple chemicals are expected (Meek *et al.* 2011; Meek 2013). It is based on a hierarchical (phased) approach that involves integrated and iterative consideration of exposure and hazard at all phases, with each tier being more refined (i.e., less cautious and more certain) than the previous one, but more labour- and data-intensive. Problem formulation in the framework addresses a specified series of questions in a structured approach as a basis to consider whether or assessment of combined exposures is warranted and if so, the nature of appropriate grouping of substances and selection of appropriate methodology. Additional guidance on combined exposures by the Organization for Economic Cooperation and Development (OECD 2018) derives from application of the Framework. The Framework is the basis also for guidance on mixtures for application in the derivation of the WHO Guidelines for Drinking Water Quality (WHO 2017). The framework also provides an organizing construct for the consideration and selection of assessment methodologies and has been applied for this purpose to "map" IPCS guidance for tools of differing complexities to provide practical advice concerning their implementation in tiered assessment and management strategies (Meek 2011).

Framing of this nature for macro-plastics, micro and nanoplastics, might include development by the relevant experts of appropriate questions in problem formulation for each as a basis for selection of relevant methodology. It would also involve mapping of available risk assessment methods for plastics based on the state of the art in their development in increasing tiers of complexity. The objective is to provide transparency on selection of appropriate tiers and relevant tools for assessment to address the relevant policy issues (questions being posed), taking into account specified considerations. These considerations would likely include (but not be limited to) perceived priority of the issue, the extent of the available knowledge base (e.g. methodological tools available) and priority for action (based on 'scoping' –e.g. the 'risk matrix' in Table 8.2 of GESAMP 93.

It was noted that set of guidelines for dealing with emerging risks has been proposed by the International Risk Governance Council (IRGC)[1], which could provide a model for dealing with the risks associated with marine litter and microplastics. The IRGC approach involves five stages:

1 https://irgc.org

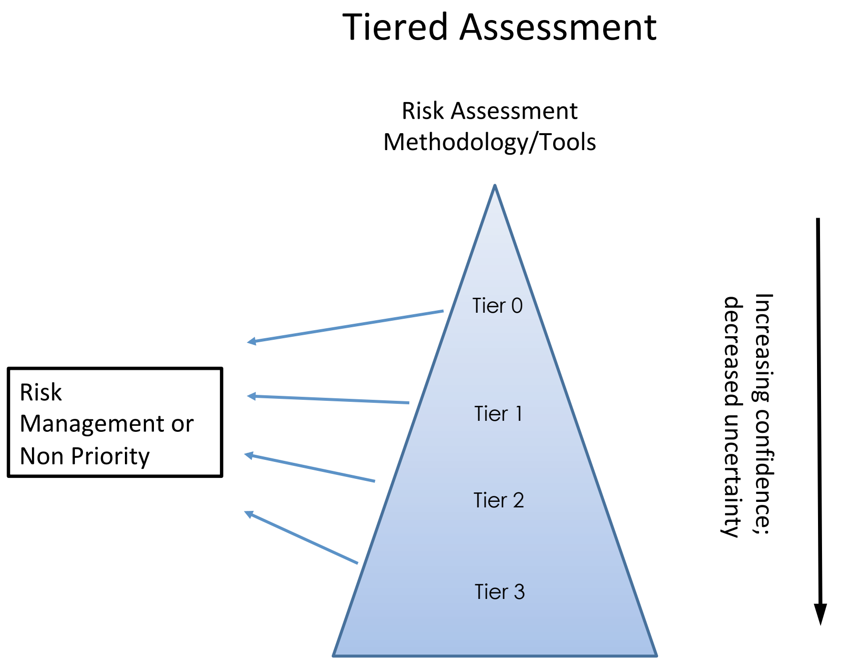

Figure 7.1 Schematic representation of a tiered approach to risk assessment, proceeding from Tier 0 (low confidence) to Tier 3 (high confidence), image courtesy of Bette Meek.

(i) Make sense of the present and explore the future;

(ii) Develop scenarios based on narratives and models;

(iii) Generate risk management option and formulate strategy;

(iv) Implement strategy; and

(v) Review risk development and decisions.

For example, Stage 1 specifically talks about identifying early warning signs and signals, which relates to our present level of understanding of the nature of the risk from nano- and microplastics. Stage 2 talks about developing scenarios that can be used to inform potential risk management options.

Under the generation risk management options, six actions are proposed:

(i) Act on the factors that contribute to the risk emergence;

(ii) Develop precautionary approaches;

(iii) Reduce vulnerability;

(iv) Modify the risk appetite in line with the new risk;

(v) Use risk governance instruments to manage familiar risk; and

(vi) Do nothing.

Having considered a number of risk management approaches, the participants used a conceptual mapping tool in plenary, to start to develop a framework encompassing the discussions during the workshop. This was an initial attempt to describe the different elements and their relationships in a risk assessment landscape. This is reproduced, as 'work-in-progress', in Annex VII, as an example of how such tools could be utilised to aid the development of a comprehensive risk assessment approach.

7.2 Exploring risk assessment approaches for macro-plastic marine litter in the marine environment

The potential risks due to the presence of macro-plastic litter are very diverse, with societal (including human health), economic and environmental consequences. The table/approach developed by the group was intended to be used as a guide that will help organise the ideas, like a stepping-stone for future work. The table (ANNEX IV) was found to be a useful way for the group to conceptualise the issues, and a framework to illustrate information needs. The key feature of this exercise was to present all the information in a simpler way in order to communicate more effectively the message in the report or the future. It is essential to communicate in a way that is accurate and transparent, while trying to operate from an innovative point of view. The table itself could support a storytelling element and clear narrative. The key question is how to take this information, captured in a large table, and develop coherent communication materials. This should be seen as a priority.

7.3 Exploring environmental risk assessment approaches for nano- and microplastics in the marine environment

This group experienced some difficulty following the table approach developed by the macro-plastic group, for example on understanding and defining 'focus' and 'scale'. The table (Annex V) was completed using the group's interpretation of these descriptors, focusing only on microplastic (not necessarily on nanoplastics). Some of the information included in the table was speculative and hypothesis-driven, due to the lack of evidence and significant uncertainty, therefore caution should be exercised if using the table to draw firm conclusions or advise on future work.

The discussion revolved around risks and how to measure the hazards and environmental levels of exposure, areas of prioritization for these measures, information gaps, causes and how prioritize the targets.

From an ecotoxicology point of view, it is difficult to make a comparison of environmental levels to reference sites, as these are novel materials that do not exist in nature and there are no reference sites in place. Thus, in nature these threshold levels would be zero.

In terms of exposure, the discussion revolved around trying to harmonize data regarding 'global' exposure and the need to use common units and common methodologies. There is also a need for capacity building and technological development, both requiring time and funding. There are many thousands of polymer/chemical combinations in production but a lack of environmental markers. In addition, plastics may act as a vector for pathogens and non-indigenous species with potential risks to human and environmental health.

In terms of effects, these are harder to assess as any effect that we may encounter, since there are challenges in differentiating effects coming directly from microplastic exposure (e.g. nutritional deficiency, inflammation) versus other stressors. There are many environmental stressors for exposure in the water environment already and a lack of a specific biomarker for microplastics. This raises the question: 'what should we be measuring?' Could the presence of microplastic in the gut be used as a proxy for potential harm?

One option is to use the chemical risk assessment approach, which is well established and accepted. Tools designed for chemicals in solution, that do not work for particles, would need to be replaced by new tools. There is a precedent because a similar approach was used for engineered nanomaterials. Of course, a new material needs new concepts and these need time to be understood and become accepted. However, methods that may seem straightforward to professional risk assessment practitioners may be difficult for others to understand. This is illustrative of the critical need for good communications.

7.4 Exploring human health risk assessment approaches for plastics, nano- and microplastics

The biggest struggle for the Human Health Group was the lack of empirical and proven information, making it hard to know where to start (i.e. problem formulation). There is a lot of speculation at the moment, and it seems unclear how this will help to prioritize how to move things forward with the limited information we have.

The group considered the table approach, developed by the macro-plastic group (Table 5.1, Annex IV), to be useful in principle. For example, the number of entries

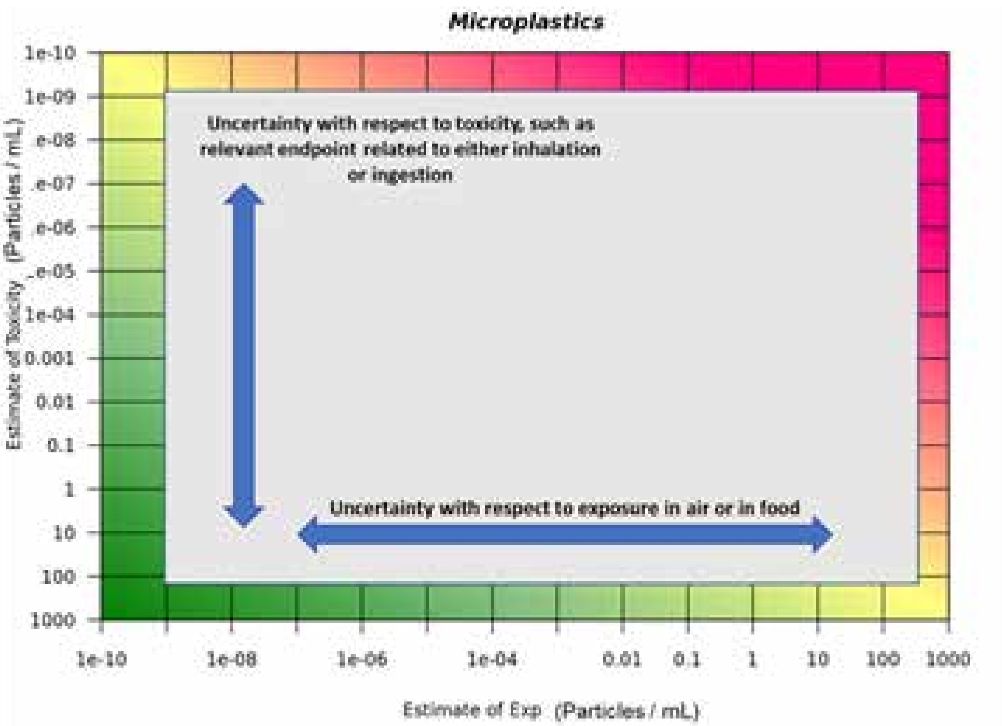

Figure 7.2 Risk matrix representing the estimate of human exposure to microplastics and human toxicity: the rectangular box illustrates an example of where our current uncertainty about risk may lie, with consensus that uncertainty is high on both the x- and y-axis (figure created by Todd Gouin as a result of discussions during the workshop).

left empty would indicate where more information is required. However, the group considered it unwise to attempt to complete the table during the workshop due to the uncertainties involved. In addition, there was a mis-match between the current structure and the data required for assessing human health risk. Instead the Group chose to use the risk matrix (hazard vs. probability of exposure) presented in the 2016 GESAMP report as an illustrative tool for stimulating discussions - having exposure probabilities, from low to high on the X axes, and the hazards from low to high in the Y axes. It was suggested that a visual representation of the risk matrix and uncertainty 'box' would be useful in reflecting the current state of knowledge (Figure 7.2). It would be possible to add axes for particle size and chemical concentration to the matrix as data become available. Clearly, from Figure 7.2, we need to improve our understanding in terms of both the exposure and hazards. However, there was a sense that potential hazards could be more readily identified, which might help us to prioritize research efforts to reduce uncertainty in terms of the exposure element.

It was pointed out that all the above issues and problems mentioned need to be addressed from a public concern perspective. It is important to communicate a balanced message, to avoid giving the impression that one 'type' of problem is more important than another. We should try to come up with a way of communicating where these three groups (macro, micro and human health) have similar relevance and are balanced.

A concern was expressed that the current lack of knowledge on potential human health risks meant it was difficult to advise on whether the current public and policy concerns on plastics and micro- and nanoplastics are well founded and properly directed. This is particularly the case for nano-sized particles which would be expected to behave differently in the body, with the potential for greater toxicity; for example, crossing the blood-brain barrier. There is a need to scope the issue more comprehensively. The challenge is to be more proactive in addressing the potential health concerns and communicating the current level of knowledge and uncertainties.

In this regard there would be a benefit in looking at the approach followed by the International Council of Risk Governance, as it provides guidelines on emerging risks, and that goes beyond what the human health group has been discussing.

The first two step would be:

- ❑ Exploration: signals to look at, early warnings; and
- ❑ Developing scenarios.

Problem formulation
A key element of the risk matrix is problem formulation. An example of problem formulation related to a specific policy concern might be: *'Are coastal communities at risk to adverse effects associated with microplastic exposure via consumption of seafood?'*

In order to progress through the risk matrix, it is first necessary to characterize and quantify exposure to microplastic; this information is key to enabling an assessment of the risk associated with adverse effects due to physical particle effects, the potential for microplastic to transport hazardous chemicals and/or to transport pathogens or other biological agents.

Three loosely defined archetype coastal populations are proposed to consider as illustrative examples with respect to addressing the exposure elements of the matrix. These include an Urban Indonesian community, Mediterranean and Arctic Indigenous. The suggestion is that these communities would represent illustrative examples of extremes with respect to various exposure pathways that might be more important to consider.

Problem formulation example:
Are coastal communities at risk to adverse effects associated with microplastic exposure via consumption of seafood?

Microplastic particles found in the marine environment have many sources, as identified in previous GESAMP reports (GESAMP 2015; GESAMP 2016) and elsewhere. Various human activities can generate microplastic that may lead to direct inputs to the aquatic environment, including storm discharge of tyre/brake wear and generation of particles, wear and tear of textiles. Fibres appear to represent a common shape of microplastic particles, potentially dominating exposure. Atmospheric releases of microplastic particles can lead to deposition in marine coastal waters and provide input to marine biota that may represent food sources for human consumption (Figure 7.3).

Microplastic particles can come back to humans through bioaccumulation of particles by seafood, with differentiation between seafood consumed whole (including digestive tract) and fish for which the digestive tract has been removed. Biological monitoring data point to important differences between these two scenarios as microplastics are typically only observed in the digestive tract, removal of which from seafood reduces exposure. Nevertheless, microplastic particles may enter the food chain as a result of processing, distribution and final preparation of the food. These entry points will be largely due to atmospheric deposition of particles onto the food (Catarino *et al.* 2018).

Ultimately, there is high uncertainty regarding the actual levels of microplastic in seafood, with broad ranges of uncertainty along the exposure axis. Refinement on this axis is considered as being critical, as without this it is not possible to conduct a quantitative assessment of risk, as qualitatively illustrated in Figure 7.3.

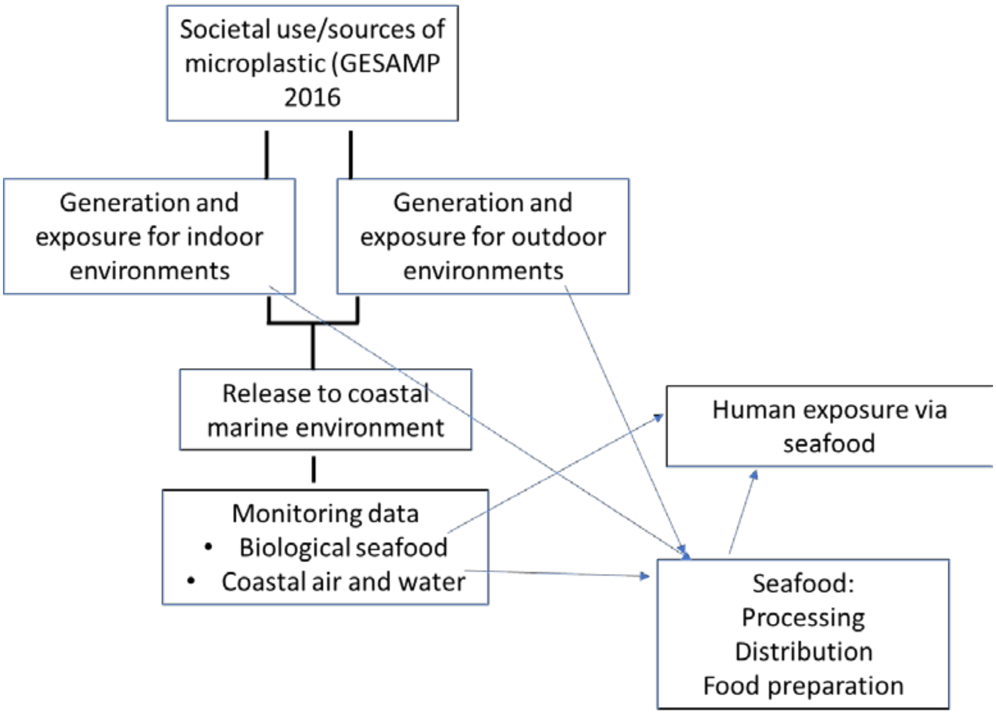

Figure 7.3 Potential human exposure pathways for microplastics from seafood consumption.

Release of microplastics, especially fibrous particles, can occur to the indoor air environment, as well as contribute to the outdoor air environment (Dris *et al*. 2017). Although the focus in the current exercise is on human oral ingestion of seafood, the group acknowledged that inhalation may represent a higher exposure pathway and requires additional attention towards assessing total/cumulative exposure.

7.5 Towards a more harmonized approach

One outcome of the workshop was to start to develop a schematic that attempted to encompass the many connections, pathways and influences involved in describing a more holistic approach to risk assessment. This is required when dealing with the complexity of societal and environmental interactions with the entire range of marine plastics and microplastics (Figure 7.1).

It was agreed that it is important to engage all stakeholders in the process from the very beginning.

One strategy would be to make sure that representative stakeholders belonging to the Major Groups, identified as part of the UNEA Sustainable Development Goals strategy (United Nations Department of Economic and Social Affairs [UNDESA] 2019), be considered:

- ❑ Business and industry;
- ❑ Children and Youth;
- ❑ Farmers (and fishers);
- ❑ Indigenous peoples;
- ❑ Local Authorities;
- ❑ Non-governmental organizations;
- ❑ Scientific and technological community;
- ❑ Women; and
- ❑ Workers and trade unions.

The social, economic and environmental impacts of macro-plastic litter can be demonstrated qualitatively and, in some cases, quantitatively. For micro- and nanoplastics particles it is much harder to demonstrate harm, although the perception by the public and policy makers may be that these pose a greater risk. It is important to acknowledge that one of the main drivers in the risk debate is the social concern. It is challenging to respond to these perceptions and offer source advice, with the data gaps and uncertainties in our knowledge. One thing we can do is to communicate clear definitions of terms that we use, such as risk, hazard, probability and the precautionary principle.

© NOAA. Japanese vessel on the Oregon shoreline following the 2011 earthquake and tsunami

8 FUTURE STEPS (SESSION 8)

8.1 Exploring opportunities for cooperation and synergies

Scale of response

The global community agrees that plastic pollution is an issue, as evidenced in UN agency plans, UNEA Resolutions, IGO activities, G7 and G20 Marine Litter Action Plans, Regional Seas, national industry, NGO and civil society initiatives. It is important to remember that previously we have addressed problems at a global scale, even though the impacts may have been experienced locally (e.g. chemical contaminants and bans in the Stockholm Convention).

One participant suggested considering the use of the Planetary Boundaries Framework (PBF hereafter) and novel entities and plastic approach as an umbrella to identify threats, scales, and how plastic connects with other major environmental threats, being aware that the current lack of information might be a barrier to apply this approach to its entirety. Thus, the working group could benefit from this framework to identify threats and potential impacts at global scale.

A second participant presented the results of research on marine plastic pollution within the context of the PBF. This framework is based on the concept that some of the collective human actions trigger changes in the environment in such a way that are capable of destabilizing fundamental dynamics of the Earth-system at a global scale. This approach is increasingly being used as an Earth system framework for global sustainability.

The PBF was first developed in 2009, when a group of scientists identified the major anthropogenic-induced environmental problems in nine Earth-system processes: climate change, biodiversity loss, biochemical change, ocean acidification, land use, freshwater, ozone depletion, atmospheric aerosols and chemical pollution. This framework sets precautionary levels for maximum human-induced change in vital environmental processes that the Earth System can tolerate (Rockström *et al.* 2009) to remain within a safe space. Planetary boundaries experts have identified variables for most of the boundaries. However, the ninth boundary, chemical pollutants or new entities, remains poorly described due to the complexity of synthetic chemicals, uncertainties about appropriate thresholds or precautionary levels, the substantial number of new chemicals generated and released to the environment each year, and a lack of understanding of how these chemicals interact with each other once they are released (Persson *et al.* 2013). Consequently, this ninth boundary remained open to group synthetic chemical pollutants having major impacts in the environment. The PBF identifies plastic as a chemical pollutant or a 'novel entity' which has the potential to create unwanted effects on the environment (Steffen *et al.* 2015).

In a recent publication setting up the case of marine plastic pollution within the PBF, Villarrubia-Gómez *et al.* (2018) do not propose to identify the 'dangerous levels' of plastic pollution in the marine environment, but rather to focus on characterising the 'dangerous pathways' by which plastic in the marine environment may alter Earth-system dynamics. In order for a chemical pollutant to pose a planetary boundary threat, it has to fulfil three conditions and a set of scenarios for each condition simultaneously (Persson *et al.* 2013; Macleod *et al.* 2014) (Figure 8.1). The list of conditions and scenarios are as follow:

Condition I. Is exposure to marine plastic pollution poorly reversible?

Condition II. Are effects of marine plastic pollution detected only when the problem is at a planetary scale?

(i) the concentrations of the contaminant are nearly homogeneous at a global scale;

(ii) the effects are rapidly distributed globally;

(iii) the effects of the contaminant are only observable at a global scale; and

(iv) there is a time delay between the exposure of the contaminant and the effects.

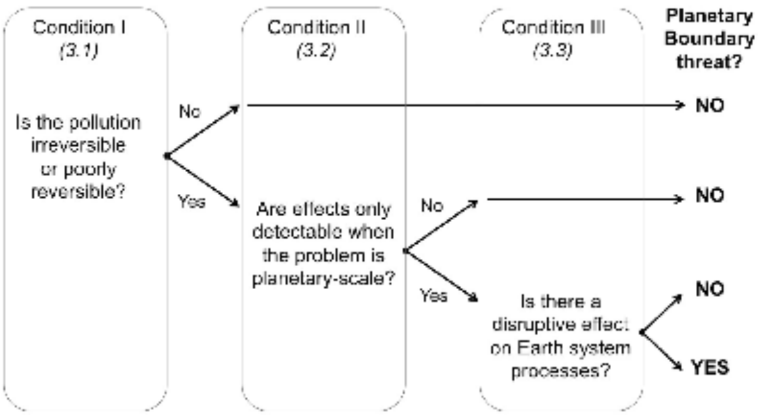

Figure 8.1 Conditions under which marine plastic litter and microplastics could be considered a threat in terms of the Planetary Boundary Framework, after Villarrubia-Gómez *et al.* 2018.

Condition III. Is there a disruptive effect on Earth-system processes?

According to Villarrubia-Gómez (2018), plastics and microplastics in the ocean fulfil two out of the three conditions (i.e. the presence of plastic pollution is irreversible in the marine environment, and plastic ubiquitous in the environment). However, the authors could not affirm than the third condition (i.e. is plastic changing or interfering in basic vital earth processes such as the carbon cycle?) is fulfilled. According to the researchers, this third condition might not be proven yet due to: the complexity of the issue, information gaps, and lack of empirical data, as well as for multiple ways of interpreting definitions such as scale. Another major challenge is that commonly plastic has been seen as an inert solid, and the PBF criteria were created for contaminants in phases: fluid and gas. Nevertheless, the criteria initially created for novel entities within PBF (Persson *et al.* 2013; MacLeod *et al.* 2014) are not set in stone and could be further developed to include a wider variety of contaminants.

It was argued that the Working Group could benefit from using this framework because the concept of planetary boundaries is already being used to communicate complex environmental problems (e.g. climate change, biodiversity loss, etc) for the creation of international policy, within UN Agencies and in relation to Agenda 2030 and the Sustainable Development Goals.

It became clear that the PBF concept was new to many of the participants and views were divided about the relevance of this approach for plastic marine litter. There is no suggestion that this approach would substitute for established risk assessment methods where these were appropriate. This is a matter for further discussion.

Communicating risk
To make a real difference we need to be able to communicate with policy makers. This means using a vocabulary or a way of explaining things that is understandable to everyone and not just to scientists. We have to demonstrate/communicate what we mean in a "simpler" way, with transparency of our work/claims, in order to build trust:

- ❑ Communication strategy with a simple message; and
- ❑ Being transparent, not only on the results that we know but also in what is uncertain.

The workshop was focussed on risk assessment approaches that can be applied in a whole series of situations, irrespective of the source of plastics (industrial effluents, wastewater discharges, run-off, fragmentation in the marine environment and on the shoreline). Microplastics sources have been reported elsewhere (e.g. GESAMP 2015; GESAMP 2016). It should be noted that there are other environmental and human health risks associated with other life stages of plastic and microplastics before (e.g. plastic and additives production) or after (e.g. waste treatment) they end up in the marine environment which is beyond the scope and mandate of GESAMP and this workshop. Nonetheless these should be considered in research and communication from a life cycle perspective of view.

The group was reminded of the necessity for GESAMP communications to be based on a careful consideration of the scientific evidence, to remain factual with the aim of providing accurate information in an understandable way. This was in response to an example being given of an NGO campaign, based in the Netherlands, that utilised the image of a plastic human foetus to raise awareness in a campaign. GESAMP holds the view that it is not appropriate to resort to sensationalism in order to receive more attention. What can be effective is to communicate from personal experience (example of the vaccines/anti-vaccine communities), for example using interviews with people that are experiencing the consequences or are involved in exploring the risk. Another approach is to tell the stories of impacts to charismatic fauna, as it has an emotional component and might help with communication.

However we choose to communicate, it is important to place this work in the wider environmental and human health context, to encourage a more informed discussion about the nature of risk and the trade-offs required to balance harm and benefits. It was emphasized that any communication should not undermine actions to reduce plastics and its impact on human health.

8.2 Recommendations for GESAMP's future work programme

The workshop participants were asked to discuss the current Terms of Reference (ToRs) of GESAMP WG40, which cover the whole size range of marine plastic litter and microplastics (Annex I), and to propose possible changes. The main conclusion was that there is a need to expand the existing ToRs. Specific suggestions included:

(i) The term 'impact' can be perceived in different ways and could be considered as carrying negative connotations – 'effect' may be a better descriptor to avoid presumptions of some unknowns and uncertainties;

(ii) There is a lack of data on exposure – perhaps reflect this in the ToRs;

(iii) Change the wording to suggest, at least in the first instance, that the WG will be working on developing the risk assessment methodology and data needs, rather than carrying out a risk assessment; a risk assessment could be considered later; and

(iv) A public perception element should be included, as this is important both for communication and for policy makers (e.g. benefits vs. dis-benefits of seafood consumption).

It was pointed out that developments of an improved risk assessment methodology might be of use to other GESAMP working groups, including the new WG43 on ‘Sea-based sources of marine litter’, covering aquaculture, shipping, port reception facilities, fiberglass boats and gear marking and quantifying losses of fishing gear.

It is anticipated that this report, and any follow-up activities carried out by WG40, will be of use to a number of UN agencies and Conventions, as well as the wider governance and scientific communities, to help focus research efforts and contribute to an improved governance framework for risk assessment and regulation. One area to explore will be the link to the SDG indicators.

Further work by WG40 will take account of geographic representation and gender balance, to ensure the outcomes are of the widest possible use and relevance. The scale and rate of progress will be determined by securing adequate funding to operate the working group.

© Nadja Ziebarth. Northern gannet (*Morus bassanus*), Helgoland, North Sea

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ANNEXES

Annex I GESAMP Working Group 40 Terms of Reference

The Current Terms of Reference of GESAMP WG40 (as of September 2018) are to provide an assessment of:

1. The impact of plastics & microplastics on food security – environmental impacts of plastics & microplastics on species at a population level, including physical and chemical effects

2. The impact of plastics & microplastics on food safety - chemical contaminants & pathogens in seafood associated with ingested microplastics

3. Transfer of biota – the social, economic and environmental effects of plastics & microplastics on the distribution of biota, including indigenous and non-indigenous species and pathogens

It is expected that the ToRs will be revised and expanded as a result of the outcome of the Geneva workshop. These will be presented to the 46th session of GESAMP in New York (9-13 September 2019) and the approved ToRs will be disseminated.

Annex II Workshop participants

Name	Affiliation	Country/Division/Other
Peter Kershaw	GESAMP Independent consultant	UK
Daoji Li	East China Normal University Shanghai	P.R.China
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Francois Galgani	IFREMER, Bastia	France
Michael Bank	Havforskningsinstituttet Institute of Marine Research, Bergen,	Norway
Bette Meek	McLaughlin Centre for Risk Science, University of Ottawa	Canada
Sabine Pahl	School of Psychology, University of Plymouth,	UK
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Todd Gouin	WHO consultant	UK
Representatives of organisations		
Jennifer de France	WHO	Geneva
Lisa Scheuermann	WHO	Geneva
Kei Ohno Woodall	Basel Rotterdam & Stockholm Convention	Governance Branch, Geneva
Joana Akrofi	UNEP	Science Division , Nairobi
Heidi Savelli	UNEP	GPA, Nairobi
Joan Fabres	UNEP	GRID-Arendal
Patricia Villarrubia-Gómez	UNEP	GRID-Arendal
Jacqueline Alvarez	UNEP	Chemicals & health, Geneva
Henrik Oksfeldt Enevoldsen	IOC-UNESCO	Ocean Science Section, GESAMP Technical Secretary, Paris
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Joao Sousa	IUCN	IUCN
Melissa Wang	Greenpeace	Exeter Univ.

Annex III Workshop agenda

Day 1		
Time	**Session**	**Chair/Speaker/Lead**
08:30 – 09:10	Registration and coffee/refreshments	
09:10 – 09:30	Opening of workshop	GESAMP – Peter Kershaw
	Welcome	UNEP- Science Division- Joana Akrofi BRS Convention Secretariat – Kei Ohno-Woodall
	Relevance of workshop to UNEA	UNEP Heidi Savelli – GPA
	Introductions – round table (name & affiliation)	
	Housekeeping	Kei Ohno-Woodall
09:30 – 09:50	Introduction to the Workshop: Purpose and objectives Expected outcomes Structure and timetable Questions	GESAMP – Peter Kershaw
Session 1	An overview of environmental and human health risks	Chair - Jennifer de France
09:50 – 10:15	Keynote – an overview of risks associated with marine plastic litter	Invited expert: Prof. Alexander Turra, Univ. Sao Paulo, Brazil
10:15 – 10:40	Keynote – environmental risk from nano- and microplastics - results of the SAPEA assessment	Invited expert: Prof. Bart Koelmans, Wageningen Univ., The Netherlands
10:40 – 11:05	Keynote – human health risks associated with nano- and microplastics	Invited expert: Stephanie Wright, Kings College London, UK
11:05- 11:30	Coffee/tea	
11:30 – 11:55	Keynote - Risk perceptions and communication	Invited expert: Sabine Pahl, Univ. Plymouth, UK
11:55 – 13:00	Panel Discussion Q&A	4 keynote speakers
13:00 – 14:00	Lunch	
Session 2 14:00 – 15:15	Overview of international response – short interventions on risk-related activities (2-3 slides, 5 mins)	Chair – Alexander Turra
14:00 – 14:45	UN agencies	
	WHO	Jennifer de France
	IOC-UNESCO	Henrik Enevoldsen
	BRS Convention Secretariat	Kei Ohno-Woodall
	FAO	Peter Kershaw
	UNIDO	Yunrui Zhou
	IMO	Peter Kershaw
	UNEP Chemicals & Health	Jacqueline Alvarez
	Q&A	
14:45 – 15:15	Related international & regional initiatives (2-3 slides, 5 mins)	
	OECD	Peter Kershaw
	ICCA – risk assessment framework	Brett Howard
	ECHA	Peter Simpson
	SAM	Dulce Boavida
	ECETOC	Todd Gouin
	Q&A	

Day 1		
Time	**Session**	**Chair/Speaker/Lead**
Session 3 15:15 – 18:00	Scoping the issues	Chair Todd Gouin
15:15 – 15:30	Introduction to session 3 – break-out groups (A, B, C) Covering: human and environmental health, micro- and macro-plastics, commonalities, SWOT analysis, priorities	
15:30 – 16:00	Coffee/tea	
16:00 – 17:30	A – scoping the issues	Melissa Wang
	B – scoping the issues	Ralph Schneider
	C – scoping the issues	Bethanie Carney Almroth
17:30 – 18:00	Reporting back	
Day 1 closes		
[evening - workshop Team to meet to evaluate Day 1 and plan Day 2]		

Day 2		
Time	**Session**	**Chair/Speaker/Lead**
09:00	Summary of Day 1, introduction to Day 2	Peter Kershaw
Session 4 09:10 – 13:00	Assessing risk and impact – introductory higher-level discussion	Chair Bette Meek
	Introduction to Session 4 – break-out groups (D, E, F)	
	D – human health risks	Todd Gouin
	E – marine environmental risks due to nano- and microplastics	Bart Koelmans
	F - marine environmental risks due to macro-plastics	Alex Turra
10:45 – 11:15	Coffee/tea	
12:15 – 13:00	Reporting back	
13:00 – 14:00	Lunch	
Session 5 14:00 – 15:30	Assessing risk and impact – ‘deep-dive’	Chair Kei Ohno
	D – human health risks	Todd Gouin
	E – marine environmental risks due to nano- and microplastics	Bart Koelmans
	F – marine environmental risks due to macro-plastics	Alex Turra
	Reporting back	
15:30 – 16:00	Coffee/tea	
Session 6 16:00 – 18:00	Identifying assessment needs and research gaps	Chair Henrik Enevoldsen
	Introduction to Session 6 - assessment needs and research gaps	
	D – human health risks	Todd Gouin
	E – marine environmental risks due to nano- and microplastics	Bart Koelmans
	F – marine environmental risks due to macro-plastics	Alex Turra
	Reporting back	
18: 00 Day 2 closes		

Day 3		
Time	**Session**	**Chair/Speaker/Lead**
09:00	Summary of Day 2, introduction to Day 3	Peter Kershaw
Session 7 09:15 – 13:00	Roadmap for improving risk assessment of marine plastics and microplastics	Chair Dick Vethaak
	Introduction to Session 7 – break-out groups (as Day 1 - A,B,C)	
	A – roadmap for improving risk assessment	Melissa Wang
	B - roadmap for improving risk assessment	Ralph Schneider
	C - roadmap for improving risk assessment	Bethanie Carney Almroth
10:45 – 11:15	Coffee/tea	
	Break-out groups continue	
12:00 – 13:00	Reporting back	
13:00 – 14:00	lunch	
Session 8 14:00 – 16:00	Next steps Opportunities for cooperation and synergies Suggestions for future GESAMP WG40 work programme	Chair Peter Kershaw
	Wrap-up	
16:00 Workshop closes		

Annex IV Summary table: environmental and societal risks due to macro-plastics – incomplete working document

Note: This table addresses exposure, hazards and risks associated with macroplastics in the marine environment. Ideas and notes here are based on discussions during the workshop.. There are large knowledge gaps and therefore a degree of speculation/hypothesis is inherent in the interpretation of this exercise.

				Chronic or acute/immediate			Occurrence and severity of a hazard (*litter)			
Policy concerns - Problems/issues	Environmental Impact/health / SocioEconomy	Description	Focus	Relevance	Scale	Inputs	What do we know?	What we need to know?	Indicator (trying to *SDG 14.1)	3. Challenges/Opportunities (**GAPS**)
Navigational and Industrial hazards										
Maritime transport/navigation (propellers/cooling systems)/safety	5	Link to UNEP (2016) UNEA Report; FAO methods Report (2017)	Loss of life; Loss or damage to vessels	Unacceptable loss of life; Economic costs to industry (shipping, fisheries, recreational, cruising, navy)	Global, with hotspots (shipping lanes, fishing areas, zones of accumulation of litter)	Nature of the material/item types	Main shipping routes Fishing routes and grounds (locations) in the highseas General distribution of macrolitter in the ocean	Distribution and abundance of litter that can affect vessels (collision; clogging cooling system; entaglement of propellers/steering gear - ropes/nets) Probability of encounter in the sea	Annual cost to a given sector/industry Annual loss of life for that particular sector/industry	IUU fishing; Governance and enforcement BNJ; Small-scale fhishing;
Divers entanglement (rescue operations, leisure)	5									
Industrial plants – cooling water, desalination plants	5									
Fisheries and Aquaculture										
Economic species and the effects on socieeconomics										
Entanglement & Ghost fishing: loss of income; food security (reduction in offer of protein)	5		economically relevant species	Loss of income Reduction of fisheries stocks Compromise food security	From local to Global		Info from beach/seafloor surveys; particular; fishermen associations; FAO; For traps in well regulated fisheries we know the number/proportion of loss gears	Map of commercial species prone to entanglement/ghost fishing. Map of lost fishing gears in the ocean (by type/region/country)	Number (or proportion) of ALDFG lost per year for a particular fisheries/location Abundance of ALDFG in the sea Proportion of ALDFG effectivelly entangling	Information on IUU fishing; Governance and enforcement BNJ; Small-scale fishing;
Pick out litter from fishing nets - damage of fishing gears; loss of income										

Annex IV continued

Policy concerns - Problems/Issues	Occurrence and vulnerability of organisms/activities/economies/sectors that could be affected by the hazard: What do we know?	What we need to know?	Indicator (trying to ~SDG 14.1)	Challenges/Opportunities (GAPS)	Risk	Target/Reference	Costs/Benefit: Transversal aspect - Consider the cost aspects to deal with issue, e.g. clean ups, in the equation	Action	Do we know the risk perception and the societal responses?	Assessment methodology that could be used Sources of information
Navigational and Industrial hazards										
Maritime transport/navigation (propellers/cooling systems)/safety	Some types of litter are more likely to cause damage (qualitative info) Reports of incidents (fragmented; not exhaustive)	Main shipping routes Fishing effort in the highseas Frequency of occurrence of incidents (probability of incidents) Ship-specific / litter-specific vulnerability to damage Severity of incidents	Number (proportion) of vessels affected Number of incidents (Hong et al., 2017) Costs: direct costs to repair; direct costs of rescue services; indirect costs of being out of commission	Getting the quantitative, compreensive, accurate information on incidents, costs, specially for recreational activities and small-scale boats		To reduce cost to an acceptable amount of money Zero loss of life Reduce cost to certain amount				Link to UNEP (2016) UNEA Report
Divers entanglement (rescue operations, leisure)										
Industrial plants – cooling water, desalination plants										
Fisheries and Aquaculture										
Economic species and the effects on socioeconomics										
Entanglement & Ghost fishing: loss of income; food security (reduction in offer of protein) Pick out litter from fishing nets - damage of fishing gears; loss of income	Well regulated fisheries inform where and how much is out there (partial information)	Commercial fish distributions (where and how much) Species-specific / gear-specific vulnerability to entanglement	Proportion of individuals entangled per species Number (biomass) of organisms dead Number of organisms injuried by entanglement Loss of income	Lack of information on impact, especially for non-regulated or poorly-regulated fisheries;	Spatial probability model based on the overlap and integration of the information	Reduce loss by X% Increase catch by Y% Increase income by Z%	There are benefits for investing in gear location and removal (environmentally sound and risk-based removal)	Marking; Targeted (lost fishing gears) removal Regulate fisheries	Traps, that are more coastal, are more tangible due to the more direct relationship between loss of traps and loss of income in comparison to open ocean loss of fishing gears, which is more driven by perception... By-catch (dolphins...)	Link to UNEP (2016) UNEA Report

Annex IV continued

Policy concerns - Problems/Issues	Environmental impact/health / Socioeconomy	Description	Focus	Chronic or acute/immediate Relevance	Scale	Inputs	Occurrence and severity of a hazard (~litter) What do we know?	What we need to know?	Indicator (trying to *SDG 14.1)	3. Challenges/Opportunities (GAPS)	Policy concerns - Problems/Issues
Biodiversity (and ecosystems)(animal welfare?) Destruction of Habitat / Mechanical damage to ecosystems (smothering coral reefs)	E		Sensitive habitas (CBD/EBSAs)	Loss of ecosystem function				Map the sensitive habitats at the relevant scale Map the damage at the relevant scale	The proportion of habitats damage and the total area of habitat damaged		**Biodiversity (and ecosystems)(animal welfare?)** Destruction of Habitat / Mechanical damage to ecosystems (smothering coral reefs)
Alteration of habitats - Reduction in light penetration in the sea (algae – photosynthesis decreases) Impact on water quality due to alterations in temperature, dissolved oxygen etc. Change of habitat (e.g. 7% plastic)(e.g., polips of jellyfish, egg laying site etc...)(*available substrate)	E E										Alteration of habitats - Reduction in light penetration in the sea (algae – photosynthesis decreases) Impact on water quality due to alterations in temperature, dissolved oxygen etc. Change of habitat (e.g. 7% plastic)(e.g., polips of jellyfish, egg laying site etc...)(*available substrate)
Entanglement & Ghost fishing: loss of biodiversity	E		All species (fisheries, of conservation concern)			Acquaculture, Fish Aggregating Devices, traps, nets...					Entanglement & Ghost fishing: loss of biodiversity
Ingestion and consequences through the food web (including Endocrine disruption)(including land-based species as cows and goats) Transportation of organisms / Vector of deseases (e.g., Fish/coral disease - bacteria/chemical compounds transported)	E		economically relevant species								Ingestion and consequences through the food web (including Endocrine disruption)(including land-based species as cows and goats) Transportation of organisms / Vector of deseases (e.g., fish/coral disease - bacteria/chemical compounds transported)
Ecological impacts of transportation of organisms / Vector of invasive species	E		Potential non-indigenous species stablishment; Receiving locations	Can invade and affect native communities and also cause ecological impacts	Impact is local; Process is regional/global		Information from the 2011 Japan Tsunami Information on litter abundances/input Information about surface currents Some information of organisms (macrofauna and pathogens) found in floating litter	Types of organisms colinizing litter Origin of the colonization of the litter (previously fouled litter vs. "virgin" litter) Transport pathways Magnitude and frequency of extreme events Magnitude of continuous losses	Amount of litter arriving with organisms on it Amount of litter arriving from potential sources Amount of oceanic litter		Ecological impacts of transportation of organisms / Vector of invasive species
Economic impacts of transportation of organisms / Vector of invasive species Leaching of chemicals from plastics economically relevant species	E Process		Potential non-indigenous species stablishment; Receiving locations	Can cause economic impacts	Impact is local; Process is regional/global						Economic impacts of transportation of organisms / Vector of invasive species Leaching of chemicals from plastics economically relevant species

Policy concerns - Problems/Issues	Occurrence and vulnerability of organisms/activities/economies/sectors that could be affected by the hazard What do we know?	What we need to know?	Indicator (trying to "SDG 14.1)	Challenges/Opportunities (GAPS)	Risk	Target/Reference	Costs/Benefit Transversal aspect - Consider the cost aspects to deal with issue, e.g, clean ups, in the equation	Action	Do we know the risk perception and the societal responses?	Assessment methodology that could be used Sources of information
Biodiversity (and ecosystems)[animal welfare?] Destruction of Habitat / Mechanical damage to ecosystems (smothering coral reefs) Alteration of habitats - Reduction in light penetration in the sea (algae – photosynthesis decreases)						Les than X% or Y km2				
Impact on water quality due to alterations in temperature, dissolved oxygen etc. Change of habitat (e.g. 7% plastic)(e.g., polips of jellyfish, egg laying site etc...)(+available substrate) Entanglement & Ghost fishing: loss of biodiversity										
Ingestion and consequences through the food web (including Endocrine disruption)(including land-based species as cows and goats)										
Transportation of organisms / Vector of deseases (e.g., fish/coral disease - bacteria/chemical compounds transported)										
Ecological Impacts of transportation of organisms / Vector of invasive species		Areas of higher probability of litter arriving from the ocean with similar characteristics of the origin area Type of organism, source area and time to be colonized in the source region For microorganism it may not matter the time of colonisation (examin the connection between pathogens and wastewater)		Niche modelling						Link to UNEP (2016) UNEA Report
Economic impacts of transportation of organisms / Vector of invasive species										
Leaching of chemicals from plastics										
economically relevant species										

Annex V Summary table: environmental risks due to microplastics – incomplete working document

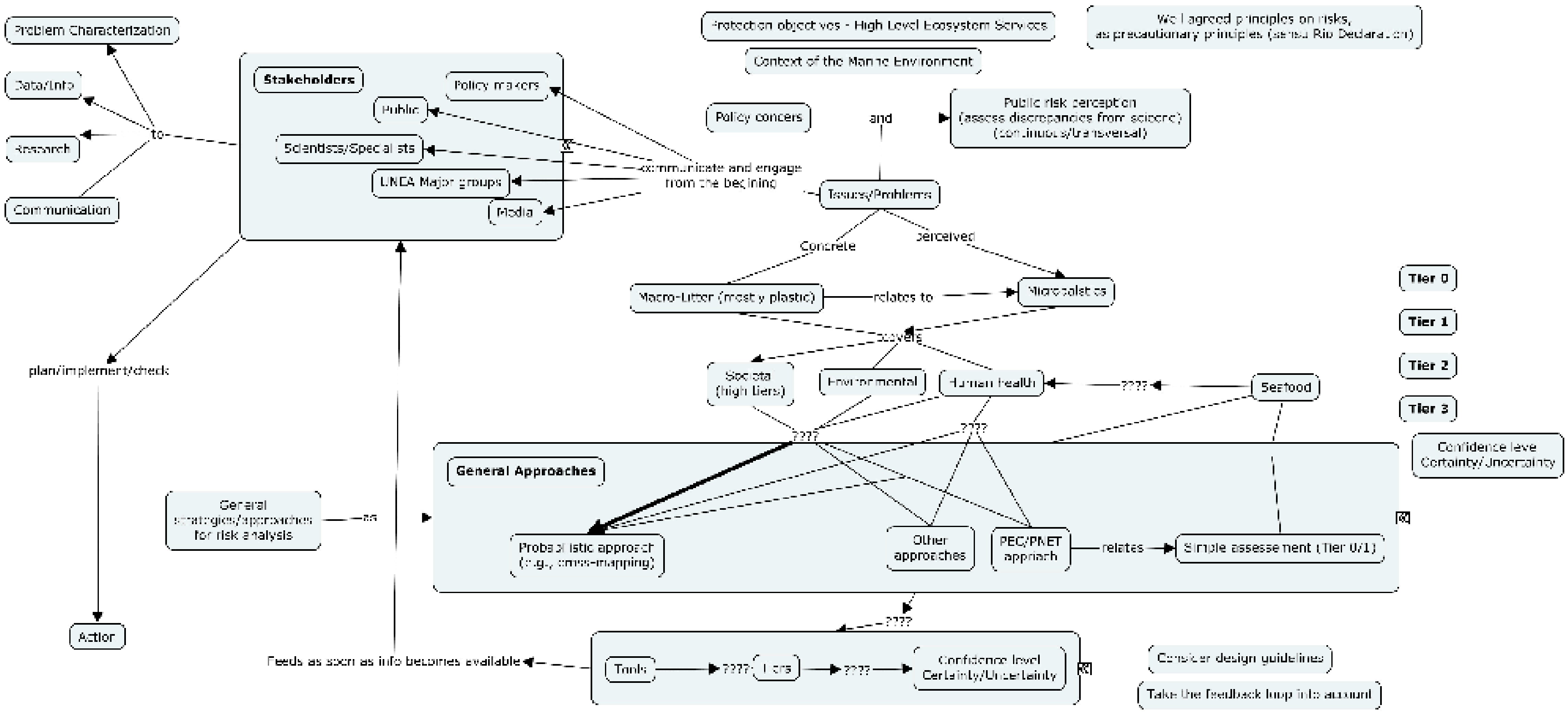
Note: This table addresses exposure, hazards and risks associated with microplastics in the marine environment. Ideas and notes here are based on discussions during the workshop. There are large knowledge gaps and therefore a degree of speculation/hypothesis is inherent in the interpretation of this exercise.

Policy concerns - Problems/Issues	Environmental impact/health	Description	Focus	Chronic or acute/immediate Relevance	Scale	Inputs	What do we know?	What we need to know?	Indicator (trying to ~SDG 14.1)	Challenges
Exposure/ environmental levels										
	E	concentrations/amounts of MPs in marine environemnts	surface water, sediment, biota, water column, hotspots, beaches/intertidal zones	half of our risk assessment -> exposure!	potentially global	primary microplastice, secondary MPs	concentration in different compartments, PNEC is exceeded in hotspots	sources, sinks, degredation rates, polymers, particle characterization (morphology, size, chemicals)	fulmar (?), sediment, filter feeders	harmonization, lack of temporatial spatial scales, nano, indicators
Particle effects										
nutritional dilution	E	physical mechanical damage to organisms/epithelial tissues, internal organs assuming uptake, nutritional dilution, gut obstruction	food chains, base of food chain, zooplankton, sediment inverts, filter feeders	individual species to large scale community impacts	local hotspots, accumulation zones, point sources	primary microplastice, secondary MPs	some edivence in lab experiments, inverts	low dose, chronic exposure, identify sensitive species	number or proportion of organisms with particles in gut , concentration of MPs in zooplankton, benthic organisms	
inflammation, immune effects	E	organismal health	all	sensitive species	local hotspots, accumulation zones, point sources	primary microplastice, secondary MPs			biomarkers - inflammatory markers, immune system effects	
	H via food	uptake of MPs via food (see health group), decreased food quality, decreased output from eg aquaculture	commercial food species	food safety, security, highly speculative, hypothetical	local hotspots, accumulation zones, point sources	primary microplastice, secondary MPs				
Chemical effects										
additives	E	chemicals included in production of plastic materials and goods, incl impurities (monomers, phthalates, pigments, UV-stabilizers, flame retardants, heat stabiliters, antistatic, NIASes, more than 1000 substances)	known toxicants, PBTs, substances of very high concern (SVHC); EDCs	(relevant for human health), relevance of MPs for spreading chemicals in environment is unknown, MPs as a vector for chemicals is thought to be small	local hotspots, accumulation zones, point sources	production of plastics, primary and secondary MPs	sporadic data from scientific literature, modelling indicates that MPs are not a major source of chemical exposure for organisms	more holisitc picture for all substances associated with different types of MPs in different environments		lack of data, costs, mixture toxicity
sorbed environmental contaminants	E	sorption of hydrophobic compounds, metals in the environment	known toxicants, PBTs, substances of very high concern (SVHC); EDCs	(relevant for human health), relevance of MPs for spreading chemicals in environment is unknown, MPs as a vector for chemicals is thought to be small	local hotspots, accumulation zones, point sources	sorption from chems in environment, polluted areas	plastics accumulate POPs, etc, but less is known about release in guts of organisms. sporadic data from scientific literature, modelling indicates that MPs are not a major source of chemical exposure for organisms	more holisitc picture for all substances associated with different types of MPs in different environments		lack of data, costs, mixture toxicity
food chain / secondary poisoning for humans	H									

Annex V continued

Policy concerns - Problems/Issues	Risk	Target/Reference	Costs Transversal aspect - Consider the cost aspects to deal with issue, e.g,	Action	Do we know the risk perception and the societal responses?
Exposure/ environmental levels					
	that we exceed the PNEC values, lack of harmonization, lack of technology, funding, lack of awareness (public, private sectors)	below PNEC	monitoring, technoligical advances, research	include in current monitoring programs	yes, some. MPs are a hot topic in USA, Europe, less so in Asia and Africa
Particle effects					
nutritional dilution					
inflammation, immune effects					
Chemical effects					
additives	we don't know enough for all substances and organisms, probably low				
sorbed environmental contaminants	we don't know enough for all substances and organisms				
food chain / secondary poisoning for humans					

Annex VI Example output from conceptual mapping tool.



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