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Marine plastic pollution as a novel entity within the Planetary Boundaries Framework

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Abstract

Could marine plastic pollution be integrated as a novel entity within the planetary boundary framework? We know that human activities are capable of changing the normal function of Earth-systems processes. One of the most evident contemporary anthropogenic activities is the use and disposal of plastic. Overall, plastics represent 10% of the solid waste weight. Furthermore, plastic items represent 95% of marine litter on a global scale. The magnitude of the effects of marine plastic pollution remains uncertain.

In this thesis, I analyse the perspectives of key experts on the social-ecological processes involved in marine plastic pollution. I use a driver-pressure-state-impact framework for the analysis of the interviews, to show how these experts see marine plastic pollution affecting Earth-system processes. I conclude that, from a qualitative perspective, marine plastic pollution does fulfil the criteria for chemical pollution to pose a planetary boundary threat, therefore it could be considered for inclusion in the planetary boundary framework.

Key words: marine plastic pollution, planetary boundaries framework, Driver-Pressure-State-Impact-Responses, microplastics, Earth-system processes, social-ecological systems.

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Abbreviations and acronyms

DPSIR	Driver-Pressure-State-Impact-Response
EEA	Environmental European Agency
MARPOL	International Convention for the Prevention of Pollution from Ships
MPP	Marine plastic pollution
OSPAR	Convention for the Environment Protection of the Marine Environment of the North-East Atlantic
PB	Planetary boundary framework

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A mis padres, por que sin sus esfuerzos, sacrificios y apoyo incondicional jamás habría llegado hasta aquí.

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I would like to thank my classmates for their unconditional help during these two long years. I would like to refer to "La Cuadrilla" for being the family I need in Stockholm. To Malin Eckel for her patience at home and for always having that special thing that will make me smile. Also, to Kari Synnøve Johansen for being the light in the dark Norwegian winter. To Elena Dawkins and Claudia Strambo for being my professional advisors and unconditional friends. To Matteo Giusti for being the ultimate savior. And finally, a special mention to Carmen Seco for teaching me the value of working with passion. Without her, this thesis would have materialised.

KAPPA

Objectives of the study

This thesis explores the feasibility of integrating marine plastic pollution (MPP) as a novel entity within the planetary boundary framework. The main body of this thesis is a draft manuscript for Ecology and Society describing my investigation. This Kappa gives more detailed reflection on methodology and other parts of my research experience that are outside the scope of a scientific article.

This Kappa is a discussion space for the systemic effects of marine plastic pollution (MPP) and it implication on the planetary boundaries, which few of the informants knew about before the interviews took place. Many of the informants coalesced around the topic and showed interest for further collaboration. That also allowed me to conduct this study as part of the project, not just as an external observer. This meant that the knowledge was gathered and the case for an MPP boundary was built up acknowledging the different perspectives and ways of action of the different stakeholders. It gave me a multi-perspective view not only about the issues of MPP but also from a professional perspective.

Methodology

The methodology chosen for this thesis is an exploratory case study (Yin 2013) to inquire into the feasibility of MPP as a novel entity. This approach was chosen because MPP represents a contemporary phenomenon dealing with a real world context in which causalities are not clearly evident; and it relies on multiple sources of data so evidence can be compared and triangulated. This allows for an in-depth description of a social context from a holistic and context-sensitive perspective. The views of the stakeholders involved (henceforth mentioned as informants) support the idea that MPP is an emergent, global, linked social-ecological issue (see section 3.1. for the chosen criteria to select the informants). MPP is currently a sensitive and politicised matter. To prevent the bias of preconceptions and to learn about this topic directly from the data, I used a grounded theory approach to inductively develop a systemic theory (Charmaz 1997;

Schutt 2011). The inductive approach for analysis of qualitative data allows significant or frequent themes to emerge as research findings from the raw data (Thomas 2003). Grounded theory allows for the development of an iterative and dynamic narrative of MPP (Bowen 2006). This approach is a good tool for learning-by-doing. However, the amount of data handled is considerable, which can slow down the process of analysis.

Literature review

A literature review was conducted to identify pertinent issues and topics regarding plastics in the marine environment.

This phase took place from September to October 2015. Searches were made on planetary boundaries and MPP research that was global in scope. Book chapters, scientific articles, documentaries, newspaper and social media information, were all drawn upon to understand the state-of-art of MPP and its political nature. This phase also revealed the leading lights in MPP and thus the key informants required for this study (see Appendix 1 for a detailed list of participants).

Internship at GRID-Arendal

In October 2015 I was contacted by Joan Fabres, GRID-Arendal Project Manager for Marine litter and State of Environment Reporting. Fabres, who became my co-supervisor, came across my profile on a Massive Open Online Course launched by the United Nations Environment Programme in cooperation with the Open University of the Netherlands and offered me an internship position at GRID-Arendal. The internship took place in Arendal, Norway, from 20th January to 30th March 2016.

In this phase, I was able to engage with other experts on the subject of MPP and participate in marine litter-related events, such as Hold Norge Rent (a marine litter conference) in Oslo and Plastic Europe Conference 2016. Joan Fabres' role was key for the understanding of the scientific, non-scientific and political dimensions of this issue. This period also gave me the opportunity, with the experience I acquired for my thesis, to participate in the process and contribute to the creation of the document *Marine Litter Vital Graphics* (Fabres, J; Savelli, H.; Schoolmeester, T.; Rucevska, I. and Baker, E.

2016. Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal. www.unep.org, www.grida.no)

Interviews and information gathering

Interview guidelines were given and ethical disclosure to informant's notes were collected during the interviews. All interviews were carried out through Skype except for two face-to-face interviews that were audiotaped. Three constraining factors should be taken into consideration in this study: there was no previous contact with any informant before this study started, thus, the network of informants had to be created from baseline; informants had very restricted time availability, therefore they focused their answers on what they considered most important according to their expertise; and third, sometimes the internet connection was poor or the server went down, so the quality of the sound made further transcriptions difficult.

Informal conversations

In some cases, informal conversations took place before or after the interviews depending on the time and willingness of participants. Although this information was not used for the data analysis, it provided me with new insights to better understand the problem. During this time, informants provided further information and deeper insights about the questions, once they did not feel pressured by being recorded as part of the interview. These notes are a valuable tool to reflect on the information that emerged, and triangulate the collected data.

Limitations of the theory and methods

The approach of Persson et al. (2013) was chosen to test the feasibility of integrating MPP as a planetary sub-boundary because so far it is the only research available on how to define chemical pollutants for the planetary boundary framework. In personal communication, Linn Persson (May 2016) suggested that this approach may not be perfect as the authors are aware that it has received many critiques.

Personal reflections

Most informants showed great interest in the social science angle of this study. Furthermore, most of them expressed the novelty, and necessity, of using the PB approach based on scientific data, acknowledging the major environmental problems that society faces in the Anthropocene, and expressed how this framing is important to convey information in a meaningful way that can spark political action.

1. Introduction

Human activities are capable of changing or destabilizing the normal functioning of Earth-systems processes (Steffen et al. 2015). One of the most evident contemporary anthropogenic activities is the use and disposal of plastic. This material has become so ubiquitous in our daily life that it has been proposed as a geological marker of the stratigraphic horizon of the Anthropocene (Corcoran et al. 2014; Zalasiewicz et al. 2016). Mass production of plastic took off rapidly during the 1940s and 50s (Thompson et al. 2009), and have shaped the development of the society as we know it (Andrady and Neal 2009; Thompson et al. 2009). A by-product of the oil industry, the development of plastics was initially part of a wildlife conservation strategy (e.g. avoid elephants being killed for their ivory or marine turtles for their carey) and signified cultural democratization following the Second World War, with the rise of the middle class (Fenichell 1996). Furthermore, it must be acknowledged that the benefits plastic brings to society are numerous (i.e. public health applications and technological advances, energy saving and societal benefits; Andrady and Neal 2009). Today, the plastic industry in Europe alone employs around 1.45 million people and has a turnover of € 350 billion (PlasticEurope 2015). Plastic resin production has increased by 620% since 1975, and by 2005 plastic represented 10% of solid waste by weight in more than half of the countries where data is available (Jambeck et al. 2015).

Carpenter and Smith first identified plastic pellets accumulation in the sea surface in the western Sargasso Sea in 1972. And just a few years before, Kenyon and Kridler (1969) first documented the impacts of MPP when ingested by seabirds. However, there was a relative silence in the scientific discourse around MPP and its socio-economic and environmental impacts until the late 1999s when new technology and investment allowed researchers to investigate these linkages. Despite progress in this field, the magnitude of impacts of MPP on both wildlife and humans remains unknown.

Box 1: Definition of marine plastic pollution

Marine litter (or marine debris) is defined as any manufactured or processed solid item or material – plastic, wood, metal, glass etc. – regardless of size that is deliberately discarded or unintentionally lost in the environment, including those transported into the marine environment (e.g. coastal areas, shores or the open ocean). This discharge comes from land by rivers, drainage or sewage systems, storm water, waves or wind or sea-source based such as discarded fishing nets (Galgani et al. 2010; UNEP & NOAA 2012). Plastic is the most abundant type of marine litter at a global scale, sometimes representing up to 95% of the waste accumulated in the marine environment (Galgani et al. 2015). Both these terms are linked to the physical presence of solid substances in the sea.

Marine pollution refers to the introduction of harmful or potentially harmful substances into the sea. However, this term can be politically ambiguous. It can refer to either the substances themselves and/or the moral responsibility for the harm caused by pollution. MPP was selected, as opposed to plastic litter or plastic debris, to highlight the socio-political nature of the material.

1.1. The nature of the problem of MPP

One of the major challenges in investigating the magnitude of impacts is the diffuse nature of plastic products among society, and the many routes they can follow to enter marine systems (Pruter 1987; Ryan et al. 2009). Thus, to understand the current problematic of MPP, it is useful to trace the stocks, sources, distribution and fates of ocean plastic as outlined in figure 1 (Cózar et al. 2014; Eriksen et al. 2014; Jambeck et al. 2015; Ryan et al. 2009).

Stocks

The amount of MPP reaching the ocean annually is unknown, however, several attempts have been made. Jambeck et al. (2015) estimate stocks of MPP in the ocean derived from mismanaged waste to be between 4.8-12.7 million tonnes, based on 2010 data. Cózar et al. (2014) estimate the mass of microplastics (particles <5 mm; UNEP & NOAA 2012) floating on the surface of the ocean to be between 7,000-35,000 tons while Eriksen et al. (2014) report over 250,000 tons of both microplastic and

macroplastics. Clearly there is discrepancy but as technology advances and more investment is made into this field it is likely this figure will become more accurate.

Sources

MPP enters the ocean from land-based and sea-based sources. Land-based sources represent the biggest inputs of MPP at around 80% of the total, however, this data is far from comprehensive (Jambeck et al. 2015). The main land-based MPP sources are untreated sewage and storm-water, run-off from landfills located in coastal areas, rubbish from the streets washed into storm drains, litter left by beach-goers, or the improper disposal of plastic material from the industrial production process. The size of the items reaching the ocean influences their effects and impacts (see section 5). Specially micro sized plastic particles like the ones used in cosmetics (e.g. toothpaste and body scrubs) or fibres used in clothes fabrics can be directly emitted into the environment through the drain and sewage system due to the inability to stop them at source (UNEP 2015). Also, extreme episodic weather events such as floods, tsunamis or cyclones represent major sources of plastic litter entering the ocean from land-based sources (Thiel & Haye 2006). These events will become more frequent because of climate change and thus become more prominent source of MPP in the future (ibid). Sea-based sources of MPP may or may not be accidental and include the loss/disposal of commercial fishing gear, and rubbish and other items discarded from boaters, big cruise ships and shipping vessels.

Distribution and fate

There is scientific agreement on the ubiquity of MPP accumulation around the convergence zones in the five sub-tropical ocean gyres as wind circulates these currents (Cózar et al. 2014; Eriksen et al. 2014; see Figure 2). However, wind is not the only driver of circulation. Marine organisms from all trophic levels redistribute plastic in the ocean by transporting and then egesting plastic in different locations from where it was ingested (Fabres et al. 2016).

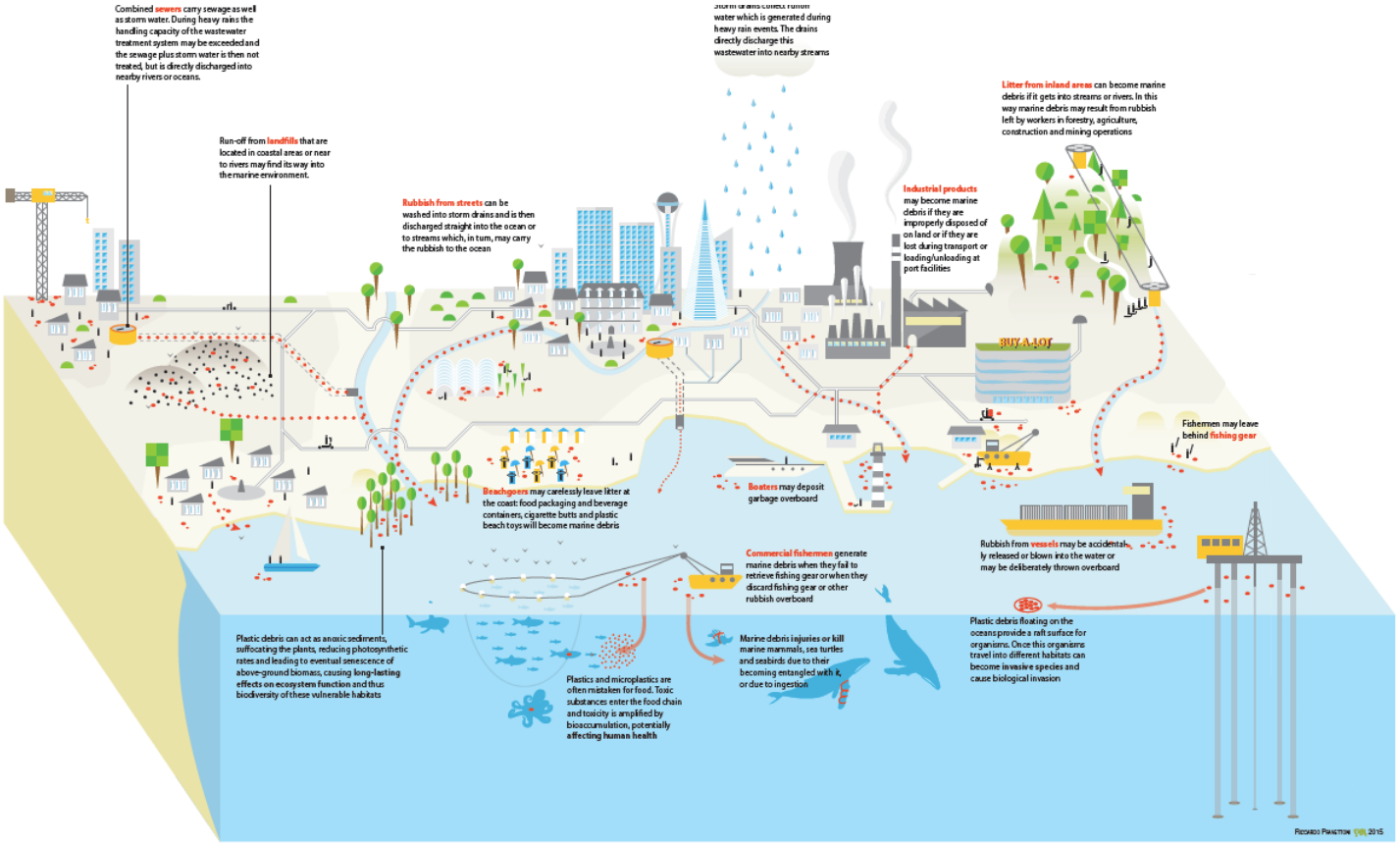

Figure 1: Sources and potential fates of marine plastic pollution. Source: Fabres et al. (2016).

Several other accumulation zones of anthropogenic material have been identified: the Mediterranean Sea with concentrations comparable to those in the sub-tropical gyres (Cózar et al. 2015); the Bay of Bengal, the South China Sea, the Gulf of Mexico (Lebreton et al. 2012) and even the remote areas of the Arctic, where microplastics particles have been reported in sea-ice (Obbard et al. 2014).

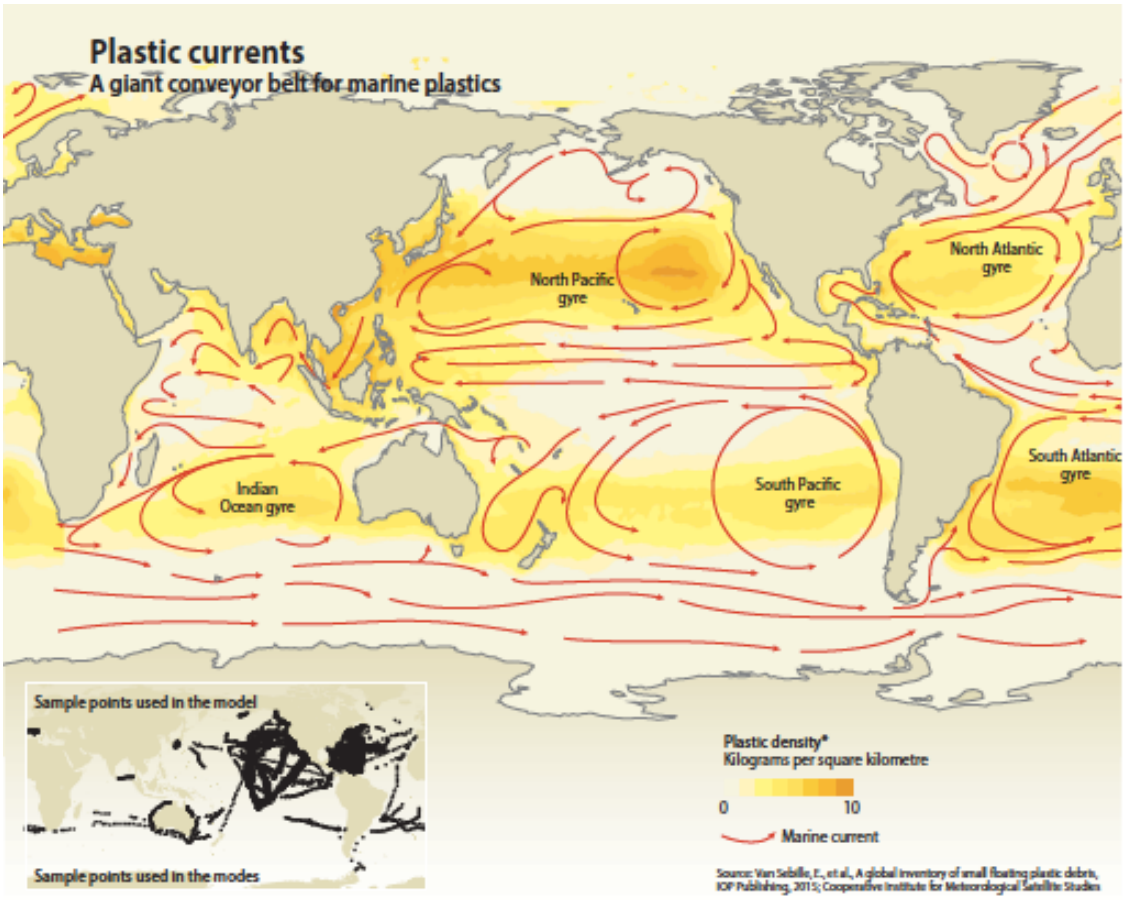

Figure 2: Global marine plastic pollution currents. Source: Fabres et al. (2016).

MPP is a global sustainability challenge. According to Freinkel (2011) MPP represents a clear example of the tragedy of the commons proposed by Garret Hardin (1968). Freinkel (2011) points out that the ocean is the largest mass of common property extension on the planet, making it difficult to deal manage and govern globally because it is a shared resource that belongs to everyone.

Vegter et al. (2014) points out that less than 5% of the literature on MPP addresses its social or economic dimensions. Thus in order to shed light on this critically important

area this study explores the feasibility of classifying MPP as a sub-boundary of the chemical pollution and novel entities boundary within the Planetary boundaries framework (Rockström et al. 2009). To do so, a qualitative analysis of stakeholder perceptions will be carried out.

Research Question

To achieve these objectives, the following question and sub-questions have been addressed:

Could MPP be considered as a novel entity that qualifies as a sub-boundary of the planetary boundary framework?

a) *What social and ecological processes involving marine plastic pollution affect Earth system processes?*

   For this analysis, in section 4, I have reviewed the literature and interviewed stakeholders involved in the current MPP debates, in order to explore the social drivers and activities that cause environmental pressure, the changes in state of the environment, the social impacts, and the responses to MPP.

b) Are these processes enough to demonstrate that marine plastic pollution should be integrated as a sub-boundary of the novel entities within the planetary boundaries framework?

   For this assessment, in section 5 I have discussed the basis of the planetary boundaries framework with scientists involved in global research and environmental monitoring on the topic of marine litter.

Conclusions are displayed in section 6.

2. Theoretical Framework

2.1. Social-Ecological Systems

Resilience thinking provides a framework that helps understand how and why a system behaves as it does (Walker & Salt 2012). The concept of resilience refers to the ability of linked human-environmental systems to cope with changes and disturbances while maintaining their inherent identity (ibid). This approach is increasingly being applied to linked social and ecological systems, where change in one domain leads to consequences in the other domain.

MPP is a consequence of our impact on our planetary system, constituting a complex social-ecological system that plays out across all scales of society, from the household scale through to the global scale, as mentioned in section 1 and outlined in Figure 3. This study draws together the evidence carried out across these scales so as to better understand links and dynamics among the social, economical and biophysical domain.

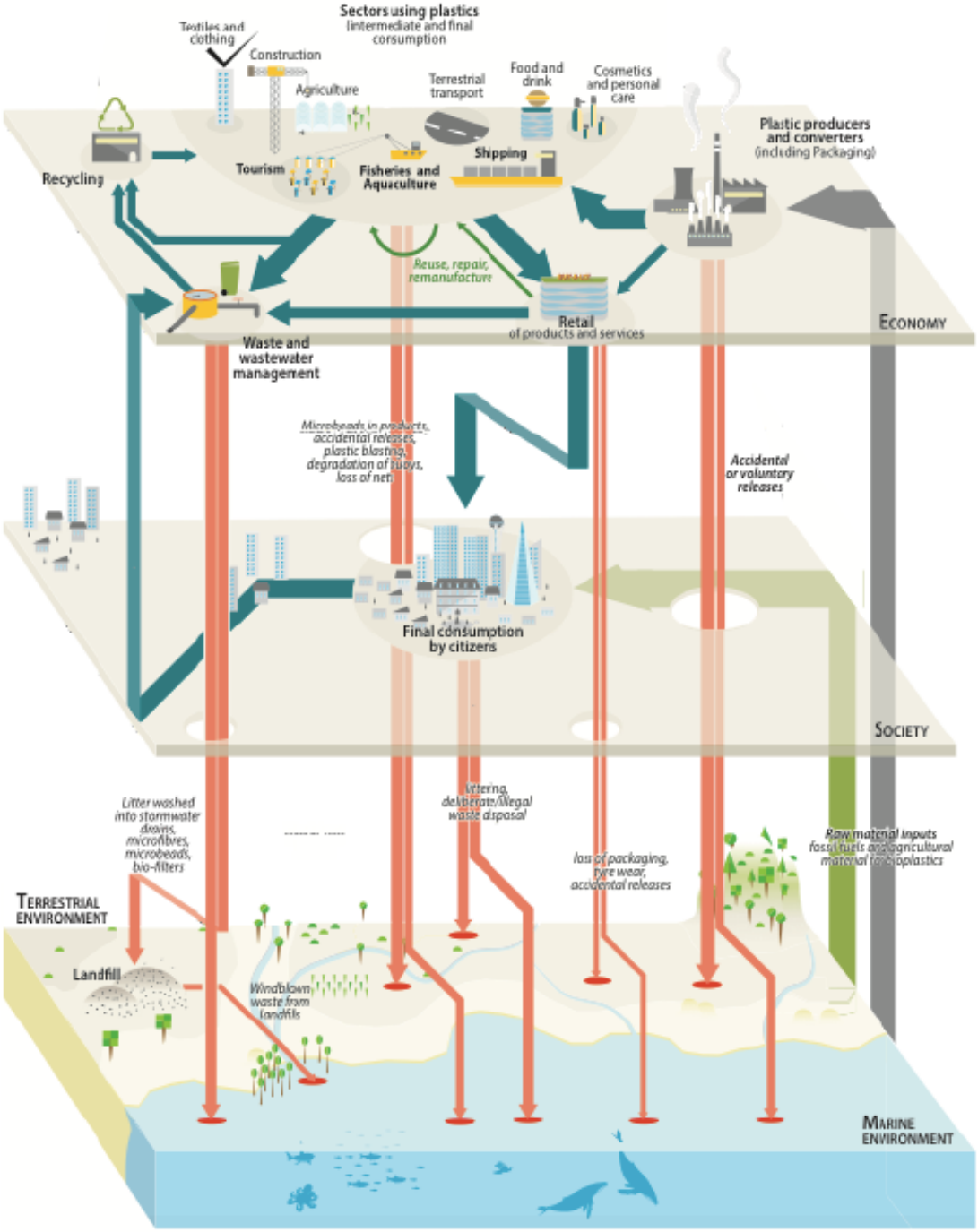

Figure 3: Representation of the social-ecological and the economic systems and how they interact with each other. Source: Fabres et al. (2016).

2.2. Driver-Pressure-State-Impact-Response Framework

In linked social-ecological systems, people's capacity for decision-making means that social systems can be prepared for change and manage change processes in ways that ecological systems cannot.

In political decision-making the driver-pressure-state-impact-response (DPSIR) framework is widely used among organisations such as the European Environment Agency. It is an integrated approach used to describe the interactions and relationships between the environment and the socio-economic domain through a chain of causal links (Maxim, Spangenberg, & Connor 2009). The DPSIR presents the causes, effects and impacts of environmental problems in a way that clearly shows the possibilities of impacting political choices (Kristensen 2004).

Figure 4 details the DPSIR framework. Drivers refer to the demands that society places on the environment, such as the need for energy or transportation. These demands lead to pressures or stress on ecosystems, which in this case are inputs of plastic litter into the marine environment. This may lead to negative effects on the state of the environment such as the entanglement of wildlife by MPP. These changes to the environment may build up and eventually impact society, which once impacted will seek to create a response to deal with the problem. All responses implemented need to consider the trade-offs between the main drivers and the desired responses towards reducing the impacts (Mee et al. 2015).

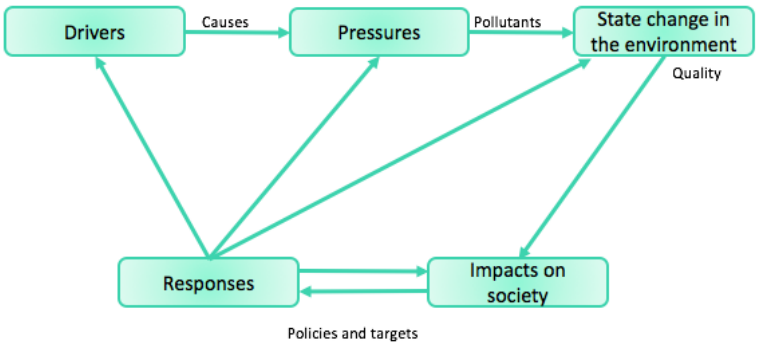

Figure 4: Visual representation of the DPSIR framework. This figure outlines the flow of causes, effects and impacts of environmental problems. Adaptation from: (Kristensen 2004) .

2.3. The planetary boundaries framework

The Anthropocene refers to a new geological epoch, signifying a time where human activities negatively impact and shape Earth System processes (Steffen et al. 2007). Among the pervasive anthropogenic changes reinforcing this epoch, hazardous manufactured chemical compounds (i.e. chlorofluorocarbons) have been identified as possible driving forces of changes in the environment (Crutzen 2002). There is growing consensus that the Anthropocene began following the post-1950 economic acceleration (Steffen et al. 2015). During this period material consumption grew rapidly. This was also when plastics became mass produced (Freinkel 2011). Steffen et al. (2015) identifies plastic as a parameter for the chemical pollution planetary boundary, but this assertion is yet to be qualified.

The planetary boundary framework (Rockström et al. 2009; Rockström & Noone 2009) outlines the need to remain within a safe operating space for humanity. The framework suggests possible measurable control variables for natural limits for social-ecological systems or processes affecting the Earth-system at global scale. By combining scientific data on the levels of anthropogenic perturbations to Earth system processes, they identified nine major environmental risks: climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading, interference with the global phosphorus and nitrogen cycles, rate of biodiversity loss, global freshwater use, land system change and chemical pollution, see Figure 5. Rockström and colleagues (2009)

also tried to identify quantitative indicators and set precautionary boundaries at a safe distance from thresholds (i.e. non-linear transitions in the Earth-system). Staying within these boundaries should enable the Earth-system to stay in a Holocene-like state. So far, there is reasonable scientific consensus that at least three boundaries, climate change, biodiversity loss and nutrient flows, have been crossed (Rockström and Noone 2009; Steffen et al. 2015). Rockström et al. (2009) were not able to set a boundary for chemical pollution. The authors indicated that this is due to the complexity of chemical pollution and insufficient data.

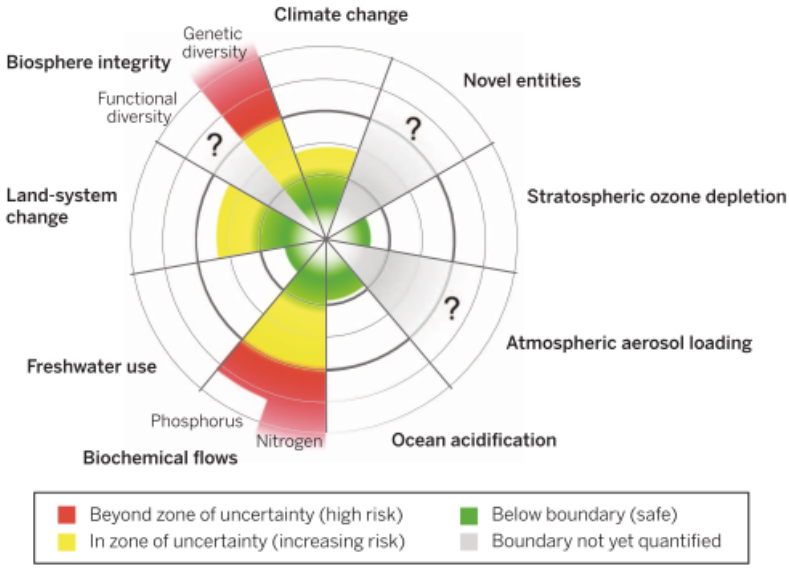

Figure 5: Representation of the current status of the control variables for seven of the nine planetary boundaries. Source: Steffen et al. (2015).

Conceptual developments in the planetary boundary framework

The diversity of chemicals released to the environment and their individual and interacting behaviour remains uncertain (Diamond et al., 2015). Thus, a fixed boundary and the thresholds that should not be crossed have not yet been defined.

Rockström et al. (2009) suggests control variables such as emissions and the concentration or effects of chemicals, i.e. persistent organic pollutants (POPs), plastics,

endocrine disruptors and heavy metals. Later, in 2015, Steffen et al. broadened the issue from just chemical pollution to a wider range of novel synthetic or anthropogenic entities released into the environment. Furthermore, MacLeod et al. (2014) indicated that the planetary boundaries threat from chemical pollution is indeed an unaddressed societal task.

The chemical pollution boundary was re-named the "novel entities" boundary to encompass the diversity of human-made products. Novel entities are defined as "new substances, new forms of existing substances, and modified life forms that have the potential for unwanted geophysical and/or biological effects" (Steffen et al. 2015, p7). These entities become a global concern when they exhibit: i) persistence, ii) cross-scale distribution and iii) the potential to impact vital Earth-systems processes or subsystems (ibid). In this same paper, plastics are identified as new entities.

Due to the complexity of this planetary boundary, Persson et al. (2013, p12619) state that "there is no single chemical pollution planetary boundary, but rather that many planetary boundary issues governed but chemical pollution exist". The authors detail three conditions that a novel entity must fulfil simultaneously to be considered within the novel entity planetary boundary framework. In the pursuit of a planetary boundary for chemical pollution, one year after, MacLeod et al. (2014) complemented this approach with a series of scenarios. These scenarios are used to identify potentially disruptive chemical pollutants. For a chemical pollutant to be classified as a novel entity in the planetary boundary framework, at least one of these scenarios must be fulfilled in addition to the conditions outlined in Persson et al. (2013). These scenarios are a first step towards defining humanity's pervasive impacts in terms of MPP. Table 1 represent the compilation of all the requirements proposed by Persson et al. (2013) and McLeod et al. (2014).

Table 1: The conditions (C) and scenarios (Sc) required for a chemical pollutant to be classified as a planetary boundary threat according to Persson et al. (2013) and McLeod et al. (2014).

C.1: Unknown disruptive effect on a vital Earth-system process
C.2: The disruptive effect is not discovered until it is, or inevitably will become, a problem at a planetary scale - Sc. C.2-1: Concentrations are nearly homogeneous - Sc. C.2-2: effects are rapidly distributed globally - Sc. C.2-3: there is a time delay between exposure and effects
C. 3: The exposure to the chemical pollution is poorly reversible - Sc. C.3-1: exposure to the chemical pollution is poorly reversible - Sc. C.3-2: The effects of the chemical pollution are poorly reversible

3. Methods and analysis

3.1. Informants selection

The initial criteria for selecting the interviewees was as follows:

- They have relevant expertise on the topic of MPP (e.g. actors in non-profit, academia, governance or the plastic industry).
- They are influential stakeholders in the wider policy or societal context, through active engagement and/or media communications (e.g. participants in documentaries and TedTalks).
- They gained research experience within developed or developing contexts, in particular around the sub-tropical gyres or other areas where plastics accumulate like coastal areas and the open ocean.

The informants' identification was iterative. Firstly, I used my own knowledge on the network of stakeholders, gained from prior experience (e.g. literature review, social media). Secondly, the criteria explained above were used to identify who would qualify as a key informant for this research study. Following each informant meeting/interview a snowball sampling technique commenced, leading to 18 key experts in the field. Care was taken to keep a balanced representation among informants. However, only one representative from the industry and one from the government agreed to participate in this study. The network of informants was made up to represent the individuals and organizations that had different interests in the MPP issue and approaches to researching/solving it (Latour 1996).

Many of the informants have overlapping roles as actors working within the issue of MPP. For simplicity, they were categorised according to their main role as identified by the informants themselves. The following categories emerged:

- Non-profit organisation and activists: they are the first to raise awareness of MPP among the public. They gather and compile information and bring it to policy makers and civil society. One of their main roles is to translate scientific information for the

layman. It should be highlighted that non-profits conduct independent research as well as education, prevention or political advocacy.

- Science and academia: they collect, monitor and analyse data to gather new knowledge that is then subject to peer reviews. Also, their role is to provide answers to scientific questions from an objective perspective. Scientists also provide support and help to implement policy making.
- Governments and policy makers: they act at many different levels, from the global to the local. They use policy as instruments to create more sustainable responses.
- The plastic industry (i.e. plastic producers, retailers, packagers, manufacturer and converters): they respond to the demands and desires of consumers. They are responsible for the innovation and improvement of product design and packaging.

Table 2 shows the different areas of influence of all the interviewees and/or their organizations.

Table 2: Areas of influence of all informants interviewed regarding marine plastic pollution (each interviewee has an associated number).

	Informants number																	
Areas of influence	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
- Providing funding	-		X				-			X						-	-	X
- Generating political support										-					X			
- Providing political support	-	-		X		X	X	X		X	X	X			X	X	X	X
- Knowledge creation	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
- Monitoring and inventories	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
- Education to children	-	X	X	X	X		X	X	-	X	-				-	X	X	X
- Awareness raising	X	X	X	X	X		X	X	-	X	X	X	X		X	X	X	X

3.2. Data analysis

Semi-structured interviews

Semi-structured, open-ended interviews were chosen in this thesis to balance reliable, comparable information and allow new insights on the topic to emerge. The DPSIR framework was used to structure the questions of the interviews. The DPSIR framework simplifies complex dynamics into the main causalities, which can be addressed with specific questions, and which can then be used to advise policy (Kristensen 2004). Furthermore, it is a useful way to frame social-ecological concepts when introducing them to the informants (see interview guidelines in Appendix 2).

Two interviews (numbers 8 and 16) were carried out face-to-face. All others were via online video conferencing (Skype) from November 2015 to March 2016. Interviews were audio or video recorded depending on the willingness of the participants, with each interview lasting around 1 hour. With the exception of the plastic industry, informants did not request anonymity. Thus, quotations and statements used are attributed directly to the participants.

Extracting qualitative data

Interviews were transcribed and grouped by recurrent themes and patterns using Nvivo software. An inductive approach was used to first analyse the data and reveal emergent themes, concepts and relationships. Then a deductive approach was applied to create codes relating to planetary boundary and DPSIR concepts.

The coding analysis was an iterative and progressive process constituted of two phases. First, all interviews were read to identify common themes, patterns, viewpoints, as well as attitudes and conflict of interests. Second, interviews were re-read to identify themes that are not common among all informants, but are relevant as results because are reflections of their specific expertise. New themes were then integrated into the analysis as they emerged (see Appendix 3 for coding guidelines). In order to avoid missing important information, all emerging categories and patterns were treated with the same level of importance.

Finally, the analysed patterns and themes were used to compare the information extracted from the interviews and identify whether MPP fulfils the necessary conditions of a planetary sub-boundary in accordance with Persson et al. (2013).

4. Findings

All results presented here are extracted from the content of informants' perceptions on the topic of MPP.

The themes resulting from coding the interviews are valuable to understand the connection between MPP and PB as they are complementary sources of insights.
First, some themes are the most recurrent answers emerging from the informants' understanding of the topic. Second, some are topics where there is either strong consensus or strong debate, and third some themes are exclusive and represent the specialized knowledge of some informants.

4.1 From social drivers to multiscale responses

The driving forces and pressure on society

Interviewees highlighted several economic and industrial drivers triggered by social demands for plastics that create pressures on the environment. One of the most mentioned drivers is that plastic brings multiple benefits to society due to its durability and inexpensiveness, for example. Such aspects could be behind consumer demand (e.g. single-use products consumption and throwaway living, dependency on convenience):

> *"I don't know if consumption has really increased consumerism, has it increased? I don't know. It is not my field of study but it sure seems like that. Just from my personal experiences as a mom and living my childhood in terms of the quantity. Let's say the quantity of toys I had and the quantity of toys my kids have; it's way more. And then, I realise, as a personal anecdotal manner, we just have more stuff in the world"*
>
> (Jenna Jambeck, University of Georgia)

However, due to both its ubiquity of use in our contemporary daily life and because this material will never degrade once it is in the marine environment, it poses a big environmental hazard. Another driver mentioned among most informants is the inefficiency of waste management systems for both developed and developing

countries. Informants gave special attention to developing countries, where a growing middle class has been associated with increases in plastic production and usage, while lacking proper waste management infrastructure. Also, the willingness of the plastic industry, whose interest remains on keeping high levels of production and manufacturing in the global market, poses an important driver according to informants:

> *"Marine litter is a symptom of an inefficient business model associated with the way that society uses plastic. (...) I firmly believe that there is a role for industry to design plastics for end of life, for policy makers to use policy instruments to help [us] to move towards more [a] sustainable use of resources and to reduce the accumulation of waste and [for] our citizens to respond to those things. I stress that it will take a long time; there is no quick fix to this because we [have] had 40 or 50 years of training [in how] to just throw things away, to use material in a linear fashion. And some of that linear use of resource is resulting in the accumulation of litter in the environment."*
>
> (Richard Thompson, Plymouth University)

Pressures to the marine environment

Pressures on the marine environment concern leakages (involuntarily or voluntarily) and inputs of plastic into the ocean. A distinction between land-based (e.g. from littering or the mismanagement of waste in coastal areas) and sea-based (e.g. lost or discarded fishing gear) inputs of MPP was highlighted as key for developing future intervention strategies.

> *"For instance, we have these mammals where you have the fishing gear around their necks. You have nets that keep fishing on the process that we called ghost fishing. They can keep entangling commercial species and endanger species. I would also classify as a top risk, fishing gear. We have: packaging from inland, and fishing from ocean based source"*
>
> (Julia Reisser, The Cleanup Project Foundation)

Two informants also mentioned extreme weather events (e.g. tsunamis and hurricanes), which are increasing due to climate change, as a pressure on the environment. Thus,

MPP can be seen as an anthropogenic driver playing out throughout the global marine environment.

MPP and the state of the marine environment

Most interviewees acknowledged potential biophysical indicators to assess MPP-impacts on the environment, such as the volume of MPP in the water column or among sediment on the marine bottom and coastal areas. They highlighted that plastic can be found even in the most remote areas of the ocean, and as such some viewed plastic as a geological marker horizon of the Anthropocene.

"*The geology of the Earth surface is going to have this long little layer of sediments that marks our time, human history. We thought it was black carbon from the industrial revolution or radioactive isotopes from all the bombs tests in 1950s; but today the most visible fossil that represent[s] us is going to be microplastics. In the deep sediments worldwide and even in the shredding of plastics in our cities, rivers and streams, there is a layer of plastics everywhere*"

(Marcus Eriksen, 5Gyres)

Ingestion and entanglement of plastic pieces by animals, most commonly sea-birds, turtles and whales, was highlighted as the most recurrent effect of plastic on the state of the environment.

"Fishing gear is made of plastic; and because it is made of plastic, once it's lost it will continue to exist because it doesn't degrade and can have [a] really large impact on [the] entanglement on marine animals"

(Nancy Wallace, NOAA's Marine Litter Program)

There was disagreement among interviewees about whether or not plastics can be transferred along the food chain, with the exception of nano-size plastic particles.

Several informants highlighted that a crucial indicator is the chemical toxicity of plastic over the ecosystem and the possible bioaccumulation of toxic compounds. This is because plastics do not only leach chemical pollutants to the environment but also

absorb additional pollutants that are already in the marine water such as e.g. persistent organic pollutants (POPs) or bisphenol-A (BPA). Some informants showed concern of the possibility of MPP being linked to the bio-magnification of contaminants.

> "*UNCW [University of North Carolina Wilmington] proved that micro-zooplankton ingests plastics, what is very significant when you look at the trophic level. When marine life ingests organisms they get 10% of the energy of that animal they've ingested, however, they get 100% of the chemical [into their organisms]. In other words, in every step of the food chain those chemicals are being added a 100% in every step of the way. And that is why it is a big concern*."
>
> (Bonnie Monteleone, Plastic Ocean Project)

In addition, MPP greatly affects the environment because it acts as vector of transport for alien species. This indicator should not be underestimated because each plastic particle could be a vector of transport for not just one but several species.

> *"5.000 billion is the number provided by Eriksen on microplastics and large plastics floating at the surface of the sea. So, 5.000 billion plastics particles are going everywhere, and slowly. These are vectors of transport. The question is if there is a potential risk. This is quite important but we don't know so much about it".*
>
> (Françoise Galgani, IFREMER)

Impacts on society

MPP effects on the environment are coupled to impacts on people's health, wealth and wellbeing. One of the biggest disagreements in informants' opinions is the potential risk for human health due to the presence of plastic along the marine food chain. Informants highlighted the detrimental effects of MPP on the marine aesthetic. They also mentioned that MPP can lead to physical risk from injury and/or death of sailors and marine professionals because, for instance, discarded plastic fishing nets can block engines and sailors can become entangled in these nets. It should be noted that the last report submitted in UNEA 2 (UNEP 2016) considered the connection between health and MPP to be limited, while my interviews took place from November 2015 to March 2016.

"Certainly, the impacts and risks associated with the fact that the more plastic pollution enters into the marine environment the higher the risk to natural resources and to our social wellbeing"

(Nancy Wallace, NOAA's Marine Litter Program)

Two informants also made a link between MPP and poverty. This social aspect related to MPP has not been broadly covered by science yet.

"An environmental issue is litter and how this litter affects ocean communities, how they affect human health in particular, and how it highlights the issue of lack of proper waste management, [which] comes back as a social issue. So the social issue around this issue in particular would be the behaviour in this age of convenience"

(Kristal Ambrose, Bahamas Plastic Movement)

"If you look at the hierarchy of social class, the poorest of the poor are living on our trash. Nobody likes to have trash within the proximity of their homes. But the richest of the rich don't mind that the poorest of the poor are living in and near our trash. And if you look at the in flows of business and government, that trash often goes to the regions where the poorest live or goes to the environment that we all want to share. So there is a social inequity, there is an environmental consequences and a lot of injustice that happens to people that don´t have the power to have a say where [the] trash should go"

(Marcus Eriksen, 5Gyres*)*

Responses to MPP

When social impacts are made evident they produce reactions in society that can promote actions to deal with the problem, by trying to prevent, mitigate, repair or adapt to the new information. As more MPP effects are proven, multilevel and multiscale responses have taken place, from political and governmental arenas to societal activism. Some informants highlighted that several international-global agendas, such as the Sustainable Development Goals (see Appendix 4, Table 6 for targets that are directly link to MPP) and the Group of 7 (G7), include MPP as one of the priority problems to tackle (see Appendix 4, Table 5 for major policies and initiatives mentioned by informants and complemented with literature).

Mitigating responses like behaviour change has been highlighted as one of the most relevant social responses. For instance, educating children, who are malleable and do not perceive life without plastic as difficult in the way adults often do, is indicated as one of the major ways of action to respond to the problem. Informants also highlighted the delay in noticing the effectiveness of those actions as they can take generations to prove successful. Thus, raising awareness among consumers towards more responsible habits (e.g. avoiding single use items and a throwaway life style) is also one of the main action responses that are being put in place. These actions are led largely by non-profit organizations (e.g. Algalita and Bahamas Plastic Movement), activists, and celebrities (e.g. Chris Jordan and Jack Johnson) through the use of documentaries, music and/or media platforms. Governments and the plastic industry (e.g. PlasticEurope) also provide funds and information resources to respond to the problem of MPP.

According to those interviewed, in the last few years, microsize plastic particles have captured the attention of a growing number of research fields from ecology, ecotoxicology or chemistry, although this creates challenges for policy makers as it results in multiple definitions, concepts and methods. Some standardization would be help to "normalise" the issue and make it more understandable for a lay audience. Also, the size of plastic particles present in the marine environment is considered to be an important topic due to the different effects, fates and interactions with the environment (see Appendix 5, Figure 6 and Figure 7). However, informants highlighted that MPP is a continuum; macroplastics from today will degrade and become the microplastics and nanoplastics of tomorrow. Thus, most remarked that policy responses should not prioritise one size over another. They conclude that all kinds and sizes of plastic should be prevented from entering marine ecosystems.

"The microplastics on the surface of the sea it's just a little percentage of the total [marine] plastic. By number it represents the 99-98%, but by weight it is 2-3% only, maybe the 10%, maximum. So, it means that the contaminants that will fix on microplastic is far less because it is related to the weight, is far less than the quantity of the contaminants that will fix on larger debris. But most people focus on microplastics, they say that - microplastics are a vector of contaminants. But it is not the microplastics, it is just the plastics. So, it is quite important to make sure that when we

are focusing on one aspect, it can not be in the microplastics only because most of the times large debris are more important."

(Françoise Galgani, IFREMER)

Most informants consider up-stream inputs and plastic production as some of the most important responses towards preventing the problem of MPP. Two informants proposed the re-classification of plastic as a toxic harmful compound. In this way the plastic industry would be compelled to make a life cycle assessment of plastic products. The relevance of this response is that the management of used plastic product would not be treated as regular household waste.

"We suggested that plastic should be reclassified as toxic compounds. In this way, we believe this can be helpful to tackle the plastic problem. This is because once plastic is considered as a toxic the industry will have to take care of what happens with products at the end of their life. In this way plastic can't be treated just as the rest of household waste"

(Lorena Ríos, University of Wisconsin Superior)

Figure 6 synthesizes the overall perceptions given by the informants about the main social and ecological processes involving marine plastics pollution affecting Earth system processes structured using the DPSIR framework.

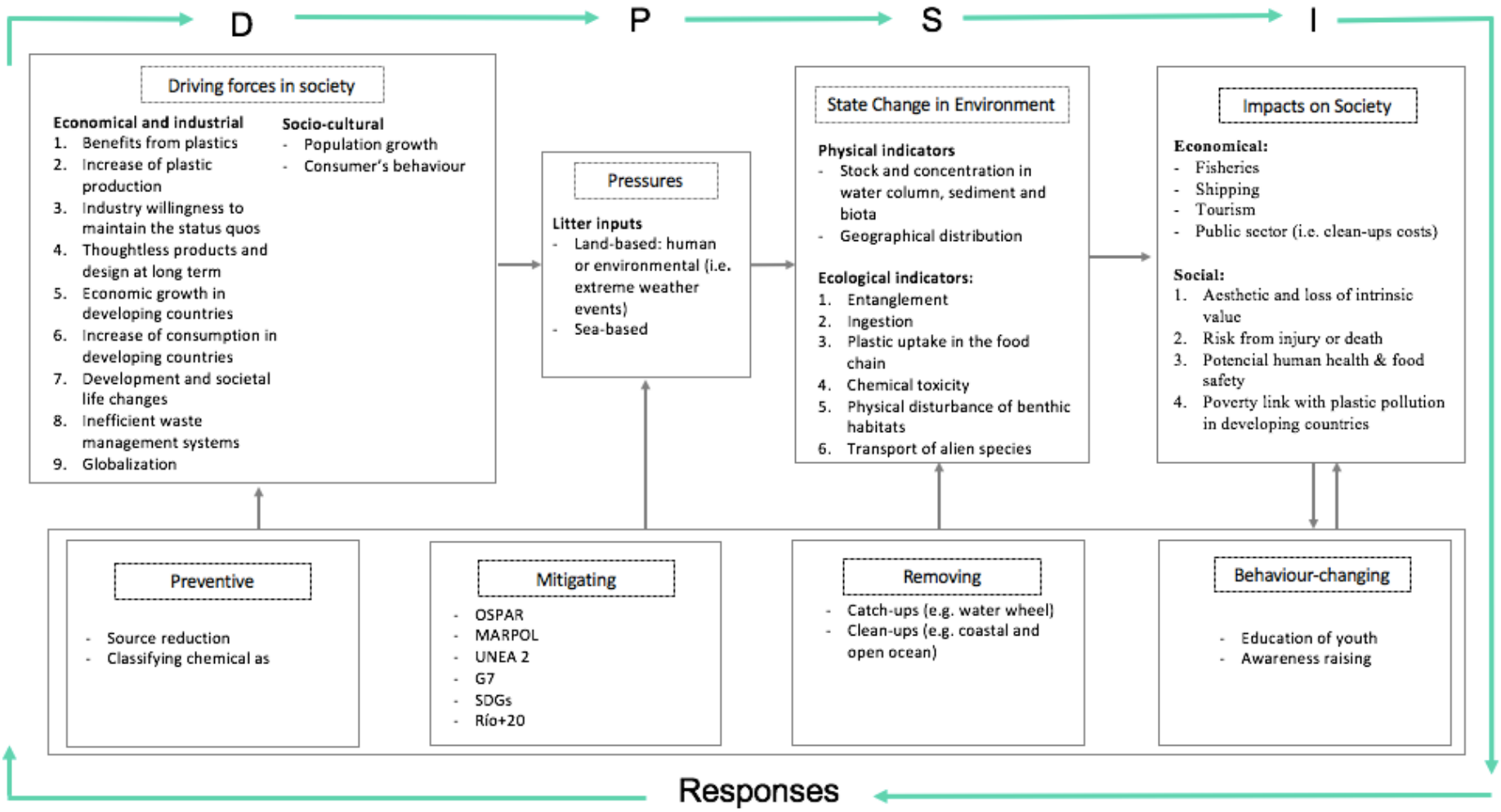

Figure 6: DPSIR built based on informants' perceptions.

5. Discussion

5.1. Marine Plastic Pollution as a sub-planetary boundary of chemical pollution

In this section MPP is discussed as a sub-planetary boundary of chemical pollution to answer the second research question, on necessary conditions and scenarios that MPP must fulfil in order to be regarded as a potential sub-planetary boundary (see Table 3):

C.1. Unknown disruptive effect on a vital Earth System.

At the same time that the interviews for this study were developed, new insights about the effects of MPP in the marine environment were published. For instance, one informant highlighted the possibility of posing MPP as vector for preventing carbon sequestration by oceans, which would decrease the buffer capacity of the ocean towards climate change. This would also decrease the flow of nutrients, N and P from the surface and the water column to the deep ocean. Just after that interview, (Cole et al. 2016) demonstrated that "microplastics can significantly alter the structural integrity, density, and sinking rates of faecal pellets egested by marine zooplankton". Faecal pellets pose a novel vector for microplastics. This would demonstrate the link of MPP with other major environmental problems, including those on the planetary boundary framework.

> *"Captain Moore pointed out that marine snow, the plankton and other organisms that fall from the surface as it decomposes… we see that these plastic fibbers are actually catching that marine snow as they are attempting to fall down the water column. And there is a direct connection between that process in the way that the ocean sequesters carbon from the atmosphere. So, it is kind of a stretch but is something to investigate and think about. Is there any connection between plastic in the ocean and climate change?"*
>
> (Katie Allen, Algalita)

Furthermore, adverse outcomes to oysters relating to structural growth, energy uptake, feeding behaviour, energy allocation and reproduction have been linked to high concentrations of microplastics particles (Sussarellu et al. 2015). Some interviewees highlighted the fact that these results were obtained from experiments in the laboratory, not in a natural marine environment. However, it could be speculated that if this situation occurs in certain natural environments they could potentially lead to trophic cascades, which could affect the dynamic of the whole food web (Österblom et al. 2007).

> *"We are seeing population levels decline, or assemblages changing from all of the plastics that are in the ocean, or we are seeing increases in chemical contaminants because of the increase in plastic, which is then causing toxic effects. So, I think, environmentally [there] is more ecological risk and harm"*
>
> (Chelsea Rochman, UC Davis)

However, the common perception among most interviewees is the uncertainty towards what are the real magnitude of effects, and the scale, of MPP. An issue of relevant concern is the uncertainty of how MPP reach humans through fish and seafood. This issue represents one of the central debates among people working on the field:

> *"…In my view, and from the data I have seen so far, the quantities of plastics in species of fish and shellfish are relatively low and you need to eat a lot of those individuals or species in order to get any kind of major dose. What is more probably, is greater exposure to microplastics from your home or work environment, from the clothes that we wear, the carpet we walk on and all of the various things that we use, like the cosmetics we use."*
>
> (Richard Thompson, Plymouth University)

> *"Socially, I think it is also awareness of the human health aspect associated with the presence of plastic in the ocean in terms of the fact that it is now in our food chain and that we know that the fish, mussels and oysters that we eat have plastic in their stomachs (or in their meat if it's a bivalve). And so, how is that causing harm to*

humans? Specially to humans that live in areas where there is a lot of plastic pollution and [where they] ingest sea food as a main source of protein"

(Chelsea Rochman, UC Davis)

Furthermore, this also links to the increase of the amount of microplastic debris in the marine environment due to the fragmentation and degradation of macroplastics into smaller particles. This should not be underestimated according to informants. Nowadays, the ratio of natural sand and micro size particle is 50:50 in beaches that are hotspots for the accumulation of this kind of debris. Thus, even if inputs of plastics into the ocean decrease substantially in the near future, or even reach the zero inputs, the macroplastic already in the marine environment will eventually become microplastics.

"Hawaii is an excellent example; if you take a sample of sand from beach you will be taking plastic. I think the ratio natural sand-micro size particles in Hilo beach is about 50-50%, 50% is sand and the other 50% is plastic. This changes the beach's dynamic, the absorption of water and everything else. The whole ecosystem life is changing there".

(Lorena Ríos, University of Wisconsin Superior)

The development in the MPP issue means that knowledge, understanding or perception about the effects or impacts we have today, for example, will greatly evolve in the coming months and years. However, many uncertainties still surround MPP.

C.2. The disruptive effect is not discovered until it is, or inevitably will become, a problem at a planetary scale

Sc. C.2.1. Concentrations are nearly homogeneous on a global scale

As exposed in Section 1, ocean currents move MPP all over the globe. Interviewees expressed a growing consensus in moving from classifying accumulation zones by patches to a more global view on accumulation and distribution zones. Some interviewees also highlighted that the magnitude of MPP accumulated in coastal areas, the water column or in the deep sea floor remain unknown. According to informants,

the water column and the deep sea floor likely contain most of the MPP. This is because, as mentioned in section 1 plastic tend to sink to the deep ocean floor.

> *"Micro-particles are everywhere. So, it is not garbage patches but a global distribution, and the best analogy is a "plastic smog", like the way we have smog of smoke over our cities and pollutants, fine particles. The same in the ocean, smog of small particles that hover of the entire ocean"*
>
> (Marcus Eriksen, 5Gyres)

Sc. C.2.2. There is a time delay between exposure and effects:

Informants mentioned the fact that plastic is a human-made material with inherent characteristics that make plastics durable and not degradable but just fragmenting into smaller pieces. Also, as mentioned above, the exposure of the chemical toxicity characteristics associated with MPP leaching toxic compounds or acting as a vector of transport and absorption of other harmful substances is a feature highlighted by informants. Thus, once plastic reaches the oceans it will have inevitably have an impact on the marine ecosystem.

> "*The biggest and the most obvious problem, of course, is that this [plastic] is a manmade (sic) material. Nature didn't design it, and therefore, it hasn't figured out what to do with it. For that reason, plastic persists for such a long time; coupled with the fact that it is made out of harmful chemicals that leach and are known to be harmful to organisms, as well as to humans - all in the name of convenience. But these chemical properties are not convenient to the planet we live on. We can give plastic different names and labels but [there needs to be an] understanding that we have created something like Frankenstein that does not fit in the dynamics of the planet we live on and why nearly every piece of plastic used is still on the planet somewhere."*
>
> (Bonnie Monteleone, Plastic Ocean Project)

C.3. The exposure to the chemical is pollution is poorly reversible:

Sc. C.3.: The exposure to the chemical pollution is poorly reversible

In relation to point 2.a, fine micro particles, including nano-size particles and microfibers, are ubiquitous, reaching all environments and organisms of the marine trophic chain:

"Maybe, one of the most relevant results or aspects is the fact that this kind of pollution has a global scale. The geographical dispersion of this material is clear and indisputable. Plastic is extended to every place, to every latitude and if we look for it properly, we could find it in almost every organism or any place of the Planet".
(Andrés Cózar, Cádiz University)

Unlike macroplastics, micro-sizes particles (i.e. micro, nano and microfibers) are often too small to be detected by the naked eye and numerically they represent the vast of MPP (Law & Thompson 2014). These authors also pointed out the unfeasibility of cleaning up or removing microplastics debris.

In sum, MPP fulfils the three necessary conditions stated by Persson et al (2013) and those outlined by MacLeod et al (2014) and thus qualifies as a Planetary Boundary Threat from chemical pollution as a novel entity; see Table 3 for summary.

In addition to fulfiling these requisites, it should be noted that in general informants do not perceive MPP as an "Earth system" issue but a worldwide issue. The MPP issue is largely targeted as a wildlife or human health issue (i.e. regional and local systems issues or "Earth component" issues). However, vital Earth systems are really concerned with the relationship between the physical and the living worlds, and the disruption of systemic connections. Thus, it is relevant to acknowledge that the timescale of global surface-ocean connectivity moves faster than other processes due to the presence and action of living organisms (Watson & Jo 2016).

Table 3: Summary of conditions and scenarios fulfilled by MPP as a planetary boundary threat from chemical pollution (Persson et al. 2013; McLeod at al. 2014).

- Green: represents the conditions and scenarios that are fulfilled though data comparison (i.e. informants and literature review).
- Yellow: information about conditions and scenarios were not compared (i.e. informants and literature review) due to lack of information at that moment. This does not mean that these conditions or scenarios could be fulfilled if more information were available.

Requirements to be fulfilled	Yes/No	
C.1: Unknown disruptive effect on a vital Earth-system		- There real magnitude of MPP effects and the scale of it remain unknown. • MPP links with other major environmental problems, but its magnitude is unknown. • Certain individuals species seem to have reproduction and populations declines.
C.2: The disruptive effect is not discovered until it is, or inevitably will become, a problem at a planetary scale		
- Sc. C.2-1: Concentrations are nearly homogeneous.		• Dispersion: ✓ Wind and ocean currents move MPP all over the globe. ✓ Animals ingesting MPP and egesting them in a different location. • Microplastic size particles are everywhere.
- Sc. C.2-2: Impacts are distributed globally.		
- Sc. C.2-3: There is a time delay between exposure and effects.		Once plastic reaches the ocean it will inevitably affect the marine ecosystem.
C. 3: The exposure to the chemical pollution is poorly reversible		
- Sc. C.3-1: exposure to the chemical pollution is poorly reversible.		• It is unfeasible to clean up or remove micro and nano size plastics particles from the environment.
- Sc. C.3-2: The effects of the chemical pollution are poorly reversible.		

The intention of planetary boundaries is to identify processes that affect global scale Earth processes (Rockström et al. 2009; Rockström and Noone 2009). However, there is an increasing consensus about the possibility of considering many of the identified boundaries where thresholds could occur at local and/or regional scales and consequently could become a global scale problem (Diamond et al, 2015). And this could be the case for MPP, according to one informant. Significant effects at local or regional level can have significant effects on a global scale. However, more research for MPP on this matter is necessary.

Furthermore, it should be noticed that lately there has been a growing debate about the chemical pollution boundary due to the scale of its effects (Steffen et al. 2015). This shows that key concepts in the planetary boundaries framework still need clarification.

Also, and as mentioned above, MPP is a relatively new human-created problem so it meets one of the criteria of the novel entities description in Steffen et al. (2015). These authors propose defining certain control variables, which would depend on whether they focus on emissions, concentrations or effects. These control variables could be identified for MPP. However, more is known about the effects of MPP at higher positions of the trophic level (e.g. turtles and whales) probably because they are the easiest to be detected. The effects at the lower levels of the trophic chain, which are the ones most related to systemic impacts in the vital Earth systems, are not well known. Table 4 summarizes what are the systemic impacts identified for the MPP issue.

Finally, the magnitude of the effects of MPP to both in marine ecosystems and humans remain largely unknown. More research on this matter should take place in the next coming years to understand the severity of MPP effects and impacts. However, the research community already has enough evidence to suggest MPP is an environmental problem with observable impacts to ecosystems and humans.

Steffen et al. (2015) state that ignoring the precautionary principle for systems covered in the PB would lead these systems away from the Holocene-like condition. Therefore, and as widely advised by informants for this study, it is safer to act now and apply the precautionary principle as one of the major responses.

"I think we have to take the precautionary principle. If you want to protect the environment you can better be safe that be sorry, and that's why I think we should stop emitting plastics to the oceans even though there is so much more that we need to know"

(Albert Koelsman, Wageningen University)

Table 4: Identified systemic impacts for marine plastic pollution

Systemic impacts	**State of knowledge**
MPP as source and transport mechanisms for toxic substances - physical/chemical behaviour.	Known mechanism, reasonably well-studied, although scale of the problem is unclear.
MPP in organisms bio-accumulating and interacting with chemical behaviour (trophic).	Unclear, often raised as a concern, but minimal evidence.
MPP as "food"." – organism effects can affect ecosystems through population change (demographic change) -	Macrodebris: - Observed in individual organisms at large scales, but debate about overall effects on populations. Microplastics: - Rate of encounter potentially much higher, affecting between populations (Oysters, perch larvae).
MPP as a physical vector of transport of non-native species to new regions (e.g. plastic rafts).	Known mechanism, reasonably well-studied.
MPP influencing physical properties of marine particles and influence sedimentary processes: settling in water column, beach dynamics.	Laboratory studies for sinking particles properties.

6. Conclusions

The DPSIR framework has been shown to be a useful tool to assess informants' views of the social-ecological causalities of MPP at a global scale. It is a good way to visually represent and connect vast amounts of "messy" information about what effects (and how) MPP has on vital Earth-systems processes.

From a qualitative point of view, the analysis of some of the leading expert's perceptions of the Earth-systems processes affected by MPP fulfil the criteria posed by Persson et al. (2013) and MacLeod et al. (2014). Thus, I conclude that MPP should be considered as a sub-planetary boundary of the novel entity boundary within the PB framework. However, setting a quantifiable control variable for the sub-boundary of MPP as Rockström et al. (2009) proposed for the rest of PB would not be feasible at this stage due to the high uncertainty regarding MPP and its impacts on vital Earth-systems. This highlights the need for more research to quantify the safe limits. However, there is enough information available to identify marine plastic pollution as a great environmental problem.

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APPENDIX

Appendix 1: Table 5. List of interviewees

Interview nº	Name	Organization	Position	Sector
1	Marcus Eriksen	5 Gyres	- Executive Director & Co-founder	Non-profit
2	Nicholas Mallos	Ocean Conservancy	- Director of the Trash Seas Program	Non-profit
3	Bonnie Monteleone	Plastic Ocean Project	- Executive Director, Director of Science, Research and Academic Partnerships	Non-profit
4	Chelsie Rochman	UC Davis	- Post-doctoral Fellow in UC Davis	Academia
5	Kristal Ambrose	Bahamas Plastic Movement	- Founder, Director and Director of Science	Non-profit
6	Albert Koelsman	Wageningen University	- Professor	Academia
7	François Galgani	Ifremer	- Chairs of the MSFD Technical Group Marine Litter for the European commission/DG Environment - CIESM committee C3 on biogeochemistry/ ecotoxicology	Academia
8	Andrés Cózar	University of Cadiz Cádiz	- Professor	Academia
9	Lorena Ríos Mendoza	University of Wisconsin-Superior	- Associate Professor of Chemistry	Academia
10	Nancy Wallace	National Oceanic and Administration (NOAA)	- Director of the Marine Debris Program	Governance
11	Peter Kershaw	GESAMP	- Chairman and head of WG40 on microplastics	Academia
12	Richard Thompson	Plymouth University	- Professor	Academia
13	Julia Reisser	The Cleanup Project Foundation	- Lead Oceanographer	Non-profit
14	Edward	Romberg Tiburon	- Professor	Academia

	Carpenter	Center for Environmental Studies		
15	Leslie Tamminen	Seas Clean Coalition		Non-profit
16	Jenna Jambeck	University of Georgia	- Professor	Academia
17	Katie Allen	Algalita Marine Research Institute	- Executive Director	Non-profit
18		PlasticEurope		Industry

Appendix 2: Interview's questions

General background

- Can you tell me briefly about your role at "…"?
- How did you become engaged in the issue of marine plastics pollution?

Defining the problem – (environmental and social dimensions)

- In your opinion, what do you think are the main environmental and social risks or problems related to plastic pollution on the ocean?
- What are the main drivers that are causing this plastic pollution?
- What do you think are the relevant actors regarding MPP? And which role do they play?
- Do you differentiate micro from macro plastics?
- What made you decide to differentiate them?

Understanding the existing policy responses to the problem

Policy responses (governments) – General awareness raising (publics) – Action responses (probably business)

- How do you consider that the differentiation between macro and micro plastics has been contemplated when making new policies?
- Do you think there is need to standardize sizes? Why?
- What types of policies do you think are required to control marine plastic pollution?
- Who needs to be involved in dealing with the problem?
- At the international level, how do you think policies have changed in the last 3 decades (before MARPOL implementation)?
- Do you think that the Honolulu strategy covers the policy gap at an international level?
- At a national level, how do you think policy makers care about the issue of the plastic pollution?

- Do you think that the decision and actions of legislation/policy makers are influenced by the scientific data that academic institutions present? Or by other kinds of data from other kinds of organisation (health campaigners, etc.)?

The networks of influence to deal with this issue

- Do you consider that more collaboration across sectors is needed to raise awareness of the issue?
- Who other actors do "your organisation/you" collaborate with?
- Are these collaborations more important internationally or nationally?
- Do you think is there inter/cross-sectorial participation (e.g. academia, activists…) towards decision-making?
- What constraints do you find/face when working with them?

Discussing the outlook – locally and globally

Many people are talking about "the Anthropocene" – the fact that human activities now shape the future of the whole Earth.

- Do you consider that the oceans are safe area for human development or wildlife nowadays?
- Looking into the present and the future, what do you think is most important right now to take action on?
- How do you think things will change from today to 2050?

Appendix 3: Table 6: Coding themes

Block	Theme	Category	Subcategory
Interviewees' background	Belonging sector (i.e. actors)	Academia	
		Government	
		Industry	
		Non-profit	
	Country of influenced or geographical scope of their work	Australia	
		Bahamas	
		Brazil	
		Canada	
		Mexico	
		Netherlands	
		Spain	
		UK	
		US	
Definition of the problem	Drivers	Economic/Industrial	Benefits from plastics
			Development
			Globalization
			Increase of plastic consumption and/or production
			Increasing consumption in developing countries
			Industry willingness to maintain their status quos
			Inefficient Waste Management Systems
			Thoughtless products and design
		Social & Cultural	Consumers' behaviour (i.e. throwaway living, convenience life style)

			Population growth
		Environmental	Weather events
	Pressures	Litter behaviour	Land-based
			Ocean-based
	State	Ecological	Chemical impacts
			Death of endanger species
			Entanglement
			Ingestion
			Physical harm to benthonic ecosystems
			Plastic uptake in the food-chain
			Plastic accumulation in the marine sediment
			Transport of alien species
		Accumulation, stocks and concentration	
		Ubiquitous geographical distribution	
	Impacts	Economic	Clean-ups costs
			Fisheries
			Shipping
			Tourism
		Social	Aesthetic and loss of intrinsic value (i.e. psychological restorative value)
			Human health and food safety
			Loss of income
			Poverty Link
			Risk from injury or death
	Relevant actors	Academicians	
		Activist and Educators	
		Consumers	
		Corporations	
		Non-profits	
		Everybody	

		Industry	
		Media and Celebrities	
		Non-profits	
		Policy makers and governments	
		Waste management entities	
	Size of the plastic particles/items found in the marine environment	Continuum from macroplastics to microplastics	
		I do differentiate	
		Important towards impacts, effects	
		Important to prevent	
		Microplastics focus is trendy	
		Need of standardization (i.e. definitions and/ or methodology)	
		Not relevant towards solutions (all need to be prevented)	
		Is it properly treated in policies?	Difficult or have no good answer
			No need to be contemplated
			Yes
Policy Responses	Current Policy Responses	Comparison between North American and European interest	
		Current policies deal properly with MPP	
		Decision making is influenced by	Industry
			Media
			Non-profits
			Science
			The public
		Honolulu Strategy	Conversations focus in consumer's behaviour
			Excludability of certain actors
			It's a good attempt
			Plastic perspective missing
			Room for improvement

		Lack of policy willingness	
		Lack of understanding	
		MARPOL	Better littering behaviour
			Is an effective policy instrument
			More specific terminology is needed
			Room for improvement
		More governmental participation is needed	
		Need of expand and enforcement of current policies	
		Need of new policies	
		Need of policy adequacy	
		Policy makers interested in MPP	
		Request of size definitions	
	Proposed Solutions	Economic /Industrial	Bans of certain products
			Circular Economy
			Developed countries helping economically developing ones
			Identify marine plastic pollution as hazardous chemical
			Improvement of recycling options
			Improvement of waste management infrastructures
			Incineration
			Life Cycle Assessment of products
			Plastics to energy (i.e. plastic to fuel)
			Producers responsibilities

			Re-design products and materials
		Environmental	Awareness raising and education
			Clean-ups
			Consumer behaviours
			Highlight the what have been done so far
			Upstream solutions
Network of influence	Networks of influence	Benefits of collaborations	Increase of efforts
			Knowledge and experience sharing
			Opportunity of dialogue and reply
		Constrains	Competition
			Cultural differences
			Different agendas and perspectives
			Different backgrounds and skills
			Division non-profits and the industry
			Financial constrains
			Jargon and miscommunication
			Keep the playing field
			Lobbying
			Power relations
			Science needs to communicate better
			Time constrains
			Trust issues
			Unequal representation of sectors
			Working with feelings and

			emotions of citizens
		Cross-sectoral collaborations are important	
		Is more cross-sectoral collaboration needed?	Absolutely
			We have enough collaboration already
		Scale of collaborations	International
			National
			Importance of the scale of collaborations
		With who do you collaborate with in other sectors?	Academicians and researchers
			Business
			Civil Society-consumers
			Educators
			Everybody
			Government
			Industry
			Media-Celebrities
			Non-profits

Appendix 4: Policy responses

Table 7: Policy Responses: List of International agreements, conventions and regional cooperation

International agreements and legal Frameworks
- European Marine Strategy - Framework Directive - Global Programme of Action for the Protection of the Marine Environment from Land-Based Activities (GPA) - Helsinki Convention - Sustainable Development Goals* - FAO code of Conduct for Responsible Fisheries Article 8
International Conventions
- International Convention for the Prevention of Pollution from Ships (MARPOL). Annex V - United Nation Convention on the Law of the Sea (UNCLOS) - London Dumping Convention - Convention for the Environment Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention)
Regional Cooperation: Regional Seas Conventions and Action Plans (RSCAPs)
- Convention of the Mediterranean - Barcelona Convention - Wider Caribbean (WCR) - East Asian Seas - Eastern Africa (Nairobi Convention) - Northwest Pacific (NOWPAP) - West and Central Africa (WACAF)

Table 8: Summary of the UN Sustainable Development Goals (SDGs) targets related to marine litter.
Source: Adaptation from UNEA 2 (UNEP, 2016)

Goal 6. Ensure availability and sustainable management of water and sanitation for all

6.3. By 2030 halve the proportion of untreated wastewater.

Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable

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

Goal 12. Ensure sustainable consumption and production patterns

12.1 All countries implement the 10-year framework of programmes on sustainable consumption and production with developed countries taking the lead, taking into account the development and capabilities of developing countries.

12.2. By 2030, achieve the sustainable management and efficient use of natural resources

12.4. By 2020 achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment.

12.5. By 2030 substantially reduce waste generation through prevention, reduction, recycling and reuse.

12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that create jobs and promote local culture and products.

Goal 14. Conserve and sustainably use the oceans, seas and marine resources for

sustainable development

14.1. By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution.

14.2. By 2020, sustainably manage and protect marine and coastal ecosystems to avoid significant adverse impacts, to strengthen their resilience, and **take action for their restoration** in order to achieve healthy and productive oceans.

14.7. By 2030 increase the economic benefits to Small Island developing States and least developed countries from the sustainable use of marine resources, including through the sustainable management of fisheries, aquaculture and tourism.

14.a. Increase scientific knowledge, develop research capacity and transfer marine technology, taking into account the Intergovernmental Oceanographic Commission Criteria and Guidelines on the Transfer of Marine Technology, in order to improve ocean health and to enhance the contribution of marine biodiversity to the development of developing countries, in particular small island developing States and least developed countries.

14.c. Enhance the conservation and sustainable use of oceans and their resources by implementing international law as reflected in UNCLOS, which provides the legal framework for the conservation and sustainable use of oceans and their resources, as recalled in paragraph 158 of The Future We Want.

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably managed forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

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

Appendix 5: Size matters

Figure 7: Effects of MPP on wildlife and the food chain.

Source: Fabres et al. (2016)

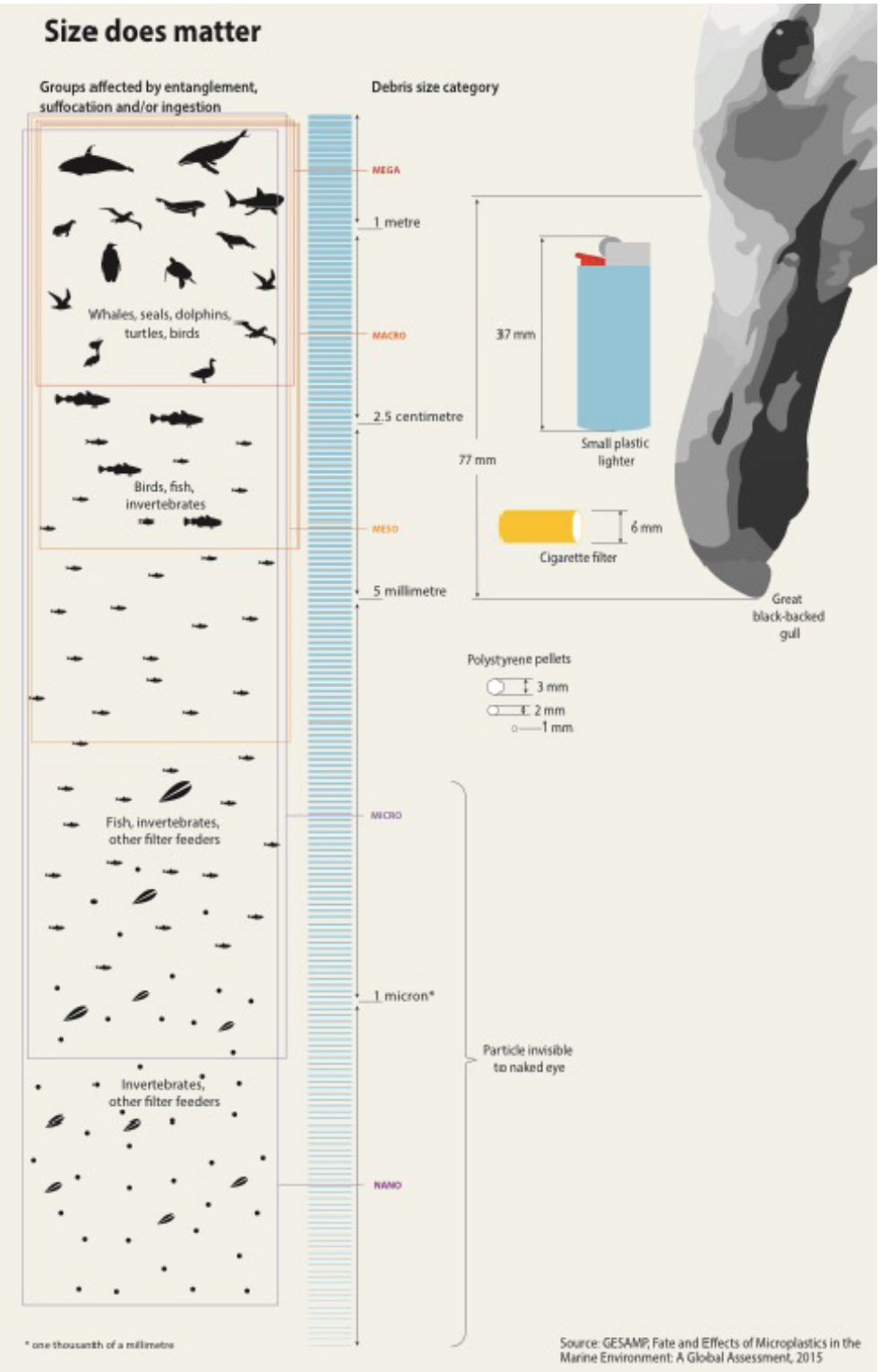

Figure 8: Paths of how plastics enter in the food web

Source: Fabres et al. 2016