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Marine Plastic Debris – Flows, Mitigation Measures and Environmental Evaluation

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Marine Plastic Debris – Flows, Mitigation Measures and Environmental Evaluation.

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Cover:
What goes in the ocean goes in you.
Surfrider Foundation, Rise above plastics.
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SUMMARY

The knowledge about the severe impacts of marine plastic debris and its widespread distribution into even the most pristine environments grows steadily. It has been documented in literature that numerous seabirds, turtles, fish and whale species suffer and die from ingestion of plastic particles mistaken for food and from entanglement in plastic items. Further, floating debris acts as a vector for the spread of alien species and can hinder gas exchange on the seafloor when sedimented. Additionally, plastic particles concentrate endocrine disrupting toxics and other persistent chemicals on their surface which are then accumulated in the food chain across trophic levels. Against this background, different problem mitigation strategies are reviewed and a life-cycle assessment of an arctic beach-cleaning operation is conducted, which tries to quantify the negative and positive effects of this particular mitigation action. The amount of plastics removed and the resulting ecological benefit for local wildlife as well as the increased societal awareness of marine litter counterbalance the carbon emissions caused by the operation. The project identified a lack of operational assessment methods for positive environmental impacts. Therefore own approaches to describe the achieved effects are set up as evaluation methods for the positive impact here. Finally, we will only manage to tackle this pervasive problem if the input of new plastic debris into the oceans will be stopped eventually or at least reduced drastically in the near future. Only then, the health of marine ecosystems can be safeguarded in order to not cross any essential ecological thresholds.

Keywords: Plastic litter, Beach clean-up, Life cycle assessment, Clean-up operation, Ocean plastic waste, Positive environmental impact, Ecobalance, Svalbard.

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1 Introduction

"Marine plastic pollution is one of the most serious emerging threats to the health of oceans and is now considered a major hazard to marine biodiversity. Plastics may fragment but do not biodegrade and so persist indefinitely, leading to a progressive rise in quantities found in the marine environment." (Environmental Investigation Agency, 2016)

Nowadays, the knowledge about the pollution of the environment by humans is well-established and widespread. Nevertheless, many people do not act according to this knowledge. Taking littering as an example, it is publicly known that littering harms the environment. Despite this, many people drop their waste just where they are – in the streets, in the woods or even into the water when they are near a lake or ocean. A big part of this waste is plastics (Plastic Europe, 2015), mostly light-weight material which floats on water and thus often ends up in the ocean. Here begins the area of interest for this study which will review the characteristics and impacts of marine plastic debris to introduce the topic. So one of the research questions to be answered is where the debris found in the oceans comes from and where it goes. This is to be visualised in Sankey diagrams, which will show the different plastic flows in order to form a global picture of the problem. As the most remarkable part of marine litter are different kinds of plastic fractions, the attention here is focused on plastics only. Additionally, the impacts of marine debris on wildlife and the ocean ecosystem in general as well as on human beings are summarised.

This review is used as the background for the second part, where an analysis regarding problem mitigation strategies will be conducted. So the description of the problem in the first part delivers the motivation for why mitigation actions against marine littering are of essential importance. Different mitigation actions will be presented and assessed for their utility in the given context. Then next, different environmental evaluation methods will be presented and applied onto the described mitigation efforts with the goal to get an idea about their effectiveness. A specific section of the second part is the environmental evaluation of an arctic clean-up operation as an example for mitigation actions, which will be conducted in terms of a life cycle assessment (LCA).

1.1 Research aims and context

The more general aim of this exploratory study is to collect and organise the growing knowledge about plastics in marine environments and to review the debris flows and their related problems. The analytical aim is to appraise the effectiveness of the analysed mitigation project *Clean Up Svalbard*; that is if the benefits for the ecosystem weight out the costs of the operation for the environment (greenhouse gas emissions). The study will be done in the context of Industrial Ecology, as it explores the impact of industrial systems (industries, human settlements) onto the ocean environment. The relevance of the topic of marine plastic debris for environmental sciences is based on the importance of the ocean ecosystem for life on earth and the growing attention for the topic from environmental researchers just now.

2 Theoretical Background

2.2 Environmental characteristics of plastic

Plastic as a production and packaging material has the strong advantage to be relatively cheap and it has an excellent user convenience "- combining unrivalled functional properties with low cost" (WEF, 2016, p.6) as the report *the New Plastics Economy* puts it. It is mainly made from crude oil which is processed into synthetic polymers that can be moulded into any kind of shape and be deformed without breaking (American Chemistry Council, 2016). But additional to the assumed low costs for producers and consumers appear external costs, as typical for many economic activities. Externalities occur first from production emissions, contributing to global warming, and second from pollution of natural systems where the plastic is not taken care of properly after its use phase. In addition, the material is lost from the cycle if plastic is littered instead of recycled or at least incinerated for energy re-generation. Consequently plastic materials are not that cheap any more if external costs on the environment are taken into account. About a third of plastic packaging is not collected suitably but instead released into surrounding ecosystems, causing substantial costs to the economy "by reducing the productivity of vital natural systems such as the ocean" (WEF, 2016, p.6). Due to its extreme durability, plastics have very a long lifetime and are estimated to persist for centuries (Engler, 2012). The impacts of plastic on the ocean in general as well as on marine ecosystems will be described further in the following.

2.3 Sources of marine plastic debris

So the first question to be answered is where does it come from; that is what different sources are there for marine plastic debris? One source is the fishing industry with its many small and big vessels that often simply dump their waste including old gear such as fishing nets into the ocean (Sheavly & Register, 2007). According to Hammer et al. (2011) stems debris from ocean-based sources from basically all kinds of ships and ocean activities that exist (merchant ships, ferries and cruise liners, military and research vessel, boats used for recreational purposes, offshore oil and gas platforms, and of course the already mentioned fishing vessels).

Most debris (80%) comes from land-based sources which include everything that is carried to the coast from inland by rivers and everything that is transported by wind or water level changes into the sea (Jambeck et al, 2015). Also, some waste is dumped into the ocean on purpose in nation states or regions where there is lack of proper waste management and of knowledge. However, small plastic particles pose an even bigger threat to ecosystems than big pieces of plastic, as the so-called microplastics (mostly described as smaller than 5 mm) are often bioavailable and accumulate in the food chain (Wright et al, 2013; Moore, 2008). Their sources are on the one side the weathering down of bigger plastic debris into smaller and smaller fragments through solar radiation and wave movements etc. (Andrady, 2011; Mani et al, 2015; Kershaw et al, 2011). This is mainly happening near the shores “where photodegradation and abrasion through wave action make plastic items brittle, increasing their fragmentation” (Barnes et al, 2009, p. 1993).

On the other side, plastic particles can also derive directly from sources like industry, cosmetic products or clothing in a very small size. If coming from industry, pellets are spilled accidentally during ship transport or emitted with waste waters from production processes (Duxbury, 1992). Next, microplastics can be found in several cosmetics such as toothpaste or facial cleansers where the particles are used for their scrubbing effect (Fendall & Sewell, 2009; Gregory, 1996). Otherwise originates a huge amount of fibres as a rub-off of synthetic clothing from washing machines every day (Browne et al, 201; Katsnelson, 2015). More than 1900 microscopic plastic fibres can be produced each time that one synthetic piece of clothing is washed, for instance a fleece pullover. The particles enter the ocean with the wastewater because the microplastics are too small to be filtered out of the water at sewage plants. (Browne et al, 2011)

2.4 Flows and distribution

Microplastics are relatively evenly distributed at coasts and often it is not possible to link measured concentrations to urban or industrial areas (Claessens et al., 2011). Thus sea currents distribute particles all around the globe, though in varying concentrations (Andrady, 2011; Derraik, 2002; Sherman & van Sebille, 2016). The role of rivers as transporters of plastic is significant as well because they carry their plastic load from inlands to the oceans (Claessens et al., 2011). In Figure 1, the distribution of litter by currents and by waterways from inland to the ocean around the North Sea and the Baltic Sea can be seen. As most debris comes from inland, most plastic particles can be found near the cost and in the so-called ocean-gyres (Cole et al, 2011). These are vast patches in between the continents where ocean currents concentrate floating particles due to their flow conditions (Cole et al, 2011). The most commonly known one of these gyres is the Great Pacific garbage patch in between North America and Southeast Asia (Kaiser, 2010).

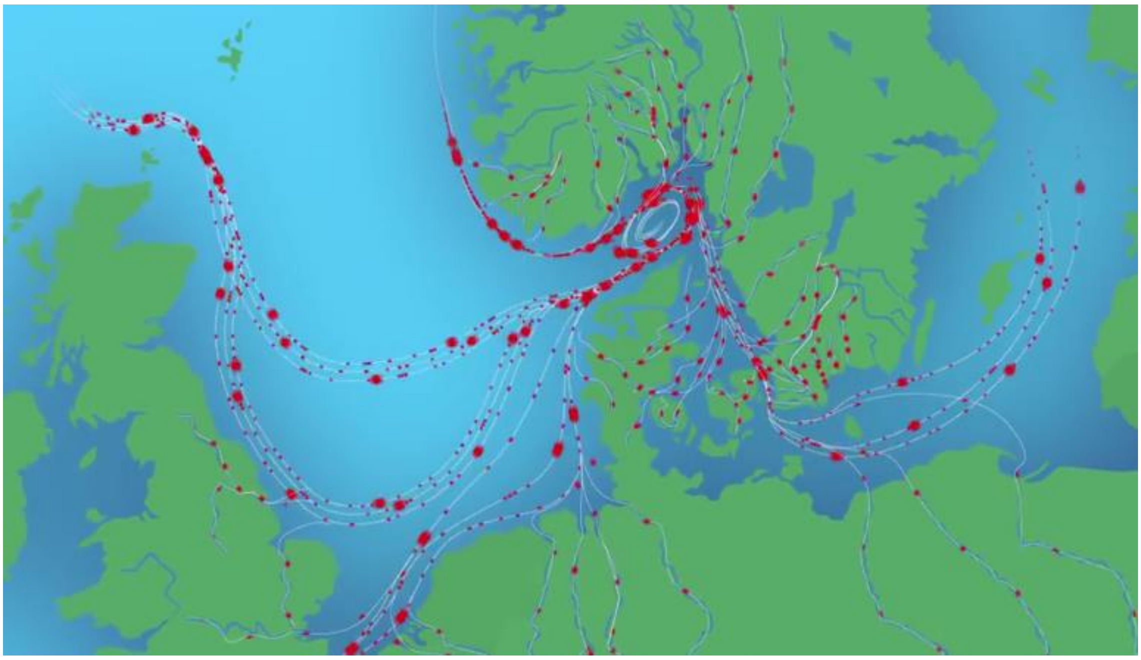

Figure 1: Plastic debris transported by sea currents and rivers around southern Sweden. From Strömmar av plast, Havsmiljöinstitut , 2014.

In Figure 2 below the flows of plastic debris from the sources to the sinks are depicted. The arrows with lines inside show transport by wind from land into the ocean, the grey arrows indicate plastic items that are moved by waterways from inland and by water currents from beaches to coastal water and to the open ocean and vice versa. There are arrows for debris stemming from big and small vessels, from sewage outfall, from beach littering and also for debris being deposited onshore again. Further, the black arrows show ingestion by different species and the dotted arrows indicate sedimentation of items to the seabed.

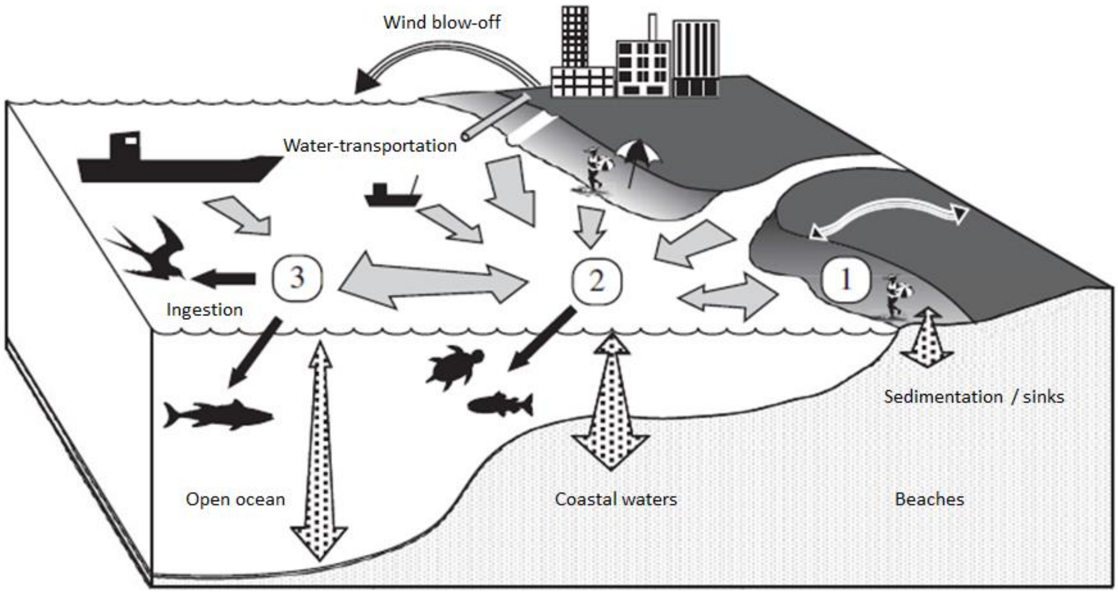

Figure 2: Schematic plastic flows, modified from Ryan et al, 2009

2.5 Impacts of marine debris

2.5.1 Threats to marine biota

Plastic items in the oceans pose an often fatal risk to a growing number of marine species. Sea turtles, whale species and seals are reported to suffer most from getting entangled into debris objects which makes them starve, strangle or suffocate to death eventually. Then, ingestion of plastic particles occurs most excessively for ocean-feeding birds and is probably known the longest for albatrosses that mistake plastic items for food and even feed plastics particles to their chicks. The smaller the items are, the smaller also the species that swallow them. So zooplankton can ingest microplastics, small fish eat that plankton including the plastic particles, bigger fish eat the small fish, which is in turn eaten by other predators like marine birds – and humans. Even turtles for instance seem to mistake plastic bags for their natural prey, jellyfish, so they feed on them. (Hammer et al, 2012; Wright et al, 2013; Wilcox et al, 2015; Gregory, 2009)

2.5.2 Other impacts

Hammer et al. (2012) estimate that 70% of all marine debris sooner or later sinks to the sea floor. Therefore the impact of particles on the bottom of the ocean also needs to be addressed. The impact of plastic accumulated on the sea floor is a hindered gas exchange between the ground sediments and the water layers on top of it, which might lead to anaerobic milieus and affects the biota that live in and on the ocean bed (Moore, 2008). A further point of concern is the spread of invasive species via plastic items as biota encrusted to floating particles can easily enter alien habitats (Gregory, 2009).

2.5.3 Pollutants from plastics

As Van Cauwenberghe and Janssen formulate it, "threats to human health through the consumption of microplastics present in seafood […] become apparent" (2014, p. 69). Their research proved that microplastics were present in both blue mussels and oysters and a conclusion is that humans who eat shellfish are thus exposed to some plastic-associated ecotoxicity as well. Yet they stated that further studies are necessary to evaluate to what extent chemical contaminants are conveyed to humans by seafood and to estimate the risk related to that (Van Cauwenberghe & Janssen, 2014).

More in detail, plastics carry toxic additives that determine their properties for the intended use which can be transferred to marine biota through plastic ingestion (Engler, 2012). Additionally, plastic particles adsorb chemical substances that the oceans contain in low concentrations and accumulate these on their surface: "plastics [tend] to sorb (take up) persistent, bioaccumulative, and toxic substances" (Seltenrich, 2015, p. A 35). The toxics are mostly durable and can cause severe disturbance in the hormone system (endocrine disruptors) as well as accrue over the food chain (Engler, 2012). PCB (polychlorinated biphenyls) and BPA (bisphenol A) are among the most well-known ones of these substances. Consequently, wildlife species that ingest plastic particles by mistake also take up these chemicals and humans are exposed to them with potentially accumulated concentrations of toxics when consuming seafood (Seltenrich, 2015).

3 Material and Methods

A literature synthesis has been done for marine litter in general and environmental valuation methods specifically. For this the database Scopus has been used as well as Google Scholar and the Web of Science. Next, overviews of the plastic flows were visualised in Sankey diagrams generated with the software e!Sankey with data taken from relevant papers found during the literature review.

The LCA modelling has been conducted in Microsoft Excel with data from different sources, mostly found on Google Scholar as well. Besides, basic life cycle assessment knowledge was gained from the book *The Hitch Hiker´s Guide to LCA* (Baumann & Tillman, 2004). The evaluation methods used in chapter 4 are taken from examples in literature and chosen for their appropriateness for the examined case. Finally, the IUCN report *No Net Loss and Net Positive Impact Approaches for Biodiversity* is used as a framework to evaluate the analysed clean-up operation as well.

4 Marine plastic flows visualised in Sankey diagrams

The knowledge and data collected about marine plastic debris are now applied in the following e!Sankey diagrams. The first one (Figure 3: Annual input of plastics into the ocean visualised in e!Sankey) shows how much of the total amount of plastics produced ends up in the ocean and through which path it enters the marine ecosystem. The four different pathways 'ocean-based', 'water transported', 'shore littering' and 'industry spills' have all the same proportions because no reliable data were found on how much comes from which source on a global scale. Besides, the grey and black lines leading to the total annual input represent the scope of figures present in literature, which vary from 6.4 to 31 million t annual input.

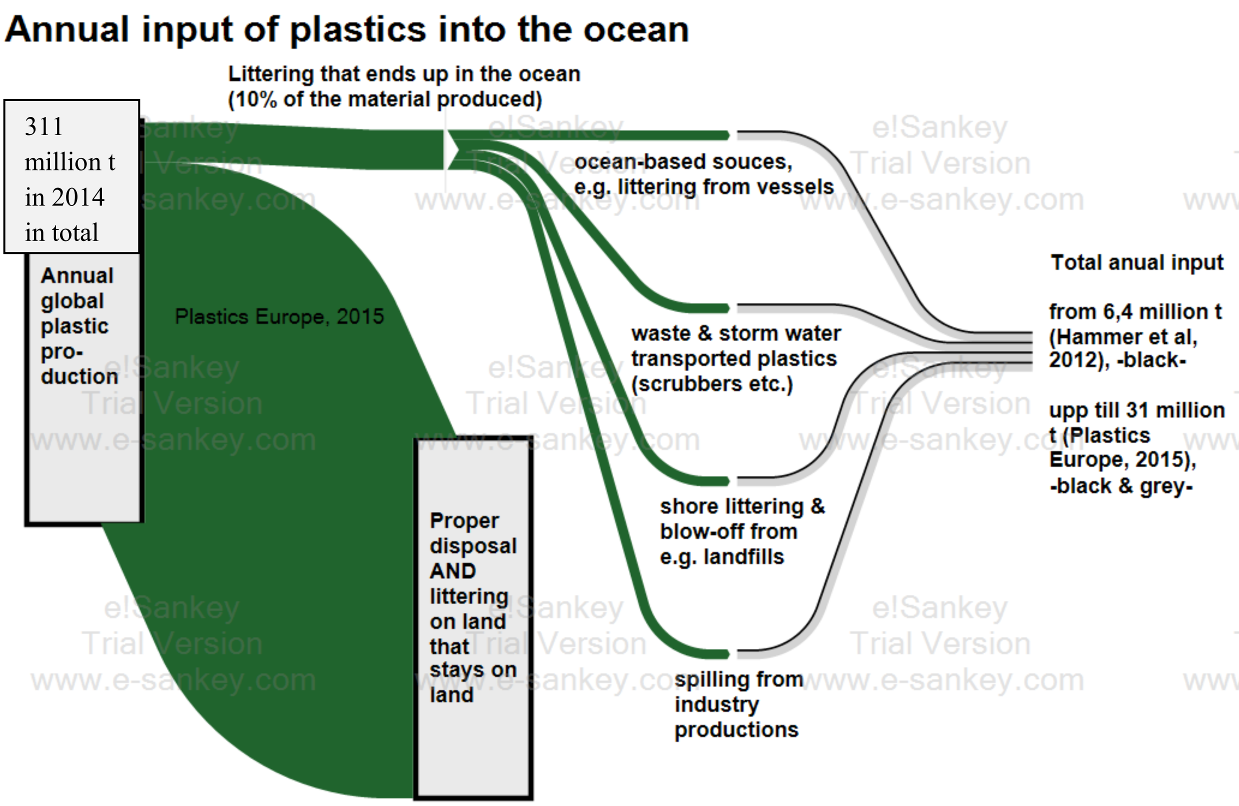

Figure 3: Annual input of plastics into the ocean visualised in e!Sankey

Further, this annual input adds up to the total plastic mass, that already exists in the oceans. The spatial dispersal of all marine plastic debris including the size distribution of floating plastic particles is shown in the second Sankey diagram (Figure 4). The total mass of marine plastic debris is unknown, only partial approximations can be found in literature. Therefore, a first attempt to estimate that number is made in the next subchapter. As can be seen in the diagram, about 15 percent of plastic litter in the ocean floats on the surface or partly in the water column, another 15 percent is washed ashore at the coast and a big part (70%) of the debris eventually sinks to the sea floor where it sediments onto the natural seabed flora and fauna. In the right part of the diagram, the size distribution of items is shown in metric tons. The arrow for large items (macroplastics) is much bigger than the others because of the depiction in weight, even though there are a few hundred thousand times more small particles than large items (see Table 1, page 8 in Eriksen et al, 2014). Overall, Figure 3 approximates the annual input of new plastic and Figure 4 depicts the total mass of plastic that already exists in the oceans to which the annual input adds up to.

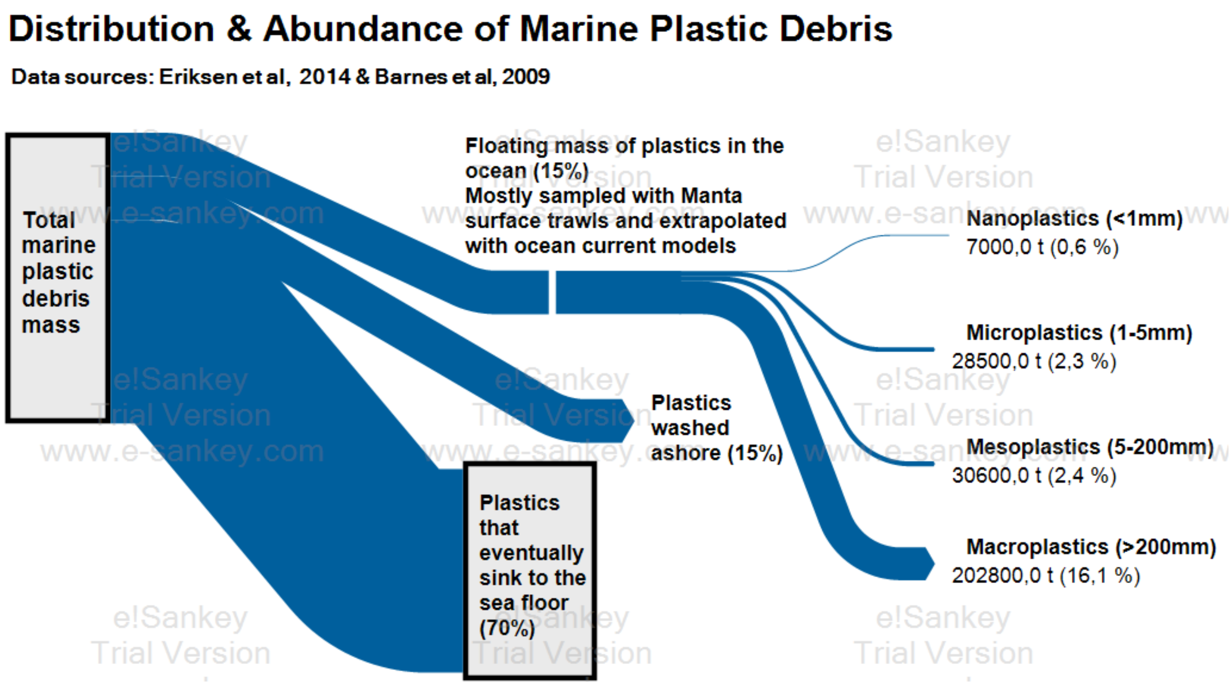

Figure 4: Distribution and Abundance of Marine Plastic Debris visualised in e!Sankey.

4.1 Debris amount estimation

Several estimates about the amount of plastics entering the ocean each year exist. Jambeck et al. (2015) estimate that amount to be about 8 million t, Hammer et al (2012) say it is 6.4 million t and Plastics Europe (2015) state it to be 10% of the plastics produced, thus 31 million t. Further, Eriksen et al. (2014) estimate that more than 260 000 t float on the surface while Cózar et al. (2014) say the floating mass should be some

10 000 t - and that it should be more, so a lot is removed by nano-fragmentation and ingestion, other sinks. So their number is still by far within the Eriksen estimate.

If these estimates are combined now - about 260 000 t floats (15%), then 260 000 t is washed ashore (15%) and 1 200 000 t sinks to the sea floor (70%) (Barnes et al, 2009). This is then 1.7 million t in total - but the annual input, according to Jambeck then is 8 million t. If any of the 3 input estimates here (6.4 million t, 8 million t or 31 million t) is anywhere near correct, then the total mass already existing in the ocean from about 50 year of incessantly increasing plastics production cannot be in the order of 1,7 t in total. With 15% washed ashore, where the waste still is in a marine ecosystem, maybe half of that is cleaned up. But a tiny part of the floating debris is cleaned up now and then as well and some other processes remove plastics that are ingested etc. Then in total approximately 10% of the debris entering the ocean is actually removed some way or another, which likely is an optimistic estimate. This would mean that 90% of the debris entering the ocean stays there. With lifetimes in the order of hundreds to thousands of years, the plastic can only be fragmented but not biodegraded, hence they do not disappear (Barnes et al, 2009), even if many studies may claim shorter lifetimes as well. Global annual plastic production started off with 1.5 million t in 1950, increasing steadily to over 300 million t nowadays (see Figure 5). The estimates from literature could probably be averaged to 10 million t for 2015 (see Figure 3), which is about 3% of the plastics produced. This number can then be used to calculate the total amount of plastic waste that must have entered the ocean since plastic production began in the 1950ies, which is approximated to be about 200 million tons (see Table 1). So instead of the given 1.7 million t of total marine debris from literature, the estimated number of 200 million t in total is proposed here.

Currently one estimate for the total amount of microplastics in the oceans that can be found in literature comes from van Sebille et al (2015) who interpolated observations with ocean circulation models. They approximated there to be up till 236 000 tons of microplastics only, which is nearly as much as the 269 000 tons that Eriksen et al (2014) estimated to be the total weight of floating debris of all sizes. Both of them considered floating plastics only, so debris that sank to the seafloor or that has been washed ashore was left out in both of them which makes the figures comparable. Still, the estimations are do not match with each other which supposedly is due to their use of different models and data in the first place.

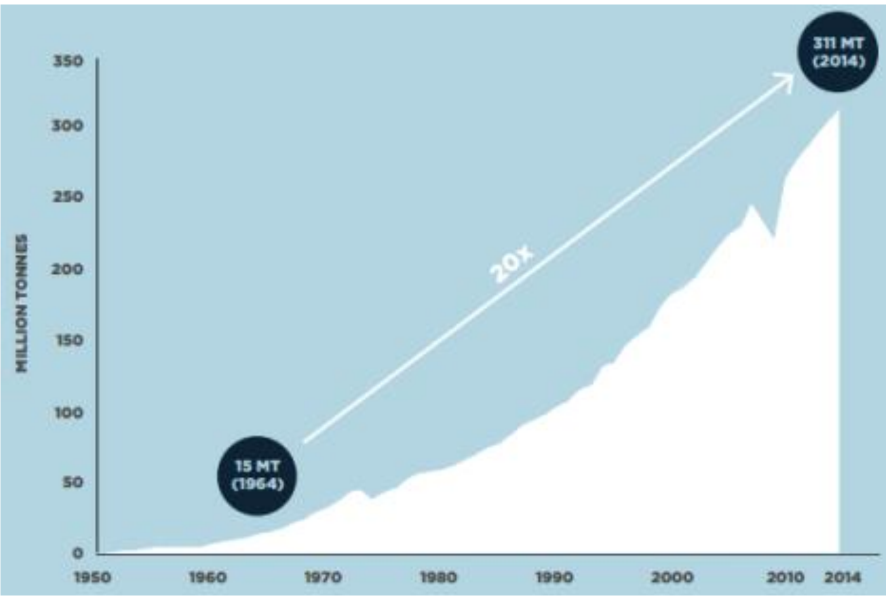

Figure 5: Growth in global plastic production 1950-2014, from Plastics Europe, the facts 2015

Table 1: Approximated marine debris amount in million t, calculated with 3% of the plastics produced enter the ocean.

Year	plastic amount	estimated waste	Year	plastic amount	estimated waste
1950	**1.5**	0.045	1983	77	2.31
1951	2	0.06	1984	80	2.4
1952	3	0.09	1985	82	2.46
1953	4	0.12	1986	85	2.55
1954	5	0.15	1987	90	2.7
1955	6	0.18	1988	96	2.88
1956	7	0.21	1989	**100**	3
1957	8	0.24	1990	107	3.21
1958	9	0.27	1991	112	3.36
1959	10	0.3	1992	120	3.6
1960	11	0.33	1993	125	3.75
1961	12	0.36	1994	130	3.9
1962	13	0.39	1995	137	4.11
1963	14	0.42	1996	140	4.2
1964	**15**	0.45	1997	150	4.5
1965	16	0.48	1998	155	4.65
1966	18	0.54	1999	160	4.8
1967	20	0.6	2000	172	5.16
1968	25	0.75	2001	185	5.55
1969	28	0.84	2002	**200**	6
1970	30	0.9	2003	208	6.24
1971	32	0.96	2004	215	6.45
1972	35	1.05	2005	225	6.75
1973	38	1.14	2006	230	6.9
1974	40	1.2	2007	240	7.2
1975	44	1.32	2008	**245**	7.35
1976	**50**	1.5	2009	**250**	7.5
1977	55	1.65	2010	**270**	8.1

1978	62	1.86	2011	**279**	8.37
1979	65	1.95	2012	**288**	8.64
1980	68	2.04	2013	**299**	8.97
1981	70	2.1	2014	**311**	9.33
1982	75	2.25	2015	320	9.6
				6773	203

5 Life cycle assessment of a clean-up operation

5.1 The concept of Industrial Ecology

Industrial ecology (IE) analyses "the impacts of industrial systems on the environment" (Garner & Keoleian, 1995; p. 2). Industrial ecology has the aim to lower impacts of production of products and services onto the surrounding ecosystems. It recognises the interrelationships between both natural and engineered systems as well as it investigates how these systems interact with each other. The focus hereby lies on the flows of energy and material through a system. In order to use resources in the most efficient way, their usage is tracked and emissions into the environment are minimised as much as possible. All of this has the goal to foster more joined and thus more sustainable systems. Processes are aimed to become circular and produce less waste by designing closed production loops. (Garner & Keoleian, 1995)

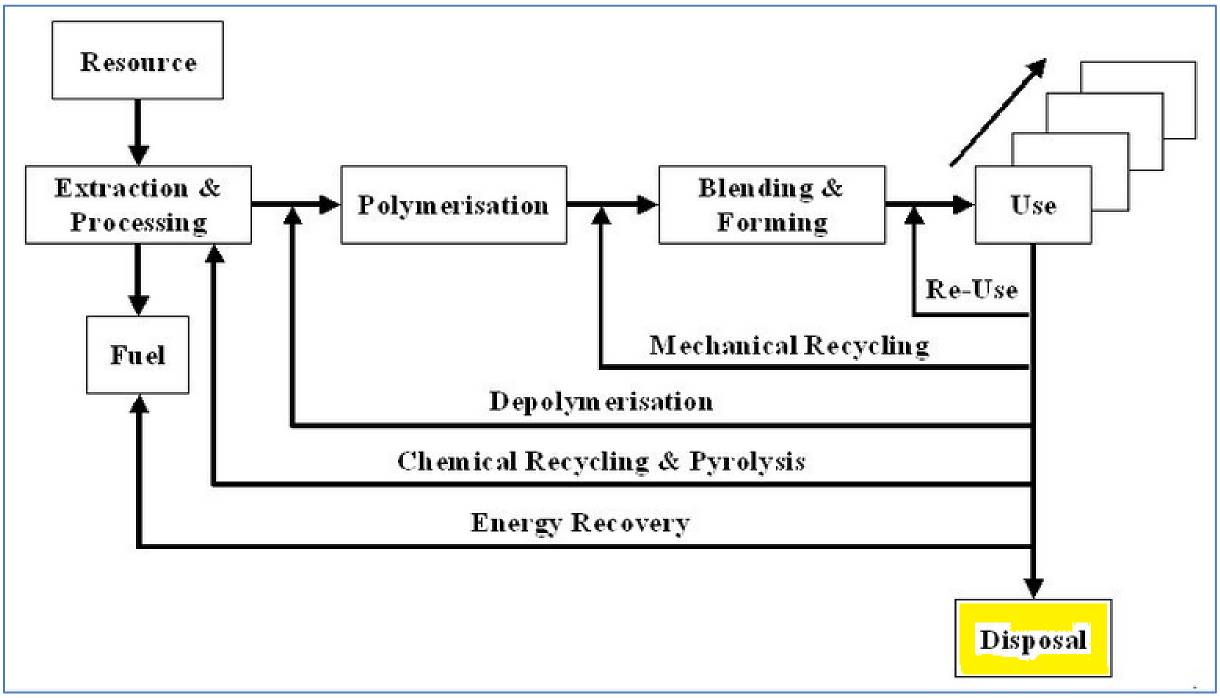

Figure 6: IE for plastics, adapted from Roland Clift, University of Surrey

Thus, this study of plastic debris flows will be done in the context of industrial ecology because it explores the impact of industrial systems onto the marine ecosystem. The respective industrial systems for this case are not only industries in the literal sense such as the fishing industry and various producing industries, but also human settlements. Human behaviour is an important factor in the waste problem as a large part of the plastic debris enters the ocean due to littering. Overall, the objective of industrial ecology to minimise the environmental impact of industry and to design circular processes would also reduce the amount of waste entering the ocean. To study the marine plastic debris is a way of following the waste outside its industrial borders. Normally, material flow systems are relatively closed – except for if they have leaks, which clearly is the case here. In Figure 6, a typical IE diagram for plastics is shown with the box for “Disposal” marked in yellow. This is where the schema for marine debris begins to expand with inappropriate disposal of items that end up in the ocean.

5.2 Life cycle inventory analysis

The concrete mitigation strategy that is assessed further here is the clean-up of remote arctic beaches by picking up plastics by hand. The example taken here is a one-week arctic boat expedition with about 120 participants that was launched in summer 2015 to collect beach trash at the Norwegian archipelago of Svalbard, far away from the mainland and long behind the Arctic Circle (AECO, 2014). The main island of the archipelago is well-known under its name Spitzbergen, the only permanently populated part with around 2 500 inhabitants (Lokalstyre, 2012). On Svalbard, a local collaboration to clean the shores started already about 15 years ago where clean-up trips for locals are organised on a regular basis as well as that vessels passing by collect trash occasionally (AECO, 2014). The litter that can be found on the beaches there does not come from the settlements at Svalbard but it is transported to the arctic from all over the world by ocean currents. According to local observations it takes about six years till a just cleaned beach is littered again to approximately the same extent as before the clean-up (Oceanwide Expeditions, 2016). The idea behind the *Oceanwide Expeditions* trip last summer then was to attract tourists to participate in special clean-up excursions by discounting the cruise price in order to make a greater effort in cleaning beaches. For the excursion, the participants first travelled to Oslo, mainly by airplane, to then fly to Longyearbyen from there, the main settlement on Svalbard, where they embarked the arctic cruise vessel “Ortelius” (AECO, 2014).

The focus of the LCA of the Svalbard clean-up operation (see Figure 7) lies on carbon dioxide emissions on the one side and impacts on biological diversity on the other. For all transport processes the CO_2 emissions to air are added up (see Table 2), as the significant impact there clearly is the combustion of fossil fuels. So the LCA approach applied here accounts for fuel use only and does neglect any infrastructure processes; that is the use of airports, roads or for instance the building and maintenance of ships and airplanes themselves. Everything is quantified in relation to the functional unit of 1 arctic clean-up operation. In this case it comprises the about 120 passengers that the deployed polar vessel can house including their transport to and from the remote location of the clean-up itself. During their one-week trip, circa half a metric ton has been collected (for explanation see below). Still, the functional unit here is the one arctic clean-up operation and not the amount of plastic collected because the emissions are specific for the chosen remote setup while 500 kg of marine plastic debris could also have been removed somewhere else with probably less effort but different side-specific effects. Furthermore, the positive environmental impacts of the removal of plastic debris from beaches, as the overall goal of the operation, will be described in the next subchapter.

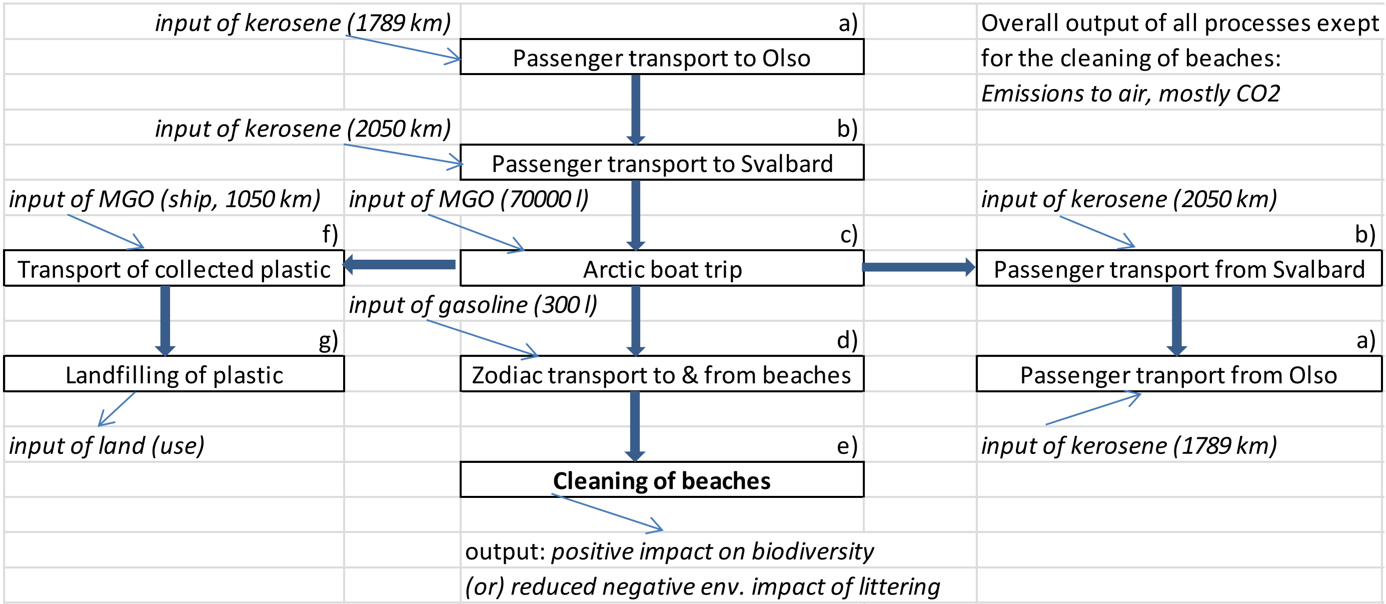

Figure 7: LCA process tree for the Svalbard clean-up operation

Table 2: Total emission balance for the functional unit of one clean-up operation

Process	Carbon emissions in t	Remarks
a) Passenger transport to Oslo	20.42	101g/km/pax
a) Passenger transport from Oslo	20.42	101g/km/pax
b) Passenger transport to Svalbard	17.61	76g/km/pax
b) Passenger transport from Svalbard	17.61	76g/km/pax
c) Arctic boat trip	191.56	from 70000 l MGO
d) Zodiac transport to & from beaches	0.695	from 300 l bensin
e) Cleaning of beaches	overall goal output	positive ecolog.
f) Transport of collected plastic	0.0065	13m³ shipped 1050km
g) Landfilling of plastic	neglectable	landuse for landfilling
	268.30	sum of emissions

a) The first process in this operation is the transportation of the passengers (pax) from their places of residence to Oslo. *Oceanwide Expeditions* provided the nationalities of the participants from which the average flight distance of 1789 km was calculated with the respective capital city as the starting point of the journey (see Table 3). The carbon emissions of 101 g per passenger kilometre given by British airways (2015, p. 6) comply well with other values from the International Civil

Aviation Organization (ICAO, 93 g/km/pax, see Figure 8) or the webside carbonindependent.org (101 g/km/pax).

Table 3: Passenger distances travelled by flight, data from Oceanwide Expeditions

Number	Nationality	mean dist. capital - Oslo	(weighted)
1	Austria	1353	1353
14	Germany	839	11746
1	Spain	2391	2391
1	France	1343	1343
11	Great	1155	12705
20	Israel	3568	71360
3	Italy	2009	6027
44	Netherlands	914	40216
6	Norway	0	0
4	Sweden	417	1668
7	USA	6239	43673
1	South	9717	9717
113			202199
	mean distance per person in km		**1789**
	plus distance Oslo-Svalbard in km		**2050**

Flight Stage Detail					
Dep Airport	Arr Airport	Distance (KM)	Aircraft	Avg Fuel Burn/Flt (KG)	Avg CO_2 per Passenger/Flt (KG)
OSL	LYR	2012.00	738, 73G, 73H, 73W	7110.80	186.50

Figure 8: ICAO carbon emissions calculator, output for Oslo – Longyearbyen equals 93 g CO2 / km / pax

b) Next, the same is calculated for the distance of 2050 km between Oslo and Longyearbyen flown with Norwegian airlines. They give 76 g/km/pax as their averaged carbon emissions. Both processes a) and b) occur again as the passengers return to their places of residence after the excursion.

c) Then, the transport process of the arctic boat trip itself followed which used up 70 m^3 of marine gas oil (MGO), a light shipping fuel with low sulphur content (Bengtsson et al, 2011, p. 98). MGO emits 74 g CO_2 per MJ and has a heating value of 43 MJ per kg (Bengtsson et al, 2011, p. 102). Together with its density of 890 kg/m^3 (Caltex, 2011), the resulting total carbon emissions of the polar expedition vessel are 192 tons.

d) Additionally, trips from the vessel to the shores were made with several zodiacs that used 300 litre of gasoline during the expedition altogether. With emissions of 16.6 kg CO_2 per 100 km (EPA, 2006), a total amount of 695 kg was emitted from this process.

e) The cleaning of beaches is done by picking up waste by hand by the passengers. They collected all waste fractions, even though the biggest part was plastics. Different attempts to quantify the positive impact of the removal of litter itself will be described in the next chapter.

f) After the expedition itself, the plastic waste collected from the beaches around the archipelago was shipped to the mainland (Tromsø) for landfilling. The reason why it cannot be incinerated for energy recovery is that the material partly consists of fishing gear. The nets and ropes would get tangled in the automatic equipment used in recycling and incineration plants (Lokalstyre Longyearbyen, 2016). It was assumed that a freighter smaller than 2000 dwt was used for the transportation which emits 9 kg of CO_2 per t of freight on the distance of 1050 km (CMP SPINE LCI dataset). The other greenhouse gas emissions were converted to CO_2 equivalence with a calculator provided by the United States Environmental Protection Agency (EPA, 2014), which delivered a total of 13 kg CO_2 equivalence. The resulting emissions for 500 kg material transported (see Table 4) are then 6.5 kg.

Table 4: Calculation of the weight of the collected plastic waste

Mean weight of 1 m³ of material in kg, packed with low density	
Plastic bags	39
Hard plastic	72
Polystyrene	14
Mean value	41.67
Calculated for 13 m³	541.67
rounded due to less packed containers	500

Data from EPA, http://www.epa.vic.gov.au/business-and-industry/lower-your-impact/~/media/Files/bus/ EREP/docs/wastematerials-densities-data.pdf

g) The landfilling itself also has an environmental impact which is very little though. As plastics are relatively inert when landfilled, there occur no emissions to air or water from the disposal. Similarly, the use of land, that is the respective part of space occupied by the landfilling site, by the 13 m³ considered here is very little and can thus be neglected.

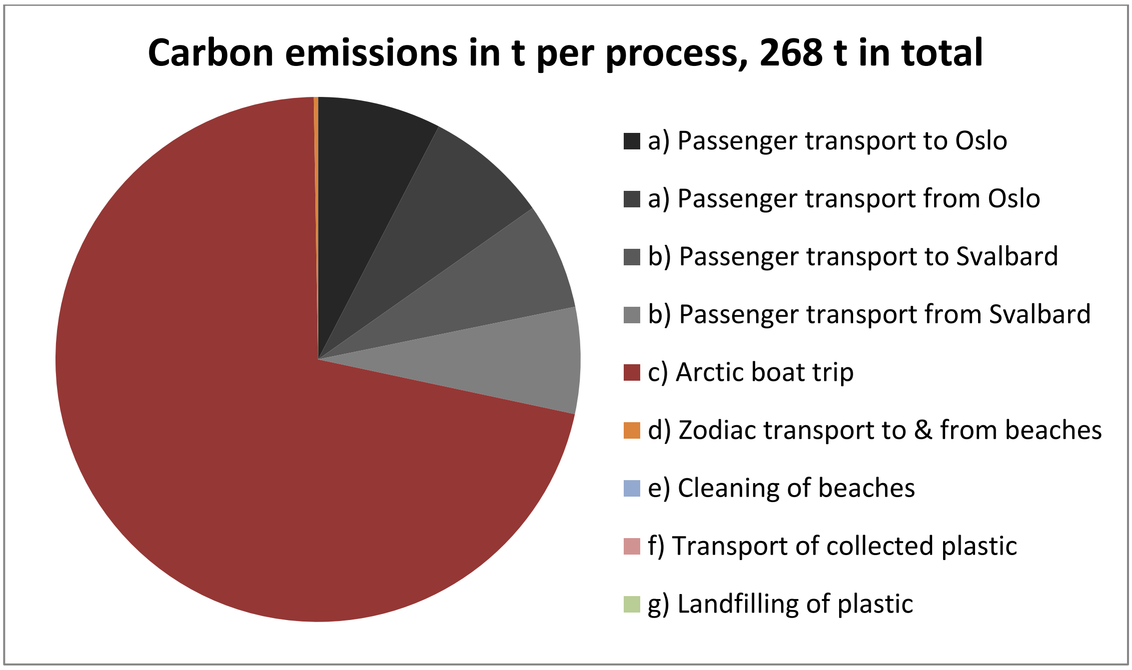

Figure 9: Carbon emission share of the different processes calculated in the LCA

In Figure 9, the calculated emissions for each process are visualised in relation to each other. It can clearly be seen that the arctic boat trip causes most of the emissions, followed by the flights (passenger transport). The other processes – that is the Zodiac trips, the transport of the collected plastic and the landfilling of the material – can be neglected due to their insignificant contribution. Besides, the process "cleaning of beaches" does not have any emissions itself because it mainly has a positive ecological impact, as described in the following chapter.

6 Environmental evaluation methods

6.1 Problem mitigation strategies

Researchers around the globe agree on that the pollution of the ocean with plastics is a severe problem. Approaches how to handle this problem however vary from cleaning up the gyres, over simply picking up plastics at beaches, till for instance altering landfills to reduce new littering. Certainly all of these mitigation actions are required to get the marine pollution under control, so the different mitigation measures are not exclusive but they complement each other. Sherman & van Sebille for example say that it is most efficient to clean-up debris near the coasts: “Oceanic plastic removal might be more effective in removing a greater microplastic mass and in reducing potential harm to marine life when closer to shore than inside the plastic accumulation zones in the centres of the gyres” (2016, p.1). They want to place plastic collectors near the coasts of China and Indonesia to remove debris directly close to where it enters the ocean, as these countries are one of the big emitters (Sherman & van Sebille, 2016).

Another approach is to clean up the big garbage patches in the middle of the ocean which is driven forward by Boyan Slat, a very young Dutch entrepreneur and inventor. He invented a stationary floating construction that uses the natural movement of the ocean currents to passively concentrate the superficial litter into a zone where it can be collected by boat and shipped to land for recycling (see The Ocean Cleanup).

Likewise, debris can also be picked up on the coastline where it is deposited by waves and tidal flows. This already happens a lot especially at beaches in tourist regions but due to the spread of floating plastics by ocean currents as explained, beaches in remote areas where normally no one cleans up are littered as well. There the debris affects the local wildlife species mainly by entanglement & ingestion (Gregory, 2009). A practical example of remote beach cleaning is the initiative “Clean Up Svalbard” by the Governor of Spitsbergen, Oceanwide Expeditions and the Association of Arctic Expedition Cruise Operators (AECO). The expectantly positive impact of this project is further assessed in chapter 5.4.

Furthermore, most plastic in the ocean is of very small size, which makes its removal very problematic (Jambeck et al., 2015). Therefore "the most effective mitigation strategies must reduce inputs" states Jambeck et al. (2015, p. 768), which also is a mitigation strategy. To reduce the amount of plastics that newly enters the ocean every year is of course absolutely necessary to diminish the problem substantially in the long term. This means that citizens, industries and municipalities worldwide have to change their behaviour and practices, which surely is no easy undertaking but one of the big global problems that humankind needs to tackle. Jambeck et al. (2015) estimated that just 20 countries produce 83% of all marine plastic debris. The American non-profit environmental organisation *Ocean conservancy* state as well that to improve waste management in the top 5 ocean polluting countries China, Indonesia, Vietnam, Thailand, Philippines could reduce the amount of waste entering the ocean each year by up to 45% (2015). Therefore to help establish and improve waste management in these countries appears to be an effective mitigation strategy as well.

6.2 Evaluation methods for positive environmental impacts

For the assessment of the mentioned positive impact of the beach cleaning, different methods are presented here and then used in combination to interpret the results. This is due to a lack of existing operational assessment methods for positive environmental impacts.

- Impact on local wildlife, observed changes
    - No records of changes exist, only increasing pollution noticed but no direct difference due to the cleaning of beaches: "The plastic pollution is increasing at Svalbard. We see more and more animals affected. However, we are not able to document any ecological impact of the collection of plastics on the beaches at Svalbard." UNIS (2016, Geir Wing Gabrielsen).
- Differences in the amount of plastics found in the stomachs of Fulmars as indicator species on Svalbard and comparable habitats elsewhere that are not cleaned

- As can be seen in Table 5 below, the beach cleaning apparently does not reflect itself in plastic ingestion rates from Svalbard and elsewhere in the Arctic. For instance, the incidence of plastic ingestion is 87.5% on Svalbard nowadays (2013), while it also is 84% in the East Canadian Arctic (2008).

Table 5: Plastic ingestion by Northern fulmars *Fulmarus glacialis*, modified from Trevail et al, 2015, p. 13

Location	Years	Incidence of plastic ingestion	References
Svalbard, Europe. 78.3˚N, 16.1˚E	1982-1984	29%	Mehlum and Gjertz 1984; Gjertz et al. 1985; Lydersen et al. 1985
	2013	87.5%	Trevail et al. 2015
Bear Island, Svalbard, Europe 74˚24'N, 19˚0E	1983	82%	Van Franeker 1985
Jan Mayen, Europe, 71˚0'N, 9˚0'W	1983	79%	Van Franeker 1985
East Canadian Arctic. 67-74˚N, 62-90˚W	2002 - 2008	Latest: 84%	Mallory et al. 2006; Mallory 2008; Provencher et al. 2009

- Effects of awareness raising actions on (littering) behaviour
  - "Marine wildlife tours can provide a range of education and conservation benefits for visitors, including emotional (i.e., affective) responses and learning (i.e., cognition)." (Zeppel, 2008).
  - "Encounters on wildlife tours motivate visitors to respect marine life, foster environmentally responsible attitudes and behaviours, and benefit marine conservation" (Zeppel & Muloin, 2008).
- Kilometres of coastline cleaned
  - 2314 km of coastline for the four main islands on Svalbard vs. about 12 km of beachline that have been cleaned. Under the assumption that one quarter of the coastline is beaches or shallow coast where debris is washed onto land, then it is 12 out of 578 km which equals 2.1% cleaned.

6.5 IUCN No net loss and net positive impact approaches

The International Union for Conservation and Nature (IUCN) published a report named "No Net Loss and Net Positive Impact Approaches for Biodiversity" in 2015 which explains these concepts and their application in different sectors. The concepts will be applied as a framework here for the evaluation of the clean-up operation. So "No Net Loss" (NNL) as defined by the IUCN report is that any negative impact triggered by a project needs to be compensated for with other measures. The focus here lies on biodiversity, thus compensation measures would need to foster biodiversity elsewhere in the region where the damage due to a considered project occurs. Further, "Net Positive Impact" is when the compensation measures taken even outweigh the damage inflicted, so that the overall outcome of a project would then be a biodiversity gain so to speak instead of losses. Nevertheless, the compensation needs to be accessed for feasibility and effectivity under the particular local conditions. Additionally, the recommendation is given to always aim for a Net Positive Impact project in order to make sure that never less than a No Net Loss is achieved in the end. This actually acknowledges that there is some uncertainty involved in biodiversity projects, that humans can restore nature only imperfectly so to say. (IUCN, 2015)

Table 6: Five main stages for a NPI approach, modified from IUCN, 2015, page 17-20; Applied to the arctic clean-up operation.

1) Identify priority values in the region and define the goal	Protect the sensitive ecosystem of the arctic → awareness raising for marine litter
2) Establish a baseline reference for comparison before and after	No excursion there otherwise is the reference
3) Estimate the full negative impact of the project itself and of the planned compensation	Neg. impact: 268 t of CO_2 emitted; Pos. impact: removal of 500 kg of plastic debris / cleaning of 9-12 km of coastline
4) Implement the project plan	Done once in 2015, next time this summer
5) Monitor the goal achievement, use the feedback to adjust the compensation if necessary	Assumed positive impact for wildlife & the desired behavioural change in people are difficult to quantify

In Table 6, the main steps for a NPI procedure are listed and applied onto the clean-up operation. The special characteristic of the considered case here is that the whole project itself could be seen as a compensation measure. Then the removal of plastics from the ecosystem would compensate for plastic pollution somewhere else, though this would not respect the rule that compensation needs to be done in the same region where the negative impact occurs. A better tactic would therefore be to regard the plastic picking as the reparation for the carbon emissions occurring from the trip (flights and boat). Hence, the resulting awareness raising would be an extra positive effect of the operation.

Moreover, the Net Positive Impact approach as adapted to the examined clean-up expedition could be developed further to a new model concept for ecotourism. Instead of aiming for to minimise the negative impact caused by tourists in the destination regions, the goal would then actually be to achieve a positive impact there. This could be done by establishing the participation in local project as a mandatory part of the tourists´ activities on site. Suitable projects would be clean-up actions in different surrounding environments, but also tree planting or wildlife protection activities for instance. In addition to the positive ecological impact and the awareness raising as described, this might even create jobs for local people who would perhaps be needed in the project management and thus stimulate encounters between locals and visitors, possibly generating better mutual understanding. All in all, the implication of an active NPI approach in ecotourism could produce several positive effects and foster behavioural changes in people participating.

7 Assessment results

The total carbon emissions from the assessed clean-up operation have been 268 tons (see Figure 9); this equals 2.37 tons per person for 4.4 kg pf plastics collected per person. In comparison, a Swedish citizen caused in average 6.7 tons of carbon equivalent emissions in 2011 (EEA, 2012). The emissions caused by the clean-up represent thus about a third of the average Swedish emissions per capita and per year, which is quite a lot. Thus, the method used here to remove marine debris is not very efficient from an overall point of view and is not recommended to be applied for the removal of plastics in general. However, the polar ecosystems on Svalbard are especially sensitive and of great value. As no suitable and applicable methods for the assessment of positive environmental impacts could be found in literature to date, an own approach has been set up to describe the benefits here.

So, the benefits of this operation are the achieved awareness raising for marine pollution and the (temporarily) lowered risk for local wildlife, which are important contributions to the overall problem mitigation. On the one hand, awareness raising should lead to reduced inputs of more plastic debris as people learn about the negative consequences of littering and thus start changing their behaviour. On the other hand, the picking up of plastics on beaches is part of the necessary cleaning up of already existing marine debris. Especially as polar ecosystems are extra sensitive to stressors (here: pollution impacts) (Bölter & Müller, 2016), the removal of litter from remote arctic areas helps to protect this fragile environment.

Even if new pollution input would stop today – which unfortunately is completely unrealistic – according to my estimation there still are about 200 million tons of plastics in the ocean environment (both floating and sedimented) which need to be removed as far as possible to reduce its harmful impacts and to minimise fragmentation. As explained, researchers assume that plastic debris becomes more dangerous the smaller the particles get due to their bioavailability. All in all, the achievements of the expedition seem definitely worth the carbon emissions it caused. Even more so as a part of the people who participated in the expedition would probably have done an arctic excursion anyway, so it could be regarded as a conversion of conventional tourism into ecotourism, see Chapter 6.5 *IUCN approach*.

8 Discussion

Global debris amount estimations

The biggest hindrance with global data collection about marine plastic debris is that different researchers nearly all look at a different part of the whole picture or use varying angles. This is due to the complexity of the thematic and leads to hardly comparable estimates about the amount of plastics in the ocean or contradictory observations. The collection of region-specific data and observations is certainly important. However, a standardisation of approaches to be able to fit the local results into a global picture would be desirable to increase the significance of research. In addition, it is difficult to get data from remote locations such as the deep sea or numbers of the amounts of plastics ingested by biota. Apart from total weights, the particle sizes and the types of material would be interesting in order to estimate their origin. Nevertheless while the exact numbers of the extent of pollution remain veiled, no one denies its severity and several initiatives to tackle the problem exist, as mentioned. Overall, there seems to be consensus about the fatal impact of marine litter on wildlife.

Different mitigation strategies

All the various mitigation strategies – that is cleaning up the gyres, picking up debris at beaches, collecting plastics near the coasts and to work on stopping new pollution – are important and urgently needed. There surely are even more approaches to mitigate ocean pollution which are not mentioned in this report due to the limited scope but which are just as important. The reason why all tactics are needed at the same time is that they tackle the problem from different angles and at varying locations. In consequence of the global expansion and the severity of ocean pollution as well as the future projections on continuously increasing plastic production, mitigation efforts need to be undertaken across borders. Knowledge transfer between nations and cultures, joined research and grassroot education might further facilitate the needed change. In conclusion, all available efforts are necessary to master the problem eventually. And we cannot mess up this one as "the oceans are the very foundation of human life" (United Nations, 2011).

Strengths and weaknesses of the different evaluation methods

- Impact on local wildlife, observed changes
  - To observe the benefit on local wildlife is a biocentric measure that cannot be quantified but only assumed which certainly is a weakness. However, observation efforts could be reinforced and documented in a centralised manner in order to establish quantifiable records for the future. Entanglements of individuals could be counted and the number corrected with a parameter for the general increase in the amount of marine debris for the purpose of quantifying impacts on wildlife by the clean-up of beaches.
- Differences in the amount of plastics found in the stomachs of Fulmars
  - As for the method before, this is a biocentric measure which would complement the entanglement records with records of ingestion if the observed amounts of plastics in birds´ stomachs would be documented with increased efforts as described above. At the current status, this method cannot be used quantitative but could be strengthened by improved documentation.
- Effects of awareness raising actions on littering behaviour
  - Even though the positive effects of ecotourism or the like are recognised, they cannot be quantified which is a weakness here. Nevertheless, the societal effects of the project are captured in this anthropocentric measure. It is not only the people themselves who went on that excursion but also their nearest friends and family who probably changed their behaviour due to awareness transmitted to them by the participants. Assuming that every participant imparts his or her knowledge to four other people, then that one clean-up trip would have influenced the attitude of 565 people.
- Kilometres of coastline cleaned
  - This is an easily quantifiable measure which is neither biocentric nor anthropocentric but in between; most likely it could be called geological. Its flaw is that even though it gives a distinct figure, this number does have a low informative value. As already mentioned for a method above, the significance here could be enhanced as well by better documentation. The amount of coastline where debris is washed ashore would need to be

estimated properly from geographic maps, that is beaches and other shallow parts of the shoreline. Now it was only assumed that one quarter of the coastline is shallow. Then, a more realistic number of kilometres of coastline which are polluted and a percentage of that which are cleaned could be given.

All in all, the evaluation methods have different strength and weaknesses, which is why a combination of various approaches might deliver the best assessment. None of the considered methods can provide a good evaluation alone, as they focus on different benefits of the project undertaken. The two biocentric approaches – that is the observed changes for wildlife and the amount of plastics found in Fulmars – together with the anthropocentric awareness raising approach and the geological percentage of coastline method combined together cover as much of the dimensions of impact for this clean-up operation as possible. Furthermore, mitigation efforts should be communicated on regional, national and global platforms for the purpose of awareness raising and the existing clean-up strategies should be promoted as well as new strategies developed.

Balancing positive and negative impacts

Traditionally, life cycle assessment only accounts for the negative impacts caused by a project or product. The new approach here to also describe the positive impacts achieved then lives up to the name of an Ecobalance. In German and Swedish the terms *Ökobilanzierung* and *Miljöbalans* or *Ekobalans* are in use next to LCA. So by evaluating the positive impacts as well, the analysis really becomes a balancing between ecological effects, thus an Ecobalance.

9 Conclusion

The research questions about where the plastic debris comes from, where it goes and what impact it has on the oceans and on us humans have been covered throughout this report. Still, the knowledge about the severe impacts of marine plastic debris and its widespread distribution into even the most pristine environments is growing steadily. It has been documented in literature that numerous seabirds, turtles, fish and whale species suffer and die from ingestion of plastic particles mistaken for food and from entanglement in plastic items. Further, floating debris acts as a vector for the spread of alien species and can hinder gas exchange on the seafloor when sedimented. Additionally, plastic particles concentrate endocrine disrupting toxics and other persistent chemicals on their surface which are then accumulated in the food chain across trophic levels.

As researchers find out more and more alarming characteristics of the problem, people also get creative and think about problem mitigation strategies. While The Ocean Cleanup probably is one of the most remarkable projects at the moment, also numberless smaller and more locally focused beach cleaning actions around the world contribute essentially to the urgently required change. In the conducted life-cycle assessment of the arctic beach-cleaning operation *Clean Up Svalbard* it was calculated that 268 t of carbon were emitted in total, with roughly 500 kg of plastic debris collected on about 12 km of coastline. The carbon emissions equal 2.37 ton per person which is about a third of annual Swedish emissions per capita. Though not quantifiable properly, the various benefits arising from the project seem to outweigh the caused negative effect of greenhouse gas emissions. One resulting benefit is an increased awareness of marine litter for all participants and their nearest acquaintances, however not measurable, which contributes to reduced littering behaviour in the long term. General awareness raising and to attain a positive impact for the local environment through participation in clean-up projects etc. could also be promoted as a new strategy for ecotourism. In addition, an ecological benefit is assumed to arise from the clean-up, although it could neither be detected in local wildlife observation nor in the amount of plastics ingested by an indicator species.

The study identified a lack of operational assessment methods for positive environmental impacts. Therefore own approaches to describe the achieved effects are set up as evaluation methods for the positive impact here. For a better quantification of the positive impact of planned or conducted mitigation projects in the future, observation efforts should to be reinforced and the harmful impacts of debris documented more systematically. Besides, standardised methods for sampling would ensure the comparability of results, so that a more consistent picture of marine pollution around the globe could be formed.

Finally, we will only manage to tackle this pervasive problem if the input of new plastic debris into the oceans will be stopped eventually or at least reduced drastically in the near future. As in the IUCN Net Positive Impact approach where the aim is to make a positive impact in order to ensure the achievement of at least No Net Loss, the goal should be to stop new pollution altogether and to remove as much of the litter that already is in the oceans as possible. Thereby, we should be able to safeguard the health of marine ecosystems and to most likely not cross any essential ecological thresholds. The oceans provide food, medicine and various vital ecosystem services that many communities rely on. Life on earth depends on the ocean, let us not jeopardise its soundness.

10 Outlook

10.1 Prognosis on plastic debris and wildlife

With the current stand of knowledge it might not be possible to quantify the effectiveness of mitigation efforts thoroughly. Nonetheless, there is distinct proof that the pollution of the oceans by plastic debris occurs widespread all around the globe and that it causes severe negative impacts on marine ecosystems. Wilcox et al. "predict that plastic will be found in the digestive tracts of 99% of all seabird species by 2050 and that 95% of the individuals within these species will have ingested plastic by the same year" (2015, p. 11901-11902). This prognosis is made under the assumption that plastic production will continue to increase with the current trend. Further, they recommend to increase the efficiency of waste management in order to lower the amount of waste that enters the ocean environment. (Wilcox et al, 2015)

Finally, if societies around the world will not manage to decrease the input of new plastic debris radically in the next years to come, then the described threats to wildlife will increase drastically. Due to the enormous durability of plastic materials which fragment into ever smaller pieces but do not biodegrade, the accumulation of plastics in the ocean seems infinite. It is of vital importance for the health of the marine ecosystems to stop its pollution. Otherwise the described negative impacts of plastic waste will lead to the extinction of species, the collapse of food chains and the contamination of human beings with plastic particles and their associated toxics by sea food.

10.2 Further research

- Total amount of plastics in the ocean – a clearer picture of the global magnitude of oceanic plastic pollution would simplify the assessment of mitigation measures plus also enable a more explicit communication to the public.
- Uptake of toxics transmitted by plastics by humans eating seafood. Seltenrich: "Plastics [tend] to sorb persistent, bioaccumulative, and toxic substances, which […] can travel into the bodies of marine organisms upon consumption, where they may concentrate and climb the food chain, ultimately into humans." Better knowledge

about seafood safety issues due to plastic pollution might help the public to see the severity of the problem.

- A method to quantify the positive impact of awareness raising through ecotourism and the like is needed in order to actually calculate the profitability of such operations.

10.3 Recommendations to industries and governments

Politicians

- Raise global awareness of the problem with educational campaigns and signs on beaches & coastal areas (no littering)
- Ban the use of microplastics in cosmetic products with national legislation
- Put stricter rules on the fishing industry worldwide to stop them from dumping
- Enhance financial incentives to reduce plastic packaging, e.g. tax on plastic bags

Industry & Companies

- Develop and imply special fibre filters mandatorily for all new washing machines
- Develop new microplastic filters for sewage plants in order to remove particles
- Install clean-up technology in river mouths and deltas in order to remove new litter from land-based sources
- Introduce & increase the use of biodegradable substitutes where reasonable
- Clean up the ocean gyres to prevent to plastics from degrading to microplastics

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