Measuring Marine Litter density, mass and composition
– including a case study on land-based litter along the Danube

Master's thesis

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Abbreviations

CBD	Secretariat of the Convention in Biological Diversity
CEINMPRMDI	Committee on the Effectiveness of International and National Measures to Prevent and Reduce Marine Debris and Its Impacts
DDT	Dichlorodiphenyltrichloroethane
EPS	Expanded polystyrene
EcoQO	Ecological Quality Objectives
H_2O_2	Hydrogen peroxide
IMO	International Maritime Organization
IUCN	International Union for Conservation of Nature and Natural Resources
MARPOL	International Convention for the Prevention of Pollution from Ships
MPSS	Munich Plastic Sediment Separator
MSFD TSG ML	Marine Strategy Framework Directive – Technical Subgroup on Marine Litter
NaCl	Natrium chloride
NaI	Natrium iodide
NGO	Non-governmental organisation
NOAA	National Oceanographic and Atmospheric Administration
OFOS	Ocean Floor Observation System
OPA	Organic plastic additives
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PA	Polyamide
PC	Polycarbonate
PCBs	Polychlorinated biphenyls

PE	Polyethylene
PE-HD/LD	High-/Low-density polypropylene
PET	Polyethylene terephthalate
POPs	Persistent organic pollutants
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinylchloride
ROV	Remotely operated vehicle
UNEP	United Nations Environmental Program
YTAE	Youth taking action for the earth
$ZnCl_2$	Zinc chloride

Abstract

Marine litter, i.e. solid waste material that enters the marine environment from any source, is an increasing problem, and gains more public attention, when for example the media is reporting of the 'Great Pacific Garbage Patch'. It furthermore negatively affects environment, economy and society. This thesis presents the results of a literature review of more than 190 scientific articles that determined marine litter quantities and composition at beaches, the sea surface and the sea floor between 2003 and August 2014. Their methods and results are being displayed and, where possible, compared. Thus, this thesis gives an overview of possible methods for monitoring marine macro- and micro-debris, as well as marine litter quantities and composition world-wide. This is completed by an excursus to aquatic litter, i.e. solid waste material present in and along rivers and lakes. A small survey along the bank of the river Danube, south of Vienna, showed that litter quantities and composition are comparable to marine litter on beaches world-wide, although the mass of items found at the Danube was higher per length of coastline than at beaches. The thesis shows that marine litter is ubiquitous and that a combination of different countermeasures will be needed to combat it.

Marine Litter, d.h. Abfälle die in die marine Umwelt durch jegliche Quelle gelangen, stellen ein wachsendes Problem dar, und bekommen in letzter Zeit mehr Aufmerksamkeit, wenn beispielsweise die Medien vom 'Großen Pazifischen Müllstrudel' berichten. Des Weiteren hat Marine Litter negative Auswirkungen auf die Umwelt, die Wirtschaft und die Gesellschaft. Die Arbeit stellt die Ergebnisse einer Literaturrecherche von mehr als 190 wissenschaftlichen Artikeln vor, die zwischen 2003 und August 2014 die Menge und Zusammensetzung von Marine Litter an Stränden, der Meeresoberfläche und dem Meeresboden ermittelten. Ihre Methoden und Ergebnisse werden wiedergegeben und, wenn möglich, verglichen. Somit gibt diese Arbeit einen Überblick über mögliche Methoden um marine Makro- und Mikroabfälle zu überwachen, sowie über Marine Litter Mengen und Zusammensetzungen weltweit. Dies wird durch einen Exkurs zum Thema aquatische Abfälle, d.h. Abfälle in und entlang von Flüssen und Seen, abgerundet. Eine kleine Studie am Ufer der Donau südlich von Wien zeigte, dass die dort gefundenen Abfallmengen und -zusammensetzung vergleichbar sind mit den Ergebnissen von Stränden weltweit, obwohl das Gewicht je Küstenlänge weitaus höher war als an Stränden. Zusammenfassend zeigt die Arbeit auf, dass Marine Litter ubiquitär ist und eine Kombination verschiedenster Gegenmaßnahmen nötig sein wird um das Problem zu lösen.

1. Introduction

In 2012, the Canadian newspaper National Post reported of beer cans and plastic cups littering the wreck of the Titanic (MACPHERSON, 2012), making a phenomenon public that is affecting the maritime environment worldwide: marine litter. From remote islands over Arctic ice to the deep sea floor - litter items or fragments can be encountered almost everywhere on the world; and its extent is still growing. Many non-governmental organisations (NGOs) have realized this and started to raise awareness for the problem and to fight it. One of them is the NGO Ocean Conservancy, which has been organizing the 'International Coastal Cleanup' for over 25 years all around the world. During this clean up volunteers free beaches, coastlines and inland waterways from litter. In 2012, 561,600 volunteers removed 4,600 tons of waste from 28,000 km coastline in 97 countries. The top ten items found (by number) were (OCEAN CONSERVANCY, 2013):

1. cigarettes/ cigarette filters
2. food wrappers/ containers
3. plastic beverage bottles
4. plastic bags
5. caps, lids
6. cutlery, cups and plates
7. straws, stirrers
8. glass beverage bottles
9. beverage cans
10. paper bags

Although these items can be found at most of the world's coasts, the actual debris accumulated may vary greatly from beach to beach. Social conditions can, for instance, have an impact on litter composition (GESAMP, 2001). WILLOUGHBY et al. (1997) report for example thousands of flip-flops and shoes washed ashore on Indonesian islands northwest of Jakarta.

But what exactly is marine litter? The definition used most often in the literature is provided by COE and ROGERS (1997, p.xxxi):

> *“marine debris [is] any manufactured or processed solid waste material (typically inert) that enters the marine environment from any source.“*

GALGANI et al. (2010) elaborate that definition further:

> *“Marine litter consists of items that have been made or used by people and [are] deliberately discarded or unintentionally lost into the sea or coastline including such materials transported into the marine environment from land by rivers, drainage or sewage systems or wind. ... This definition does not include semi-solid remains of for example mineral and vegetable oils, paraffin and chemicals that sometime litter sea and shores.”*

Although COE and ROGERS (1997) state that the term “marine litter” may be used instead of “marine debris” to indicate intended release of the material (i.e. littering), the two terms will be used interchangeably in this thesis.

One of the many problems concerning marine litter is that no one knows how much debris reaches the oceans every year or how much litter the oceans already contain. Only few estimates have been made, concern only plastic debris and differ widely:

- CLARK (1997, cit. in DERRAIK (2002)) suggested, that ships dispose of 6.5 million tons of plastic per year;

- CÓZAR et al. (2014) derived from models of major accumulation zones that 10,000 – 40,000 tons of plastic exist in the oceans world-wide.

Other estimates only assess a specific country or region:

- KIESSLING (2003) derives from survey data that every year around 2,400 tons of fishing gear and up to 6,500 tons of waste from ships are lost or discarded in Australian waters alone;

- According to the South Korean government (MLTM et al. cit. in CHO (2011)), South Korea is responsible for the entry of 159,800 tons of waste into the ocean every year, whereof 109,400 tons are land- and 50,400 tons sea-based.

- BARNES et al. (2009) estimate that in the Mediterranean Sea three billion floating or sunk debris items (= 3×10^9), consisting to 70 – 80% of plastic, are present, whereas SUARIA and ALIANI (2014) state that 62 million items (= 6.2×10^7) are floating in the Mediterranean (> 2 cm);

- LECHNER et al. (2014) calculated the entry of microplastic debris into the Black Sea via the Danube to reach about 7.5 g per 1000 m^3/s. This equals a total entry of 1,533 tons per year;

- the estimated total amount of plastic in the North Atlantic Subtropical Gyre equals 8×10^{10} items or 1,100 metric tons, according to LAW et al. (2010), and the estimated total amount of plastic in the Eastern North Pacific Subtropical Gyre are 18,280 – 21,290 metric tons (LAW et al. 2014).

This thesis summarizes relevant knowledge concerning marine litter, its quantities in and around oceans and seas worldwide and how it can be measured. The first chapter will give an overview of marine debris, its sources and pathways and what impacts it may have on environment, economy and society. The following chapter presents the results of a literature review. Here, methods and surveys are listed that examine marine debris in the different compartments of the ocean and for different litter sizes. An extra chapter contains the results of a small survey for debris on the banks of the river Danube.

2. Marine Litter

> "*The logic of the marine debris problem is clear. Marine debris is a fundamental manifestation of population growth and the industrial-technological revolution. Economic development increases consumption that increases persistent solid wastes, which are released into the environment from many sources. ... this debris is transported by wind, water, gravity, and human and animal activity, to temporary or permanent 'sinks' in the environment. Debris is constantly accumulating in these sinks: shorelines, estuaries, lakes, and the sea floor. In the absence of large-scale efforts to control it*, marine debris will get progressively worse." (COE and ROGERS, 1997, p.xxxii)

Different characteristics can be used to describe marine litter, beginning with the *material* it is made of. Although the composition of marine litter varies in different regions of the world, the largest proportion of marine litter is by far made of plastic, reaching often 60 to 80% (DERRAIK, 2002; NAKASHIMA et al., 2011; VALAVANIDIS and VLACHOGIANNI, n.d.). Other common materials include glass, metal, rubber and wood. SHEAVLY and REGISTER (2007) remark that the composition of marine debris has changed in the last decades from organic, biodegradable ("natural") materials to synthetic and more persistent ones. The very characteristics that spread the use of plastics and other synthetic materials worldwide and in all aspects of life are the ones representing the greatest threat if items made of these materials reach the marine environment, namely their persistence, abundance and strength (MARINE MAMMAL COMMISSION, 2001). No data exists how long plastic items will persist in the marine environment, as they have only been in general use since the 1950s (BARNES et al., 2009). However, in 2005, a piece of plastic was found in an albatross stomach that bore a serial number, making it possible to trace it's origin: a World War II seaplane, shot down in 1944 (WEISS, 2006).

The original *purpose* of the items found can also be used to characterize marine litter. TEN BRINK et al. (2009) suggest that the most common debris is either fishing-related (e.g. nets and fishing line), food- and beverage related waste (e.g. bottles, cans and wrappings), smoking-related waste (e.g. cigarette filters), household items (e.g. clothing and appliances), sewage and sanitary-related, or related to manufacturing and transportation (e.g. resin pellets and plastic sheeting).

Another characteristic is the *size* and *weight* of debris. Some of the largest litter items found, derelict fishing nets, can measure several kilometer in length and weigh as much as nine tons (KIESSLING, 2003). The smallest items found were plastic particles measuring 1.6 µm. However, it might be that nanometer particles exist, as their detection is for now limited by monitoring techniques (GALGANI et al., 2010). One possibility to categorize debris sizes, which is used for this thesis, is presented by BARNES et al. (2009):

mega-debris (> 100 mm)	meso-debris (5 – 20 mm)
macro-debris (20 – 100 mm)	micro-debris (< 5 mm)

Microplastics

In the last decade a 'new' subgroup of marine debris has gained increasing attention, the so-called microplastics. They are defined as

“plastic particles smaller than 5mm.”

(ARTHUR et al., 2009, p.10)

As monitoring methods keep improving, scientists detect ever smaller particles and it is generally acknowledged that they originate from two main sources: (i) the manufacturing of plastic particles supposed to be of microscopic size, and (ii) the fragmentation of larger plastic items through UV-light, mechanical and microbial degradation (GALGANI et al., 2010; WRIGHT et al., 2013).

Polyethylene (PE) and polystyrene particles (PS), smaller than 1 mm, form part of some industrial and domestic products e.g. hand, body, and facial cleansers. Acrylic, melamine, and polyester particles, ranging from 0.25 to 1.7 mm in size, are used for a process called “media blasting”, i.e. cleaning machinery and boat hulls from rust and paint (during this process they often become contaminated with heavy metals (COLE et al., 2009)). Microplastics are further used in a variety of medical applications, e.g. drug delivery systems, and as industrial raw material (i.e. virgin plastic pellets) (BROWNE et al., 2007). Washing clothes made of synthetic fibers as polyester, polyamid or acrylic constitute another source of microplastics[1]. On the other side, large marine plastic items can become brittle and fall apart due to sunlight that oxidizes the chemical structure. C. EBBESMEYER has estimated that the photodegradation of a 1 liter plastic water bottle will result in enough small particles to put one plastic particle on every mile of beach in the world (MOORE, 2008). Mechanical degradation may happen through the combined efforts of wave action and abrasion from sediment particles. Furthermore, bacteria and fungi are able to degrade plastic particles (BROWNE et al., 2007). CORCORAN et al. (2009) analyzed small beached plastic particles and found out that most particles were degraded through mechanical erosion processes and that these fractures seem to attract more often chemical weathering processes. They concluded that the degradation of plastic items is more favorable to occur on land than on sea, as beaches combine high degrees of mechanical and chemical weathering and that the processes seem to reinforce themselves. Microplastics represent a great threat as they are difficult to remove from the environment (BARNES et al., 2009) and thus will be separately referred to in this thesis, when a distinction seems appropriate.

1 BROWNE et al. (2011) showed that washing garments made of polyester can shed more than 1,900 fibers per wash. They also analyzed the treated effluent of sewage treatment plants in the UK and found on average one microplastic particle per liter of effluent.

2.1 Sources and pathways

“The problems caused by marine debris are multifaceted and essentially rooted in inadequate solid waste management practices, product designs that do not consider life-cycle impacts, consumer choices, accidental loss or intentional dumping of fishing gear or ship-generated waste, lack of waste management infrastructure, littering, and the public’s poor understanding of the potential consequences of their actions.” (NOAA and UNEP, n.d., p.4)

2.1.1 Sources

Marine debris can be generated at sea or on land. A distinction is necessary, as the origin has an influence on the type of reaction. However, making that distinction is not as easy as it might seem, as many debris items can originate from both sea- and land-based activities. Objects lost or discarded by ships might be used for everyday life activities (e.g. consuming, smoking) and could thus falsely be accounted to land-based sources. The contribution of land- and sea-based activities to marine litter pollution varies in different regions; sea-based sources predominate for example in the North and Baltic Sea (ZESCHMAR-LAHL and LAHL, 2014). Beach surveys furthermore suggest that secluded coasts receive their share of debris mostly from sea-based sources (especially fisheries), whereas land-based and mostly local sources are the main cause in populated areas (WACE, 1995). In general, there is a significant correlation between abundance of larger size fractions of plastics and human population (BARNES et al., 2009).

Some of the major sea-based sources of marine debris are shipping and fishing activities, offshore mining and extraction, legal and illegal dumping at sea, natural disasters, and sea-based aquaculture activities (KIESSLING, 2003; JEFTIC et al., 2009; GESAMP 2010). The influence of debris originating from shipping can be seen at approaches to ports, and along coasts and islands close to heavily frequented shipping routes (WACE, 1995).Some types of debris are characteristic for sea-based activities, e.g. abandoned, lost or otherwise discarded fishing-gear. It may be lost due to storms, get caught on reefs, or is dumped into the sea. Reasons for discarding gear may be that it is economically more viable for the fishermen to get new gear instead of repairing the old, or to avoid paying discharge fees. Another possible intention might be to abandon illegal gear types (e.g. drift nets) (KIESSLING, 2003).

Land-based debris is generated when litter is transported from roads, parking lots, recreational areas and other surfaces to rivers and lakes by rain, wind and snowmelt, or when it is directly discarded into waterways (SHEAVLY and REGISTER, 2007). Therein it will be transported further downstream and eventually reach the oceans. Some of the major land-based litter sources are inadequately covered dumpsites, waste container and vehicles, rivers and floods, industrial sites, municipal sewerage, beaches and coastal picnic and recreation areas, fishing-industry activities, ship-breaking yards and natural storm-related events (SHEAVLY and REGISTER, 2007; JEFTIC et al., 2009; GESAMP 2010). As a consequence, all handling of (waste) materials, be it legal or illegal, may contribute to the problem, even the production of raw materials (SHEAVLY and REGISTER, 2007).

2.1.2 Pathways

Two things can happen to litter that is discarded into the ocean: (i) it floats – and may later be washed ashore, or (ii) it sinks to the bottom of the ocean. As many marine debris items are buoyant, their distribution depends on hydrodynamics, geomorphology and human factors (e.g. how it is released), including local wind and current conditions, and coastline geography. Annex I.a. shows for example a global map of ocean surface currents that influence debris distribution. MAXIMENKO et al. (2012) used data from the Surface Velocity Program (later Global Drifter Program) to model possible pathways of marine litter. The input of the trajectories of 10,561 drifters, reaching from February 1979 to January 2007, and an integration over long time periods provided a model solution, identifying five main areas of debris accumulation in the subtropics at around 30° latitude (see figure 1), known as subtropical gyres or convergent zones[2].

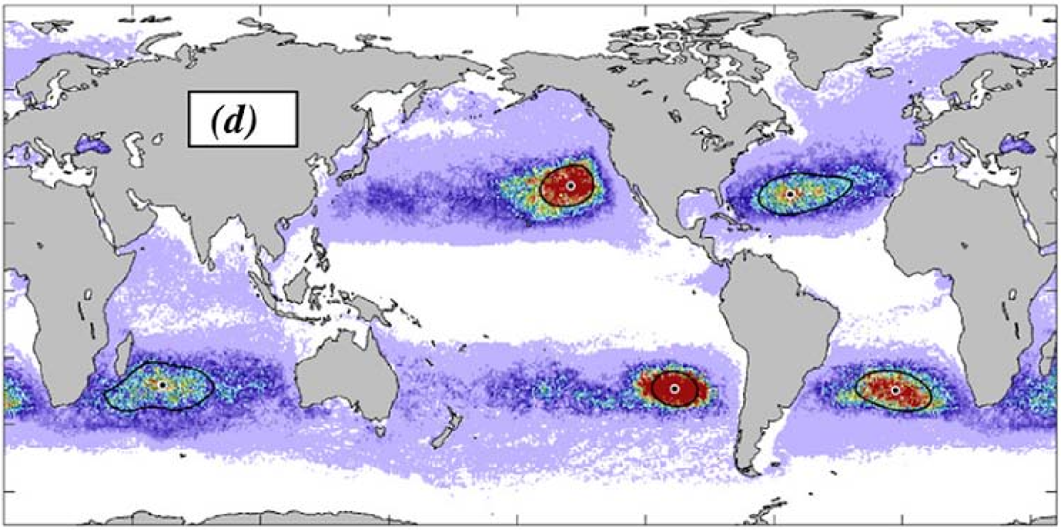

Fig. 1: Accumulation zones for floating marine debris (Maximenko et al., 2012)

A simulation by LEBRETON et al. (2012), who modeled an increasing input of particles over 30 years into the world's oceans, using different scenarios to differentiate between sea- and land-based sources, supports these accumulation zones. Besides, it shows that any semi-enclosed sea surrounded by highly populated and developed areas (e.g. Mediterranean Sea, Gulf of Mexico) is vulnerable to debris accumulation, which can be seen in Annex I.b.. The simulation further identifies regional contributions from land-based sources to every subtropical accumulation zone, as shown in table 1. The first column represents a scenario where litter is introduced to the ocean according to watershed areas (a), the second according to population density (b). As stated in this study Central/ North America is for instance the main contributor to marine litter in the North Atlantic, followed by Europe.

2 The authors explain this with the convergence and divergence of near-surface, wind-generated Ekman currents (i.e. in their paper the full current associated with the local wind), causing a counter clockwise (in the southern hemisphere) and clockwise (in the northern hemisphere) movement of the gyres and the transport of floating objects to subtropical and away from subpolar gyres.

Sources	Accumulation zones									
	Indian Ocean		North Atlantic		North Pacific		South Atlantic		South Pacific	
	a	b	a	b	a	b	a	b	a	b
Europe			24.00	16.84		0.0	0.0			
Australia/New Zealand	0.11	0.18			0.0	0.0	0.04	0.01	40.71	20.19
South America	7.54	4.44	5.32	6.57	0.05	0.08	58.55	79.59	21.91	36.63
Central/ North America	0.01	0.0	64.30	65.77	13.18	8.13			5.59	1.52
Africa/ Middle East	29.06	9.11	6.10	10.75		0.0	39.91	17.34	9.88	3.13
India	17.43	8.30					0.89	0.82	1.70	1.13
South East Asia/ Indo.	38.39	65.79			2.73	5.79	0.54	1.99	17.64	33.02
China	7.24	11.59			65.78	58.04	0.08	0.23	2.46	4.11
Japan	0.20	0.58			10.86	27.22	0.0	0.01	0.10	0.27
Russia	0.02	0.01	0.28	0.08	7.39	0.74			0.01	0.0

Tab. 1: Regional contributions to accumulation zones from land-based sources according to watershed areas (a) and population density (b) (LEBRETON et al., 2012)

A model by VAN SEBILLE et al. (2012) suggests a sixth accumulation zone in the Barents Sea as well as changes in size of the zones over centuries. Distribution varies also with time and some geographical regions tend to accumulate higher concentrations on their coasts than others. Seasonal variations can occur due to seasonal changes in flow rates of rivers, as well as changes in the position of water fronts and the intensity of currents, swell, winds and upwelling (BARNES et al., 2009). Another factor are the particle's characteristics, as shape, size and density determine the minimum velocity of water that is required to transport it (BROWNE et al., 2010). The density of the particle, as well as the attached organisms, influence it's vertical position in the water column (COLE et al., 2009), which is further influenced through the wind speed, that induces mixing in the subsurface layer (KUKULKA et al., 2012).

Floating debris may eventually wash ashore and accumulate along strandlines (see chapter 3.1.1). The model by LEBRETON et al. (2012) shows that items released at sea are more likely to remain circulating in the ocean (with only 28% of particles being beached) compared to items originating on land (36 – 40% of particles being beached). Beached debris may be buried beneath sand and resurface after some time. Strong on-shore winds can blow light items inland and may thus contribute to the degradation of dune fields behind the beaches (GREGORY, 2009). However, beached debris can also (re)enter the ocean through high tides, storms and other influences, thus sinking to the bottom of the sea or, if buoyant, starting to float and circulate the world's oceans.

Furthermore, once buoyant items may also eventually sink (sometimes after traveling long distances), due to for example bio fouling[3] (COLE et al., 2009). Turning into bottom or benthic debris, they are then often trapped in areas of low circulation and

3 i.e. colonization by algae and invertebrates on a microbial biofilm (COLE et al., 2009)

high sediment accumulation. Influencing factors include strong currents resulting from river inlets and their deep submarine extensions or coastal canyons, as well as human activities, e.g. fishing and urban development (BARNES et al., 2009). Submerged debris can re-suspend following turbulence as for example from a storm (COLE et al., 2009) or when grazing organisms clean the biofilm from its surface (YE and ANDRADY, 1991 cit. in GREGORY, 2009). Nevertheless, the sea bottom is seen by many as the ultimate sink for marine debris (GREGORY, 2009).

Thus, there is a flux between the three stages of litter (floating, benthic and beached); long periods of time in one stage may take turns with periods of rapid change. Estimates exist indicating that approximately 70% of marine litter sinks to the ground, 15% floats in the water column and another 15% is beached (OSPAR, 1995 cit. in (MOUAT et al., 2010). An illustration of this cycle can be seen in Annex I.c.

2.2 Impacts of marine litter

Marine litter can cause substantial harm that can be divided in environmental, economic and social harm.

2.2.1 Environment

This section gives a short overview of how marine litter may impact the environment. A more detailed description is found in Annex I.d. Impacts on the environment include:

- Entanglement of animals
- Ingestion of debris
- Accumulation of chemicals in the food chain
- Habitat destruction
- Transport of species

Lost or discarded fishing-gear, as nets and lines, is mostly responsible for the *entanglement* of marine wildlife. Entangled animals experience limited mobility and restricted movement, which might lead to exhaustion and therefore drowning, starvation, predation, suffocation and strangulation, laceration and infection and even mortality (MARINE MAMMAL COMMISSION, 2001; NOAA and UNEP, n.d.). 192 species have been reported to get entangled in marine debris, 45% of marine mammals (52 species), 66 species of fish and 21% of seabirds (67 species) (CBD, 2012).

Studies show that many animals *ingest* marine debris mistaking it for food or taking it up unintentionally, especially small or degraded plastic items (NOAA and UNEP, n.d.). These items can puncture or block digestive tracks and thus injure or kill animals. They might also cause the blockage of gastric enzyme production, a diminished feeding stimulus, nutrient dilution, reduced growth rates, lowered steroid hormone levels and delayed ovulation and reproductive failure (GALGANI et al., 2010). More than 200 marine animal species have been reported to ingest marine debris. Seabirds seem to be especially affected (119 species, i.e. 38% of known species) as they forage on the open sea for food, as well as turtles (100% of known species) (CBD, 2012). CBD (2012) reports further that about 15% of the species affected by marine debris through entanglement and ingestion are on the IUCN Red List[4], whereas TEN BRINK et al. (2009) estimate that every year approximately 100.000 marine mammals die because they ingest or get entangled in marine litter.

Potentially harmful *chemicals* might reach marine organisms through marine debris in two ways: they might be released from ingested debris (i) after they have been incorporated into the material during the manufacturing process or (ii) after they adsorbed to the debris in the marine environment (GALGANI et al., 2010). Studies confirmed the presence of Persistent Organic Pollutants (POPs), such as polychlorinated biphenyls (PCBs) and dichlorodiphenyltrichloroethane (DDT), on plastic particles (THOMPSON et al., 2009). Evidence indicates that adsorbed and utilized chemicals can be incorporated into living tissues and therefore might accumulate through the food chain and pose a threat to humans (NOAA and UNEP, n.d.). Microplastics are of special concern, as they posses a relatively large surface area to volume ratio and might therefore facilitate the transport of contaminants. They are moreover so small that a wide range of organisms is able to ingest them (THOMPSON et al., 2009).

Marine *habitats* can be altered, degraded and eventually destroyed through physical contact with marine litter; obstruction of sunlight, surface scoring, and abrasion are some possible effects. Especially living coral reefs are at a high risk (NOAA and UNEP, n.d.). Introducing marine litter to the benthic environment can change the characteristics of those habitats; debris may function as hard substrata and attract marine life, thus influencing inter- and intraspecific interactions (KATSANEVAKIS et al., 2007). The same holds true for the sea surface (GOLDSTEIN et al., 2012). Moreover, not only habitats in oceans are threatened by marine litter but also habitats bordering on oceans. Beaches and coastlines receive their own share of marine litter that may endanger their ecosystems. DEFEO et al. (2009) determined stressors that might have negative impacts on sandy beach ecosystems, which include the cleaning of beaches from marine litter and other non-aesthetic objects, thus weakening the local meiofauna communities, macroinvertebrates, and shorebirds, turtles and fish (by destroying eggs and killing hatchlings). However, also the direct pollution through marine debris may negatively impact the sandy shore and impair the physiology, survival, reproduction and behavior of species.

The abundance and availability of marine rafts, e.g. buoyant, synthetic debris especially made of plastic, has increased through human activities (NOAA and UNEP, n.d.), thus providing more opportunities for *species* to travel to foreign ecosystems. Rafting communities[5] can be transported for long distances and harm or compete with native species (TEN BRINK et al., 2009). Furthermore, MASÓ et al. (2003) suggest that floating plastic debris favors the probability of success in microalgae dispersal and thus potentially spread Harmful Algae Bloom species[6].

4 The Red List of the Union for Conservation of Nature and Natural Resources is an objective, global approach to evaluate the conservation status of plants and animals
5 entire communities of organisms including microbes encrusted and attached to objects
6 Harmful Algae Bloom (HAB), also known as red tides, produces toxins that affect and kill fish and shellfish, thus endangering (even fatally) marine mammals, birds and humans (NOAA 2014)

They found temporary cysts of an HAB species (*Alexandrium taylori)* that were able to stick to plastic marine debris and could hence form clusters to overcome short-term unfavorable meteorological conditions.

2.2.2 Economy

The disturbance (and thus partial destruction) of ecosystems through marine litter can result in great economic losses. CONSTANZA et al. (1997,1998, cit. in (OFIARA and SENECA, 2006) estimated the value of ecosystem services generated by the marine biome at 20.9 trillion US dollar per year (1994 $). Ecological effects may thus result directly in economic loss, e.g. a decrease in site-specific fish productivity can result in a decrease in economic surplus for commercial and recreational fishing (OFIARA and SENECA, 2006). Marine debris may also cause direct costs for local economies; beaches have to be cleaned and maintained to keep tourists, derelict traps may catch commercially valuable animals and marine litter may damage vessels, for example when nets or ropes entangle propellers and rudders and plastic bags clog or block water-intakes, causing burned-out water pumps. Thus, marine debris results in costly repairs, loss of time, and endangers the people aboard vessels (SHEAVLY and REGISTER, 2007). MCILGORM et al. (2011) identify two different categories of economic costs that might result from marine litter:

- direct economic costs: they arise from damage to an industry or to an economic activity, e.g. loss of time due to an entangled propeller

- indirect economic impacts: costs that arise indirectly, e.g. marine debris inhibits new tourism development investment

The following economic sectors can be affected by marine litter:

- tourism
- fishing industry
- aquaculture
- shipping
- power stations and industry
- voluntary organisations
- municipalities

The *tourism* sector might be impacted by marine debris through for instance reduced recreational opportunities, negative publicity and reputation, criteria for beach awards (e.g Blue Flag and Seaside Awards), beach cleansing costs and reduced revenue (MOUAT et al., 2010). An interview survey by BALLANCE et al. (2000) found out that cleanliness is the most important factor influencing the choice for a beach and that people were willing to spend more than seven times the average trip costs to visit a clean beach. They concluded that littered beaches could mean potential losses of millions of US dollar for the South African economy. JANG et al. (2014) estimate the economic effects (i.e. lost sales of producer/ decreased tourism revenue) to Geoje Island, South Korea, caused by a marine debris pollution during the summer of 2011, between 29 – 37 million US $. The number of people visiting the island decreased from 2010 to 2011 by 63% of which about 70 – 100% were probably due to the marine debris pollution, according to the authors. The same happened in the year 1976, when some Long Island beaches in New York had to close due to marine litter being washed ashore. Aided by exaggerated press releases, severely polluted and thus closed beaches as well as clean and open beaches suffered losses of expenditure between one (clean beach) and 28 million US $ (severely polluted beach), as 50 – 60% less people visited the beaches compared to 1975 (OFIARA and SENECA, 2006).

The *fishing industry* might be impacted by marine debris through for instance contamination incidents, restricted catch due to litter by-catch, reduced catch due to ghost-fishing, lost and damaged fishing-gear and vessel damage and staff downtime (MOUAT et al., 2010). MOUAT et al. (2010) concluded from a survey with the Scottish fishing fleet that marine litter costs each vessel in between 17,000 – 19,000 €/year, mostly due to loss of fishing-time while cleaning nets of marine debris. The authors estimated that each vessel spends 41 hours and about 12,000 €/year for removing litter from their nets. They end with a calculation that based on these average costs, marine litter decreases the revenues of the Scottish fishing fleet by up to 5% per year. CLARK et al. (2012) experimented with 'discarded' fish traps and estimated an economic loss of 52.25 US $ per trap per year due to mortality of marketable fish. ANDERSON and ALFORD (2014) calculated a loss of about four million US $ (two million kg of potential harvest) caused by ghost-fishing of derelict blue crap traps in Louisiana.

Aquaculture might be impacted by marine debris through for instance the manual removal of litter, as well as vessel damage and staff downtime (MOUAT et al., 2010). Aquaculture operators spend time removing debris floating in and around stock cages, thus causing considerable costs. According to a survey by MOUAT et al. (2010) for some operators marine debris is no issue, while others spend up to half a day per month to remove debris, whereas the average is about one to two hours per month. The same survey concluded that on average marine litter costs aquaculture operators 580 €/year, more than half of it to untangle propellers.

Coastal *agriculture* might be impacted by light marine litter that gets blown further inland and might cause harm to livestock and vet fees or block drainage ditches (MOUAT et al., 2010). Through interviews with crofters in Shetland, MOUAT et al. (2010) found out that the crofters spent between one and 30 hours per month removing marine litter from their fences and half an hour to eight hours cleaning drainage ditches from debris. The overall costs to crofters due to marine litter could thus be as high as 4,700 €/year, with the average at about 840 €/year.

Shipping might be impacted by marine debris through for instance vessel damage and incidents which might cause costs for coastguard rescue, as well as through the removal of litter from harbors and marinas (MOUAT et al., 2010). MCILGORM et al. (2009, cit. in (MCILGORM et al., 2011) found out that Hong Kong's high speed ferry service operators experience every year losses of about 19,000 US $ per ferry due to downtime and delays caused by marine debris. In 2005, floating and submerged objects generated property damage of three million US $ to boats in the USA (MOORE, 2008). The survey by MOUAT et al. (2010) calculated the average costs for UK harbors to remove marine debris at 8,000 €/year, although some harbors pay up to 73,000 €/year. The disposal of the removed litter costs the harbors the most, followed by the removal of the litter itself and dredging. The same study further showed, that the average costs of marine litter for harbors in Spain are 61,000 €/year, 89% due to the manual removal of litter, which is more than seven times higher as in the UK.

Power stations might be impacted by marine debris through for instance the removal of litter from screens, damage to equipment, increased maintenance, and plant and staff downtime (MOUAT et al., 2010). Similar impacts can also afflict desalination plants, especially damage to cooling-water intakes and blocking water-flow (JEFTIC et al., 2009).

The removal of marine debris from coasts by *voluntary organisations* costs the volunteers' time, financial assistance from other organisations, as well as operational costs (MOUAT et al., 2010).

MOUAT et al. (2010) describe different topics that *municipalities* have to deal with, for example public health risks and negative publicity. Cleaning beaches and keeping them free of marine debris is the principle economic impact caused by marine litter to municipalities. A review by MCILGORM et al. (2011) concluded that the costs for beach cleaning may vary according to the method of cleaning and the type of marine debris. They found beach cleaning costs reaching from 100 US $/t (using volunteers) to over 20,000 US $/t (for heavy fishing gear), with an average of about 1,500 US $/t. A survey by MOUAT et al. (2010) reported average yearly costs by municipalities around Europe to remove beach litter of 140,000 € (UK) to 227,000 € (Netherlands and Belgium) per municipality. Removal costs per kilometer of coast and year reached from 171 € - 97,300 €, with an average of about 7,150 € (UK) to 34,440 € (Netherlands and Belgium), depending on the intensity of cleaning the beach. The survey furthermore showed, that the average costs for cleaning beaches have risen in the UK by 37.4% from 2000 to 2010.

2.2.3 Society

Marine debris affects intrinsic and social values that are associated with coastal and marine environments. The NATIONAL RESEARCH COUNCIL (2008, cit. in (NOAA and UNEP, n.d.) identified two intrinsic values that are mainly reduced by marine litter:

- *non-use value*: knowledge that quality coastal ecosystems exist
- *option value*: ability to use the coastal environments.

Marine litter along coasts can prevent people from fishing, boating, swimming, and visiting these coasts (SHEAVLY and REGISTER, 2007), as well as lower surrounding property values (NOAA and UNEP, n.d.). Another social impact, that has not been studied yet, is the effect marine debris may have on indigenous peoples and their way of life. The northern coast of Australia for example is primarily inhabited by Indigenous communities that are closely linked to the sea with respect to culture and livelihood (e.g. subsistence fishing) and impacts on the coastline thus may exert a large influence on these remote and isolated communities (GUNN et al., 2010). Indigenous residents of Hawaii are another example as they are linked to the ocean through activities that are essential to their lifestyle and culture, as fishing, surfing, and canoeing (CARSON et al., 2013). Furthermore, marine debris represents an immediate threat to human health and life. Beach users may be harmed by broken glass, medical waste, and fishing line. If they venture into the water, swimmers, divers and snorkelers may get entangled in submerged or floating debris (SHEAVLY and REGISTER, 2007). In 2005, 269 boating accidents occurred in the USA due to submerged and floating items, resulting in 15 deaths and 116 injuries (MOORE, 2008). In 1993, a South Korean ferry sunk, taking 292 of its 362 passengers with it. After re-floating the ferry, derelict fishing ropes with a 10 mm diameter were found entangled around both shafts and the right-side propeller (CHO, 2005). Water quality might also be affected through the release of medical and personal hygiene debris thus endangering human health through bacterial contamination, e.g. by *Escherichia coli*. Contact with contaminated water can induce infectious hepatitis, diarrhea, bacillary dysentery, skin rashes or even typhoid and cholera (SHEAVLY and REGISTER, 2007).

3. Monitoring marine litter

LOVETT et al. (2007) stress the importance of monitoring as part of integrated environmental research programs that help policy makers evaluate their policies and inform the public. Rees and Pond (1995) think in the same direction, when they state the purposes of monitoring marine litter:

"1. To provide information on the types, quantities and distribution of marine debris.

2. To provide an insight into problems and threats associated with an area.

3. To assess the effectiveness of appropriate legislation and coastal management policies.

4. To identify source of marine debris.

5. To explore public health issues relating to marine debris.

6. To increase public awareness of the condition of the coastline."

After defining the questions to be answered by the monitoring program, accurate methods to measure marine debris quantities and, if desired, investigate its composition, have to be identified. This chapter gives an overview of methods that have been used or are being developed to quantify marine litter. They were derived through a literature review of over 190 research articles and scientific publications published from January 2003 to August 2014. Furthermore, the results of 184 papers and documents are presented. As can be seen in figure 2 more than half of these papers have been published between 2011 and 2014, thus implying that the marine debris problem is gaining more (scientific) attention. Also the number, as well as the proportion of papers measuring microplastics (marked yellow) is increasing every year, reaching a new maximum in 2014 (with only publications until August included).

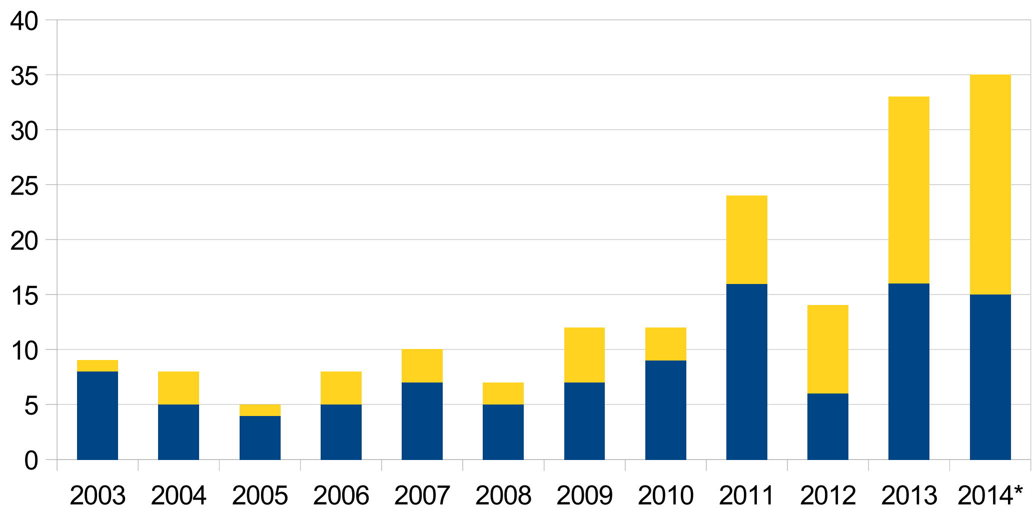

Fig. 2: Number of published research articles per year (*for 2014 only January - August) in which marine debris has been measured; articles that assessed microplastics are marked yellow .

The methods are distinguished according to the different stages marine litter can reach: beach, sea surface and sea-floor. They are furthermore subdivided according to size – micro (< 5mm), meso (5 – 20 mm) and macro (>20 mm). Most papers (80) analyze beach/coastline debris. 37 surveyed debris smaller than 2 cm, whereof 27 assessed micro-debris. Floating debris has been assessed in 62 papers, of which one examined ice-cores and more than half (45) studied micro-debris. Of the 42 papers examining benthic debris, only eight surveyed micro-debris.

3.1 Macro- and meso-debris

This chapter looks at methods for monitoring macro-debris and sometimes meso-debris, if the same method can be used. Methods for measuring micro-debris will be presented in chapter 3.2.

3.1.1 Beach debris

Figure 3 gives an overview over the world-wide distribution of surveys for beached macro-debris. Upturned triangles signal surveys, that sample on a wide regional scale and have been repeated over many years (they are for the most part monitoring programs).

Fig. 3: Worldwide distribution of beached macro-debris surveys (yellow triangles). Upturned triangles highlight long-term and/or regional wide studies. (Figure was created by the author)

The literature review showed that although beach surveys are simple tools, results cannot always be compared as the surveys differ in the exact method used and the reporting unit. Figure 4 presents an overview of methods that were encountered during the review, as well as the number of surveys using this method.

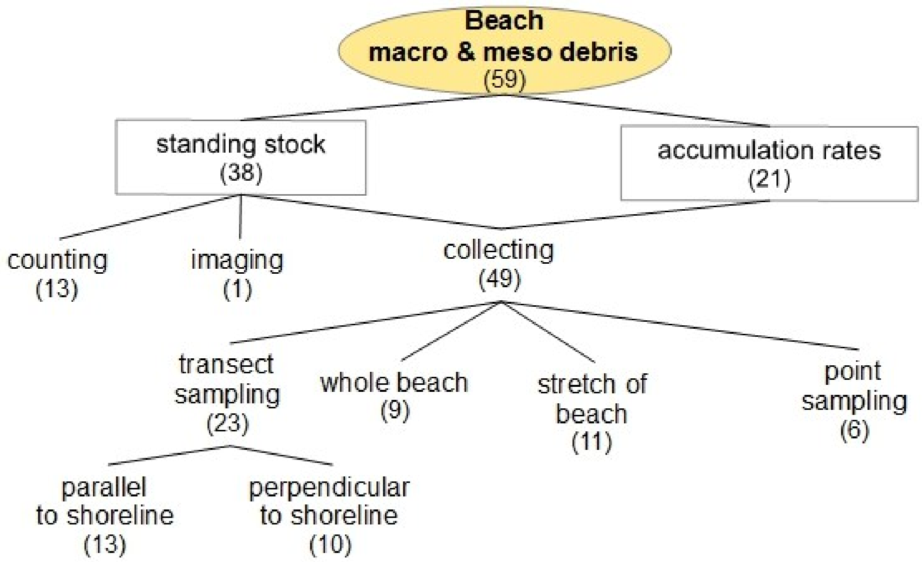

Fig. 4: Methods for surveying macro and meso beach debris. Numbers in parentheses show the number of publications using this method.

In the following paragraphs, the methods and terms shown in figure 4 are explained in detail.

1) *Type of survey*

In general, two types of beach litter surveys can be distinguished:

- standing-stock surveys
- surveys of accumulation rates

Standing-stock surveys assess the amount of debris present at a beach at a certain time. They can be used to establish a baseline and/or to get a first impression of the dimension of the problem. This can be done through one or more samples. They are the most common type of survey and *"reflect the long-term balance between inputs (both local, land-based sources and strandings) and removal (through export, burial, degradation and cleanups)."* (RYAN et al., 2009, p.2002)

However, to monitor changes in litter abundances at beaches, it is necessary to regularly assess the rate at which debris accumulates there. This is portrayed through net accumulation rates, which represent the amount of litter that accumulates per unit of time (for instance a day, a week or a month) at a beach (ESCARDÓ-BOOMSMA et al., 1995 cit. in RYAN et al. (2009)). Accumulation surveys require one or more initial cleanups, where all debris present is removed. They are followed by regular surveys that clear away the debris that has been accumulating in the meantime. As litter from adjacent parts of the beach might drift laterally to the monitoring site, thus influencing the results, the cleaning of buffer zones might be necessary. Their appropriate width can be determined through pilot studies (RYAN et al., 2009). Disagreement exists in the literature about the interval between the regular surveys. Although most accumulation studies have sampled monthly or bi-monthly, some authors argue that this underestimates the actual flux of litter. They compared accumulation rates derived from daily and monthly surveys and showed that rates derived from daily sampling were an order of magnitude higher. Their studies can be looked up in Annex II.a.

2) *Sampling Method*

When determining the standing-stock of macro (and meso) beach litter, one can choose between simply counting the litter or collecting it. However, when determining accumulation rates it is essential to collect and thus remove all debris. Another advantage of collecting the litter, is the possibility to weigh it. Imaging technologies are being developed that can also be used to assess litter densities and mass. In general, they count the amount of pixels with a specific color characteristic on digitally converted pictures and are presented in Annex II.b.

3) *Sampling Area*

For a better understanding of the description of the sampling areas some terms should be introduced first. For this, figure 6 shows the drawing of a beach during low tide.

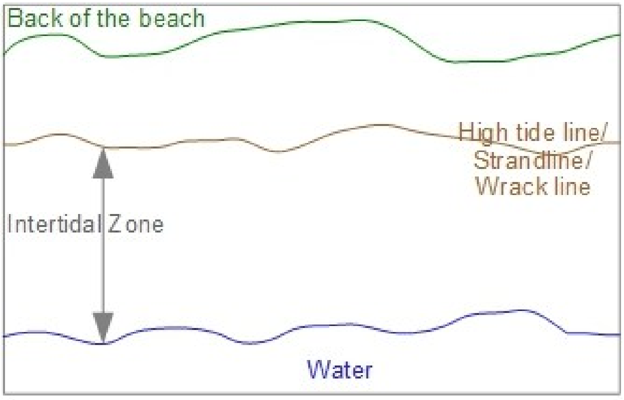

Fig. 6: Drawing of a beach, indicating high tide line and intertidal zone.

Fig. 5: Photo of a beach with strandline (N. Chadwick, www.geograph.org.uk)

The beach is bordered by the sea on the one side and by the back of the beach (i.e. vegetation, dunes, roads, other infrastructure) on the other side. It is visually characterized by the high tide line, also called strandline or wrack line. This is the area, until where the high tide advances, depositing anthropogenic and natural debris, demonstrated in figure 5. Depending on the tidal cycle, a beach may have more than one strandline, as the intensity (height) of the high tide varies. The area between the water edge and the high tide line is called intertidal zone, as this area is subject to the tides. During high tide it is covered by the sea, during low tide it extends the beach.

To survey a beach, the following sampling areas can be chosen and will be presented together with the results found during the literature review:

- whole beach
- stretch of beach
- transect(s) perpendicular to the shoreline
- transect(s) parallel to the shoreline
- point samples

Whole Beach

The most simple but also time consuming variant (depending on the area) is to survey the whole beach, from the water edge to the back of the beach and from left to right. This can be done by either walking perpendicular to the shoreline in straight lines, up and down the beach (see figure 7), or parallel to the shoreline in meandering tracks (see 8).

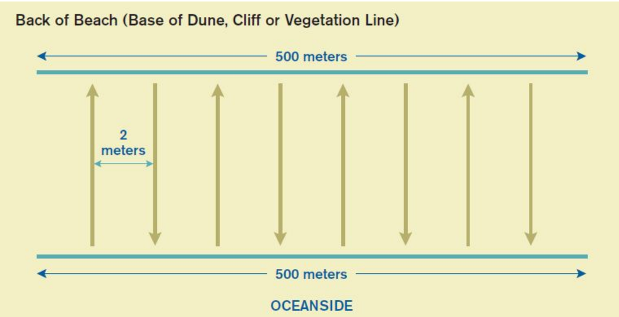

Fig. 7: Walking pattern perpendicular to the shoreline (SHEAVLY, 2007).

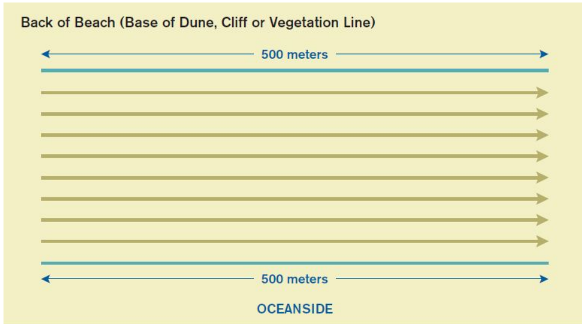

Fig. 8: Walking pattern parallel to the shoreline (SHEAVLY, 2007).

Table 2 presents the results of surveys of whole beaches. Average litter densities range from 33 (Heard Island, Southern Ocean) to 2,015 items/km of shoreline (Australia, Arafura and Timor Sea), with peak values reaching 10,000 items/km at Tamandaré Beach, Brazil. Daily, monthly, bimonthly and yearly accumulation rates were assessed in different studies. If compared on a monthly basis (30 days), which should be done with caution, accumulation rates range from 77 items/km per month at the Falkland Islands in the Atlantic to 482.4 items/km per month at Heard Island in the Southern Ocean. Litter mass was only seldomly determined and averages reach from 2 – 3 kg/km of shoreline at Anxious Bay, Southern Australia to 168 kg/km in Northern Australia, with peak values reaching 242 kg/km at the same location.

Location	Method/ size/ interval	Litter density [items/km]	Litter mass [kg/km]	Author(s)
Heard Island, Antarctic, Southern Ocean	collecting ≥1 cm/ daily	16.1[AD] (0 - 565)	-	ERIKSSON et al. (2013)
Heard Island, Antarctic, Southern Ocean	collecting ≥1 cm	33 (0 - 132)	-	-”-
Macquerie Island, Antarctic, Southern Ocean	collecting ≥ 1cm/ daily	6.1[AD]	-	-”-
Macquerie Island, Antarctic, Southern Ocean	collecting ≥1 cm	48	-	-”-
Anxious Bay, South Australia, Pacific	collecting ≥2 cm/ yearly	-	2 – 3	EDYVANE et al. (2004)
Northern New South Wales, Australia, Pacific	collecting	214 (138 – 298)	-	TAFFS and CULLEN (2005)
Northern Territory, Australia, Arafura and Timor Sea	collecting >9 cm²	2,015 (max 6,287)	168 (max 242)	WHITE (2006)
Hassakubana Beach, Goto Island, Japan, Pacific	collecting bimonthly	200[AB] (71 – 586)	-	SEINO et al. (2009)/ KAKO et al. (2010b) cit. in KAKO et al. (2011)
Tern Island, French Frigate Shaols, NW Hawaiian Islands, USA, Pacific	collecting biweekly	3,085[AA] (1,116 – 5,195)	-	MORISHIGE et al. (2007)

Location	Method/ size/ interval	Litter density [items/km]	Litter mass [kg/km]	Author(s)
Volunteer Beach, Falkland Islands, Atlantic	collecting monthly	77 ± 25^{AM}	17.1 ±12^{AM}	OTLEY and INGHAM (2003)
Volunteer Beach, Falkland Islands, Atlantic	collecting	125	32.9	OTLEY and INGHAM (2003)
Tamandaré Beach, Recife, Brazil, Atlantic	counting	0 – 10,000	-	ARAÚJO and COSTA (2007)
Kachelotplate and East Frisian Islands, Germany, North Sea	counting >20 cm	16 – 170	-	LIEBEZEIT (2011)

Tab. 2: Results of beach surveys for macro-debris assessing the **whole beach**. ^{AM} signifies monthly, ^{AD} daily, ^{AA} annual and ^{AB} bimonthly accumulation rate. Litter density and mass represent the mean value, the numbers in parentheses show the range.

Stretch of beach

Sometimes only a stretch of beach (50 – 1000 m) is surveyed. This can be done the same way as for a whole beach. The starting points for the stretch were either randomly chosen (RIBIC et al., 2012) or selected with special criteria in mind, e.g. around the access point to the beach (BALAS et al., 2004). RYAN et al. (2009) recommend to record all litter from the sea edge to the highest strandline, on a stretch of beach of at least 50 m for standing-stock and 500 m for accumulation studies.

Tables 3 and 4 display the results of surveys conducted on stretches of beach. The studies in table 3 were reported or could be transformed into number and mass of litter per area sampled. Average litter densities are the lowest in salt marshes situated in Carteret County, USA and the highest in Port Dickson, Malaysia with 0.4 items/m². Peak values reach at the same location 0.6 items/m². The lowest mean mass of debris was however weighed at the South China Sea in China, whereas the highest mean mass was also found in Port Dickson (24.0 g/m²), with the peak value reaching 53.4 g/m².

Location	Method details	Litter density [items/m²]	Litter mass [g/m²]	Author(s)
Carteret County, NC, USA, Atlantic	whole area, collecting >1.5 cm	0.6×10^{-4} (0 – 0.005)	0.01	VIEHMAN et al. (2011)
Oman, Gulf of Oman	100 m (15 m)°, collecting	0.1* (0.03 – 0.4)	1.8* (0.5 – 5.0)	CLAEREBOUDT (2004)
Port Dickson, Malaysia, Pacific	100/180 m, collecting	0.4 (0.2 – 0.6)	24.0 (0.8 – 53.4)	KHAIRUNNISA et al. (2012)
China, South China Sea	counting	*0.04 (0.003 – 0.4)*	*$3.4x10^{-4}$*	ZHOU et al. (2011)

Tab. 3: Results of beach surveys for macro-debris on **stretches of a beach**. The column *Method details* lists (if known) the stretch width, (length of the stretch), if debris was collected or counted and its size. ° marks surveys assessing only from the wrack like to end the of the beach, * marks cells which units were converted by the author. Litter density and mass represent the mean value, the numbers in parentheses show the range. Numbers in italic were corrected by the author.

Table 4 presents surveys that reported their results in number and mass of items per length of coastline. Mean litter densities range from 1,790 items/km in Oman to 64,290 items/km at the Belgian coast, with peak values reaching at the same location 217,440 items/km. Two surveys determined monthly accumulation rates, while one calculated a bimonthly accumulation rate. Only few surveys assessed litter mass, with the highest mean value being measured again at the Belgian coast (92.7 kg/km), where peak values reach 329 kg/km.

Location	Method details	Litter density [items/km]	Litter mass [kg/km]	Author(s)
Point Pleasant Park, Nova Scotia, Canada, Atlantic	70 m (intertidal), collecting	5,070* AM	29* AM	WALKER et al. (2006)
Sweden, Denmark, Ireland, Netherlands, Spain, France, UK, North Sea/ Atlantic	100 m/1 km, collecting 4x/ year	7,190	-	OSPAR COMMISSION (2013)
Southern North Seas	-”-	6,203	-	-“-
Northern North Seas	-”-	10,035	-	-“-
Celtic Seas	-”-	7,001	-	-“-
Galicia, Spain, Atlantic	100 m/1 km, collecting 4x/ year	4,882 (max 55,000)	-	GAGO et al. (2014)
Belgium, North Sea	100 m, collecting	64,290 (3,390 – 217,440)	92.7 (15.2 – 329.0)	VAN CAUWENBERGHE et al. (2013)
Turkish Riviera (Antalya), Mediterranean	100 m, collecting	180 – 7,430	-	BALAS et al. (2004)
Oman, Gulf of Oman	100 m (15 m)°, collecting	1,790 (430 – 6,010)	27.0 (7.8 – 75.4)	CLAEREBOUDT (2004)
South Korea	100 m, collecting >2.5 cm bimonthly	4,809 AB (1,500 – 12,070)	865 AB (179 – 3,458)	HONG et al. (2014)
Sand Island, Midway Atoll, Hawaii, USA, Pacific	150 m, collecting >2.5 cm	2,371 (609 – 3,522)	-	RIBIC et al. (2012)
Sand Island, Midway Atoll, Hawaii, USA, Pacific	150 m, collecting >2.5 cm monthly	11,012 AM (2,032 – 18,456)	-	RIBIC et al. (2012)

Tab. 4: Results of beach surveys for macro-debris on **stretches of beaches**. The column *Method details* lists (if known) stretch width, (length of the stretch), if debris was collected or counted and its size. AM signifies monthly and AB bimonthly accumulation rate, ° marks surveys assessing debris only from wrack like to the end of the beach. Litter density and mass represent the mean value, the numbers in parentheses show the range.

Perpendicular transects

Perpendicular transects reach from the water edge to the back of the beach, and are surveyed by walking their length (see figure 9). However, sometimes only the intertidal area or the area between the high tide line and the back of the beach are sampled. Transect widths reach from 1 – 50 m but are typically between 5 – 10 m. The results of a study which tested different transect widths can be seen in Annex II.c.

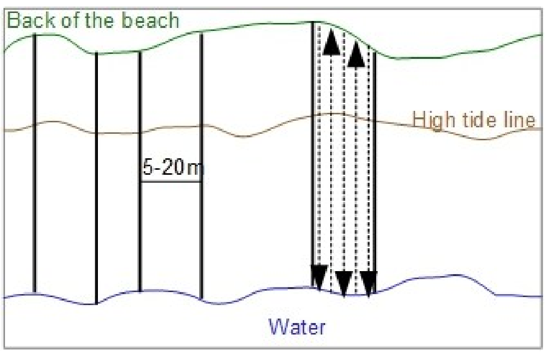

Fig. 9: Transects perpendicular to the shoreline.

Sometimes only one transect per beach was surveyed (DEBROT et al., 2013a), but most often more transect per beach were sampled, depending on the beach width, reaching up to 26 per beach (BRAVO et al., 2009). Most surveys do not explicitly state how they chose the number of transect or their location on the beach; however, some did: IVAR DO SUL et al. (2011) placed randomly six transects on every 5 km of coast. TOURINHO and FILLMANN (2011) specifically chose sampling sites that differed in their occupation characteristics (beach users and recreational fishing activities) and then selected four transects per site randomly. ARAÚJO et al. (2006) picked four transects on a beach, based on different morphodynamical characteristics of the beach, frequency and density of its use, presence of vegetation and level of urban occupation. Yet another approach is represented by LEITE et al. (2014), who divided their 300 m wide beach into thirty 10 m wide transects and randomly chose three for sampling.

Tables 5 and 6 show the results for surveys using perpendicular transects. Table 5 presents the results as density and mass of litter per area sampled. The lowest mean litter density was found with 0.2 items/m² at the Russian coast of the Sea of Japan, whereas the highest mean value is with 6.5 items/m² at windward beaches on Bonaire in the Caribbean. The highest value overall was, however, counted in Chile, with 82.7 items/m². Litter mass is by far highest at Salvador, Brazil with an average of 1,800 g/m² and a peak value of 3,600 g/m².

Location	Method details	Litter density [items/m²]	Litter mass [g/m²]	Author(s)
Gulf of Aqaba, Red Sea, Jordan	50 m (10 – 20 m), collecting ≥2 cm monthly	0.3^{AM} (0.2 – 0.4)	-	ABU-HILAL and AL-NAJJAR (2004)
Turkish Western Black Sea	20 m (11 – 40 m), collecting >2 cm	0.9 (0.09 – 5.1)	-	TOPÇU et al. (2013)
Chilean coast, Pacific	3 m, collecting	1.8 (0.5 – 82.7)	-	BRAVO et al. (2009)
Japan, Sea of Japan	10 m, collecting	3.4 (0.5 – 12.7)	21.4 (1.4 – 73.3)	KUSUI and NODA (2003)
Russia, Sea of Japan	10 m, collecting	0.2	13.4	KUSUI and NODA (2003)
Goiana Estuary, Brazil, Atlantic	20 m, collecting monthly	0.1^{AM} (0.04 – 0.2)	-	IVAR DO SUL and COSTA (2013)
Tamandaré and Varzea do Una Beach, Recife, Brazil, Atlantic	50 m (50 m), collecting	0.2 – 2.1^{P}	-	ARAÚJO et al. (2006)
Salvador, Bahia, Brazil, Atlantic	10 m (16 – 61 m), collecting	0.9 (0.3 – 2)	1,800 (600 – 3,600)	LEITE et al. (2014)
Lac Bay, Bonaire, SE Caribbean	5 m, collecting	5.8 – 23.2	0.4 – 0.7	DEBROT et al. (2013b)
Bonaire, SE Caribbean windward beaches	5 m/10 – 170 m (9 – 65 m), collecting ≥5 cm + rake	6.5* (0.2 – 33)	199* (11 – 706)	DEBROT et al. (2013a)
Bonaire, SE Caribbean leeward beaches		0.06 (0 – 0.1)	3 (0.1 – 14)	

Tab. 5: Results of beach surveys for macro-debris using transects **perpendicular** to the shoreline. The column *Method details* lists (if known) transect width, (length), if debris was collected or counted, its size. ^{AM} signifies monthly accumulation rate, ^{P} only plastic was collected, * marks cells which units were converted by the author. Litter density and mass represent the mean value, the numbers in parentheses show the range.

Table 6 presents surveys that reported in number and mass of litter per length of shoreline sampled. The last survey is insofar special, as the lower size limit was 1 mm, thus also assessing micro- and meso-debris. Average litter densities range from 1,400 items/km on leeward beaches at Bonaire in the Caribbean to 291,000 items/km at windward beaches at the same island, with peak values reaching 160,000 items/km at the same location. Only few times litter mass was measured, ranging from 111 kg/km at the leeward beaches to 7,751 kg/km at the windward beaches at Bonaire and peaking there at 35,306 kg/km.

Location	Method details	Litter density [items/km]	Litter mass [kg/km]	Author(s)
Lac Bay, Bonaire, SE Caribbean	5 m, collecting	90.000 (44,000 – 116,000)	5,100 (3,700 – 6,600)	DEBROT et al. (2013b)
Bonaire, SE Caribbean windward beaches	5 m/10 – 170 m (9 – 65 m), collecting ≥5 cm + rake	291,000 (9,000 – $1.6x10^6$)	7,751 (545 – 35,306)	DEBROT et al. (2013a)
Bonaire, SE Caribbean leeward beaches		1,400 (100 – 5,000)	111 (5 - 716)	
Costa dos Coqueiros, Bahia, Brazil, Atlantic	10-100 m, collecting >1 cm	8,400 – 30,500	-	IVAR DO SUL et al. (2011)
Costa do Dendê, Bahia, Brazil, Atlantic	10 m, counting >2 cm	9,100 (500 – 30,100)	-	SANTOS et al. (2009)
Cassino Beach, Brazil, Atlantic	10 m, counting	7,300 (5,300 – 10,700)	-	TOURINHO and FILLMANN (2011)
Costa dos Coqueiros, Bahia, Brazil, Atlantic	10 m, counting	2,000 – 8,000	-	IVAR DO SUL et al. (2011)
Turkish Western Black Sea	20 m (11 – 40 m), collecting >2 cm	27,470	-	TOPÇU et al. (2013)
Balearic Islands, Mediterranean Sea	2 m, collecting **> 1mm** + raked	36,000 (17,000 – 59,000)	33 (21 - 75)	MARTINEZ-RIBES et al. (2007)

Tab. 6: Results of beach surveys for macro-debris (except the last) using transects **perpendicular** to the shoreline. The column *Method details* lists (if known) transect width, (length), if debris was collected or counted and its size. Litter density and mass represent the mean value, the numbers in parentheses show the range.

Parallel transects

Parallel transects run parallel to the shoreline for 10 to 800 m (in the following referred to as width as for the perpendicular transects). Their length is between 1 and 20 m, and they can be located at any part of the beach (intertidal area, high tide line, or random). One transect can be sampled by itself or more than one, parallel to each other and the shoreline, can be surveyed, as can be seen in figures 10 and 11.

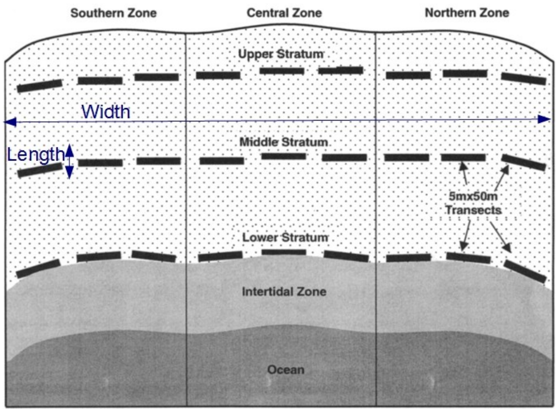

Fig. 10: Example for transects parallel to the shoreline (CUNNINGHAM and WILSON, 2003).

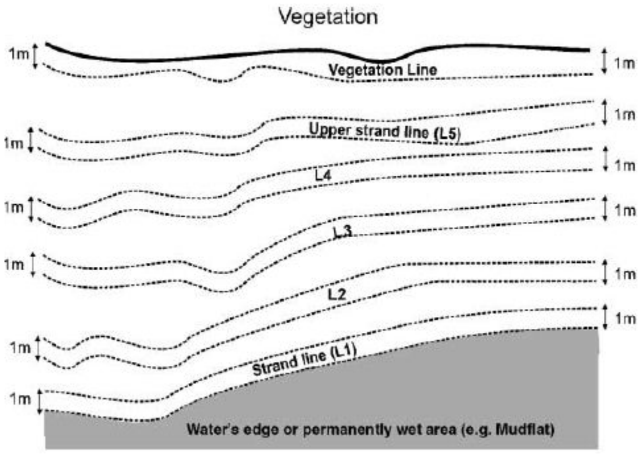

Fig. 11: Example for transects parallel to shoreline (SILVA-IÑIGUEZ and FISCHER, 2003).

Point sampling

The last variant is using point sampling, i.e. sampling squares or circles either at the strandline, at the maximum and minimum amount of visible litter or at a random spot.

Table 7 present results of surveys using parallel transect or point sampling anywhere except at the high tide line. Table 8 shows results for surveying with parallel transects or point sampling at the high tide line. Surveys using transects are shaded light gray.

Location	Method details	Litter density [items/m²]	Litter mass [g/m²]	Author(s)
Awaji Island, Japan, Pacific	10 m x 20 m, collecting bimonthly	3[AB] (0.1 – 27)	-	SHIMIZU et al. (2008)
Amami Islands, Japan, Pacific	10 m (3x10 m), collecting >27 cm³	1.2 – 3.5	-	KEI (2005)
Ookushi Beach, Goto Island, Nagasaki, Japan, Pacific	Aerial photos + 2 m x 2 m, collecting >1 cm²	-	5,800 (2,600 – 12,600)	NAKASHIMA et al. (2011)
Sand bar Nakdong River + Geoje Island, South Korea, Pacific	10 m x 10 m (max + min), collecting >2.5 cm	1.0 (0.09 – 2.7)	-	LEE et al. (2013)
Northern Coast of Taiwan, Pacific	100 m (10 m), collecting	0.2 (0.03- 0.6)	-	KUO and HUANG (2014)
Motupore Island, Papua New Guinea, Pacific	1 m x 2 m (max), collect >5 mm	15.3 (1.2 – 78.3)	-	SMITH (2012)
Charlesworth Bay, NWS, Australia, Pacific	350 m (intertidal), collecting	0.05[AD]	-	SMITH and MARKIC (2013)
Charlesworth Bay, NWS, Australia, Pacific	350 m (intertidal), collecting	0.2	-	SMITH and MARKIC (2013)
Greater Sydney Region, Australia, Pacific	50 m (3x5 m), collecting	0.1 (0.02 – 0.6)	-	CUNNINGHAM and WILSON (2003)
Santos – Sao Vicente Estuary Complex, Brazil, Atlantic	10 m x 10 m, collecting	1.3 (0.2 – 4.4)	129.7 (53.0 – 232.7)	CORDEIRO and COSTA (2010)

Location	Method details	Litter density [items/m²]	Litter mass [g/m²]	Author(s)
Rio de la Plata estuary, Brazil, Atlantic	20 m (intertidal), collecting	-	62.5 (9.4 – 150.9)	ACHA et al. (2003)
Santa Catarina Island, Brazil, Atlantic	50 m (2 m, frontal dunes), collecting >5 mm	1.0 (0.3 – 1.8)	2.2 (wet weight)	WIDMER and HENNEMANN (2010)
Accra, Ghana, Atlantic	100 m (2x5 m), collecting + raked	0.8	19.3	TSAGBEY et al. (2009)
Ensenada, Baja California, Mexico, Pacific	100 m (6x1 m), counting	1.5[N]	-	SILVA-IÑIGUEZ and FISCHER (2003)

Tab. 7: Results of beach surveys for macro-debris using transects **parallel** to the shoreline (light gray) or **point sampling**. The column *Method details* lists (if known) transect width, (how many parallel transects x their length, location (e.g. maximum/minimum amount of visible debris)), if debris was collected or counted and its size. [AB] signifies bimonthly, [AD] daily accumulation rate and [N] that natural debris is included. Litter density and mass represent the mean value, the numbers in parentheses show the range.

The average litter densities displayed in table 7 range from 0.1 items/m² in the Greater Sydney Region to 15.3 items/m² at Motupore Island, Papua New Guinea, with the highest density measured being 78.3 items/m² at the same location. Mean litter mass reaches from 2.2 g/m² at Santa Catarina Island, Brazil to 5,800 g/m² at a Japanese Island, peaking at the same location at 12,600 g/m².

Average litter densities at the high tide line (table 8) reach per area sampled from 0.1 items/m² in Armação dos Búzios, Brazil to 1 item/m² in Scotland and the US West Coast, with peak values reaching 25.2 items/m² at Guanabara Bay, Brazil. For length of coastline sampled they reach from 500 items/km at Cable Beach, Australia to 2,529 items/km on Tasmania, with the highest number counted (25,200 items/km) also at Guanabara Bay, Brazil. Only two studies assessed litter mass at the high tide line, with the greater average of 36.6 g/m² being measured in the Gulf of Mannar, India.

Location	Method details	Litter density [items/m²]	Litter density [items/km]	Litter mass [g/m²]	Author(s)
Gulf of Mannar, India, Indian Ocean	100 m², collecting	0.6 (0.4 – 0.1)	-	36.6 (20.9 – 65.9)	GANESPANDI-AN et al. (2011)
Cijin Island, Kaohsiung, Taiwan, Pacific	100 m (5 m), collecting bimonthly	0.9[AB] (0.4 – 1.4)	4,500*[AB] (2,000 – 7,000)	-	LIU et al. (2013)
Cable Beach, Broome, Australia, Indian Ocean	100 m (2 m), counting	0.3 (0.02 – 0.5)	500* (40 – 1,060)	-	FOSTER-SMITH et al. (2007)
Tasmania, Pacific	50/100 m (3x3 m), collecting >5 mm	*0.3 (0.02 – 2.0)*	*2,529* (144 – 18,306)*	*1.7 (0.01 – 8.4)*	SLAVIN et al. (2012)
Coastal system of Coquimbo, Chile, Pacific	collecting	-	9 – 280	-	THIEL et al. (2013)
Central Chile, Pacific	3 m x 3 m (2x), counting >1.5 cm	0.6 – 4	-	-	RECH et al. (2014)
Monterey Bay, USA, Pacific	2 m (2x2 m in 50 m), collecting + raked monthly	1 ± 2.1[AM] (0.03 – 17.1)	-	-	ROSEVELT et al. (2013)
Guanabara Bay, Brazil, Atlantic	10 m (1 m), collecting	1.4 – 25.2	1,400 – 25,200	-	NETO and FONSECA (2011)

Location	Method details	Litter density [items/m²]	Litter density [items/km]	Litter mass [g/m²]	Author(s)
Armação dos Búzios, Rio de Janeiro, Brazil, Atlantic	47 – 818 m (4 m), counting	0.1 (0.03 – 0.2)	560* (136 - 920)	-	OIGMAN-PSZCZOL and CREED (2007)
Boa Viagem Beach, Recife, Brazil, Atlantic	(2x1 m), counting >5 cm	0 – 5*	0 – 10,000	-	SILVA-CAVALCANTI et al. (2009)
Firth of Forth, Scotland, North Sea	100 m (1 m), counting	1 (0 – 3.1)	1,000* (0 – 3,060)	-	Storrier et al. (2007)

Tab. 8: Results of beach surveys for macro-debris collecting debris at/around the **high tide line**. The column *Method details* lists (if known) transect width, (how many transects parallel x length), if debris was collected or counted and its size. AB signifies bimonthly and AM monthly accumulation rate, * marks cells which units were converted by the author. Litter density and mass represent the mean value, the numbers in parentheses show the range. Numbers in italic were corrected by the author.

4) *Choice of units*

Another reason why so few surveys can be compared to each other is the use of different units; numbers and weights are either given per square meter or per length of coastline (either one meter or one kilometer) and without further information, these units cannot be converted into a common unit. To heighten the comparability of a study, it is therefore useful to assess the numbers and weights per square meter and per length of shoreline.

5) *Choice of categories*

After counting or collecting the debris and identifying it, it can be categorized according to material, probable source/use and/or size. All studies, except one, identified during the literature review have classified their marine litter according to the material, with the number of categories reaching from three (plastics, multiple material products and expanded polystyrene (NAKASHIMA et al., 2011); plastics, wood and polystyrene (DEBROT et al., 2013b); plastics, cloth and metal (SMITH and MARKIC, 2013)) to 17 (soft and hard plastics, glass, paper, metal, wooden, Styrofoam, polyurethane foam, composite, synthetic fibers, rubber, vinyl, cigarette ends, artificial sponge, ceramic, cork, fabric and other (TOPÇU et al., 2013)) and depending on regional characteristic or occurrence, e.g. polystyrene is very common on Asian beaches. On average, eight material categories have been used. About one quarter of surveys categorized marine debris according to its possible source or usage, using two (household and fishing (THIEL et al., 2013)) to 15 categories (beverage related, food packaging, general packaging, recreational, fisheries related, ropes, domestic/household related, construction materials, medical utensils, foams/sponges, smoking related, clothing, aerosols and pumps for foams, miscellaneous and unidentified (TOPÇU et al., 2013)), with an average of 4.7 categories. Only few beached macro-debris surveys classified the found items according to size. Those that did were thus able to report on the abundance of different size classes, showing that most items are smaller than 10 cm, or the dependence between size and composition (see Annex II.d.).

6) *Use of volunteers*

Many beach debris surveys have been conducted with the help of volunteers. Such "citizen science" projects can generate large data sets at comparably low costs, as they do not need sophisticated equipment or specific scientific education of the surveyors. However, if the data is provided by volunteers, quality control should be included to identify possible errors and to determine the accuracy of the data collected by the volunteers (HIDALGO-RUZ and THIEL, 2013). For a nationwide study of Chilean beaches, HIDALGO-RUZ and THIEL (2013) used 39 schools to gather data, showing that school children as young as eight years are able to collect environmentally relevant and accurate data.

7) *Assessing meso-debris*

When collecting or counting macro-litter, meso-debris can be included as it is still visible by the naked eye (being larger than 0.5 cm). However, RYAN et al. (2009) recommend to assess meso-debris through a combination of sieving, dry sorting and floatation, on a stretch at least 0.5 m wide and reaching from the most recent strandline to the back of the shore and to a depth of 5 cm. This method is similar to determining micro-debris amounts. Nonetheless, whether meso-debris is included or not, it is essential to mention the lower size limit of the survey to keep comparability.

Guidelines and monitoring programs

The following monitoring programs and/or guidelines have been used in Europe:

- UNEP
- OSPAR
- EU

In 2009, *UNEP* published "Guidelines on Survey and Monitoring of Marine Litter", presenting methods and protocols for monitoring marine debris at the beach, floating in the sea and on the sea floor (CHESHIRE et al., 2009). The protocol for beach surveys can be seen in Annex II.e.

Under the *Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR)* a pilot project for monitoring marine debris was implemented for six years (2000 – 2006). This pilot project determined suitable methods and protocols that are being used for monitoring marine litter at North Sea beaches in Sweden, Denmark, Ireland, the Netherlands, Spain, France and the United Kingdom. The method and the protocol, as well as the results of the pilot study, are presented in OSPAR COMMISSION (2007), and the protocol also in Annex II.f.

In 2008, the European Commission passed the so called "Marine Strategy Framework Directive" (MSFD) that aims to achieve or maintain a good environmental status in European seas. It introduces marine litter as descriptor 10, thus demanding monitoring of marine debris. The most recent publication by the Technical Subgroup on Marine Litter (TSG ML) contains recommendations for monitoring programs for all types of marine debris that are presented in Annex II.g. (MSFD TECHNICAL SUBGROUP ON MARINE LITTER, 2013).

3.1.2 Floating litter

The literature review showed that for measuring floating macro-debris most surveys report visual sightings from ships. Trawls can also be used, however, as they commonly use mesh sizes smaller than 5 mm, they will be discussed in the micro-debris section. Another possibility are visual surveys using airplanes, with the disadvantage that only large debris items can be determined. Figure 12 gives an overview of all methods used so far to measure macro floating marine debris. New methods using imaging technologies are being developed; they are presented in Annex II.b. together with new imaging methods for beach surveys.

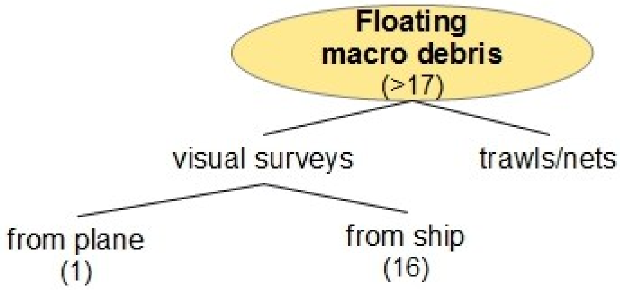

Fig. 12: Methods for surveying macro floating debris. Numbers in parentheses show the number of publications using this method.

Visual surveys

Sighting surveys of marine debris report the *“direct observation of large debris items”* at sea (RYAN et al., 2009). They are carried out by one or more observers, standing on a vessel, scanning the ship's surroundings either by naked eye or with the aide of binoculars, and recording all visible debris. The result thus depends on the observer, who should be competent and motivated (RYAN et al., 2009). Some surveys mention the lower size limit of debris they used, which ranges between 1 and 10 cm. Items are then allocated to a certain size bin, e.g. 2 – 10 cm, 10 – 30 cm and larger than 30 cm (TITMUS and HYRENBACH, 2011). Usually, the perpendicular distance of the observed items to the ship is recorded, either by estimating it based on known distances as the vessel width or length (HINOJOSA et al., 2011), or using a range finder, i.e. a stick that has been marked to indicate certain distances, e.g. 30, 50 and 100 m from the ship, and is held at arms-length, the top being aligned with the horizon (RYAN, 2013).

To determine litter densities different methods exist, for instance:

- the strip transect method,
- and a size and distance-based technique developed by RYAN et al. (2013).

The *strip* or *line transect method* calculates the density (D) based on the items seen and the area surveyed using the following equation:

$$D = \frac{N}{((W/1000)\,x\,L)}$$

where N is the number of floating items, W the width of the transect (effective strip width) in meters and L the total length of the transect in kilometers. The transect width can be determined based on preliminary data, for which different methods exist. The observed data is for instance pooled and the distance at which the probability of detection of items is 80 to 95% is identified (HINOJOSA et al., 2011).

Other possibilities include the search for a distance after which the number of observed items decreased substantially and using this distance as transect width (SHIOMOTO and KAMEDA, 2005), or plotting the perpendicular distance of all sighted items and determining the strip width by assuming that the number of items detected beyond the transect equals the number of items missed within (SUARIA and ALIANI, 2014). They all have in common that they assume to detect all items perpendicular to the vessel, that items are detected at their initial location and that distances are measured accurately (BUCKLAND et al. (2001) cit. in WILLIAMS et al. (2011)). They are thus generating a result that underestimates real litter densities.

The *size and distance-based technique* developed by RYAN et al. (2013) uses correction factors to compensate for 'missed' items. For this, the frequency of encounters is summed as a function of distance from the vessel (so called detection functions, see figure 13 as example for size-based detection functions) and it is assumed that all items are detected in the 10 m wide distance bin with the largest number of encounters. All other 10 m wide distance bins within 50 m of the ship are standardized relative to the maximum count by setting the maximum count equal to 1 and expressing the other counts as proportions. For instance, if the maximum count is 30 and another count 15, the standardized numbers are 1 and 0.5, respectively. These standardized numbers are then summed up across the 50 m. To calculate the correction factor, 5 (for the five distance bins) is divided by the sum of the standardized counts. Afterwards, the correction factors are applied by multiplying it with the observed number of items. The correction factors should be determined for every region separately.

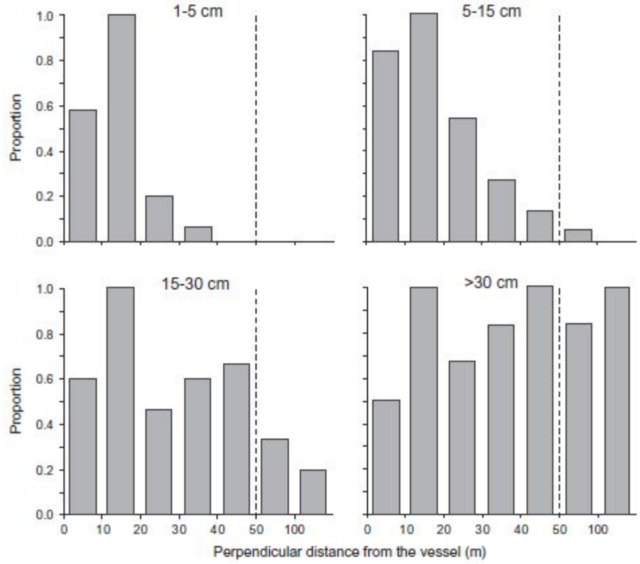

Fig. 13: Detection functions for marine litter items of different size bins used to determine correction factors (RYAN, 2013).

The studies examined during the literature review used between three (petrochemical products, Styrofoam and fishing-related (SHIOMOTO and KAMEDA, 2005)) and nine (plastic packaging, fishery-related plastic products, other plastic user items, other plastic pieces, glass jars/bottles, light bulbs, tin/aerosols, cardboard/paper and wood (RYAN, 2013)) categories to classify floating marine debris items, mostly according to material, sometimes according to their source.

Figure 14 gives an overview of the world-wide trajectories of sighting surveys examined during the literature review.

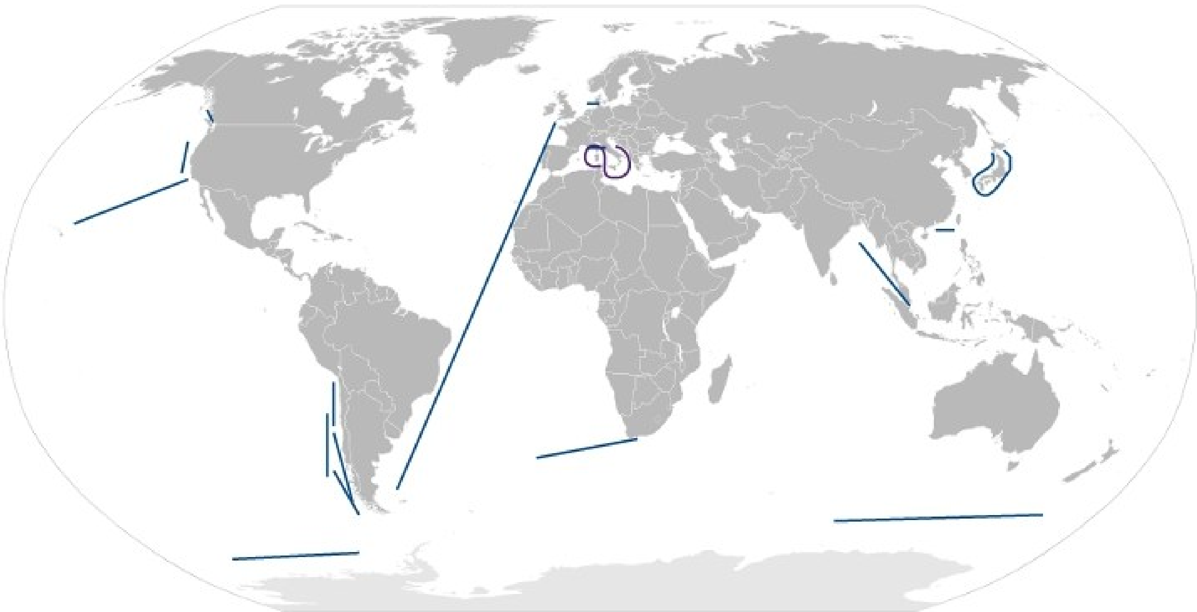

Fig. 14: Worldwide trajectories of floating macro-debris surveys. (Figure was created by the author)

Results

The results of sighting surveys for macro-debris are presented in table 9, together with details about the method used, as the effective transect width or the employment of binoculars. The average litter densities determined range between 0.37 items/km² in the Pacific near the Japan coast, and 1,900 items/km² in the North East Pacific (between 20 – 40°N and 120 – 155°W), with peak values reaching 15,222 items/km² also in the North East Pacific Ocean.

Location	Method details	Litter density [items/km²]	Mean density [items/km²]	Author(s)
North Pacific SCZ	Aerial survey	0 – 2.5	-	PICHEL et al. (2007)
NE Pacific Ocean (20–40°N, 120–155°W)	on one side, >2 cm	1,400 – 3,200	1,900	GOLDSTEIN et al. (2013)
North East Pacific	33.2 m on one side, 8 h, >2 cm	0 – 15,222	-	TITMUS and HYRENBACH (2011)
Pacific Ocean, British Columbia, Canada	100 m on both sides	0.2 – 23.3	1.5	WILLIAMS et al. (2011)
Pacific Ocean, Chile	20 m on one side, during day time, binoculars	0 – 100	-	HINOJOSA et al. (2011)
Pacific Ocean, Patagonia		0 – 300	-	
Pacific Ocean, Patagonia	20 m on one side, daylight hours, binoculars	5 – 50 (max 240)	-	HINOJOSA and THIEL (2009)
Pacific Ocean, coastal waters Chile (18-50°S)	10 m on both sides, daylight hours	18 – 40°S: 1 – 40 > 40°S: <1	-	THIEL et al. (2003)
Pacific Ocean, Coquimbo, Chile	10 m on both sides, daylight hours	1 – 130	-	THIEL et al. (2013)
Southern Ocean, Antarctica	Binoculars, 1 h/d	0 – 1	-	BARNES et al. (2010)
Atlantic Ocean, southern hemisphere	Binoculars, 2 h/d, >10 cm	0 - 10	-	BARNES and MILNER (2005)
Atlantic Ocean, Cape Town to Tristan da Cunha	50 m on one side, up to 11.5 h/d, (binoculars), >1 cm	coastal waters: 0 – 100 (3-8°E: max oceanic)	Coastal: 67 oceanic: 2.9	RYAN (2014)
Atlantic Ocean, northern hemisphere	Binoculars, 2 h/d, >10 cm	0 – 100	-	BARNES and MILNER (2005)
Ligurian Sea, Mediterranean	50 m both sides + stations with r = 200 m	1.6 – 25	-	ALIANI et al. (2003)
Mediterranean Sea	31 m on one side, during day time, (binoculars), >2 cm	0 – 162.1	24.9 ± 2.4	SUARIA and ALIANI (2014)
→ Mid Adriatic Sea		→ max	54.6 ± 11.1	
→ Mid Tyrrhenian Sea		→ min	4.9 ± 2.8	
Belgian harbors, North Sea	Thomsea net (7 m wide) + visual observation	-	2.8	VANAGT et al. (2012)
German Bight, North Sea	50 m on one side, (binoculars)	0 - >300 (mean: 32.4)	-	THIEL et al.(2011)
Indian Ocean, Straits of Malacca	50 m on one side + stations (330°), 12 h/d, (binoculars), >1 cm	89 – 977 (max 4,000)	578 ± 219	RYAN (2013)
Bay of Bengal		-	8.7± 1.4	-“-
South China Sea	-	*2 – 289*	*25*	ZHOU et al. (2011)
Pacific Ocean, near-shore Japan	100 m on both sides, daylight hours, >5 cm	0 – 3.31	0.4 ± 0.5	SHIOMOTO and KAMEDA (2005)

Tab. 9: Results of sighting surveys, one aerial and one trawl survey; the column *Method details* states (if available) effective strip width, daily observation time, use of binoculars (parentheses signify rare use and/or use only for identification of litter not searching) and size of reported items. Number in italics were corrected by the author. SCZ: Subtropical Convergence Zone.

3.1.3 Benthic litter

The literature review showed that for measuring macro (and meso) benthic debris a variety of methods are available, as can be seen in figure 15.

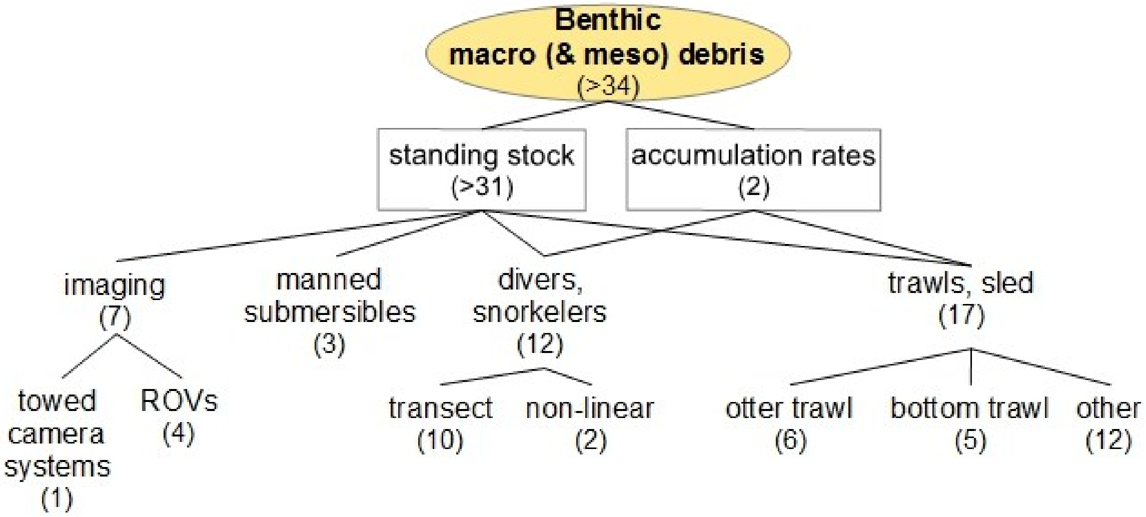

Fig. 15: Methods for surveying macro benthic debris. Numbers in parentheses show the number of publications using this method. ROV: Remotely operated vehicle

The method most often used are benthic trawls, although they are limited to certain types of sea floors (SPENGLER and COSTA, 2008). For this, divers and snorkelers present an alternative, especially in shallow areas. Imaging technologies using remotely operated vehicles (ROV) or manned submersibles are notably an option if studying the deep sea floor. In the following, the methods and results from the literature review concerning macro- and meso-debris will be presented. The abundance of micro-debris in seafloor sediment has also been assessed and will be discussed in the subsequent chapter. The distribution of macro-debris surveys worldwide can be seen in figure 16.

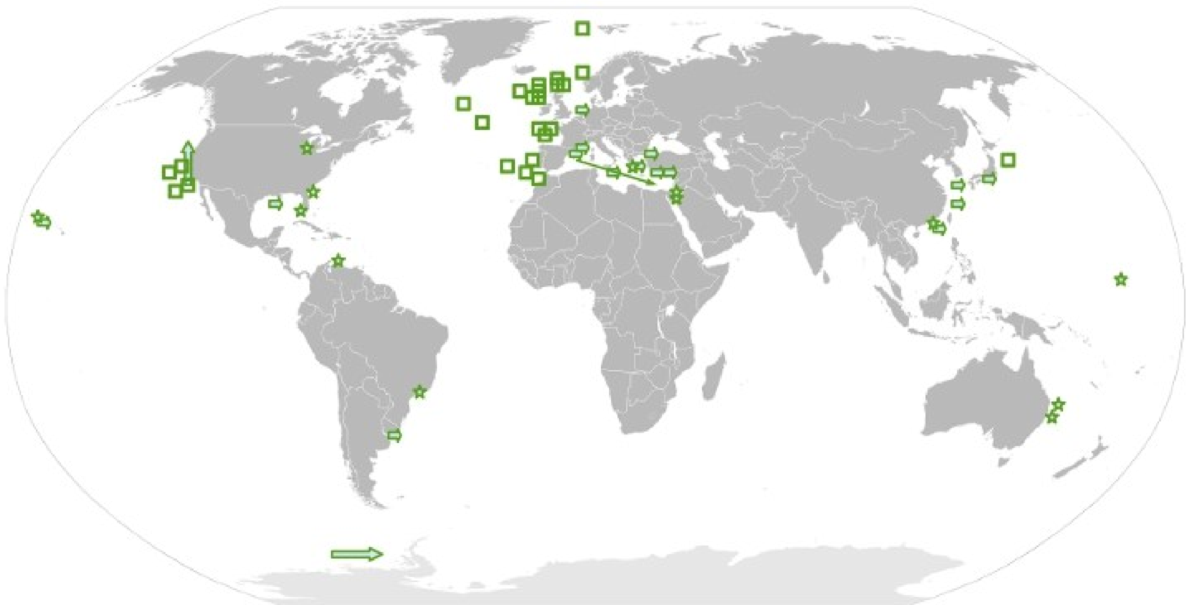

Fig. 16: Worldwide distribution of benthic macro-debris surveys. Arrows represent benthic trawling, stars diving surveys and squares the use of imaging technologies. (Figure was created by the author)

1) Divers/snorkelers

Surveys using divers and snorkelers count and in the majority of cases also remove debris from the sea-floor in shallow areas (<25 m). For this, the divers/snorkelers usually either assessed a marked area (one transect) or swam along a line (strip transect method) noting all visible debris within one to two meters on either side, see figure 17. The transect size varied between four and 20 m width and 20 – 50 m length. Litter was often removed where possible and e.g. given to snorkelers or a vessel using lifting bags (AL-NAJJAR and AL-WAHAB AL-SHIYAB, 2011). The surveys used between two (fishing-gear, non fishing-gear (BAUER et al., 2008)) and eight categories (plastic, metal, rubber, paper-cardboard, clothing, glass, ceramic, others (KATSANEVAKIS and KATSAROU, 2004)) to classify debris items. BOLAND et al. (2006) is the only study that monitored debris mass and determined accumulation rates. They examined sites at three atolls for four years annually, towing divers about ten meters behind a small boat at one to two knots speed along a strip transect. The divers used plywood boards to navigate from the surface to the depth, and from side to side. At the beginning and end of each transect, the water clarity was visually estimated thus determining the effective width of the observed transect.

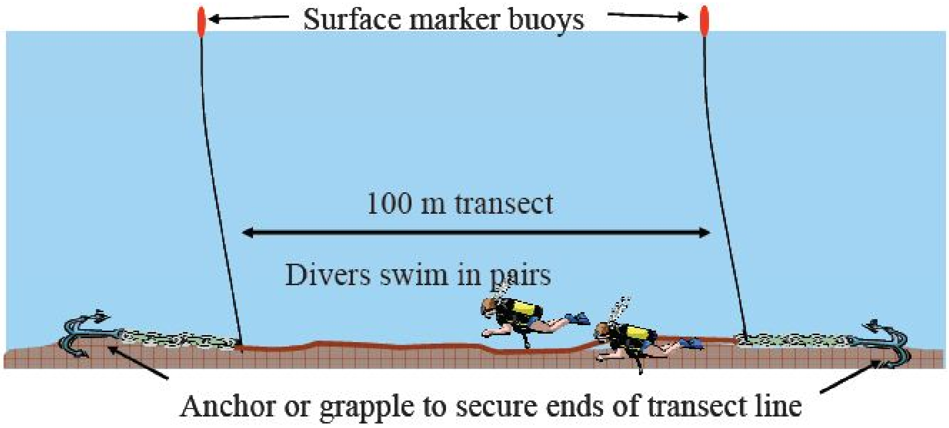

Fig. 17: Example of diving survey along a line transect (CHESHIRE et al., 2009).

The great advantages of diver/snorkeler surveys are that they can be used for all types of sea floor (also in reefs), that also small items can be counted as litter is assessed in situ and that the environment is not disturbed. On the other side, only small areas can be surveyed and only sea-floors up to a certain depth (SPENGLER and COSTA, 2008).

Results

In table 10 the results of diving and snorkeling surveys can be found, together with the sea floor depth. Mean litter densities range from 87 items/km² at the Hawaiian Islands to 3,040,000 items/km² in the Gulf of Aqaba at the Jordan coast, with peak values reaching at the same location 15,000,000 items/km². The litter mass was only assessed in some surveys and average values reach from 21,000 kg/km² at Bonaire in the Caribbean to 860,000 kg/km² in the Gulf of Aqaba, where also the largest mass (2,980,000 kg/km², i.e. about 3 kg/m²) was found.

Location	Depth	Litter density [items/km²]	Litter mass [kg/km²]	Authors
Gulf of Aqaba, Red Sea, Jordan	< 10 m	2,800,000 (800,000 – 5,900,000)	310,000 (60,000 – 1,060,000)	ABU-HILAL and AL-NAJJAR (2009a)
Gulf of Aqaba, Red Sea, Jordan	-	3,040,000 (8,000 – 15,000,000)	860,000 (5,000 – 2,980,000)	AIL-NAJJAR and AL-WAHAB AL-SHIYAB (2011)
Mediterranean Sea, Greece	< 25 m	14,900 (0 – 251,000)	-	KATSANEVAKIS and KATSAROU (2004)
Atlantic Ocean, Georgia, USA	16 – 20 m	5,200 (0 – 100,000)	-	BAUER et al. (2008)
Atlantic Ocean, Florida Keys, USA	1 – 7 m	11,900 (3,800 – 23,800)	-	CHIAPPONE et al. (2004)
Southeastern Caribbean, Lac Bay, Bonaire*	2 – 3 m	490,000 (260,000 – 710,000)	21,000 (5,000 – 36,000)	DEBROT et al. (2013b)
Atlantic Ocean, Armação dos Búzios, Rio de Janeiro, Brazil	< 4 m	2,900 (3,000 – 6,500)	-	OIGMAN-PSZCZOL and CREED (2007)
Pacific Ocean, NW Hawaiian Islands, USA	0.5 – 10 m	standing stock: 87 (25 – 170) accumulation: 32 (5 – 70)	-	BOLAND et al. (2006)
Pacific Ocean, Majuro Atoll, Marshall Islands	< 10 m	*140,536 (5,000 – 265,000)*	-	RICHARDS and BEGER (2011)
Pacific Ocean, eastern Australia	8 – 12 m	8,000 (0 – 28,000)	-	SMITH et al. (2008)
Pacific Ocean, New South Wales, Australia	-	(0 – 1,744,000)	-	SMITH and EDGAR (2014)

Tab. 10: Results of surveys with divers and/or snorkelers. Litter density and mass represent the mean value, the numbers in parentheses show the range. Numbers in italic were corrected by the author.

2) *Benthic Trawls*

If the sea floor at the survey site is to deep to use divers, or if information for a large area shall be acquired, trawls can be used to assess litter density and composition. It is the oldest and most commonly used method. In most cases the data is generated by surveys that assess primarily other parameters, e.g. biological surveys (WEI et al., 2012). Although most studies were carried out using otter or bottom (beam) trawls (see figures 18 and 19), their mesh size, as well as their net opening (between 4 – 21.6 m width and 1.4 – 5 m height) varied greatly.

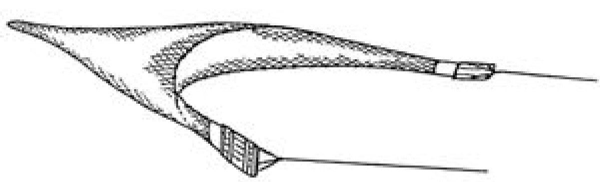

Fig. 19: Drawing of an otter trawl (www.fao.org)

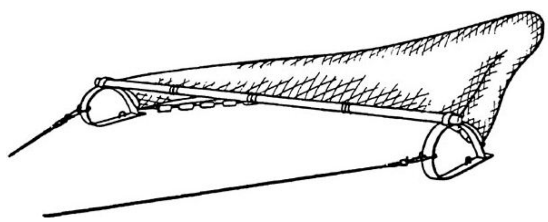

Fig. 18: Drawing of a beam trawl (www.fao.org)

Therefore the results shown in table 11 can only be compared with caution. Other gear types used include Agassiz trawl, epibenthic sled and surface dredge (see figure 20). The surveys trawled in depths between 15 – 3000 m, for 10 to 270 minutes at two to four knots. The removed litter was sorted into four (plastic, plastic bags, cans, other (ACHA et al., 2003); plastic, metal, glass, other (GÜVEN et al., 2013)) to 14 categories (fish pot, net, octupus jar, fishing line, rope, drum, rubber, glass bottle, cloth, wood, vinyl, metal, plastic, others (LEE et al., 2006)). The only monitoring study thus far has been realized by DAMERON et al. (2007) through a combination of manta tows in evenly deep backreef habitats and non-linear swimming surveys in high-relief reef habitats.

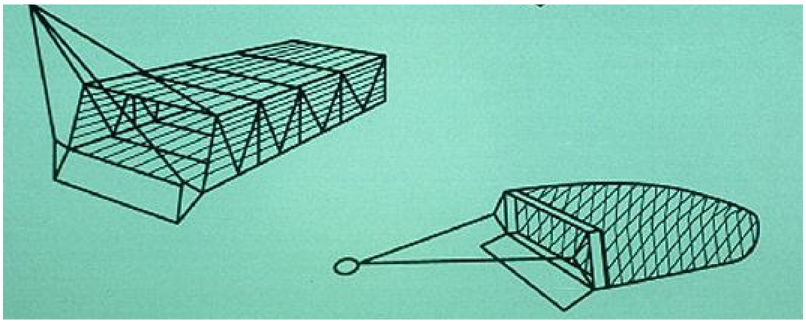

Fig. 20: Drawings of surface dredges (www.fao.org)

Although trawl surveys can assess large areas (LEE et al., 2006), drawbacks are, that they cannot be used on every type of bottom, e.g. reefs, and that the amount of litter on the sea-floor can easily be underestimated, as the trawl might not collect all debris, and items can be lost during the return of the net to the ship (SPENGLER and COSTA, 2008). It furthermore disturbs the environment during the sampling process.

Results

The results generated through bottom trawl surveys are presented in table 11. Average litter density was smallest in the Southern Ocean, where no debris was retrieved. The largest average density was found in the Mediterranean Sea, off the central Tyrrherian Coast (5,960 items/km²), with peak values reaching 40,500 items/km². 116.6 kg/km² in the North Pacific, off the US West Coast, is the largest average litter mass determined, although in the Blanes Canyon and the Catalan Margin, Mediterranean Sea, up to 3,264.6 kg/km² were found. The only accumulation study calculated an annual accumulation of up to 1,065 kg/km² at the Hawaiian Islands.

Location	Depth	Method (mesh size)	Litter density [items/km²]	Litter mass [kg/km²]	Authors
South Atlantic, Rio de la Plata estuary	-	Bottom (102 mm)	36 (0 - >150)	-	ACHA et al. (2003)
Northern Gulf of Mexico	-	otter (38 mm)	(0 – 6,540)	-	WEI et al.(2012)
North Sea, Belgium	-	bottom + otter (10 mm)	3,125 ± 2,830 (1,250 – 11,527)	0.4 (0.08 – 2.7)	VAN CAUWEN-BERGHE et al. (2013)
Mediterranean, Murcian coast	40 – 80 m	surface dredge (10 mm)	2,460 – 4,305	-	SÁNCHEZ et al. (2013)
Mediterranean, Blanes Canyon and Catalan Margin	900 – 3000 m	otter + Agassiz (12 mm)	-	0.02 – 3,264.6	RAMIREZ-LLODRA et al. (2013)

Location	Depth	Method (mesh size)	Litter density [items/km²]	Litter mass [kg/km²]	Authors
Mediterranean, Catalan coast	40 – 80 m	surface dredge (10 mm)	3,200 – 9,761	-	SÁNCHEZ et al. (2013)
Mediterranean, Gulf of Lion + Canyon	52 m + 510 m	otter	40	-	PHAM et al. (2013)
Mediterranean, West to East transit	900 – 3000 m	otter + Agassiz (12 mm)	-	14.7 – 1,536.6	RAMIREZ-LLODRA et al. (2013)
Mediterranean, central Tyrrhenian Coast	40 – 80 m	surface dredge (10 mm)	5,960 (0 – 40,500)	-	SÁNCHEZ et al. (2013)
Mediterranean, Malta	49 – 713 m	otter (20 mm)	97±78	-	MIFSUD et al. (2013)
Mediterranean, Greek Gulfs	15 – 320 m	commercial (15 mm)	165 (72 – 437)	13.4 (6.7 – 47.4)	KOUTSODENDRIS et al. (2008)
Mediterranean, eastern Ionian coast	40 – 80 m	surface dredge (10 mm)	1,712 – 2,700	-	SÁNCHEZ et al. (2013)
Mediterranean, Bathyal Ground, Antalya Bay	200 – 800 m	bottom	(115 – 2,762)	18 – 2,186	GÜVEN et al. (2013)
Mediterranean, Mersin Bay, Turkey	19 – 178 m	commercial trawler	-	0.15 kg/**km** (0 – 1.2 kg/**km**)	ERYASAR et al. (2014)
Western Turkish Black Sea	21 – 103 m	- (22 mm)	541 (128 – 1,320)	0.3 – 218	TOPÇU and ÖZTÜRK (2010)
Southern Ocean, Bellinghausen/ Amundsen Sea	-	Agassiz (10 mm) + epibenthic sled (300 µm)	0	0	BARNES et al. (2010)
North Pacific, US West Coast	55 – 1280 m	bottom (Aberdeen net; 28 mm)	67 (19.4 – 154.4)	116.6 (14.9 – 344.2)	KELLER et al. (2010)
Pacific Ocean, NW Hawaiian Islands, USA	<10 m	manta + non-linear diver (accumulation)	-	445.6 – 1,065.0 per year	DAMERON et al. (2007)
Pacific Ocean, Tokyo Bay, Japan	-	-	185	10.4	KURIYAMA et al. (2003)
South Sea of Korea	-	bottom + trawl of ships (60 mm)	-	78.6 (5 –255.8)	LEE et al. (2006)
East China Sea	-	bottom + trawl of ships (60 mm)	-	37.1 (0 – 113.3)	LEE et al. (2006)
Northern South China Sea	0.5 – 9 m	Trawl net + line diver	*693 (147 – 5,000)*	-	ZHOU et al. (2011)

Tab. 11: Results of surveys with different trawls, litter density and mass represent the mean value, the numbers in parentheses show the range. Numbers in italic were corrected by the author, as the authors miscalculated the density.

3) Imaging

Another possibility to quantify debris amounts at the sea-floor is the use of imaging technologies. Videos or photos can be taken by ROVs, manned submersibles (in combination with visual sightings) and towed camera systems.

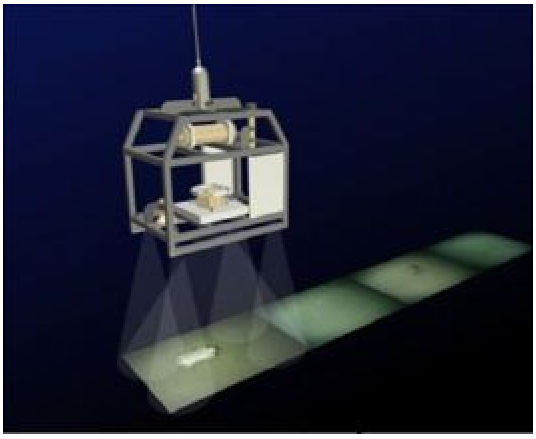

Fig. 21: Ocean Floor Observation System (OFOS) used at HAUSGARTEN (BERGMANN and KLAGES, 2012).

ROVs and submersibles can reach great depths and dived in the presented surveys between seven and 450 minutes covering 102 – 7400 m long tracks. For towed camera systems, cameras are attached to a (metal) frame (for the best results at an oblique angle) and towed behind a boat, one to three meters above the bottom (BULLIMORE et al., 2013). An example for a towed camera system is the 'Ocean Floor Observation System' (OFOS) at the deep sea observatory HAUSGARTEN, situated at 2.5 km depth in the eastern Fram strait west of Svalbard. With a camera track (see figure 21), images were taken at a set 30 or 50 second interval for four hours, 1.5 m above the sea floor (BERGMANN and KLAGES, 2012). After taking images, the recorded videos and/or photos are then reviewed and all litter items (often also their depth) noted and if possible identified. Archived videos of dives that served other purposes can also be used to quantify debris on the sea-floor. Litter density can then be calculated by dividing the number of observed litter items by the area covered, i.e. track length times average width of view of the platform used (PHAM et al., 2014). The surveys classified the identified litter items in six (plastic, derelict fishing gear, metal, glass, clinker, other (PHAM et al., 2014)) to 16 categories (abandoned research equipment, battery, clothing, other fabric, glass, concrete, manufactured wood, military debris, paper, rope, rubber, ship wreckage, plastic, metal, fishing debris and unidentified debris items (SCHLINING et al., 2013)).

Advantages of imaging methods are the large area covered and the great depth reached, as well as that they do not disturb the environment. Disadvantages are the great costs (especially for ROVs and manned submersibles) and the fact that they are indirect methods, i.e. the debris items can be seen but neither removed nor closely inspected (SPENGLER and COSTA, 2008).

Results

Table 12 displays the results of surveys using imaging technologies, mostly video cameras attached to ROVs, manned submersibles or towed systems. Mean values for litter density reach from 30 items/km² in the North Faeroe-Shetland Channel to 14,000 items/km² in the Pacific Ocean off the coast of central California, where also the highest number was counted (152,000 items/km²).

Location	Depth	Method	Litter density [items/km²]	Authors
Pacific Ocean, off central (2007) California, USA	20 – 365 m	submersible	14,000 (0 – 152,000)	WATTERS et al. (2010)
Pacific Ocean, off southern California, USA	20 – 365 m	submersible	800 (0 – 12,000)	WATTERS et al. (2010)
Pacific Ocean, Monterey Canyon, California, USA	25 – 4000 m	ROV (archived)	630	SCHLINING et al. (2013)
Pacific Ocean, Santa Catalina Island, USA	< 366 m	submersible	3,000	LOVE et al. (2010)
Eastern Fram Strait, Hausgarten	2500 m	OFOS	3,210 (278 – 7,710)	BERGMANN and KLAGES (2012)
Atlantic Ocean, submarine canyons Portugal	741 – 4574 m	ROV	1,100 (0 – 6,616)	MORDECAI et al. (2011)
NE Atlantic Ocean, Condor seamount, Azores, Portugal	185 – 1092 m	ROV	summit: 1,439 northern flank: 397 mean: 975	PHAM et al. (2013)
Atlantic Ocean:	mean depth:			PHAM et al. (2014)
North Faeroe-Shetland Channel	657 m	TC	30	
NE Faeroe-Shetland Channel	501 m	TC	190	
Norwegian Margin	304 m	submersible	970	
Dangeard and Explorer Canyons	578 m	TC	720	
Guilvinec Canyon	661 m	ROV	3.190	
Whittard Canyon	2668 m	ROV-TC	140	
Anton Dohrn Seamount	992 m	TC	190	
Josephine Seamount	1455 m	ROV	570	
Hatton Bank	706 m	ROV-TC	190	
Rockall Bank	702 m	ROV-TC	70	
Rosemary Bank	577 m	TC	330	
Pen Duick Alpha/Beta Mound	534 m	ROV	250	
Darwin Mounds	1007 m	ROV	970	
N Charlie Gibbs Fracture Zone	2300 m	ROV	40	
S Charlie Gibbs Fracture Zone	2600 m	ROV	290	
Wyville-Thomson Ridge	670 m	TC	1,090	

Tab. 12: Results of surveys with: OFOS (still photos with Ocean Floor Observation System), ROV (video footage with ROVs), submersibles (video footage and observation with manned submersibles), TC (video footage with towed camera systems). Litter density represents the mean value, the numbers in parentheses show the range.

3.1.4 Composition and origin of macro-debris

Plastic dominates marine litter worldwide and at every stage (beach, floating, benthic) by number of items, as table 13 shows. The averages were derived from surveys found during the literature review, see Annex II.h. for the whole list. Plastic plays the smallest role in benthic environments (with 'only' 63% of items), where metal is the material that the second most items are made of (13%), followed by glass (6%). With 87%, the highest plastic ratio is reached for floating litter. Both at the beach and the sea surface expanded polystyrene (EPS) constitutes a large part of plastic items (19 – 24%). Overall it should be noted that this comparison should only give an idea of debris composition, as surveys attribute objects sometimes to different categories: for instance, fishing debris is often a material category by its own, while other times it is a part of plastic litter. Another example are cigarette butts that are often allocated to plastic debris, sometimes to organic debris, sometimes to other items and some surveys use an extra category for it.

Stage	**n**	**Plastic [%]**	**EPS [%]**	**Glass [%]**	**Metal [%]**	**Paper [%]**
Beached debris	33	65	15	4	2	4
Floating debris	11	71	21	1	0.5	1
Benthic debris	18	63		6	13	2

Tab. 13: Average **composition** of marine macro litter by **number of items,** derived from n surveys, see Annex II.h.

In contrast, table 14 displays the average composition of macro-debris by weight, showing that plastic contribution is lower than by abundance. However, plastic still contributes over 1/3 of marine litter mass, thus being the largest single fraction. Nevertheless, glass and metal items gain importance, being heavier than items made of plastic.

Stage	**n**	**Plastic [%]**	**EPS [%]**	**Glass [%]**	**Metal [%]**	**Paper [%]**
Beached debris	14	**36**	**5**	**7**	**4**	**5**
Benthic debris	2	**36**		**10**	**16**	**0**

Tab. 14: Average **composition** of marine macro litter by **weight**, derived from n surveys, see Annex II.h.

Only few surveys, and only surveys for beached debris, attribute their found debris items to source categories; table 15 gives an overview of their results. Thereafter, 1/3 to over half of the beach litter found seems to be generated by recreational activities and tourism (land-based source). The second largest source seems to be fishing. However, large differences between regions exist. Again, the comparison should be viewed with caution, as the surveys use different categories and also allocate items differently. For a comparison of different source classifications see TUDOR and WILLIAMS (2004).

Location	Fishing [%]	Industry/ Shipping [%]	Sewage/ Sanitary [%]	Recreational [%]	Other [%]	Authors
Oman, Gulf of Oman	25	6	-	68	1	CLAEREBOUDT et al. (2004)
Greater Sydney Region	7	5	-	20	68	CUNNINGHAM and WILSON (2003)
South Korea	49		0.1	45	6	HONG et al. (2014)
Galicia, Spain	19	5	23	15	38	GAGO et al. (2014)
India, Gulf of Mannar	34	7	13	31	15	GANESPANDIAN et al. (2011)
Goiana Estuary, Brazil	22	-	-	-	78	IVAR DO SUL and COSTA (2013)
Taiwan	16		-	75	9	KUO and HUANG (2014)
Point Pleasant Park, Canada	7		14	52	27	WALKER et al. (2006)

Tab. 15: **Origin** of beached marine macro-debris by abundance.

This chapter gave an overview of methods that have been used to assess macro-debris and sometimes meso-debris quantities in the different stages (beach, floating, benthic). Figure 22 shows the worldwide distribution of all surveys for macro-debris.

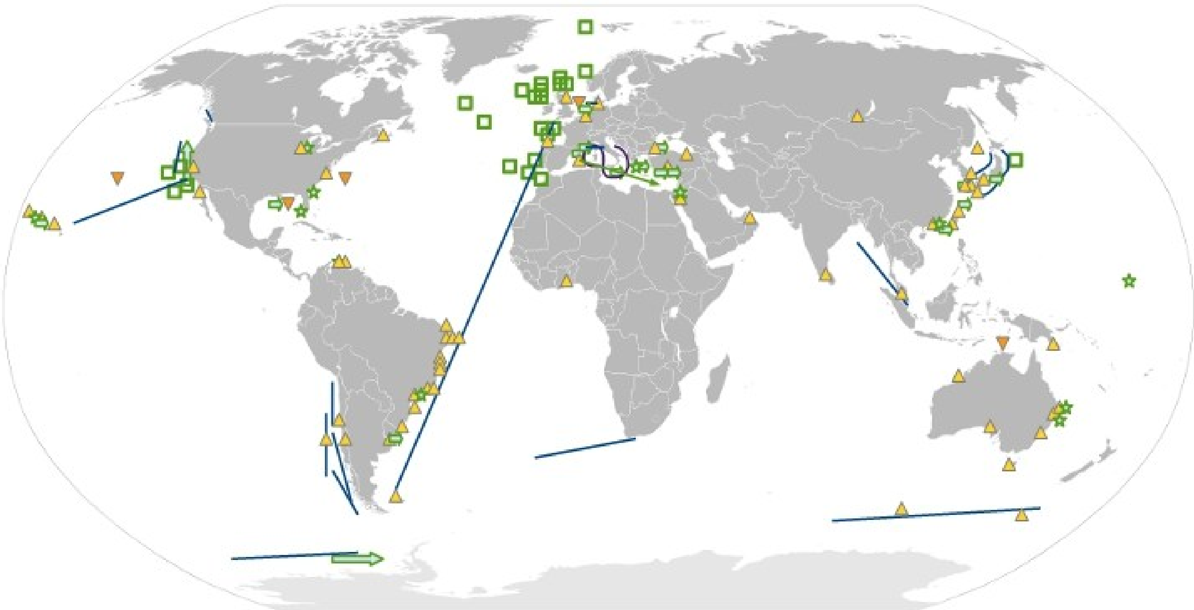

Fig. 22: Worldwide distribution of macro-debris surveys. Triangles represent beach, green arrows trawl, stars diving surveys, squares imaging technology for benthic debris and blue arrows visual sightings of floating debris. (Figure was created by the author)

3.2 Micro- and meso-debris

This chapter delves into methods to measure micro-debris. However, some methods are also viable for meso-debris.

3.2.1 Intertidal sediments (beach)

Surveying small debris at beaches is not as common as surveying macro-debris, nevertheless, studies have been done around the world, as depicted in figure 23.

Fig. 23: Worldwide distribution of beached micro-debris surveys. (Figure was created by the author)

As microplastics might be ingested by a wide range of organisms and might lead to other impacts, the missing studies constitute a major lack of data. Furthermore, MARTINS and SOBRAL (2011) found out that 72% of plastic debris found at five Portuguese beaches were smaller than five millimeter, thus being microplastics. However, they also showed that microplastics do not constitute a great part according to weight (~6%) and stress that the results varied between the surveyed beaches.

To study beached small debris a choice has to be made between different sampling strategies and methods, as well as different methods for extracting the litter particles from the sediment sample.

Sampling Strategies

The literature review showed that most studies take their samples with a stainless steel spoon as point samples from the high tide line. Figure 24 shows such a sampling scheme. Usually the upper one to five cm of a square are sampled; the most common used size of the square was 0.5 x 0.5 m, see figure 25. Only seldom a Van Veen grab was used to take the sample. Other sampling areas are the intertidal zone, the part of the beach where the maximum and/or minimum amount of litter is visible, or random points.

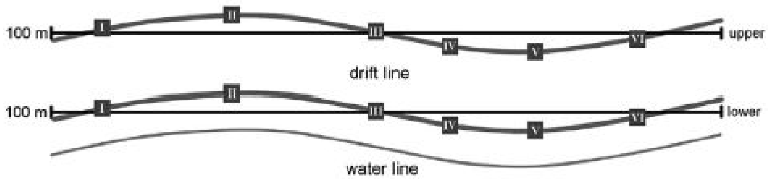

Fig. 24: Sampling squares along upper and lower strandline (DEKIFF et al., 2014).

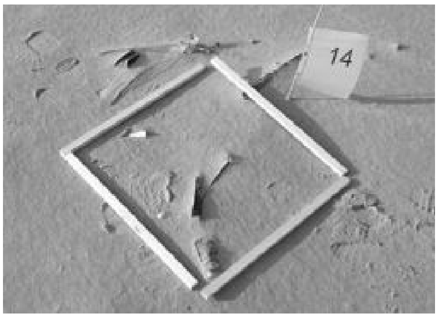

Fig. 25: Photo of a 0.5 x 0.5 m sampling square (DEKIFF et al., 2014).

Only two surveys examined transects perpendicular to the shore from the water's edge to the back of the beach, and the results of one of them, the study by MARTINEZ-RIBES et al. (2007), were already presented in the macro-debris chapter. HEO et al. (2013) examined the distribution of small plastic debris items (>1 mm) along the beach, perpendicular to the shoreline. They found out that the highest amounts of small debris were not at the high tide line, where the highest amount of macro-debris was visible, but in the upper littoral zone, i.e. the area closer to the back of the beach. This held true for all kinds of microplastics, especially Styrofoam. Their results can be seen in Annex II.i.

Extraction Methods

The decision on how to analyze a sediment sample depends on the size class that is to be examined. As meso-debris (>5 mm <20 mm) can still easily be detected by the naked eye, their examination does not need as advanced identification methods as micro-debris. Sieving the sediment and examining it in the lab can often be sufficient. LEE et al. (2013) analyzed the correlation between macro-, meso- and micro-debris at the high strandline, showing that meso- and microplastics were strongly correlated in all categories except intact plastics, as well as in total abundance of items (see Annex II.j.). They concluded that mesoplastic surveys could be used as approximation for microplastic monitoring.

Different methods exists to extract microplastics from the sediment sample and to identify it, the common factor being the use of density separation:

The simplest method is to mix the sediment sample with freshwater or seawater. MCDERMID and MCMULLEN (2004) used freshwater to wet sort sub-samples of dry sorted sediment samples. They placed small amounts of samples into a container of freshwater, swirled it for one minute and sieved the floating particles out. KUSUI and NODA (2003) mixed their samples with seawater, stirred the mixture and filtered the supernatant.

The extraction method most commonly used, sometimes with small adaptions, was developed by THOMPSON et al. (2004). For this, 250 ml of sediment are added to concentrated sodium chloride solution (1.2 kg NaCl/l) and stirred for 30 seconds. It is left to settle for two minutes, then the supernatant is filtered (they used Whatman GF/A filters which have a pore size of 1.6 µm), the filters are dried at 20°C, sealed in petri-dishes to prevent contamination and examined with a microscope.

Another comparable technique was used by LIEBEZEIT and DUBAISH (2012); instead of seawater or a NaCl solution, they mixed their sediment samples, after an overnight pretreatment with 30% hydrogen peroxide (H_2O_2) which destroyed the organic matter, with a zinc chloride solution ($ZnCl_2$) with a density of 1.5 g/cm³ and filtered the supernatant (they give, however, no details on the filtration process).

IMHOF et al. (2012) developed the Munich Plastic Sediment Separator (MPSS) that separates the debris also by density: first the sediment is introduced in $ZnCl_2$ solution (density of 1.6 – 1.7 kg/l), stirred for at least 15 minutes and then left to settle for one to two hours. Afterwards, the supernatant can directly be vacuum filtrated. If a lot of organic matter is present on the filters, the authors recommend the use of 30% H_2O_2 after the separation process or, if the samples are highly contaminated, the addition of sulphuric (H_2SO_4) or hydrochloric acid (HCl) to the $ZnCl_2$ solution to decompose the organic matter. In the end, the filters are dried and stored in PetriSlides™ for further analyzing. A detailed description of the procedure as well as a drawing of the MPSS can be found in Annex II.k.

CLAESSENS et al. (2013) created a method with two steps: (i) volume reduction of the sample by elutriation[7] followed by (ii) density separation using a high density sodium iodide (NaI) solution (density of approximately 1.6 g/cm³). The NaI extraction should be repeated two to three times to maximize the removal of particles from the sample. The optical analysis of the filter is then carried out with a dissecting microscope. A detailed description of the procedure as well as a drawing of the elutriation column can also be found in Annex II.k.

NUELLE et al. (2014) also developed a method to separate microplastics from sediment using two steps: (i) an air-induced (AIO) overflow method, based on fluidisation in a saturated NaCl solution and (ii) a subsequent flotation in a high density salt solution (NaI). First, the sediment sample is added to a NaCl solution which is moderately bubbling due to a constant air flow. Extra NaCl solution is pumped into the mixture, thus inducing an overflow of the top layer (containing the lighter particles). The supernatant is filtered and the filter is oven-dried at 60°C for 12 hours. For the second extraction step the dried filter residue is added to a NaI solution (density of 1.8 g/cm³). After a procedure of repeated shaking and refilling, the supernatant is decanted. This is repeated five times. Afterwards the supernatant is vacuum filtrated. If a large amount of organic matter is present on the filter, the authors recommend an oxidation step with 35% H_2O_2 solution. The optical analysis of the filter is then carried out with a stereomicroscope. A detailed description of the procedure and the oxidation step, as well as a drawing of the lab set up can also be found in Annex II.k.

A possible method that has not been established yet, is proposed by DEKIFF et al. (2014), who found out that almost all marine plastic items contain organic plastic additives (OPAs). In their opinion, this characteristic could be used to distinguish between natural materials and polymers.

Table 16 gives an overview of the advantages and disadvantages of the evolved methods presented above.

7 i.e. a process separating lighter particles from heavier ones with an upward stream of gas or liquid

Separation Method	Advantages	Disadvantages
NaCl	- eco-friendly, relatively inexpensive salt	- low density
$ZnCl_2$	- high density - simple set up	- $ZnCl_2$: severely hazardous to waters - large amounts of $ZnCl_2$
MPSS ($ZnCl_2$)	- high density - $ZnCl_2$ rather inexpensive - time efficient (no need of sequential extraction step)	- $ZnCl_2$: severely hazardous to waters - extra set up/materials necessary (not available in conventional lab)
Elutriation + NaI	- high density - cut costs of lost NaI solution (through elutriation and reuse) to 0.56 €/kg of sediment - NaI is 'minor threat to water' (compared with other high density salts)	- NaI: minor threat to water (compared to NaCl)
NaCl + NaI	- high density - cut cost while increasing sample - NaI is 'minor threat to water' (compared with other high density salts) - low material costs	- NaI: minor threat to water (compared to NaCl) - more time-consuming (two-step extraction)

Tab. 16: Advantages and disadvantages of the presented separation methods (NUELLE et al. (2014), IMHOF et al. (2012), CLAESSENS et al. (2013)).

The disadvantage of NaCl solution (low density) is the reason why so many new methods are being developed. Some common polymers as PET and PVC have higher densities than NaCl, as well as some polymers containing additives, as PE, and may thus not be separated when using NaCl as separation fluid (see Annex II.I. for a table with densities of common polymers, minerals and floatation fluids). Therefore, new methods usually use fluids with higher densities. No matter what method is chosen, the handling of the samples should be managed with care to avoid falsification of the result, especially if taking fibers into account. NUELLE et al. (2014) and others stress the importance of performing blank samples, thus determining the background contamination in the lab to inhibit overestimation of the microplastic pollution in the sample. However, they also underline that it can be difficult to obtain sediment samples that are free of fibers for running the procedural blank.

Before or after the extraction process, the samples are typically passed through a number of Tyler sieves, to establish different size bins. Any number of sieves can be chosen. ERIKSEN et al. (2013a) used for instance two Tyler sieves (1 and 4.75 mm) to generate the three size classes 0.355 – 0.999 mm, 1 – 4.749 mm and >4.75 mm, whereas ERIKSEN et al. (2013b) created six size bins: 0.355 – 0.499 mm, 0.5 – 0.709 mm, 0.71 – 0.999 mm, 1 – 2.79 mm, 2.7 – 4.749 mm and >4.75 mm.

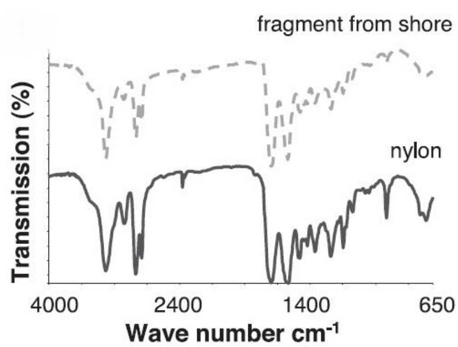

Fig. 26: Comparison of spectrum generated by a fragment found on a shore to a reference spectrum of nylon (THOMPSON et al., 2004).

After extracting the microplastics from the sediment sample, they are examined under a microscope and often sorted according to their color and form. The range of form categories used reaches from two (fibers and fragments (DESFORGES et al., 2014)) to eight categories (plastic resin pellets, plastic products, fragments of plastic products, rubber, fiber, Styrofoam, plastic sheets and sponge (YAMASHITA and TANIMURA, 2007)). To determine the polymer types of the particles and to rule out an overestimation, because some particles might be of natural origin, another set of instruments can be used. Most studies use for this Fourier Transform infrared spectroscopy (FT-IR) for this and compare the obtained spectra with specific reference library databases, shown in figure 26. For further information see for example VIANELLO et al. (2013). IMHOF et al. (2012) used Raman microspectroscopy (RM), which is a combination of Raman spectroscopy[8] and optical microscopy for the same purpose. Yet another possibility is presented by NUELLE et al. (2014), who use a pyrolysis gas chromatography/ mass spectrometry (Pyr-GC/MS). An advantage of this instrument is that polymer types and OPAs can be analyzed in one run (DEKIFF et al., 2014).

Results

Tables 17 and 18 present the results of intertidal sediment surveys, the separation method that was used, and if (and which kind of) further analysis, e.g. FT-IR, was carried out. Table 17 displays studies that have reported their results as litter density or mass per volume or mass of sampled sediment. To compare the studies, those results reported per mass of sampled sediment were standardized to volume of sediment according to CLAESSENS et al. (2011) by assuming an average density of sediment of 1,600 kg/m³ and a wet to dry sediment ratio of 1.25. Average litter densities determined range from 0.18 items/100 ml in the Singapore Strait to 602.9 items/100 ml at Minsener Oog and the Jadebusen, North Sea, with peak values reaching 8,128 items/100 ml of sediment sampled at Kachelotplate and Spiekeroog, North Sea. Only few surveys determined litter mass, and these vary greatly. Average mass reaches from 0.05 mg/100 ml in beach sediments of Belgium to 313.6 mg/100 ml at Fernando de Noronja, Atlantic, with the highest mass found being 10,900 mg/100 ml sediment sampled at the Canary Islands, Atlantic.

Location	Method	Particle size	Litter density [items/100 ml]	Litter mass [mg/100 ml]	Authors
Nova Scotia, Canada, Atlantic	3-4 cm, 0.02 m², high/ mid/low tide, H_2O_2 +NaCl	>0.8 µm^M	537.6^S (192 – 1,088)	-	MATHALON and HILL (2014)
Virginia, USA, Atlantic	1 cm, downwind high tide, NaCl, FT-IR	-	4 – 7	-	BROWNE et al. (2011)
Fernando de Noronha, Atlantic	2 cm, 0.09 m², high tide, seawater	≥1 mm^M	-	313.6^S	IVAR DO SUL et al. (2009)
Plymouth, UK, Atlantic	NaCl, FT-IR	most 20 µm	1^F	-	THOMPSON et al. (2004)
UK, Atlantic	1 cm, downwind high tide, NaCl, FT-IR	-	12	-	BROWNE et al. (2011)
Belgium, North Sea	Van Veen grab, high tide/ inter-/ subtidal, NaCl	38 µm – 1 mm^M	11.9	0.1	CLAESSENS et al. (2011)
Belgian Coast, North Sea	5 cm, 2 l, low/high tide, elutration column + NAI	>5 µm^M	1.7 (0.2 – 6) high tide: 2.3^S	-	VAN CAUWEN-BERGHE et al. (2013)

8 which is based on the effect of inelastic light scattering by molecules (Imhof et al., 2012)

Location	Method	Particle size	Litter density [items/100 ml]	Litter mass [mg/100 ml]	Authors
Norderney, North Sea	3 cm, 0.25 m², low/high tide, NaCl + NaI, GC/MS	<1 mm^M	0.2^S (0.1 – 0.5)	-	DEKIFF et al. (2014)
Kachelotplate + Spiekeroog, North Sea	1 cm, 500 g, H_2O_2 + $ZnCl_2$	>1.2 µm^M	85.9^S (13 – 8,128)	-	LIEBEZEIT and DUBAISH (2012)
Minsener Oog + Jadebusen, North Sea	Van Veen grab, 1 cm, H_2O_2 + $ZnCl_2$	>1.2 µm^M	602.9^S (51 – 3,379)	-	LIEBEZEIT (2012)
Portugal, Atlantic	1 cm, downwind high tide, NaCl, FT-IR	-	12	-	BROWNE et al. (2011)
Azores, Atlantic	1 cm, downwind high tide, NaCl, FT-IR	-	8 – 11	-	BROWNE et al. (2011)
Canary Islands, Atlantic	1 cm, 0.25 m², high tide, NaCl	<5 mm^M	-	0 – 10,900	BAZTAN et al. (2014)
United Arab Emirates, Red Sea	1 cm, downwind high tide, NaCl, FT-IR	-	0.4 – 6	-	BROWNE et al. (2011)
Oman, Indian Ocean	1 cm, downwind high tide, NaCl, FT-IR	-	4 – 7	-	BROWNE et al. (2011)
South Africa, Atlantic	1 cm, downwind high tide, NaCl, FT-IR	-	8 – 11	-	BROWNE et al. (2011)
Mozambique, Indian Ocean	1 cm, downwind high tide, NaCl, FT-IR	-	8 – 11	-	BROWNE et al. (2011)
Alang-Sosiya, India, Indian Ocean	5 cm, 5-10 kg, intertidal, NaCl, FT-IR	-	-	10.4^S (8 – 11)	REDDY et al. (2006)
Singapore, Singapore Strait	1 cm, 1 kg, 0.5 m from high tide, NaCl, FT-IR	>1.6 µm^M	0.2^S (0 – 2)	-	NG and OBBARD (2006)
Singapore, Singapore Strait	3-4 cm, 2.25 m², NaCl, FT-IR	<20 - > 5000 µm	4.7^S (1.5 – 8)	-	NOR and OBBARD (2014)r
W Australia, Indian Ocean	1 cm, downwind high tide, NaCl, FT-IR	-	8 – 11	-	BROWNE et al. (2011)
E Australia, Pacific	1 cm, downwind high tide, NaCl, FT-IR	-	0.8	-	BROWNE et al. (2011)
Chile, Pacific	1 cm, downwind high tide, NaCl, FT-IR	-	4 – 7	-	BROWNE et al. (2011)
Japan, Pacific	1cm, downwind high tide, NaCl, FT-IR	-	8 – 11	-	BROWNE et al. (2011)
Philippines, Pacific	1 cm, downwind high tide, NaCl, FT-IR	-	0.4 – 6	-	BROWNE et al. (2011)
Hawaii, USA, Pacific	5.5 cm, 0.37 m², high tide/upper, freshwater	1 – 15 mm	4.34 (0.01 – 44.1)	116.9 (37.5 – 197.5)	MCDERMID and MCMULLEN (2004)
California, Pacific	1 cm, downwind high tide, NaCl, FT-IR	-	0.4 – 6	-	BROWNE et al. (2011)

Tab. 17: Results of beach sediment surveys per 100ml sediment; The column *Method* states (if available) type of sampler (other than stainless steel spoons); depth, size and location of taken sample; separation method and if other instruments besides a microscope were used. The particle size refers to the observed sizes. ^M signifies the sieve size used, if no other size was available. Litter density and mass represent the mean value, the numbers in parentheses show the range. ^F marks surveys that only counted fibers, ^S highlights results that were standardized (because they used other units) according to CLAESSENS et al. (2011) assuming an average density of sediment of 1,600 kg/m³ and a wet to dry sediment ratio of 1.25.

Table 18 presents surveys that reported their results in litter density and mass per area sampled, and are thus not comparable to the results in table 17. However, they can be compared to a certain degree with the results from macro-debris surveys, if keeping the different sizes in mind. The mean litter density reaches from 27 items/m² in Chile to 41,000 items/m² in Jordan, with the highest value measured at the same location (878,400 items/m²). The highest average mass of micro-debris particles was found on Geoje Island, South Korea with 683 g/m³, while the lowest average mass was determined in Mumbai, India with 7.49 g/m².

Location	Method	Particle size	Litter density [items/m²]	Litter mass [g/m²]	Authors
Recife, Brazil, Atlantic	2 cm, 988 cm²	0.5 – 20 mm	3,000	-	COSTA et al. (2010)
Fernando de Noronha, Atlantic	2 cm, 0.09 m², high tide, seawater	≥1 mm	33 – 258	3.2 – 33.3	IVAR DO SUL et al. (2009)
Portugal, Atlantic	2 cm, 4 m², high tide	>2 mm	2,421	326	ANTUNES et al. (2013)
Portugal, Atlantic	2 cm, 0.25 m² + 4 m², high tide, NaCl, FT-IR	50 µm – 20 cm	185.1 (28.6 – 392.8)	36.4	MARTINS and SOBRAL (2011)
Jordan, Gulf of Aqaba, Red Sea	1 m², intertidal	~5 mm	41,000^{P} (1,200 – 878,400)	-	ABU-HILAL and AL-NAJJAR (2009b)
Mumbai, India, Indian, Ocean	2 cm, 0.25 m², high tide, NaCl	>1 mm	68.8 (12 – 960)	7.5 (0.2 – 56.3)	JAYASIRI et al. (2013)
Russia, Sea of Japan	5 cm, 0.16 m², seawater	-	31.3	8.8	KUSUI and NODA (2003)
Japan, Sea of Japan	5 cm, 0.16 m², seawater	-	2,610	13.6	KUSUI and NODA (2003)
Sand bar,Geoje Island, South Korea, Pacific	5 cm, 0.25 m², max/min mass	5 – 25 mm	238 (0 – 940)	-	LEE et al. (2013)
Sand bar Nakdong River + Geoje Island, South Korea, Pacific	5 cm, 0.25 m², max/min amount	1 – 5 mm	8,205 after rainy season: 27,606 (1.6 – 92,217)	-	LEE et al. (2013)
Geoje Island, South Korea, Pacifc	5 cm, 0.25 m², high tide	>2 mm	976 ± 405 (32 – 3,692)	683	HEO et al. (2013)
Geoje Island, South Korea, Pacifc	5 cm, 0.25 m², perpendicular transect	>2 mm	473 ± 124 (0 – 3,918)	94.6	HEO et al. (2013)
Hawaii, USA, Pacific	5.5 cm, 0.37 m², high tide/upper, freshwater	1 – 15 mm	2,333 (5 – 23,710)	63 (20 – 106)	MCDERMID and MCMULLEN (2004)
Easter Island, Pacific	2 cm, 0.25 m², high tide	1 – 10 mm	805 (250 – 2,000)	-	HIDALGO-RUZ and THIEL (2013)
Chile, Pacific	2 cm, 0.25 m², high tide	1 – 10 mm	27 (1 - 169)	-	HIDALGO-RUZ and THIELl (2013)

Tab. 18: Results of beach sediment surveys per m² of beach surface; the column *Method* states (if available) depth, size and location of taken sample; separation method and if other instruments besides a microscope were used. The particle size refers to the observed sizes. Litter density and mass represent the mean value, the numbers in parentheses show the range. ^{P}marks surveys that only counted pellets.

3.2.2 Subtidal sediments (benthic)

Until now only few surveys have assessed micro-debris in subtidal sediments, figure 27 gives on overview of their worldwide distribution.

Fig. 27: Worldwide distribution of benthic micro-debris surveys. (Figure was created by the author)

In the existing studies, different techniques to gather the sediment samples were used, namely divers who collected a bucket full of sediment, a trowel, a Van Veen grab or different kinds of corers[9]. Another possibility could be an epibenthic sled with an adequate mesh size. However, surveys using epibenthic sleds were reported in the floating debris section as it can not be distinguished between particles originating in the sediment and particles floating above the bottom. To extract microplastics from the sediment, the same methods that have been presented for intertidal sediments can be used and are thus referred to in tables 19 and 20.

Results

Tables 19 and 20 present the results for surveys of subtidal sediments. Table 19 displays studies that have reported their results as litter density or mass per sampled sediment. To compare the studies, those results reported per mass of sampled sediment were standardized to volume of sediment, as described above. The lowest density of microplastics was found in the Goiana Estuary, Atlantic Ocean (0.001 items/100 ml), whereas the highest density was found at Stenungsund, North Sea (332 items/100 ml). The only two surveys weighing the plastic particles they found, reached from 0.1 mg/100 ml at the Belgian coast to 0.4 mg/100 ml in Belgian harbors.

9 i.e. a device used to obtain a sediment core

Location	Method	Particle size	Litter density [items/100ml]	Litter mass [mg/100ml]	Author(s)
Stenungsund, Sweden, North Sea	Trowel + Ekman sampler, NaCl	≥ 0.5 mm	93 (2 - 332)	-	NORÉN (2007)
Belgian harbors, North Sea	Van Veen grab, NaCl	38 µm – 1 mm	21.3[S]	0.4[S]	CLAESSENS et al. (2011)
Belgian coastal waters, North Sea	Van Veen grab, NaCl	38 µm – 1 mm	12.4[S]	0.1[S]	CLAESSENS et al. (2011)
Plymouth, UK, Atlantic	NaCl, FT-IR	most 20 µm	Estuarine 4[F] Subtidal: 11[F]	-	THOMPSON et al. (2004)
Lagoon of Venice, Italy, Mediterranean	<1.5m, box-corer, NaCl, FT-IR	30 µm – 2.5 mm	86 – 278[S]	-	VIANELLO et al. (2013)
Florida + Maine, USA, Atlantic	5-6l by divers, graduation column, NaI	0.25 – 4 mm	10.5 – 21.4	-	GRAHAM and THOMPSON (2009)
Goiana Estuary, NE Brazil, Atlantic	Cylindrical corer, intertidal	≥ 1 mm[M]	0.001	-	COSTA et al. (2011)

Tab. 19: Results of benthic sediment surveys; The column *Method* states (if available) depth, type of sampler, separation method and if other instruments besides a microscope were used. The particle size refers to the observed sizes. [M]signifies the sieve size used, if no other size was available. Litter density and mass represent the mean value, the numbers in parentheses show the range. [F]marks surveys that only counted fibers, [S]highlights results that were standardized according to CLAESSENS et al. (2011)

Table 20 shows the results of one survey in deep see sediments at different locations that reported its results in items per area sampled. This survey found no microplastics in the sediment of the Congo Canyon, Gulf of Guinea, and the most at the Porcupine Abyssal Plain the the northern Atlantic Ocean.

Location	Depth [m]	Method	Particle size	Litter density [items/25 cm²]	Authors
Polar front, Southern Ocean	2479 – 4881	Multicorer, NaI, Raman	118µm	0.33	VAN CAUWEN-BERGHE et al. (2013)
Porcupine Abyssal Plain, Atlantic	4842 – 4844	Multicorer, NaI, Raman	83 - 161µm	1	-“-
Congo Canyon, Gulf of Guinea	4785	ROV, NaI, Raman	-	0	-“-
Nile Deep Sea Fan, Mediterranean	1176	Multicorer, NaI, Raman	75µm	0.5	-“-

Tab. 20: Results of benthic sediment surveys; The column *Method* states type of sampler, separation method and if other instruments besides a microscope were used. The particle size refers to the observed longest side of the particles. Litter density represents the mean value.

3.2.3 Pelagic micro-debris (floating)

Small debris items floating in the ocean (mostly at the surface) have been analyzed more often than larger items. In general, two different methods can be distinguished that can be used to monitor small litter item abundance at sea, namely pelagic trawls and the examination of the stomach contents of seabirds.

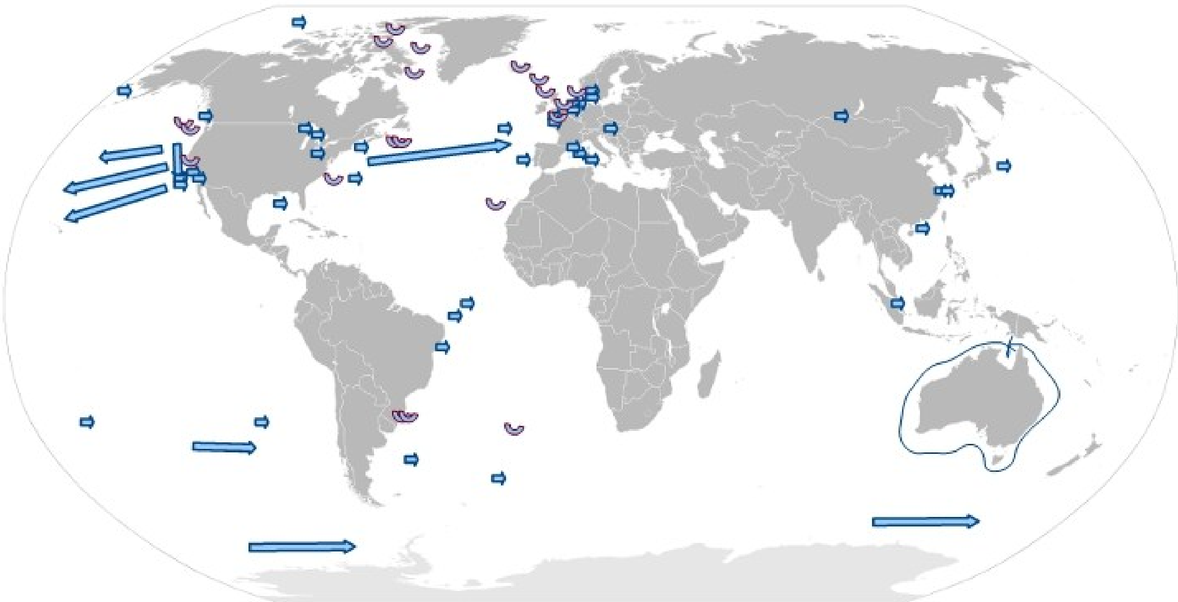

Fig. 28: Worldwide distribution of floating micro- and meso-debris surveys. Arrows indicate trawl surveys, semicircles surveys that analyzed stomach contents of seabirds. (Figure was created by the author)

Both can generate data describing long-term trends. The distribution of both surveys worldwide is shown in figure 28. However, as they represent totally different methods, they are not comparable to one another (e.g. the reporting unit differs widely) and separately presented here.

1) Trawls and similar methods

Net-based surveys are more objective than visual sightings of larger debris items, but the area that can be sampled is limited. Therefore a large number of tows is required to determine the average abundance of litter at sea (RYAN et al., 2009). For sampling and afterwards extracting micro-debris from the sample, several methods are available.

Sampling Methods

Trawls are the method used most often, however, the trawl employed varies between the different surveys. Table 21 gives an overview of common nets and their characteristics. The manta net is used most often, followed by the neuston net. For subsurface tows bongo samplers are used and for samples just above the sea floor epibenthic sleds. Besides these common trawls, a variety of other instruments has been used to survey small floating marine litter, as driftnets, pumps and surface water samples (e.g. with PET bottles) amongst other things.

Net Type	Size opening	Mesh size	Trawl duration and speed	Picture	Reference(s)
Manta	16 x 61 cm (15 – 20 cm height x 60 – 100 cm width) 3/4 submerged	333 µm (333 - 505 µm)	15 – 20 min (10 – 60 min); 1 – 4 knots		CÓZAR et al. (2014), REISSER et al. (2013)
Neuston	10 – 100 cm height x 40 – 200 cm width 1/2 submerged	280 – 1000 µm	10 – 15 min (3 – 30 min) 1 – 4 knots		CÓZAR et al. (2014), REISSER et al. (2013)
Plankton	diameter: 60 cm	300 – 450 µm	3 – 30 min 1 – 4 knots		Earthobser-vatory.nasa.gov
WP2	diameter: 57/58 cm	180 – 200 µm	3 – 30 min 1 – 4 knots		www.iopan.gda.pl

Net Type	Size opening	Mesh size	Trawl duration and speed	Picture	Reference(s)
Longhurst Hardy Plankton Recorder	Apparatus around a 42 cm diameter plankton net	355 µm	3 – 30 min 1 – 4 knots		blog.antarc-tica.ac.uk
Bongo	diameter: 61 or 71 cm subsurface tows, 5 – 212 m depth	202 – 505 µm	10 min 1 – 2 knots		oceanexplor er.noaa.gov
Epibenthic sled	no data bottom samples	300 µm	no data		links.baruch. sc.edu

Tab. 21: Different kinds of nets used for trawling, their opening size, mesh size, trawl duration and speed, as well as a picture. Numbers for size opening, mesh size and trawl duration and speed are those most often used. The respective range is presented in parentheses.

A very important point for trawl surveys is to report environmental data, especially about the wind conditions. Details on the effect that wind may have on pelagic samples can be seen in Annex II.m. To assess the volume of water sampled, RYAN et al. (2009) strongly recommend the use of flowmeters. If no flowmeter is employed, the volume can be calculated using the opening of the net, the length of the tow (optimally confirmed by GPS) and if available a filtering efficiency. Thus, COLE et al. (2014) calculated the volume sampled using the formula $V = (\pi r^2) \times L \times 0.95$, where r is the radius of the net aperture, L the length of the tow and 0.95 the specific filtering efficiency of a 200 µm WP2 net. Besides taking new samples, the examination of archived plankton samples or routine plankton surveys is another possibility to cost-efficiently monitor small floating marine debris. FRIAS et al. (2014) stress that the analysis of regularly performed plankton surveys for microplastics can contribute to monitoring floating marine debris without further costs of days at sea and showed that they were able to identify microplastic particles in such samples.

Extraction Methods

After retrieving the water sample, and carefully rinsing the net to collect all debris items stuck in the net, the sample is often fixed. The following substances have been used for this:

- formalin (2.5% (ZHAO et al., 2014), 4% (IVAR DO SUL et al., 2013; IVAR DO SUL et al., 2014; LIMA et al., 2014), 5% (ROCHMAN et al., 2014))
- 5% formalin in the field, later soaked in fresh water and transferred to 70% isopropyl alcohol (LATTIN et al., 2004; MOORE et al., 2005),
- 5-10% HCl (DESFORGES et al., 2014),
- 4% borax-buffered formaldehyde (FRIAS et al., 2014),
- and 70% ethanol (FREE et al., 2014).

The choice of the extraction method depends on the location of the extraction (typically in the lab, rarely directly after sampling at the vessel) and the parameters that are to be measured, e.g. if zooplankton is also assessed or not.

The simplest and most common method was used for example by LECHNER et al. (2014) who suspended each sample in a fresh water bath and carefully removed buoyant plastic particles. The samples can also be transferred to a container of seawater and the plastic pieces picked up with forceps, as did for example Reisser et al. (2013).

COLLIGNON et al. (2012) introduced their samples into graduated cylinders, to separate the light plastic particles from organic tissue, which sank to the bottom of the cylinder.

DESFORGES et al. (2014) acid-digested the organic matter in their samples with concentrated HCl for three hours at 80-90°C.

COLE et al. (2014) examined and compared different methods to extract microplastics from biota rich seawater samples. In the end, they suggest an enzymatic digestion treatment with Proteinase-K. See Annex II.n. for details on the method. Using this method, the authors were able to digest more than 97% of organic matter present in the samples, thus allowing an easy isolation and identification of present plastic particles.

ZHAO et al. (2014) first used 30% H_2O_2 to oxidatively clean the samples of organic matter and then introduced the samples into a saturated $ZnCl_2$ solution, following the method of Liebezeit and Dubaish (2012), presented in chapter 3.2.1.

The microplastics extracted are also sorted according to size, color and shape, and if possible their polymer type is identified.

Results

Tables 22 and 23 present the results of the surveys found during the literature review. The surveys in table 22 reported litter density and mass *per volume*. The litter density measured was the lowest at the bottom of the Southern Ocean, where no microplastics were found, followed by (sub)surface water samples off Portugal and at the St. Peter and Paul Archipelago in the Atlantic Ocean. The highest density was measured with an average of 865,500 items/100 m³ of water sampled at Stenungsund, Sweden, in the North Sea. The average litter mass found ranges from 0 mg/100 m³ in the Southern Ocean to 30 mg/100 m³ in Santa Monica Bay, USA with peak values reaching 240 mg/100 m³.

Location	Trawl details	Method	Mesh size	Litter density [items/100 m³]	Litter mass [mg/100 m³]	Author(s)
Southern Ocean	Epibenthic sled, bottom	-	300 µm	0	0	BARNES et al. (2010)
Goiana estuary, Brazil, Atlantic	Plankton[F] (d: 0.6 m), + bottom, 15 min/2.7 kn	-	300 µm	2.2 (0.4 – 14.0)	-	LIMA et al. (2014)
St.Peter and Paul Archipelago, Atlantic	existing, Plankton[F] (d: 0.6 m), 5-10 min/2 kn	-	300 µm	1 (2 – 10)	-	IVAR DO SUL et al. (2013)
Islands W Tropical Atlantic	Manta[F] (0.15x0.9 m), 15 min/1.5 kn	-	333 µm	3 (0 – 13)	-	IVAR DO SUL et al. (2014)
Stenungsund, Sweden, North Sea	Plankton, 10 min/1-2 kn	-	450 µm	6 (1 – 14)	-	NORÉN (2007)
Stenungsund, Sweden, North Sea	Surface water sample	-	80 µm	865,500 (16,700 – 1x10^7)	-	NORÉN (2007)
Jade System, North Sea	PE bottles, bucket	H_2O_2	1.2/ 40 µm	1.5x10^7 (0 – 24.2x10^7)	-	DUBAISH and LIEBEZEIT(2013)
Jade System, North Sea	Surface water samples	-	-	0 – 64x10^7	-	LIEBEZEIT (2012)
W English Channel	WP2, for 500 m	Enzymatic digestion, FT-IR	200 µm	30	-	COLE et al. (2014)
Tamar Estuary, UK, Atlantic	Manta (0.15x0.5 m), 30 min/4 kn	FT-IR	333 µm	2.8	-	SADRI and THOMPSON (2014)
Off Portugal, Atlantic	WP2[F] (d:0.58 m) + Neuston[F] (0.2x1 m), both 3 min/1.5 kn; Plankton Recorder[F] (d:0.42 m), 30 min/4 kn, 25 m	FT-IR	180 µm 280 µm 355 µm	0.2 – 3.6	-	FRIAS et al. (2014)
Sardinia, Mediterranean	Manta[F], 20 min/2 kn	-	500 µm	15 (1 – 35)	-	DE LUCIA et al. (2014)
Pelagos Sanctuary, Mediterranean	WP2[F] (d:0.57 m), 15 min/1 kn + water column	-	200 µm	62 (0 – 967)	-	FOSSI et al. (2012)
Singapore, Singapore Strait	Rotating drum sampler + pump	FT-IR	1.6 µm	65,000 (0 – 200,000)	-	NG and OBBARD (2006)

Location	Trawl details	Method	Mesh size	Litter density [items/100 m³]	Litter mass [mg/100 m³]	Author(s)
Yangtse Estuary, East China Sea	Pump, 1 m depth	H_2O_2+ $ZnCl_2$	32 µm/ 500 µm	413,730 (50,000 – 1,020,000)	-	ZHAO et al. (2014)
Coastal waters, East China Sea	Neuston (0.3x0.4 m), 25-30 min/2 kn	H_2O_2+ $ZnCl_2$	333 µm 500 µm	16.7 (3 – 45.5)	-	ZHAO et al. (2014)
California to North Pacific Central Gyre	Manta[F] (0.15x0.9 m)	fresh water	333 µm	43 – 500	-	MOORE et al. (2005)
California to North Pacific Central Gyre	Bongo[F] (d:0.61 m), 10 + 30 m depth	fresh water	333 µm	152 - 300	-	MOORE et al. (2005)
Santa Monica Bay, California, Pacific	Manta[F] (0.15x0.9 m); Bongo[F] (d:0.61 m), 5 m depth; both 10 min/1-2.3 kn	fresh water	333 µm	392 (50 – 1,800)	30 (2 – 240)	LATTIN et al. (2004)
Santa Monica Bay, California, Pacific	Epibenthic sled[F] (31 cm²), bottom, 10 min/ 1-2.3 m/s	fresh water	300 µm	375 (150 - 600)	20 (14 - 27)	LATTIN et al. (2004)
US West Coast, Pacific	Manta[F] (0.15x0.86 m), 15 min; Bongo[F] (d:0.71 m), 212 m depth + 15 m above bottom	FT-IR	505 µm	0.4 – 19	2.4 – 20.9	DOYLE et al. (2011)
Coastal British Columbia, Canada, Pacific	Saltwater intake system of vessel[F], 4.5 m, 10-20 min	HCl, vacuum filtration	62 – 5,000 µm	208,000 (80 – 918,000)	-	DESFORGES et al. (2014)
SE Bering Sea	Neuston[F] (30x50cm), 10min/2kn	FT-IR	505 µm	1.7 – 7.2	4 – 8	DOYLE et al. (2011)
Arctic	sea ice cores (1-3.5 m length)	FT-IR	0.22 µm	3,800 – 23,400 /100 m³ ice	-	OBBARD et al. (2014)

Tab. 22: Results of (sub)surface trawl surveys; the column *Trawl details* clarifies type and size of net used, duration and speed of trawl and depth for subsurface trawls. [F] marks trawls that used flowmeters. The column *Method* states separation method and if other instruments besides a microscope were used. Litter density and mass represent the mean value, the numbers in parentheses show the range.

The surveys in table 23 report their results as litter density and mass *per area sampled*. Average litter densities range from 0 items/km² in a non-accumulation zone (i.e. no convergence zone) in the Pacific Ocean to 1,299,000 items/km² in the Pacific Ocean between the US West Coast and Hawaii, with peak values reaching 6,530,000 items/km². The litter mass determined reaches from 0 to 153,000 g/km² with the highest average value, 3,600 g/km², measured in the Koroshio Current in the Pacific Ocean.

Location	Trawl details	Method	Mesh size	Litter density [items/km²]	Litter mass [g/km²]	Authors
South Atlantic	Manta (0.16x0.61 m), 60 min/0.5 m/s	seawater	333 µm	63,400 (14,127 – 204,182)	-	ROCHMAN et al. (2014)
SW Atlantic	Neuston[F] (0.5x1.0 m), 10-15 min/2-3 kn	seawater, RM	200 µm	-	0 - 50	CÓZAR et al. (2014)
NW Atlantic + Caribbean Sea	Neuston (0.5x1.0 m), 30 min/2 kn	-	355 µm	0 – 580,000	-	LAW et al. (2010)
Caribbean Sea	-"-	-	355 µm	1,414 ± 112	-	-"-
Gulf of Maine	-"-	-	355 µm	1,534 ± 200	-	-"-
near 30°N	-"-	-	355 µm	20,328 ± 2,324	-	-"-
Trans N Atlantic	Neuston[F] (0.5x1.0 m), 10-15 min/2-3 kn	seawater, RM	200 µm	-	0 – 2,500	CÓZAR et al. (2014)
NE Atlantic	Neuston[F] (0.5x1.0 m), 10-15 min/2-3 kn	seawater, RM	200 µm	-	0 - 200	CÓZAR et al. (2014)
Belgium, North Sea	Neuston (1x2 m), 1 km/1-2 kn	-	1 mm	3,875 ± 2,724 (500 – 13,000)	255.2 ± 829.1 (1.3 – 4,112.2)	VAN CAUWENBERGHE et al. (2013)
NW Mediterranean	Manta (0.2x0.6 m), 20 min/2.5 kn	Graduated cylinder	333 µm	116,000 (0 – 900,000)	202 (0 – 2,280)	COLLIGNON et al. (2012)
Australian waters	Neuston (0.6x1.2 m) +Manta (0.17x1.0 m), both 15 min/2-4 kn	seawater, FT-IR	355 µm 333 µm	4,256 ± 757 (0 – 48,896)	-	REISSER et al. (2013)
Mid S Pacific	Neuston[F] (0.5x1.0 m), 10-15 min/2-3 kn	seawater, RM	200 µm	-	0 – 2,500	CÓZAR et al. (2014)
South Pacific Subtropical Gyre	Manta (0.16x0.61 m), 60 min/0.5-1.5 m/s	seawater	333 µm	26,898 (0 – 396,342)	71.0 (0 – 732)	ERIKSEN et al. (2013b)
SE Pacific	Neuston[F] (0.5x1.0 m), 10-15 min/2-3 kn	seawater, RM	200 µm	-	0 – 200	CÓZAR et al. (2014)
E Pacific, non accumulation	Neuston[(F)](0.5x1.0 m), 30 min/3 kn	-	355 µm	0[Md]	-	LAW et al. (2014)
Pacific, between US West Coast and Hawaii	Manta[F] (0.2x0.86 m), 15 min/0.7-1 m/s; Bongo[F] (d:0.71 m), 15 min, 210 m depth	FT-IR	333 µm 202 µm	1,299,000 (0 – 6,530,000)	-	GOLDSTEIN et al. (2013)
E Pacific, (25 – 41°N, 130 - 180°W)	Neuston[(F)] (0.5x1.0 m), 30 min/3 kn	-	355 µm	33,090[Md] (0 – 12,320,000)	-	LAW et al. (2014)
Kuroshio Current, Pacific	Neuston (0.5x0.5 m), 10 min/2 kn	-	330 µm	174,000 ± 467,000 (0 – 3,520,000)	3,600 ± 18,100 (0 – 153,000)	YAMASHITA and TANIMURA (2007)
N South China Sea	Trawl	-	-	*4,922 (274 – 16,807)*	76.3	ZHOU et al. (2011)

Tab. 23: Results of (sub)surface trawl surveys; The column *Trawl details* clarifies type and size of net used, duration and speed of trawl and depth for subsurface trawls. [F] marks trawls using flowmeters. The column *Method* states separation method and if other instruments besides a microscope were used. Litter density and mass represent the mean value, except studies marked with [Md], where the value represents the median. The numbers in parentheses show the range. Numbers in italic were corrected by the author.

2) Stomach contents of seabirds

From 1982 to 1984, a Dutch study examined the stomach contents of beachwashed Northern Fulmars (*Fulmarus glacialis*) for plastic items. The method used was further developed and tried, resulting in a monitoring protocol for northern fulmars presented by VAN FRANEKER and MEIJBOOM (2002) that has gained international reputation and is followed (with small adjustments) by most studies. For the proposed method the birds are stored at -20°C until one day prior to dissection. During external examination and dissection certain data should be reported, namely date, finder, location details; plumage color, moult and plumage condition and fouling; external measurements (e.g. head- and winglength), sex and age; external signs of injury, condition and internal injuries and organ health; cause of death. During dissection, the stomach is removed and proventriculus and gizzard are separated. The stomachs are then opened over their full length and the contents carefully flushed out with cold water over a 5 mm sieve to guarantee that all small debris particles are removed (the sieve size has often been smaller to assess microplastics). The sieve containing the material is then rinsed under running cold water. If some parts cling together due to sticky substances (e.g. mineral oil, chemicals), a sub-sample of the substance is taken, its total mass in the sample estimated and the material rinsed with hot water or even detergents to remove it. Afterwards, the sample is sorted using a binocular microscope into the following categories:

- industrial plastic pellets,
- user plastics (sheets, threads, foam, fragments, other),
- waste other than plastic (paper, kitchenfood, various, fishhook),
- pollutants (slags, tar, chemical (e.g. parafine), featherlump),
- natural food remains,
- natural non-food remains (plant-remains, seaweed, pumice, stone, other).

The reporting units used for each (sub)category and stomach are: incidence (percentage of plastic ingestion), abundance by number and by mass (weight in g after one to two days of air drying). VAN FRANEKER and MEIJBOOM (2002) further conclude, that a monitoring program is possible if 40 birds can be examined per year over at least four to eight years.

Results

Table 24 presents the results of surveys that examined stomach contents of northern fulmars (the last survey used southern fulmars, another species) following more or less the method explained above. The table lists how the fulmar corpses were collected and shows the incidence of plastic particles as well as litter density and mass per examined bird. In 2002, a system of Ecological Quality Objectives (EcoQO) for the North Sea to be looked after by OSPAR was established in the Bergen Declaration. One of these objectives concerns marine litter and uses the stomach contents of the northern fulmar, to monitor its development (VAN FRANEKER and SNS FULMAR STUDY GROUP, 2008):

> *"There should be less than 10% of Northern Fulmars having 0.1 gram or more plastic in the stomach in samples of 50-100 beachwashed fulmars from each of 5 different regions of the North Sea over a period of at least 5 years".*

The table indicates what proportion of sampled birds contained more than the target value (0.1 g) in their stomachs. The highest incidence of micro-debris have fulmars in the Channel area (100%). This is also where the largest average density (56.7 items/bird) has been determined. The highest mean mass, however, was found in birds on Sable Island, Canada (1.09 g/bird). The data shows, in general, a decrease in density, mass and incidence from South to North. For instance, the lowest average litter density and mass was found in the Davis Strait, Canadian Arctic.

Location	Method	Sieve size	n	Incidence [%]	EcoQO [%]	Litter density [items/bird]	Litter mass [g/bird]	Author(s)
Davis Strait, Canada, Arctic	Long-lines	-	42	36	-	1.3 ± 2.3	0.02 – 0.3	MALLORY et al. (2006)
N Devon Island, Canadian Arctic	shot/Nose poole	-	102	31	-	2.3 (0 – 54)	0.3 ± 0.2 (0 – 1.4)	MALLORY (2008)
Prince Leopold Island, Arctic	shot	-	10	84	10	2.5 ± 3.5	0.05 ± 0.1	PROVENCHER et al. (2009)
Cape Searle, Canadian Arctic	shot	-	15	84	40	7.6 ± 6.6	0.1 ± 0.2	PROVENCHER et al. (2009)
Sable Island, Canada,Atlantic	beached	-	176	93	66	26.4 ± 37.5 (0 – 205)	1.1 ± 1.9	BOND et al. (2014)
Iceland, Atlantic	Long-lines	1 mm	58	79	28	6 ± 0.1	0.1 ± 0.04 (0 – 2)	KÜHN and VAN FRANEKER (2012)
North Sea	beached	1 mm	1,295	95	58	34.5 ± 2.5	0.3 ± 0.02	VAN FRANEKER et al. (2011)
Scottish Islands	-"-	-"-	95	92	48	18.9 ± 3.0	0.2 ± 0.03	-"-
East England	-"-	-"-	60	95	60	35 ± 6.9	0.2 ± 0.03	-"-
Channel area	-"-	-"-	107	100	78	56.7 ± 8.3	0.2 ± 0.03	-"-
SE North Sea	-"-	-"-	842	94	58	30.4 ± 3	0.3 ± 0.02	-"-
Skagerrak	-"-	-"-	191	95	50	47.7 ± 8.6	0.4 ± 0.1	-"-
NE Pacific Ocean	beached	0.5 mm	67	92.5	54	36.8 ± 9.8 (0 – 454)	0.4 ± 0.1 (0 – 3.65)	AVERY-GOMM et al. (2012)
Monterey Bay, USA, Pacific	beached	0.5 mm	185	98	-	22.3 ± 2.0 (0 – 223)	0.5 ± 0.1 (0 – 10.12)	DONNELLY-GREENAN et al. (2014)
Faeroe Islands, Atlantic	shot	0.5 mm	35	51	-	1.7 (1 - 7)	-	PROVENCHER et al. (2014)
Southern Brazil, Atlantic	Long-lines + beached	-	9	79	-	30	-	COLABUONO et al. (2009)

Tab. 24: Results of surveys of Northern Fulmars (except the last line, that concerns Southern Fulmars) giving details about the collection method, the mesh size of the sieve if one was used during the analysis, the number of birds containing any micro-debris and the rate of birds containing more than 0.1g of plastics in their stomach (EcoQO performance). Litter density and mass represent the mean value, the numbers in parentheses show the range.

In recent years, scientists tried to use other seabirds than Northern Fulmars to monitor marine debris. Table 25 presents surveys examining the stomach contents of Cory's Shearwaters, Sooty Shearwaters and Great Shearwaters, using the same method as for Northern Fulmars. As the birds differ in feeding and physical characteristics, the results can only be compared between birds of the same species. However, up to now most surveys of Shearwaters do not consist of large samples, so that no reliable trends can be determined.

Location	Method	Bird species	n	Incidence [%]	Litter density [items/bird]	Litter mass [g/bird]	Author(s)
Sable Island, Canada, Atlantic	beached	Cory's Shearwater	3	0	0	0	BOND et al. (2014)
S Brazil, Atlantic	Long-lines + beached	Cory's Shearwater	5	100	6	-	COLABUONO et al. (2009)
Tenerife, Atlantic	beached	Cory's Shearwater	85	84	8.0 ± 7.9 (0 – 36)	3.0 ± 4.0 (0 – 39.3)	RODRíGUEZ et al. (2012)
Catalan Coast, Mediterranean	Long-lines	Cory's Shearwater	49	96	14.6 ± 24.0	0.02 ± 0.05	CODINA-GARCÍA et al. (2013)
Sable Island, Canada, Atlantic	beached	Sooty Shearwater	50	72	2.5 ± 2.7 (0 – 12)	0.07 ± 0.2	BOND et al. (2014)
BC, Canada + WA, USA, Pacific	-	Sooty Shearwater	1	100	43	1.6	AVERY-GOMM et al. (2013)
Sable Island, Canada, Atlantic	beached	Great Shearwater	84	88	11.8 ± 16.9 (0 – 128)	0.2 ± 0.3	BOND et al. (2014)
US coast, Atlantic	beached	Great Shearwater	17	71	7.4 (0 – 36)	0.1 ± 0.2	PROVENCHER et al. (2014)
S Brazil, Atlantic	Long-lines + beached	Great Shearwater	18	89	17.5 (0 – 72)	-	COLABUONO et al. (2009)
Tristan da Cunha, Atlantic	shot + long-lines	Great Shearwater	53	-	11.8 ± 18.9	-	RYAN (2008)

Tab. 25: Results of surveys of different species of seabirds, giving details about the collection method and the number of birds containing any micro-debris. Litter density and mass represent the mean value, the numbers in parentheses show the range.

4. Aquatic litter

The literature review showed that until now few surveys have assessed the pollution of fresh water habitats by litter. Those that were found are presented in this chapter (concerning coastline macro-debris) or in Annex III.a. However, the topic gets more attention as most surveys date to 2013 or 2014. Still, this signifies a major lack of data as rivers are one of the main sources for marine debris (see chapter 2.). As long as no quantification exists on how much litter enters the oceans through rivers, a large piece of the picture is missing.

Two projects can be found in the internet that try to monitor the pollution through litter on river banks, both taking place in France; one is being realized at the Adour watershed by the NGO Surfrider Foundation Europe (http://riverineinput.surfrider.eu/en/) and one at the Seine, organized by the NGO S.O.S. Mal de Seine (http://maldeseine.free.fr/). Both try to raise awareness for the pollution of the river and gather data on the amount and composition of litter. Data of the Seine is presented in this chapter (by COLASSE, 2014), however the Riverine Input project has not yet published data, and will present their 12 month data set in March 2015 (DUSSAUSSOIS, 2014).

Within the framework of this master's thesis, a small survey along the Danube was conducted and is presented below.

4.1.1 Background and Study Area

The youth group of the WWF Austria, Youth taking Action for the Earth (YTAE), organizes regularly (usually twice a year) cleanups of flood areas situated in the Donau-Auen National Park, downstream from Vienna, Austria. On October 5th 2014 the 7th clean up since 2011 took place and more than 20 people met outside the small town Wildungsmauer to collect for about three and a half hours litter washed ashore through floods on a 900 m long stretch of the river, see GPS-coordinates in figures 29 and 30. This stretch of the river bank was cleaned for the first time and the last flood had taken place about a month before the event.

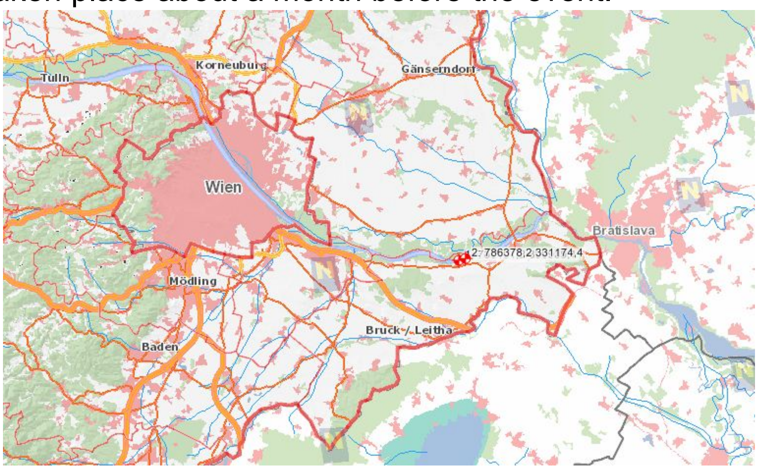

Fig. 29: Map of area between Vienna and Bratislava. Red dots mark survey site (atlas.noe.gv.at).

Fig. 30: Detailed map of survey area: red dots mark beginning and end of cleaned stretch (atlas.noe.gv.at).

4.1.2 Methods and Material

This section gives an overview of the methods and material used. The volunteers from YTAE collected all visible litter except wood (they were told by the national park ranger to let manufactured wood were it was found, as it would degrade) between the river and an oxbow lake, especially at a track along the river, for four hours. As the items were mostly larger than 2 cm, with the exception of some expanded polystyrene (EPS) and plastic pieces, this was a macro- (and mega-) debris cleanup. The full trash bags were brought to a sorting station, where they were sorted into the categories described below, counted and weighed them.

At present no monitoring protocol for aquatic litter exists, although the MSFD TSG ML is supposed to publish monitoring methods and a protocol for river debris by the end of 2014 (MSFD TECHNICAL SUBGROUP ON MARINE LITTER, 2013). For this reason the 'Master List of Categories of Litter Items' by the MSFD TSG ML (see Annex II.g.) was taken as a basis for the sorting protocol, together with the categories of a litter study in Vienna, as well as of a study of the litter getting caught in the rakes of a power station in Vienna (not publicly available). Furthermore, YTAE had communicated that they would separate the litter they found along the Danube into the following fractions:

- PET
- residual waste (Restmüll)
- glass (Glas)
- metal (Metall)
- hazardous wastes (Problemstoffe)
- construction material (Baumaterialien)
- bulky waste (Sperrmüll)

For this reason, all categories that were decided on, were allocated to one of these waste fractions. To save time on site, as the sorting could only take place on one day and there were over 60 categories, it was decided to sort all litter smaller than 10 cm in the categories 33 (Other plastic items), XXXVIII (other residual waste <10 cm) and XLVII (other metal items <10 cm) and take these back to the university to sort them the following day. The 67 categories including those which were not sorted on site can be seen in table in Annex As the study took place in Austria they are in German. From the list of categories, a sorting protocol was derived (also in German, see Annex III.c.), taking into account the size restriction of items(10 cm) as well as the information of YTAE concerning the separately collected fractions.

During the sorting, the sorting team decided to split some categories (pieces of plastic and EPS) due to the abundance of EPS pieces. For this is the reason the sorting protocol was adapted on site, and EPS and plastic pieces separated, i.e. EPS pieces were sorted on site into three categories: pieces smaller than 10 cm, pieces in between 10 and 50 cm and pieces larger than 50 cm. All plastic pieces that were found were sorted to category 33 (Other plastic items), and sorted the after at the university. Furthermore, as the volunteers were not supposed to collect wood, category 43 (pieces of wood <10 cm) was renamed “sorting rest”, i.e. litter pieces smaller than 2.5 cm (especially small EPS beads), little twigs, dirt, etc.

At the university, the bags filled with categories 33 (other plastic items), XXXVIII (other residual waste <10 cm) and XLVII (other metal items <10 cm) and a couple of bags that could not be sorted the previous day due to the sun setting, were sorted into the categories of the sorting protocol, as well as the extra categories (those marked with an 'x' in table 56). Due to their abundance, a new category for cigarette lighters was created during sorting. The entire results for all categories presented in table 56 plus the new categories described above are shown in Annex III.d.

As described above, the full trash bags were brought to a sorting station which consisted of a sorting table, a weighing table (the balance's resolution was 10 g and it had an upper weight limit of 30 kg) and about 30 labeled buckets, in which the sorted items were put, see figure 31. The sorting team comprised of seven people of which four were sorting, one weighing, one writing the protocol and one person transporting the trash bags by car to the sorting station as they were often too to be carried by the YTAE volunteers.

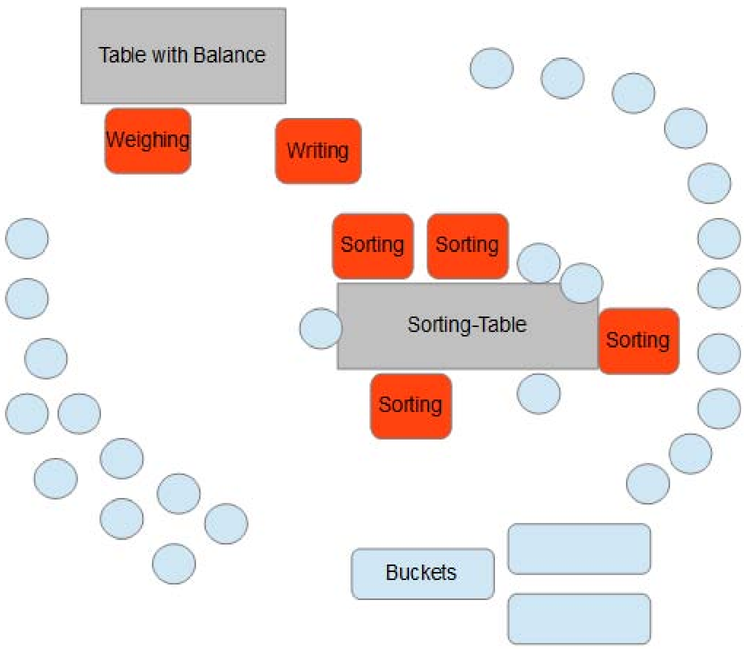

Fig. 31: Abstraction of sorting station at the bank of the Danube. Red rectangles represent people, blue rectangles and circles large and small buckets, respectively.

At the sorting station the full bags were weighed, emptied on top of the sorting table and sorted. After finishing the sorting, the buckets were brought to the balance and every category was weighed. Then the contents of the buckets were counted and put back into the trash bag. After finishing all buckets, the trash bag was marked with a white sticker, put to the side and the next bag was sorted. Contrary to the original information that the litter would be collected in seven different waste fractions, the volunteers collected all litter together. Thus the original idea to sort one fraction after the other had to be dismissed and all fractions were sorted simultaneously. The sorting team worked for six hours, the final sorting at the university – conducted by one person, took another six hours.

After finishing the sorting, the data was entered into a spreadsheet program (Apache Open Office 4.0.1) and the weight of the empty buckets was subtracted from the field results. This lead in some cases to a negative weight. These fields were checked again and were set to zero, if no mistake could be found. Reasons for the negative values could be the resolution of the balance, as well as the possible mistakes discussed below in chapter 4.1.3. Afterwards, the weight of all items belonging to one trash bag was summed up and compared with the initial weight of the trash bag. These two numbers did also in some cases not correspond to each other: for three bags there was a difference in between ten and 15% of the initial weight and for another three bags (out of 57) of more than 15%. Neglecting this, the number and weight for items of each category were summed up. In the end, the categories containing no items or only a few items were attributed to some other categories, resulting in the final 38 categories. To calculate litter densities and mass, the length of the cleaned stretch was determined and its area estimated using a GIS map of Lower Austria (http://atlas.noe.gv.at/webgisatlas).

4.1.3 Results

The results for all categories (before merging) can be seen in Annex III.d., whereas table 26 presents the final results. The columns on the left side show the index numbers for the categories, used in this study, by EU, OSPAR and UNEP (derived from the MSFD TSG ML master list). The categories that do not have a number in the column for this study were created during sorting, e.g. the sorting protocol contains categories for plastic and EPS pieces together, however, due to the large amount of EPS pieces, they were assessed separately. Overall, 7,721 items were retrieved, weighing together 367 kg (without a large tractor tire that was not weighed, as it was too heavy for the scale). By weight, the most abundant item were PET drink bottles larger than 0.5 l, followed by PET drink bottles smaller and equal to 0.5 l, together constituting 27 wt%. Other abundant items by weight were glass bottles (13 wt%), tires (9 wt%) and other plastic items (8 wt%). Figure 32 shows the distribution of materials found by weight. Plastic-made items are the largest fraction, however, items made of glass and rubber also weighed a lot. The most abundant items by number were small EPS pieces (>2.5 cm <10 cm), representing 35% of items. Other items that were abundant by number were PET drink bottles, larger EPS pieces (>10 cm <50 cm) and other foamed plastics. Figure 33 displays the proportions of the different materials found by number of items. Hence, 92% of items found were made of plastic.

As many of the PET bottles still contained liquids, empty PET bottles from the supermarket were weighed and multiplied with the number of bottles found. Furthermore, two of the tires found had a rim; for them a standard weight was also assessed and the weight of the rims contributed to the metal category. Details can be seen in Annex III.e. and the results in table 26. After this correction, most abundant items by weight were glass drink bottles (16%), followed by other plastic items, tires and other. If adding the two PET Drink bottle categories they are the second most abundant item by weight (12%). The largest material fraction by weight is also still plastic, see figure 34.

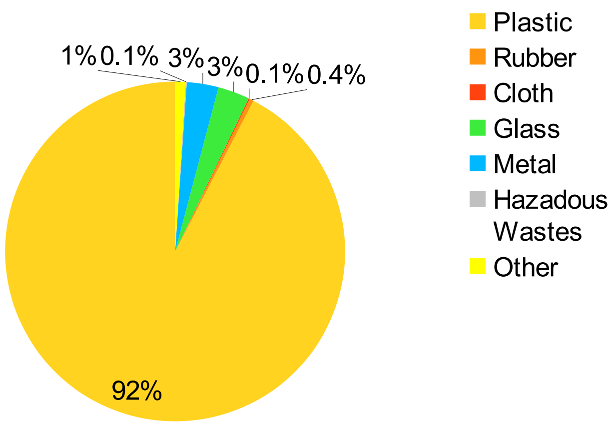

Fig. 33: Proportion of materials by **number of items**

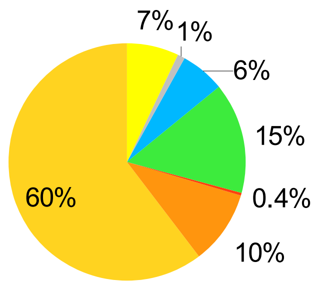

Fig. 32: Proportion of materials by **weight**

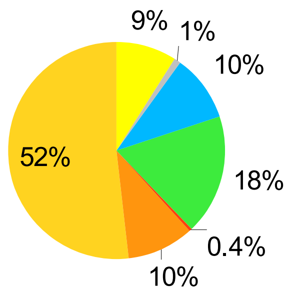

Fig. 34: Proportion of material by **corrected weight**

Mistakes could have been generated among other things through the wind, the scale, miscommunication and wrong classification of items. While sorting and weighing the trash bags at the river side a mild but gusty wind was blowing. These gusts influenced the weight of large containers and trash bags by moving them. Thus, it proved difficult to determine the exact weight as the number displayed for the same bag or container kept changing. Furthermore, the scale had a resolution of 10 g, thus light fractions could not be measured. While one person was weighing the different categories, the others were counting items of other categories and all reported to one person who wrote down the data. As this information sometimes overlapped, there might have been miscommunication between the different parties involved. Another possible mistake might be that some items were not classified rightly. For instance, figure 35 shows an item that was attributed to the category 'Toys' as it was thought to be a small ball used to play with dogs. However, it is also possible that it is a small buoy used to mark swimming and boating lanes.

Fig. 35: Photo of object classified as 'toy' (ball).

Nr.	EU	OSPAR	UNEP	Material	Subkategorie	Number		Weight		Weight (cor.)	
						Count	%	g	%	g	%
1	G7	4	PL02		PET Drink bottles <= 0.5l	770	10%	37,290	10%	15,400	5%
2	G8	4	PL02		PET Drink bottles > 0.5l	666	9%	63,970	17%	21,700	7%
6	G10	6	PL06		Food containers incl. Fast food containers and pieces	287	4%	980	0.3%	980	0.3%
7	G11-12	7	PL02		Cosmetics bottles and containers	66	1%	4,220	1%	4,220	1%
8	G14,15	8,9	PL03		Engine oil bottles & containers	7	0.1%	8,500	2%	8,500	3%
9	G150,151	62,118	PC03		Tetrapack	19	0.2%	1,020	0.3%	1,020	0.3%
3,10	G13	12	PL02		Other bottles and containers	124	2%	16,480	4%	16,480	5%
11	G67	40	PL16		Plastic sheets	258	3%	4,950	1%	4,950	2%
4,5,12, 13					Other plastic packaging	130	2%	1,527	0.4%	1,527	1%
15	G20-24	15	PL01		Caps and lids	109	1%	590	0.2%	590	0.2%
	G26	16	PL10		Cigarette lighters	55	1%	760	0.2%	760	0.3%
17	G32	20	PL08	Artificial polymer material	Toys	115	1%	6,310	2%	6,310	2%
18	G33-35	21-23	PL04,6		Dishes, Curtlery, Straws, Cups	17	0.2%	310	0.1%	310	0.1%
20,21	G48-50, G66	31,32, 39	PL19, PL21		Rope and Cord, Strapping bands	21	0.3%	1,060	0.3%	1,060	0.3%
30	G95-98	98-101	OT02		Sanitary Waste (sanitary towels, tissues)	15	0.2%	60	0.0%	60	0.0%
32	G71	44	CL01		Shoes	15	0.2%	3,870	1%	3,870	1%
23	G63	37	PL14		Buoys	4	0.1%	430	0.1%	430	0.1%
	G82				Expanded polystyrene pieces (Styropor) >10 <50cm	763	10%	16,270	4%	16,270	5%
	G83				Expanded polystyrene pieces (Styropor) >50cm	7	0.1%	1,750	0.5%	1,750	1%
	G82				Expanded polystyrene pieces (Styropor) >2.5 <10cm	2,666	35%	5,230	1%	5,230	2%
	G79				Plastic pieces >2,5 <10cm	285	4%	820	0.2%	820	0.3%
	G79				Plastic pieces >10 <50cm	165	2%	5,970	2%	5,970	2%
	G80				Plastic pieces >50cm	4	0.1%	660	0.2%	660	0.2%
56					Other foamed plastics (>2,5 <50cm)	479	6%	6,900	2%	6,900	2%
14,16,19,22,24,25,31,33	G124	48	PL24		Other plastic items (non packaging)	65	1%	31,050	8%	31,050	10%
34	G102		RB02		Flip-Flops	24	0.3%	2,920	1%	2,920	1%
37	G128	52	RB04	Rubber	Tires (without tractor tire)	3	0.0%	34,540	9%	25,410	8%
35,36,38	G134	53	RB08		Other rubber items	4	0.1%	480	0.1%	480	0.2%
39,40	G137-45	54-57,59	CL01-6	Cloth		7	0.1%	1,500	0.4%	1,500	0.5%
47	G200	91	GC02		Drink bottles incl. Pieces	178	2%	47,040	13%	47,040	16%
48	G201,203		GC02,3	Glass	Other glass packaging	28	0.4%	6,890	2%	6,890	2%
49	G202-210	92,95,96	GC04-08		Other glass items (non packaging)	24	0.3%	530	0.1%	530	0.2%
50	G175	78	ME03		Beverage cans	66	1%	3,560	1%	3,560	1%
51	G174	76		Metal	Aerosol/spray cans	117	2%	12,920	4%	12,920	4%
52,53	G176-178	77,81,82	ME02,4,6		Other metal packaging	24	0.3%	3,770	1%	3,770	1%
55	G185-199	83-90	ME4,5,10		Other metal items (non packaging)	20	0.3%	1,120	0.3%	10,250	3%
59,60				Hazardous Wastes		4	0.1%	4,130	1%	4,130	1%
41,42, 43,44,45,46,64, 66				Other	Organic (coffee capsules), paper (Vignette, flower descriptions), candles, wood/bulky waste	110	1%	26,660	7%	26,660	9%
					Total:	7,721	100%	367,037	100%	302,877	100%

Tab. 26: Results of the macro-debris cleanup at a flood area of the river Danube

4.1.4 Discussion

Compared to studies surveying macro-debris on lake shores (see table 27) the number and mass of litter items found at the Danube are higher, by one to four orders of magnitude. However, compared with surveys of river banks, litter density and mass are low to very low at the banks of the Danube; litter densities at Chilean rivers are 10 – 28 times higher and densities at the river Seine are 5 – 47 times higher. Reasons could be a better waste management system in Austria than in Chile, less littering by Austrians in general and differences in the survey site. For instance, although the survey sites both at the Seine and the Danube are flood areas, the Seine site seems to be flooded more often through waves generated by passing cargo vessels (COLASSE, 2014). Another reason might be possible mistakes, that will be looked at in more detail in the following section.

Location	Method details	Litter density [items/m²]	Litter mass [g/m²]	Litter density [items/km]	Litter mass [kg/km]	Authors
Danube, Austria	900m (5-20m), collecting >2cm	0.21	10	8.429	401	This study
Chicago, Lake Michigan, USA	400m (50m), collecting	0.01	0.1	100	5	HOELLEIN et al. (2014)
Lake Hovsgol, Mongolia	0.1 – 2km, collecting	-	-	1.5 – 211	0.037 – 5.34	FREE et al. (2014)
Rivers Elqui, Maipo, Maule and BioBio, Chile	3 -5 circles (r=1.5m) at river shore, mid + upper bank, counting >1.5cm	1 – 6	-	-	-	RECH et al. (2014)
2014 Berville-sur-seine, France	117m (triangle of 108x44m), collecting >1cm	2.4	34	48,726	690	COLASSE (2014)
2013 Berville-sur-seine, France		10.0	72	203,026	1,462	

Tab. 27: Results of macro-debris surveys at **lake and river shores**. The column *Method details* lists (if possible) length of surveyed stretch of river/lake shore (width), if debris was collected or counted and its size.

Compared to studies of stretches of beaches (see chapter 3.1.1) the litter density found along the Danube in items/m² lies in the middle of the range found at beaches (0 – 0.38 items/m²); the same is correct for the litter mass (0.01 – 24.01 g/m²). If the reporting unit is litter density per length of coastline, the numbers encountered along the Danube are in the middle of those found at stretches of beaches (100 – 64,290 items/km). However, compared to surveys of whole beaches (see also chapter 3.1.1), a higher litter density was found at the Danube than at the beaches, were average litter densities ranged from 33 to 2,015 items/km. Furthermore, the mass of litter found along the Danube per length of coastline was two, respectively three times higher than the mass determined during surveys of whole beaches and stretches of beach (1 – 168 kg/km at whole beaches, 5 – 92.7 kg/km for stretches of beach).

In 2013, the NGO SOS Mal de Seine completed an OSPAR protocol during their cleanup at the river Seine (see Annex III.f.). The most abundant item (26%) were pieces of plastic and expanded polystyrene (>2.5 cm <50 cm), the same as along the

Danube, followed by cotton buds (15%), candy wrappers (8%), plastic caps and lids (8%), food containers (6%) and other plastic or polystyrene items (6%). In contrast to the Danube, only 1% of items were plastic drink bottles. However, neither at the Seine, nor at the Danube cigarette butts were found (at the Danube only two e-cigarette cartridges were encountered), whereas cigarette butts constitute 30% of items found at a Lake Michigan beach (HOELLEIN et al., 2014) and 5.2 – 11.8% of items counted along Chilean rivers (RECH et al., 2014).

As can be seen from table 28, plastic is almost always the largest fraction by number of items, except at two Chilean rivers, where concrete/pottery (Elqui) and manufactured wood (BioBio) dominated. The contribution of plastic thus ranges from 22 – 99.2%, with an average of 72.6%. On the other side, glass and metal are not very numerous categories, each mostly representing 0.3 – 4% of items. Paper is often absent, or almost absent (Danube, Seine, Lake Hovsgol).

Location	Plastic [%] (incl. rubber)	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Danube, Austria	92.4	3	3	0	1.6	This study
Chicago, Lake Michigan, USA	68	4	8	8	12	HOELLEIN et al. (2014)
Lake Hovsgol, Mongolia	84	0	0.6	0.6	14.8	FREE et al. (2014)
River Elqui, Chile	32.7	2.8	3.1	14.3	47.1	RECH et al. (2014)
River Maipo, Chile	79.1	3.6	2.1	9.7	5.5	
River Maule, Chile	77.1	0.7	1.4	7.6	13.2	
River BioBio, Chile	22	1.2	2.3	5.3	69.2	
2014 , Berville-sur-seine, France	98.7	0.3	0.3	0	0.7	COLASSE (2014)
2013, Berville-sur-seine, France	99.3	0.1	0.3	0	0.3	

Tab. 28: Composition of materials by **number of items**

The distribution of materials by weight is shown in table 29. Although plastic items are mostly light weighted, they still represent more than half of the litter by weight. In Austria and Mongolia another important material was glass, whereas in France manufactured wood ('other' in the table) constituted a large part.

Location	Plastic [%] (incl. rubber)	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Danube, Austria	70	15	6	0	9	This study
Lake Hovsgol, Mongolia	62	24	6	1	7	FREE et al. (2014)
2014 , Berville-sur-seine, France	52.9 (incl. metal)	2.7	-	-	44.4	COLASSE (2014)

Tab. 29: Composition of materials by **weight**

These results show that plastic is not only dominating beaches but also river and lake shores worldwide, both by number and weight of items. Heavy materials as glass and metal are also always present, but represent only a small part of items. The presence of paper/cardboard, manufactured wood and other materials seems to depend on the other hand on local circumstances.

5. Discussion

A variety of studies show that when litter enters the marine environment, it may negatively impact marine animals; this is visible whenever animals get entangled in marine litter and are washed ashore. Less visible impacts may be triggered for example through the ingestion of marine debris. In this context microplastics are of special concern, as they are so small that many marine animals can easily ingest them. This becomes an economic problem, when commercially valuable species decline thus impacting the local or regional fishing industry. Furthermore, it might threaten human health when humans eat for instance fish that ingested marine debris, hence influencing society. To avoid these impacts, the sources of marine litter and its pathways in the marine environment have to be determined. This can only be done by monitoring the amounts of litter present in the world's oceans. To do so, different methods for measuring marine debris in the three stages and of every size exist. The results of 184 scientific articles, which assessed marine debris quantities around the world between 2003 and August 2014, have been presented in this study, together with the methods used. Until now beached macro-debris has gained the most attention with 59 articles that determined litter amounts on beaches. The second largest group of articles assessed pelagic micro-debris amounts in the world's oceans (45), followed by surveys for benthic macro-debris (34). Beach sediments have been analyzed for micro-debris in 27 surveys, while 17 estimated floating macro-debris. The fewest surveys exist about benthic sediments (8 surveys).

The 'oldest' method to determine the number of debris items present on a beach is to count them. As beached marine debris is highly visible and may disturb residents and tourists, many surveys have determined its amount and tried to identify its source. However, the area sampled and the reporting unit as well as the categories used vary greatly in these studies. For this reason, a comparison of studies is only possible to a limited extent. Nevertheless, the surveys indicate that the amount of marine debris present on beaches is spread heterogeneously and does not so much depend on the region of the world, but rather on the exact location, where it is assessed, and the location's specific characteristics. Still, the methods used need to be standardized, to allow inter-regional comparison. In the European Union this is being done under the framework of the MSFD and a method as well as a protocol have been published that scientists should use all over Europe in their future studies. The proposed strategy should be reviewed in an ongoing process to integrate new research and adapt it to local circumstances. The MSFD TSG ML proposes for example surveys every three months – although studies have shown that daily surveys generate more accurate data (see chapter 3.1.1 and Annex II.a.). Furthermore, the European Union should either decide on a reporting unit or make it mandatory to assess amounts of marine litter per area sampled as well as per length of coastline. As simple as beach surveys are, they are also time-consuming. That is one of the reasons why new methods using imaging technologies are being developed – to monitor more beaches while needing less working hours.

The use of pelagic trawls for micro-debris surveys is widely distributed and have also been used to compare data from different decades, showing an increase in microplastic abundance over time (GOLDSTEIN et al., 2012). Nevertheless, few monitoring surveys exist that determine the development of micro-debris density over time. For them, the same location should be sampled regularly and the effect of the wind's speed needs to be taken into account, as did for example CÓZAR et al. (2014). Further research still needs to be done on the effect of wind on debris concentration and its distribution in the water column.

For the assessment of benthic macro-debris amounts, three different methods exist that can be used complementary to each other: divers/snorkelers in shallow waters, benthic trawls for deeper waters and ROVs/submersibles/towed camera systems for the deep sea floor. However,attention should be paid that the same reporting unit is used to be able to compare results of surveys using different methods. Furthermore, as only two surveys determined accumulation rates, more monitoring studies have to be implemented. Especially divers and snorkelers can easily assess the same area in regular intervals, but also trawls should be able to sample the same locations again, as well as ROVs and towed camera systems.

The existing surveys of beach sediments for micro-debris used different sampling as well as extraction methods. Therefore, a common sampling method should be developed and the different extraction methods compared, to agree on the most effective one. The development of a monitoring program would further be interesting and also challenging (e.g. sampling method, sampling interval, etc.), as an initial clean-up will be difficult to achieve. More research needs to be done on the fate of micro-debris at the beach and its interactions with the ocean.

A lack of monitoring programs also exists for visual surveys of floating marine macro-debris, as marine litter at the sea surface is always in motion. The existing surveys used quite similar methods, although different possibilities exist to determine the abundance of items per area sampled. Furthermore, the number of surveys is quite small. Thus, more surveys should assess floating marine macro-debris, optimally trying to establish monitoring programs that sample the same region in regular intervals and take wind and wave action, as well as sighting conditions into account.

Only a couple of surveys assessed benthic sediments for micro-debris. Here, a sampling strategy comparable to the sampling of beach sediment should be introduced, as the same extraction methods are already used. This would make a comparison between beach and benthic sediment feasible, which could lead to new insights into micro-debris behavior and flux.

Overall, plastic is the material that is dominating marine debris composition worldwide. The few studies concerning aquatic litter – litter in and along rivers and lakes that may eventually turn into marine litter when it reaches the sea – indicate a similar dominance of plastic. Since only little information exists on aquatic litter, more research has to be done in this context, especially on entries of litter into the oceans via rivers. To be able to fight marine debris, its sources and pathways have to be determined, on local as well as on regional scale. If the main sources for marine litter are found, they can be specifically targeted by countermeasures.

The scientific community seems to agree that to fight marine litter, first the entry of litter into the marine environment has to be stopped by preventive measurements, and then the debris already present in the marine environment can be targeted (ABU-HILAL and AL-NAJJAR, 2009b; IVAR DO SUL and COSTA, 2014). At the 5th International Marine Debris Conference, which took place in Honolulu, Hawaii, USA in March 2011, the following recommendations for the prevention of marine debris were given (NOAA and UNEP, 2011):

- accelerate policy, institutional and legislative/regulatory reforms
- increase research, monitoring and analysis
- improve public awareness, education and partnerships
- use financial/economic incentives
- build capacity for waste management
- promote industry-led initiatives to reduce waste.

RISK and POLICY ANALYSTS LIMITED (2013) on the other hand identified three major types of measures to reduce littering in general: by influencing behavior (awareness rising techniques, formal education and training, economic incentives and disincentives), by preventing littering (provision of infrastructure for litter prevention or correct disposal, design of products or packaging), and to clean up litter. They furthermore recommend consumers, the plastic industry, retailers, the tourism and recreational sector, waste management professionals and policy makers actions to prevent the creation of marine litter.

An example of international legislation and policy that is combating marine debris is Annex V of the *International Convention for the Prevention of Pollution from Ships* (MARPOL), which entered into force in 1988 and was extensively amended in 2011. It prohibits the discarding of all kinds of waste from ships into the sea (IMO, 2014). Another example is the London *Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matters 1972*, which was modernized and replaced by the *London Protocol* after 1996. The protocol also prohibits all discarding of wastes into the sea (IMO, 2012). Other examples are the *Honolulu Strategy* which was developed at the 5th International Marine Debris Conference and represents a global framework for prevention and management of marine debris (NOAA and UNEP, n.d.), as well as the *Marine Strategy Framework Directive* of the European Union which has already been presented. Examples of regional legislation are the smoking bans on some US beaches by over 100 local governments, as cigarette butts are one of the most abundant litter items on US beaches (ARIZA and LEATHERMAN, 2012). In the context of legislation and policies, the WORKING GROUP on AQUATIC LITTER (2009) demands that existing regulations should be enforced, and police, state authorities, coastal guards and magistrates should prosecute for instance illegal dumping of litter into the sea.

Besides legislation a plethora of possible actions exist to prevent marine litter. GUNN et al. (2010) report for instance of a prawn fish company that changed the color of their nets for a period of time to identify them more easily if they became derelict fishing gear and were found, which would enable them to act internally. CHO et al. (2009) present the South Korean incentives program for fishing for litter, which pays fisherman to collect and bring marine debris back to port. They are paid 5 US$/40l bag whereas the direct removal by the city would cost 48 US$/40l bag. Through the incentives program 11,000 tons of marine debris have been bought between 2003 and 2006. CHEN and LIU (2013) propose bottle compactors for fishermen, to minimize the volume of waste on board. However, the use of biodegradable plastics for goods that might end up in the ocean, which is proposed by some authors (e.g. DERRAIK et al. (2002)), does not seem to be part of the solution as ACCINELLI et al. (2012) stress. The scientists found out that biodegradable plastics only slowly degrade in the marine environment.

A variety of ideas also exists on what to do with the existing marine debris in and around the world's oceans. Some proposals divided the scientific community, as well as media and general public, while others are barely known. One project that is getting a lot of media attention is called “The Ocean Cleanup”. The inventor of the project wants to clean the oceans passively from plastic litter by using large booms that follow the wave motion and capture floating plastic debris. The captured plastic shall then be transformed into oil and be sold to reduce the costs of the project. In 2014, a feasibility study has been published proclaiming the project feasible (THE OCEAN CLEANUP, 2014). However, some scientists argue that although the project is a good idea, the feasibility study is still not answering all questions and lacks technical accuracy (MARTINI, 2014). The clothing company G STAR RAW raised public awareness for marine litter through launching a series of clothing made of Bionic Yarn, which is produced of ocean plastic (i.e. marine plastic litter) in 2014 (G-STAR RAW, 2014). *GhostNet Gear* is a project in northern Australia that uses derelict fishing-gear and other marine debris to create products, for instance hammocks and baskets (GUNN et al., 2010). CHO et al. (2005) present a Styrofoam Volume Reduction System, which reduces the volume of Styrofoam litter and makes it reusable for the plastic recycling industry, while JUNG et al. (2010) provide information on possible treatments of collected marine debris, e.g. as refuse derived fuel, thermal volume reduction, direct melting system, or incineration. Another example is the project *The Plastic Bank*. This project tries to end marine litter and poverty at the same time, by giving plastic more value. The idea is that people can collect plastic items that have been washed ashore, bring them to the plastic bank and get money in return. The plastic litter is then processed and used as feedstock material for a 3D-printer. The first plastic bank is supposed to open in the beginning of December in Peru (THE PLASTIC BANK, 2014).

6. Conclusion

Marine Litter impacts and harms environment, society and economy. It is a growing problem, as long as more debris enters the marine environment than is removed from it. However, the topic also attracts more attention; by scientists, media, politicians and the general public. This might also be because nowadays marine litter is ubiquitous – it has been found on remote island beaches, the deep sea floor, on the shores of lakes and rivers and even in Arctic ice cores.

A wide range of methods for measuring marine debris quantities and composition, of all sizes and in all stages (beach, sea surface, benthic), is available. However, they need to be standardized to ensure comparability between different studies and between different locations. For this, the scientific community has to start discussing the different options and try to find a compromise incorporating all knowledge generated so far. If this does not happen, national or supranational legislation should generate standardized protocols, as it was done by the European Union. Overall, there is a lack of comprehensive data sets, which are necessary to determine long term trends, sources and pathways of marine debris. To generate these sets, monitoring programs have to be implemented. This should be done for all sizes and stages of marine debris – macro- and micro-debris, as well as beached, floating and benthic debris. The lack of comprehensive data sets is worsened by a lack of system knowledge, for instance of freshwater habitats. As long as rivers and lakes are not assessed in the frequency marine environments are, no data can be generated on the amount of debris entering the oceans through rivers, thus inhibiting targeted countermeasures.

A plethora of countermeasures already exists. However, they have to be implemented and adopted to local circumstances. There is not a single solution that will free the world from marine litter; more likely, a combination of all available measures will be needed. Nevertheless, every single human on the planet can start today to prevent marine litter, for instance through producing less waste and disposing of the waste produced properly.

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Annex

Table of contents

I. Marine Litter

I.a. Ocean surface currents

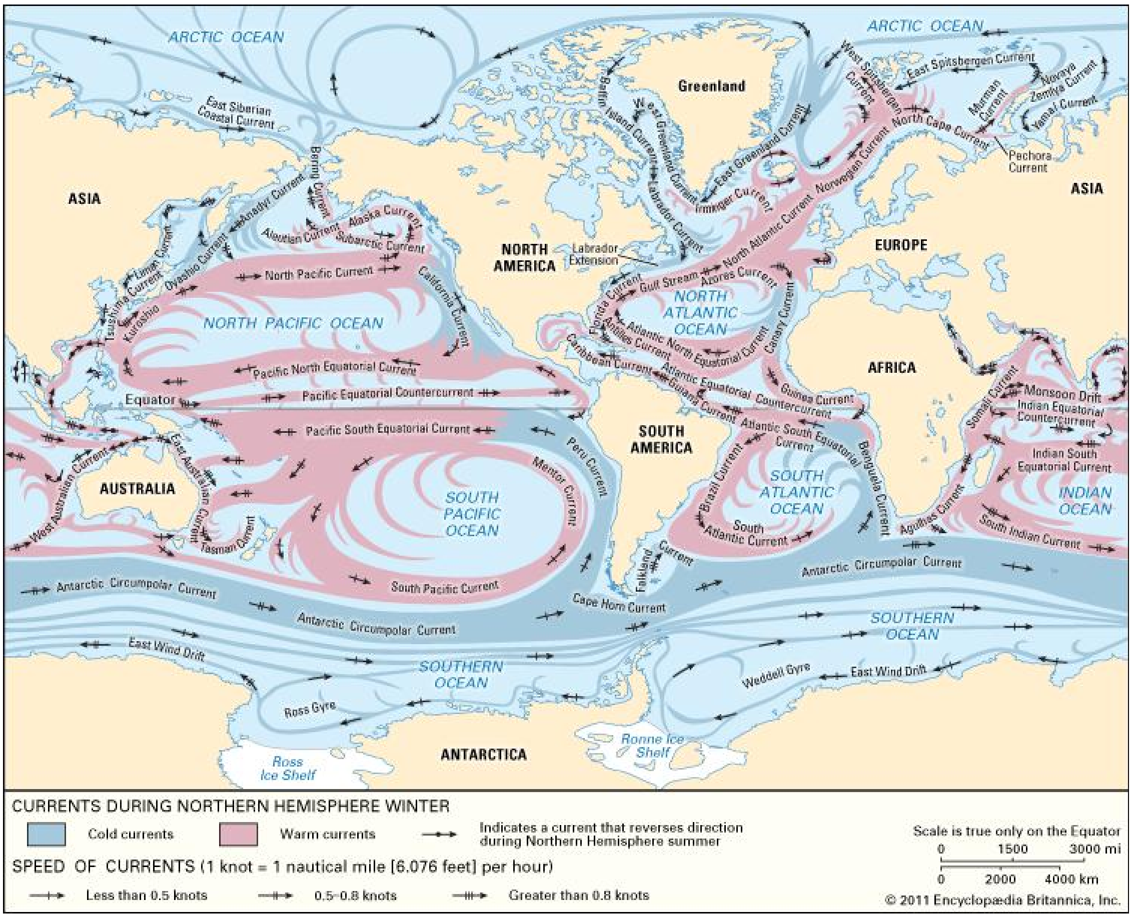

Fig. 36: Ocean surface currents

I.b. Accumulation zones modelled by Lebreton et al. (2012)

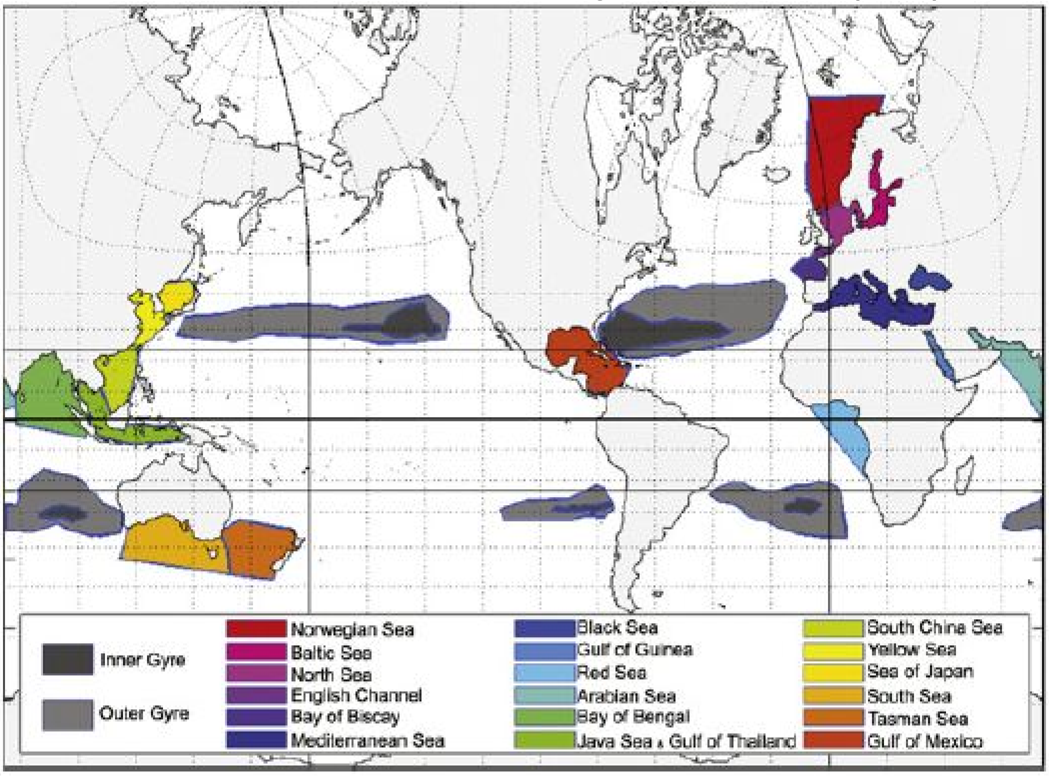

Fig. 37: Accumulation zones for floating marine debris (LEBRETON et al., 2012)

I.c. Flows of marine litter

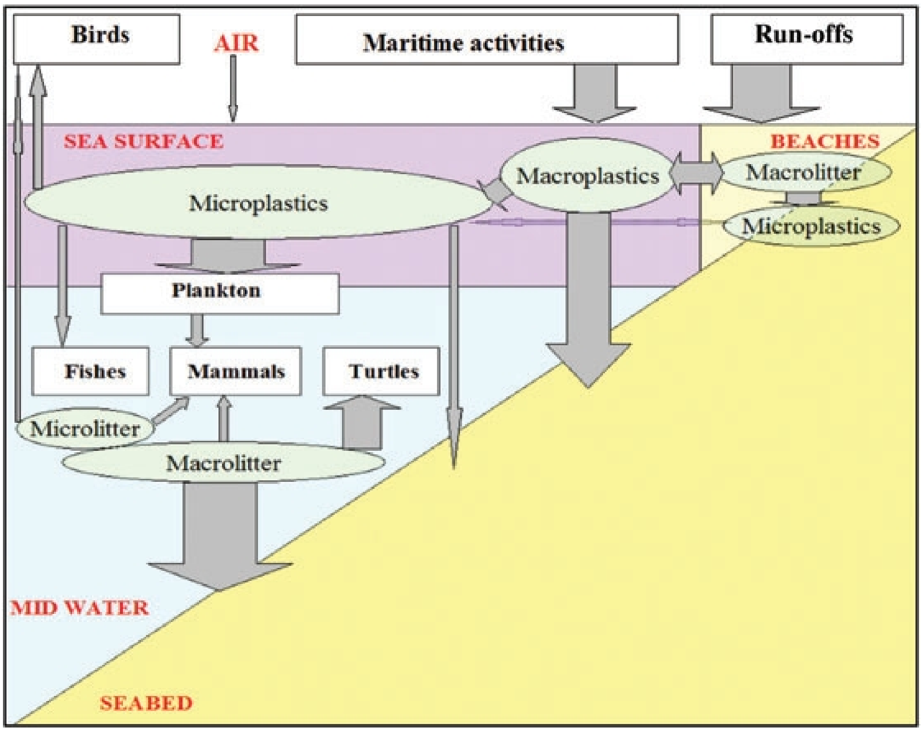

Fig. 38: Flows of marine debris (GALGANI et al., 2013)

I.d. Harm to the environment

Entanglement/Entrapment

Lost or discarded fishing-gear, as nets and lines, is mostly responsible for the entanglement of marine wildlife. Young animals seem to be particular vulnerable, especially young seals, as they are more often entangled than adult animals. They might be attracted to marine litter by their curiosity or eagerness to play (MARINE MAMMAL COMMISSION, 2001). Abandoned or lost traps and nets continue to catch target and non-target species (this process has been termed 'ghost-fishing'), many of them listed as endangered or threatened or of commercial value. For example, during the removal of derelict blue crap traps from areas in the Gulf of Mexico, Louisiana, in 2012 and 2013, 67% of all removed traps were found to keep actively ghost-fishing, resulting in the entrapment of blue craps and other marine animals, e.g. oysters and fish. Those traps that were ghost-fishing contained on average 2.4 to 3.6 crabs and resulted in the death of about eight percent of entrapped crabs (ANDERSON and ALFORD, 2014).

Animals that are getting entangled in marine debris experience limited mobility and restricted movement what might lead to exhaustion and therefore drowning, starvation, predation, suffocation and strangulation, laceration and infection and even mortality (MARINE MAMMAL COMMISSION, 2001; NOAA and UNEP, n.d.). 142 species of marine animals have been recorded to get entangled in marine debris (see table 30), especially marine mammals (29% of known species) and turtles (all known species). A review by the Secretariat of the Convention on Biological Diversity mentions even higher numbers; thereafter 192 species have been reported to get entangled in marine debris, 45% of marine mammals (52 species), 66 species of fish and 21% of seabirds (67 species) (CBD, 2012). However, as dead entangled animals may sink fast or be eaten by predators, it is hard to estimate the effect of marine litter entanglement on mortality rates and populations dynamics. Thus, current estimates could underestimate the extent of the problem (GALGANI et al., 2010). Marine debris, chiefly trawl netting and strapping bands, was for example one of the major causes for a more than 50%-decline in 15 years of a population of northern fur seals in the Pribilof Islands, Alaska (MARINE MAMMAL COMMISSION, 2001). Another example are turtle hatchlings that experience entrapment and entanglement in marine debris while hurrying from their nest to the sea. TRIESSNIG et al. (2012) found our that hatchlings do not try to avoid marine litter and about two thirds get in contact with it. In their experiment the rate of success to escape depended on the type of litter and reached from 100% success (plastic bottles) to only about 20% success for plastic canisters and nets.

Figure 39 shows ingestion and entanglement records for different taxonomic groups according to number of individuals, species and reporting papers. As can be seen, plastic is the type of debris most responsible for impacts on wildlife, as it accounts for 80% of records.

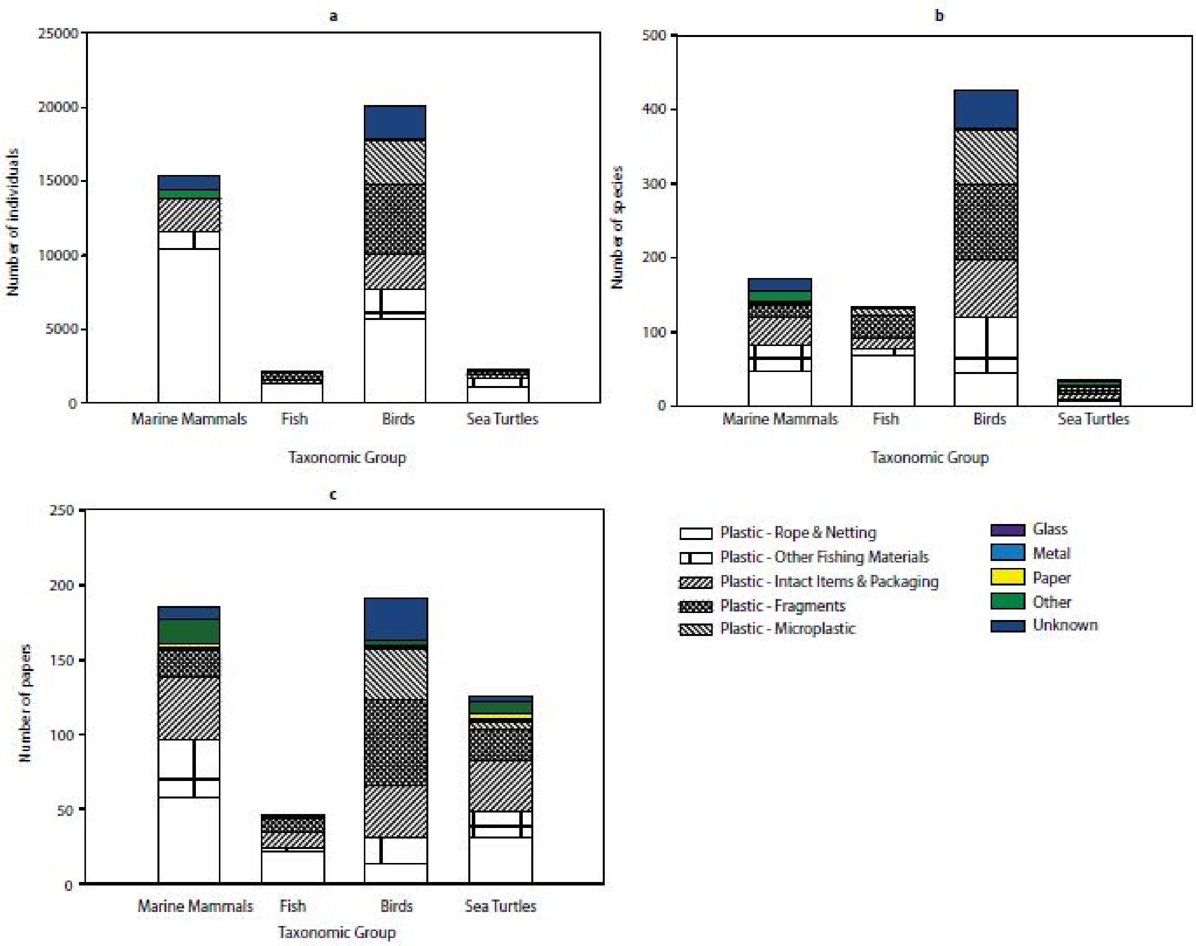

Fig. 39: Entanglement/Ingestion records of/by marine debris for number of a) individuals, b) species and c) papers/documents reporting an incident per taxonomic group. Bars show responsible debris types (CBD, 2012).

Ingestion

Studies show that many animals ingest marine debris mistaking it for food or taking it up unintentionally during feeding and normal behavior, especially small or degraded plastic items (NOAA and UNEP, n.d.), notably plastic pellets, plastic bags and plastic sheeting. These items can puncture or block digestive tracks and thus injure or kill animals. They might also cause the blockage of gastric enzyme production, a diminished feeding stimulus, nutrient dilution, reduced growth rates, lowered steroid hormone levels and delayed ovulation and reproductive failure (GALGANI et al., 2010). As table 30 documents, 202 marine animal species have been reported to ingest marine debris. Seabirds seem to be especially affected (36% of known species, according to (CBD, 2012) even 38%/119 species) as they forage on the open sea for food, as well as turtles who might mistake plastic bags for jellyfish

(MARINE MAMMAL COMMISSION, 2001; TEN BRINK et al., 2009). In some seabird populations incidence of litter ingestion can reach up to 100% (MPMMG, 2002 cit. in (TEN BRINK et al., 2009). CBD (2012) reports also higher ingestion incidence for fish with 41 affected species. They furthermore mention, that about 15% of the species affected by marine debris through entanglement and ingestion are on the IUCN Red List.

Species Group	Total No. of Species worldwide	Entanglement Records	Ingestion Records	One or Both Types of Records	IUCN CR	IUCN EN	IUCN VU
Sea Turtles	**7**	**7 (100%)**	**7 (100%)**	**7 (100%)**	**2**	**2**	**2**
Seabirds	**312**	**51 (16%)**	**111 (36%)**	**138 (44%)**			
Penguins	16	6 (38%)	1 (6%)	6 (38%)			
Grebes	19	2 (10%)	0 (0%)	2 (10%)			
Albatrosses, Petrels, and Shearwaters	99	10 (10%)	62 (63%)	63 (64%)			
Pelicans, Boobies, Gannets, Cormorants, Frigatebirds, and Tropicbirds	51	11 (22%)	8 (16%)	17 (33%)			
Shorebirds, Skuas, Gulls, Terns, and Auks	122	22 (18%)	40 (33%)	50 (41%)			
Other Birds	**-**	**5**	**0**	**5**			
Marine Mammals	**126**	**36 (29%)**	**50 (40%)**	**72 (58%)**	**2**	**4**	**10**
Baleen Whales	14	6 (43%)	8 (57%)	10 (71%)		2	
Toothed Whales	72	8 (11%)	39 (54%)	40 (56%)			4
Seals and Sea Lions	35	20 (57%)	2 (6%)	20 (57%)	2	1	2
Manatees and Dugongs	4	1 (25%)	1 (25%)	1 (25%)			4
Sea Otter	1	1 (100%)	0 (0%)	1 (100%)		1	
Fish	**-**	**34**	**33**	**60**			
Sea Snake	**-**	**1**	**0**	**1**			
Crustaceans	**-**	**8**	**0**	**8**			
Squid	**-**	**0**	**1**	**1**			
Species Total	**-**	**142**	**202**	**292**			

Tab. 30: Entanglement and ingestion records for marine animals and (where possible) animals listed on the IUCN Red List as critically endangered (CR), endangered (EN), or vulnerable (VU) (MARINE MAMMAL COMMISSION, 2001; KATSANEVAKIS, 2008; CBD, 2012; IUCN, 2013; UDYAWER et al., 2013; BAULCH and PERRY, 2014).

Fig. 40: Amount of litter ingested by a northern fulmar (right) scaled to human size (right) (GALGANI et al., 2010).

Figure 40 shows the amount of debris a human would have in his stomach if he would ingest as much debris as was found in the stomach of a northern fulmar, i.e. a seabird (compared by body weight). TEN BRINK et al. (2009) estimate that every year approximately 100.000 marine mammals die because they ingest or get entangled in marine litter.

Furthermore, smaller organism also seem to be able to ingest debris, especially microplastics. Known organisms include filter feeders, deposit feeders and detritivores (THOMPSON et al., 2009), and plastic particles have been shown to stay in mussels for over 48 days (BROWNE et al., 2008 cit. in (THOMPSON et al., 2009). Table 31 gives an overview over known species to ingest microplastics. Once ingested, plastic particles seem to easily translocate within the organism (BROWNE et al., 2007). (COLE et al., 2013) demonstrated that the majority (13 out of 15) of zooplankton that was exposed to polystyrene beads during an experiment ingested these microplastics, possibly causing a significant decrease of algal ingestion. (HOLM et al., 2013) showed that the uptake of microplastics by mussels could weaken cells.

Species	Encounter pathway
Marine algae	Adsorbs nanoplastics
Grazing microzooplankton	Size-based selectivity
Benthic deposit feeders	Some species selectively ingest plastic particles
Benthic scavengers	Ingestion via food or sediment
Mesozooplankton	Size-based selectivity
Benthic suspension feeders	Susceptible to sinking microplastics

Tab. 31: Marine organisms able to ingest microplastics (WRIGHT et al., 2013)

Chemicals and accumulation in the food chain

Although the POPs incorporated or adsorbed to the plastic items may not be readily bioavailable, many of them are known endocrine disruptors and developmental toxicants, thus posing an immediate and chronic threat to marine wildlife as well as food chains. Furthermore, these chemicals have been detected in the fatty tissue and blood of marine animals and might cause adverse effects in those organisms, e.g. by attacking their immune system. Evidence indicates that adsorbed and utilized chemicals can be incorporated into living tissues and therefore might accumulate through the food chain and pose a threat to humans (NOAA and UNEP, n.d.). TEUTEN et al.(2009) fed streaked shearwater chicks with polyethylene resin pellets containing significant amounts of PCBs and demonstrated their transfer, particularly of lower chlorinated congeners, to the chicks' tissue. (TANAKA et al., 2013) analyzed polybrominated diphenyl ethers (PBDE) in seabirds (short-tailed shearwaters) and found elevated levels of higher-brominated congeners (BDE209 and BDE183) in three of the twelve birds, while these congeners were not present in their natural prey (pelagic fish). However, the congeners were detected on plastic marine debris in the birds' stomachs, thus indicating a transfer from the debris to the bird. Microplastics are deemed to be of special concern, as they posses a relatively large surface area to volume ratio and might therefore facilitate the transport of contaminants. They are moreover so small that a wide range of organisms is able to ingest them (THOMPSON et al., 2009). WRIGHT et al. (2013) suggest that microplastics might be transferred through the pelagic food chain, for example from zooplankton to myctophid fish to sea lions or fur seals. They therefore argue that the lower trophic organisms represent vectors for microplastic transfer and their associated chemicals. SETÄLÄ et al. (2014) proved that microplastics can be passed on from mesozooplankton to the next trophic level (in their experiment pelagic mysid shrimps) through predation.

Habitat Destruction

Marine habitats can be altered, degraded and eventually destroyed through physical contact with marine litter; obstruction of sunlight, surface scoring, and abrasion are some possible effects. Especially living coral reefs are at a high risk, as they can be smothered and abraded by discarded fishing-gear or plastic bags (NOAA and UNEP, n.d.). Entangled litter may also increase siltation and turbidity and harm sea-grass beds (TEN BRINK et al., 2009). GOLDBERG (1997, cit. in (GREGORY, 2009) believes that plastic sheeting on the sea floor could interrupt the gas exchange between pore and sea water, thus causing anoxia and hypoxia. Furthermore, communities living on or in the sediment can be disturbed by marine litter (GALGANI et al., 2013).

Introducing marine litter to the benthic environment can change the characteristics of those habitats; debris may function as hard substrata and attract marine life and thus alter the wave field and current patterns causing scour and changes in sediment grain size and grain texture. This can result in organic enrichment and modification of granulometry and the attraction of predators (AKOUMIANAKI et al., 2008). KATSANEVAKIS et al. (2007) showed through a manipulative field experiment in the Aegean Sea that the introduction of litter (1,6 items/m², consisting to 75% of plastic and 25% of glass) on soft-bottom (medium to very fine sand) habitats increased both total abundance and number of species compared to a 'clean' control area. They give two primary reasons: (i) the debris was colonized by hard-substratum sessile species using it as new habitat, and (ii) it provided refuge for mobile species. Furthermore, relationships in the community changed; new inter- and intraspecific competition and new predator-prey interactions were observed. In spite of these results that seem to promote that litter is positive for soft-bottom habitats, the authors stress that long-term effects of the occurring ecological changes still have to be assessed and might be negative for native soft bottom species. Not only the bottom of the ocean is a habitat; GOLDSTEIN et al. (2012) proved that higher concentrations of particles in the North Pacific Subtropical Gyre result in an increasing number of eggs and juveniles/adults of a pelagic insect (*Halobates sericeus*), releasing it from substrate limitation for oviposition.

Moreover, not only habitats in oceans are threatened by marine litter but also habitats bordering on oceans. Beaches and coastlines receive their own share of marine litter that may endanger their ecosystems. The world's single largest type of open shoreline are sandy beaches which are in turn linked to surf zones and coastal dunes through sand storage and exchange. Impacts to either one thus may have consequences in the adjacent habitats (DEFEO et al., 2009). Most beach species only exist there and their food webs are mainly based on marine sources. DEFEO et al. (2009) identified 14 important ecosystem services that are provided by sandy shores including water filtration and purification, nursery areas for juvenile fishes and nesting sites for turtles and shorebirds. They furthermore determined stressors that might have negative impacts on sandy beach ecosystems. These stressors include the cleaning of beaches, often with heavy equipment, from marine litter and other non-aesthetic objects, thus weakening the local meiofauna communities, macroinvertebrates, and shorebirds, turtles and fish (by destroying eggs and killing hatchlings). However, also the direct pollution through marine debris may negatively impact the sandy shore and impair the physiology, survival, reproduction and behavior of species. CARSON et al. (2011) analyzed sediments from a beach known to accumulate marine debris and compared them to a 'clean' beach. They found out that the presence of small plastic particles (< 10 mm), that are mostly not subject of beach-cleanups, increases the permeability of the sediments and the thermal insulation. A change in the permeability of the beach may modify biogeochemical and trace element cycling in the sediments, as the water flowing into beaches carries oxygen and organic matter and returns nutrients to the sea. Furthermore, a higher permeability might lead to higher rates of desiccation of beach organisms. The authors further stress the possible impact of thermal insulation (slower warming, reduced subsurface temperature) to beach organisms (e.g. longer incubation periods for eggs), particularly if their sex-determination is temperature-dependent. The difference between a 100% male and 100% female offspring for Hawksbill turtles in Antigua was for example only 1.8°C (MROSOVSKY et al., 1992 cit. in (CARSON et al., 2011), and CARSON et al. (2011) showed that already 1.5% of plastic in the sediment, reduced the maximum temperature by 0.75°C.

Invasive Species

So called rafting communities[10] have always crossed the oceans using natural occurring marine debris such as wood, algae and pumice. However, the abundance and availability of marine rafts, e.g. buoyant, synthetic debris especially made of plastic, has increased through human activities (NOAA and UNEP, n.d.). It is estimated that transport opportunities have been doubled in tropical latitudes and tripled in high latitudes (BARNES, 2002 and 2003 cit. in (TEN BRINK et al., 2009). Rafting communities can be transported for long distances and harm or compete with native species (TEN BRINK et al., 2009). BARNES et al. (2009) fear that species could be transported to less biodiverse, mid-ocean islands by prevailing currents. They found out that an increasing part of debris reaching Ascension Island contained colonies, reaching 41% of debris in 2005. Once landed, invasive species can disrupt local ecosystems, especially if they are aggressive. According to MCKINNEY (1998, cit. in DERRAIK (2002)) estimates exists that global marine species diversity may decrease by as much as 58%, if world-wide biotic mixing occurs.

Furthermore, MASÓ et al. (2003) suggest that floating plastic debris favors the probability of success in microalgae dispersal and thus potentially spread Harmful Algae Bloom species[11]. They found temporary cysts of an HAB species (*Alexandrium taylori)* that were able to stick to plastic marine debris and could hence form clusters to overcome short-term unfavorable meteorological conditions.

10 entire communities of organisms including microbes encrusted and attached to objects
11 Harmful Algae Bloom (HAB), also known as red tides, produces toxins that affect and kill fish and shellfish, thus endangering (even fatally) marine mammals, birds and humans (NOAA, 2014)

II. Monitoring marine litter

II.a. Length of intervals for accumulation studies

ERIKSSON et al. (2013) compared their sampled daily accumulation rates with daily accumulation rates derived from monthly collections (dividing the monthly rate by 30) at the same beach. The mean value of the daily collections was about ten times higher (i.e. one order of magnitude greater) than the estimated value from the monthly collections. They therefore conclude that 12 days of consecutive sampling are far more useful than 12 monthly samplings. In line with this are the results generated by SMITH and MARKIC (2013). They examined the difference in calculated daily accumulation rates derived from surveys that were conducted at intervals ranging from 1 to 165 days. They showed that already the daily accumulation rate derived from surveys every three days was over 50% smaller than the mean rate calculated from daily sampling. If the daily accumulation rate was derived from monthly surveys, the loads decreased by an order of magnitude – the same as in ERIKSSON et al. (2013). The results of SMITH and MARKIC (2013) can be seen in the figure. They furthermore calculated the coefficient of variation, showing that it clearly grows with increasing interval (i.e. the larger the interval between the samples, the larger the variation of the results). As daily sampling might not be feasible for every survey, they propose to sample at a range of intervals and construct site-specific accumulation models.

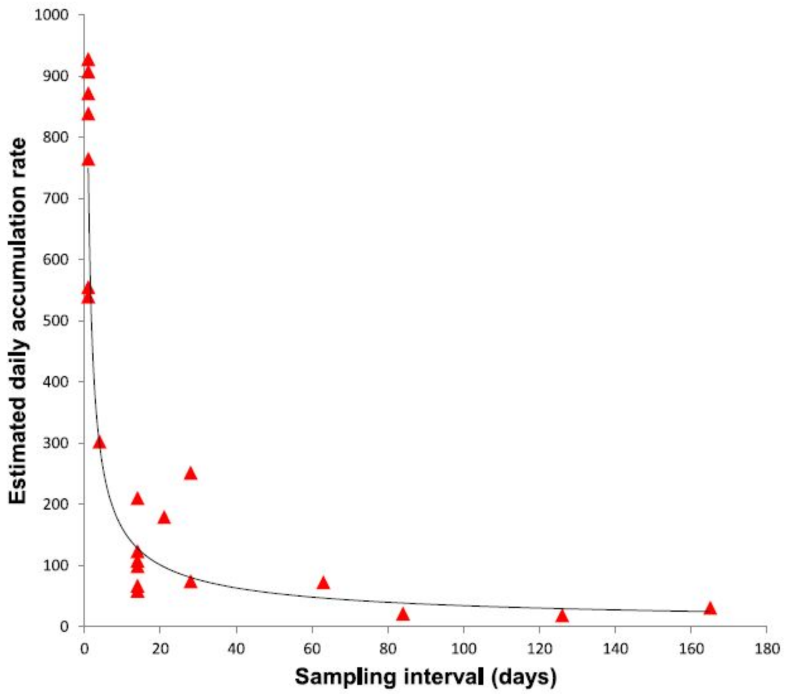

Fig. 41: Estimated daily accumulation rate depending on the sampling interval (SMITH and MARKIC, 2013).

II.b. New methods for marine litter surveys, mostly on beaches

NAKASHIMA et al. (2011) combined aerial pictures with a density-survey; they took photos with a remotely controlled digital camera attached to a helium balloon that was pulled on a cord along the beach. The pictures were converted digitally and used to calculate the area of the beach covered by (more or less white) litter by counting the pixel that were lighter than a threshold value. The day after they took the pictures they went to the beach and collected and weighed litter from ten square boxes (2x2m) that were completely covered by litter. They were thus able to determine the litter amount per square meter and on the whole beach.

KAKO et al. (2010) used webcameras to monitor marine debris at a beach. They placed two webcams at the beach, one in the middle where they supposed the highest intensity of litter, and one on the eastern side to monitor the whole beach. For one and a half years they took pictures every ninety minutes that were afterwards computed. They also counted all pixels that were lighter than a threshold value to determine the litter density and found out that there was a high fluctuation of debris at the beach at a monthly time scale or less.

KAKO et al. (2012) also used a digital camera attached to a helium balloon to assess colored marine debris floating on the open sea and stranded on a beach. They converted the pictures and used color difference to determine litter items.

VEENSTRA and CHURNSIDE (2012) give an overview over airborne sensors that can be used to detect marine litter. They recommend the combination of a multi- or hyperspectral imager with an automated detection algorithm and a lidar[12] that is aimed at targets detected by the algorithm.

Forecasting models can be used to decide when and where to clean up beaches and to detect large debris and derelict fishing gear floating in the ocean. There exist different possibilities how to combine data, and what kind of data, to develop such models. Examples are given in BALAS et al. (2004), DAMERON et al. (2007), PICHEL et al. (2007), KAKO et al. (2011) and KAKO et al. (2014).

12 A detection system which works on the principle of radar, but uses light from a laser (OXFORD UNIVERSITY PRESS, 2014).

II.c. Width of transects perpendicular to the shoreline

ARAÚJO et al. (2006) compared quantitative and qualitative results for plastic debris on transects with differing widths. All transects reached from the back of the beach (dunes) to the water edge during low tide, but varied in their widths from 2.5 – 50 m. They found out that for a quantitative analysis (i.e. the accumulated density in items/m² in their paper) a transect width of 5 m is sufficient. For a qualitative assessment (i.e. composition of plastic debris) they defined seven categories for classifying the plastic debris. Figure 42 shows the categories found plotted against different transect widths used for different beaches and beach sections (A – E). They concluded that for a qualitative assessment a transect width of at least 20 m is necessary as they were able to identify 75% of their categories within this range.

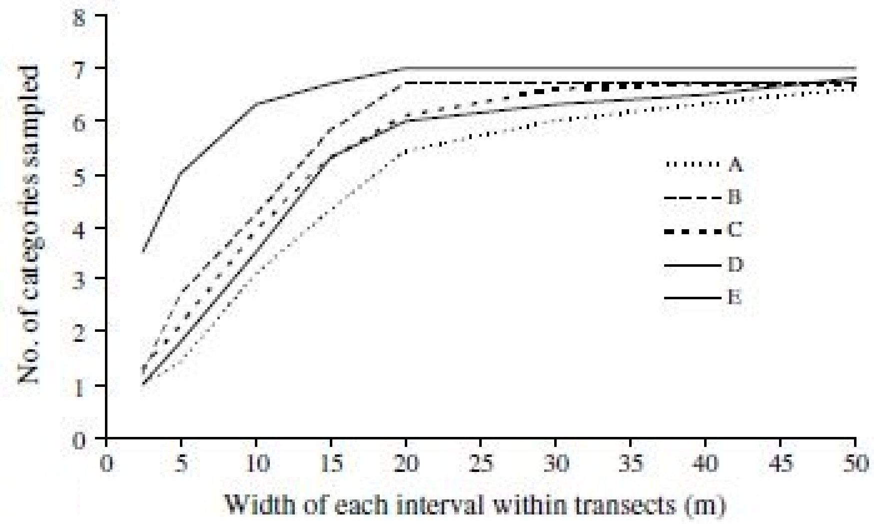

Fig. 42: Number of categories found depending on the transect width for different sites (A-E) (ARAÚJO et al., 2006).

II.d. Distribution of size and dependence with composition found by macro-debris beach surveys

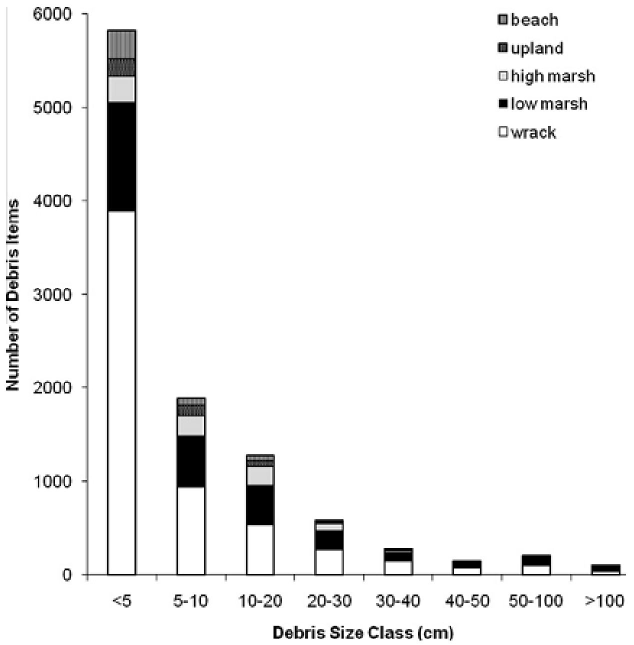

Fig. 43: Distribution of macro-debris size classes found during survey of a saltmarsh (VIEHMAN et al., 2011).

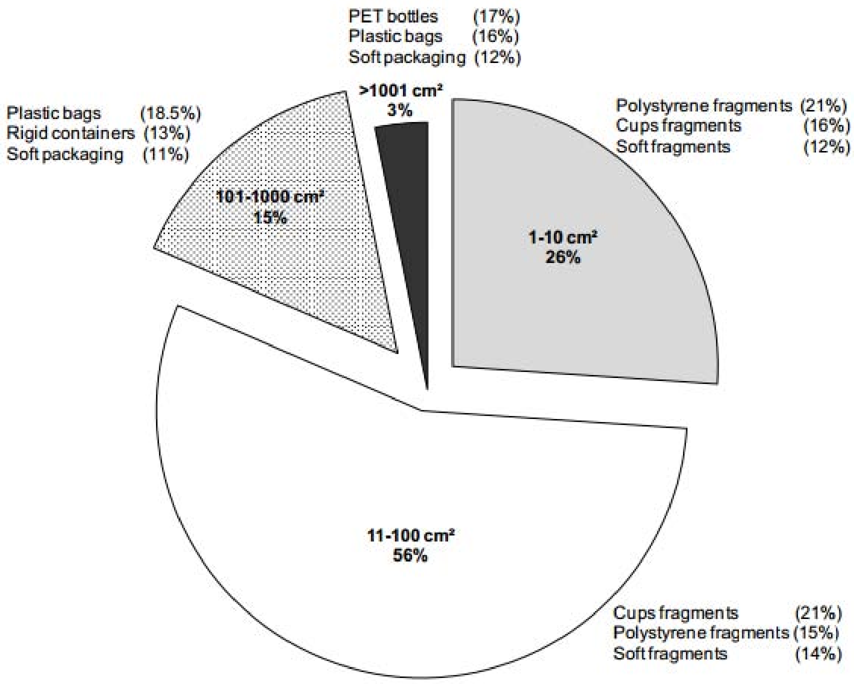

Fig. 44: roportion of different size classes of debris found during beach survey (IVAR DO SUL and COSTA, 2013).

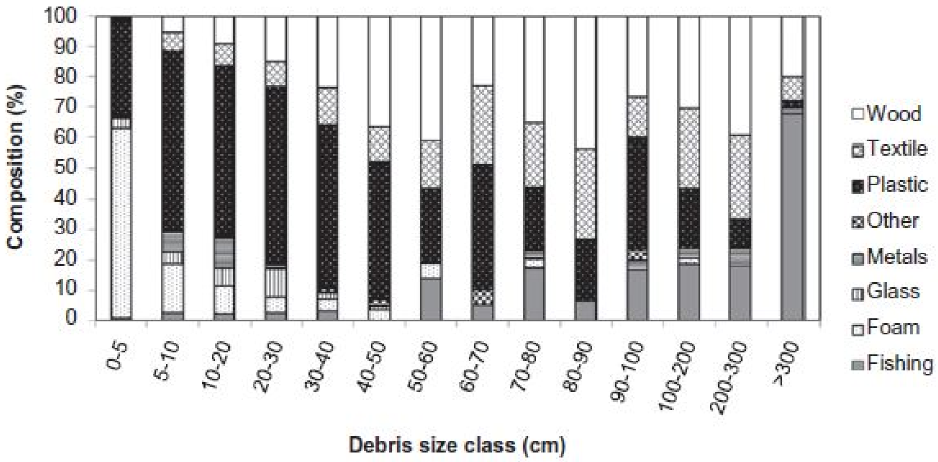

Fig. 45: Composition of beach debris for different size classes (VIEHMAN et al., 2011).

II.e. UNEP Beach Protocol – List of items

Number	Material	Code	Litter type
1	Plastic	PL01	Bottle caps & lids
2	Plastic	PL02	Bottles < 2 L
3	Plastic	PL03	Bottles, drums, jerrycans & buckets > 2 L
4	Plastic	PL04	Knives, forks, spoons, straws, stirrers, (cutlery)
5	Plastic	PL05	Drink package rings, six-pack rings, ring carriers
6	Plastic	PL06	Food containers (fast food, cups, lunch boxes & similar)
7	Plastic	PL07	Plastic bags (opaque & clear)
8	Plastic	PL08	Toys & party poppers
9	Plastic	PL09	Gloves
10	Plastic	PL10	Cigarette lighters
11	Plastic	PL11	Cigarettes, butts & filters
12	Plastic	PL12	Syringes
13	Plastic	PL13	Baskets, crates & trays
14	Plastic	PL14	Plastic buoys
15	Plastic	PL15	Mesh bags (vegetable, oyster nets & mussel bags)
16	Plastic	PL16	Sheeting (tarpaulin or other woven plastic bags, palette wrap)
17	Plastic	PL17	Fishing gear (lures, traps & pots)
18	Plastic	PL18	Monofilament line
19	Plastic	PL19	Rope
20	Plastic	PL20	Fishing net
21	Plastic	PL21	Strapping
22	Plastic	PL22	Fibreglass fragments
23	Plastic	PL23	Resin pellets
24	Plastic	PL24	Other (specify)
25	Foamed Plastic	FP01	Foam sponge
26	Foamed Plastic	FP02	Cups & food packs
27	Foamed Plastic	FP03	Foam buoys
28	Foamed Plastic	FP04	Foam (insulation & packaging)
29	Foamed Plastic	FP05	Other (specify)
30	Cloth	CL01	Clothing, shoes, hats & towels
31	Cloth	CL02	Backpacks & bags
32	Cloth	CL03	Canvas, sailcloth & sacking (hessian)
33	Cloth	CL04	Rope & string
34	Cloth	CL05	Carpet & furnishing
35	Cloth	CL06	Other cloth (including rags)
36	Glass & ceramic	GC01	Construction material (brick, cement, pipes)

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Number	Material	Code	Litter type
37	Glass & ceramic	GC02	Bottles & jars
38	Glass & ceramic	GC03	Tableware (plates & cups)
39	Glass & ceramic	GC04	Light globes/bulbs
40	Glass & ceramic	GC05	Fluorescent light tubes
41	Glass & ceramic	GC06	Glass buoys
42	Glass & ceramic	GC07	Glass or ceramic fragments
43	Glass & ceramic	GC08	Other (specify)
44	Metal	ME01	Tableware (plates, cups & cutlery)
45	Metal	ME02	Bottle caps, lids & pull tabs
46	Metal	ME03	Aluminium drink cans
47	Metal	ME04	Other cans (< 4 L)
48	Metal	ME05	Gas bottles, drums & buckets (> 4 L)
49	Metal	ME06	Foil wrappers
50	Metal	ME07	Fishing related (sinkers, lures, hooks, traps & pots)
51	Metal	ME08	Fragments
52	Metal	ME09	Wire, wire mesh & barbed wire
53	Metal	ME10	Other (specify), including appliances
54	Paper & cardboard	PC01	Paper (including newspapers & magazines)
55	Paper & cardboard	PC02	Cardboard boxes & fragments
56	Paper & cardboard	PC03	Cups, food trays, food wrappers, cigarette packs, drink containers
57	Paper & cardboard	PC04	Tubes for fireworks
58	Paper & cardboard	PC05	Other (specify)
59	Rubber	RB01	Balloons, balls & toys
60	Rubber	RB02	Footwear (flip-flops)
61	Rubber	RB03	Gloves
62	Rubber	RB04	Tyres
63	Rubber	RB05	Inner-tubes and rubber sheet
64	Rubber	RB06	Rubber bands
65	Rubber	RB07	Condoms
66	Rubber	RB08	Other (specify)
67	Wood	WD01	Corks
68	Wood	WD02	Fishing traps and pots
69	Wood	WD03	Ice-cream sticks, chip forks, chopsticks & toothpicks
70	Wood	WD04	Processed timber and pallet crates
71	Wood	WD05	Matches & fireworks
72	Wood	WD06	Other (specify)
73	Other	OT01	Paraffin or wax
74	Other	OT02	Sanitary (nappies, cotton buds, tampon applicators, toothbrushes)
75	Other	OT03	Appliances & Electronics
76	Other	OT04	Batteries (torch type)
77	Other	OT05	Other (specify)

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II.f. OSPAR Beach Protocol

		Total
	Plastic/ Polystyrene	
1	4/6-pack yokes	
2	Bags (shopping)	
3	Small plastic bags, e.g., freezer bags	
	Bottles, containers, and drums	
4	Drinks	
5	Cleaner	
6	Food incl. fast food containers	
7	Cosmetics (e.g. sun lotion, shampoo, shower gel, deodorant)	
8	Engine oil <50 cm	
9	Engine oil > 50 cm	
10	Jerry cans (square plastic containers with handle)	
11	Injection gun containers	
12	Other	
13	Crates	
14	Car parts	
15	Caps/lids	
16	Cigarette lighters	
17	Pens	
18	Combs/hair brushes	
19	Crisp/sweet packets and lolly sticks	
20	Toys & party poppers	
21	Cups	
22	Cutlery/trays/straws	
23	Fertiliser/animal feed bags	
24	Mesh vegetable bags	
25	Gloves	
26	Crab/lobster pots	
27	Octopus pots	
28	Oyster nets or mussel bags	
29	Oyster trays (round from oyster cultures)	
30	Plastic sheeting from mussel culture (Tahitians)	
31	Rope/cord/nets < 50 cm	
32	Rope/cord/nets > 50 cm	
33	Tangled nets/cord	
34	Fish boxes	
35	Fishing line (angling)	
36	Light sticks (tubes with fluid)	
37	Floats/Buoys	
38	Buckets	
39	Strapping bands	
40	Industrial packaging, plastic sheeting	

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41	Fibre glass	
42	Hard hats	
43	Shotgun cartridges	
44	Shoes/sandals	
45	Foam sponge	
46	Plastic/polystyrene pieces < 50 cm	
47	Plastic/polystyrene pieces > 50 cm	
48	Other plastic/polystyrene items *(please specify below)*	
	Rubber	
49	Balloons	
50	Boots	
51	Gloves	
52	Tyres and belts	
53	Other rubber pieces *(please specify below)*	
	Cloth	
54	Clothing	
55	Furnishing	
56	Sacking	
57	Shoes	
58	Rope/strings	
59	Other textiles *(please specify below)*	
	Paper • Cardboard	
60	Bags	
61	Cardboard	
62	Cartons/Tetrapaks	
63	Cigarette packets	
64	Cigarette butts	
65	Cups	
66	Newspapers & magazines	
67	Other paper items *(please specify below)*	
	Wood (machined)	
68	Corks	
69	Pallets	
70	Crates	
71	Crab/lobster pots	
72	Ice lolly sticks / chip forks	
73	Paint brushes	
74	Other wood < 50 cm *(please specify below)*	
75	Other wood > 50 cm *(please specify below)*	
	Metal	
76	Aerosol/Spray cans	
77	Bottle caps	
78	Drink cans	
79	Electric appliances	
80	Fishing weights	

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81	Foil wrappers	
82	Food cans	
83	Industrial scrap	
84	Oil drums (new not rusty)	
85	Oil drums (old/rusty)	
86	Paint tins	
87	Lobster/crab pots	
88	Wire, wire mesh, barbed wire	
89	Other metal pieces < 50 cm *(please specify below)*	
90	Other metal pieces > 50 cm *(please specify below)*	
	Glass	
91	Bottles	
92	Light bulbs/tubes	
93	Other glass items *(please specify below)*	
	Pottery • Ceramics	
94	Construction material e.g. tiles	
95	Octopus pots	
96	Other ceramic/pottery items *(please specify below)*	
	Sanitary waste	
97	Condoms	
98	Cotton bud sticks	
99	Sanitary towels/panty liners/backing strips	
100	Tampons and tampon applicators	
101	Toilet fresheners	
102	Other sanitary items *(please specify below)*	
	Medical waste	
103	Containers / tubes	
104	Syringes	
105	Other medical items (swabs, bandaging etc.)	
	Faeces *(don'touch!)*	
106	Human	
107	Animal	

Presence of other pollutants

Pollutant	**Size of pieces or lumps** *(estimates)*	**Frequency (estimated number per metre of strandline)**
Paraffin or wax pieces	*Size range*	
108	0–1 cm	❒
109	1–10 cm	❒
110	> 10 cm	❒
Other (please specify below)		
111		❒

Presence of plastic pellets: ❒ Yes ❒ No

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II.g. Marine Strategy Framework Directive Technical Subgroup on Marine Litter (MSFD TSG ML) - Master list

Master List of Categories of Litter Items										
TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
G1	1	PL05	4/6-pack yokes, six-pack rings	Artificial polymer materials	x	x				
G2		PL07	Bags	Artificial polymer materials	x		x	x		
G3	2	PL07	Shopping Bags incl. pieces	Artificial polymer materials		x				
G4	3	PL07	Small plastic bags, *e.g.* freezer bags incl. pieces	Artificial polymer materials		x				
G5	112		Plastic bag collective role; what remains from rip-off plastic bags	Artificial polymer materials		x				
G6	4	PL02	Bottles	Artificial polymer materials	x		x	x		
G7	4	PL02	Drink bottles <=0.5l	Artificial polymer materials		x				
G8	4	PL02	Drink bottles >0.5l	Artificial polymer materials		x				
G9	5	PL02	Cleaner bottles & containers	Artificial polymer materials	x	x				
G10	6	PL06	Food containers incl. fast food containers	Artificial polymer materials	x	x	x			
G11	7	PL02	Beach use related cosmetic bottles and containers, *e.g.* Sunblocks	Artificial polymer materials		x				
G12	7	PL02	Other cosmetics bottles & containers	Artificial polymer materials	x	x				
G13	12	PL02	Other bottles & containers (drums)	Artificial polymer materials	x	x				
G14	8		Engine oil bottles & containers <50 cm	Artificial polymer materials		x				
G15	9	PL03	Engine oil bottles & containers >50 cm	Artificial polymer materials		x				
G16	10	PL03	Jerry cans (square plastic containers with handle)	Artificial polymer materials		x				
G17	11		Injection gun containers	Artificial polymer materials		x				
G18	13	PL13	Crates and containers / baskets	Artificial polymer materials		x	x	x		
G19	14		Car parts	Artificial polymer materials		x				
G20		PL01	Plastic caps and lids	Artificial polymer materials			x			
G21	15	PL01	Plastic caps/lids drinks	Artificial polymer materials		x				
G22	15	PL01	Plastic caps/lids chemicals, detergents (non-food)	Artificial polymer materials	x	x				
G23	15	PL01	Plastic caps/lids unidentified	Artificial polymer materials		x				
G24	15	PL01	Plastic rings from bottle caps/lids	Artificial polymer materials		x				
G25			Tobacco pouches / plastic cigarette box packaging	Artificial polymer materials		x				
G26	16	PL10	Cigarette lighters	Artificial polymer materials	x	x				
G27	64	PL11	Cigarette butts and filters	Artificial polymer materials		x	x			
G28	17		Pens and pen lids	Artificial polymer materials		x				
G29	18		Combs/hair brushes/sunglasses	Artificial polymer materials		x				
G30	19		Crisps packets/sweets wrappers	Artificial polymer materials		x				

Tab. 37: MSFD TSG Master List - page 1

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
G31	19		Lolly sticks	Artificial polymer materials		x				
G32	20	PL08	Toys and party poppers	Artificial polymer materials	x	x				
G33	21	PL06	Cups and cup lids	Artificial polymer materials	x	x				
G34	22	PL04	Cutlery and trays	Artificial polymer materials		x				
G35	22	PL04	Straws and stirrers	Artificial polymer materials		x				
G36	23		Fertiliser/animal feed bags	Artificial polymer materials		x				
G37	24	PL15	Mesh vegetable bags	Artificial polymer materials		x				
G38			Cover / packaging	Artificial polymer materials				x		
G39		PL09	Gloves	Artificial polymer materials			x	x		
G40	25	PL09	Gloves (washing up)	Artificial polymer materials	x	x				
G41	113	RB03	Gloves (industrial/professional rubber gloves)	Artificial polymer materials	x	x				
G42	26	PL17	Crab/lobster pots and tops	Artificial polymer materials		x				
G43	114		Tags (fishing and industry)	Artificial polymer materials		x				
G44	27	PL17	Octopus pots	Artificial polymer materials		x				
G45	28	PL15	Mussels nets, Oyster nets	Artificial polymer materials		x				
G46	29		Oyster trays (round from oyster cultures)	Artificial polymer materials		x				
G47	30		Plastic sheeting from mussel culture (Tahitians)	Artificial polymer materials		x				
G48			Synthetic rope	Artificial polymer materials			x	x		
G49	31	PL19	Rope (diameter more than 1cm)	Artificial polymer materials	x	x				
G50	32	PL19	String and cord (diameter less than 1cm)	Artificial polymer materials	x	x				
G51		PL20	Fishing net	Artificial polymer materials			x	x		
G52		PL20	Nets and pieces of net	Artificial polymer materials	x	x				
G53	115	PL20	Nets and pieces of net < 50 cm	Artificial polymer materials		x				
G54	116	PL20	Nets and pieces of net > 50 cm	Artificial polymer materials		x				
G55		PL18	Fishing line (entangled)	Artificial polymer materials			x			
G56	33	PL20	Tangled nets/cord	Artificial polymer materials		x				
G57	34	PL17	Fish boxes - plastic	Artificial polymer materials		x		x		
G58	34	PL17	Fish boxes - expanded polystyrene	Artificial polymer materials		x		x		
G59	35	PL18	Fishing line/monofilament (angling)	Artificial polymer materials	x	x	x			
G60	36	PL17	Light sticks (tubes with fluid) incl. packaging	Artificial polymer materials		x				
G61			Other fishing related	Artificial polymer materials			x			
G62	37	PL14	Floats for fishing nets	Artificial polymer materials	x	x				
G63	37	PL14	Buoys	Artificial polymer materials		x		x		

Tab. 38: MSFD TSG Master List - page 2

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
Master List of Categories of Litter Items										
G64			Fenders	Artificial polymer materials		x				
G65	38	PL03	Buckets	Artificial polymer materials		x				
G66	39	PL21	Strapping bands	Artificial polymer materials	x	x	x			
G67	40	PL16	Sheets, industrial packaging, plastic sheeting	Artificial polymer materials		x	x	x		
G68	41	PL22	Fibre glass/fragments	Artificial polymer materials		x				
G69	42		Hard hats/Helmets	Artificial polymer materials		x				
G70	43		Shotgun cartridges	Artificial polymer materials		x				
G71	44	CL01	Shoes/sandals	Artificial polymer materials		x				
G72			Traffic cones	Artificial polymer materials		x				
G73	45	FP01	Foam sponge	Artificial polymer materials		x				
G74			Foam packaging/insulation/polyurethane	Artificial polymer materials				x		
G75	117		Plastic/polystyrene pieces 0 - 2.5 cm	Artificial polymer materials		x				
G76	46		Plastic/polystyrene pieces 2.5 cm > < 50cm	Artificial polymer materials		x				
G77	47		Plastic/polystyrene pieces > 50 cm	Artificial polymer materials		x				
G78			Plastic pieces 0 - 2.5 cm	Artificial polymer materials		x				
G79			Plastic pieces 2.5 cm > < 50cm	Artificial polymer materials		x		x		
G80			Plastic pieces > 50 cm	Artificial polymer materials		x		x		
G81			Polystyrene pieces 0 - 2.5 cm	Artificial polymer materials		x				
G82			Polystyrene pieces 2.5 cm > < 50cm	Artificial polymer materials		x		x		
G83			Polystyrene pieces > 50 cm	Artificial polymer materials		x		x		
G84			CD, CD-box	Artificial polymer materials		x				
G85			Salt packaging	Artificial polymer materials		x				
G86			Fin trees (from fins for scuba diving)	Artificial polymer materials		x				
G87			Masking tape	Artificial polymer materials		x				
G88			Telephone (incl. parts)	Artificial polymer materials		x				
G89			Plastic construction waste	Artificial polymer materials		x				
G90			Plastic flower pots	Artificial polymer materials		x				
G91			Biomass holder from sewage treatment plants	Artificial polymer materials		x				
G92			Bait containers/packaging	Artificial polymer materials		x				
G93			Cable ties	Artificial polymer materials		x	x			
G94			Table cloth	Artificial polymer materials				x		
G95	98	OT02	Cotton bud sticks	Artificial polymer materials	x	x	x			
G96	99	OT02	Sanitary towels/panty liners/backing strips	Artificial polymer materials		x	x			

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Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
G97	101	OT02	Toilet fresheners	Artificial polymer materials		x				
G98		OT02	Diapers/nappies	Artificial polymer materials		x	x			
G99	104	PL12	Syringes/needles	Artificial polymer materials		x	x			
G100	103		Medical/Pharmaceuticals containers/tubes	Artificial polymer materials		x				
G101	121		Dog faeces bag	Artificial polymer materials	x	x				
G102		RB02	Flip-flops	Artificial polymer materials		x				
G103			Plastic fragments rounded <5mm	Artificial polymer materials						x
G104			Plastic fragments subrounded <5mm	Artificial polymer materials						x
G105			Plastic fragments subangular <5mm	Artificial polymer materials						x
G106			Plastic fragments angular <5mm	Artificial polymer materials						x
G107			cylindrical pellets <5mm	Artificial polymer materials						x
G108			disks pellets <5mm	Artificial polymer materials						x
G109			flat pellets <5mm	Artificial polymer materials						x
G110			ovoid pellets <5mm	Artificial polymer materials						x
G111			spheruloids pellets <5mm	Artificial polymer materials						x
G112		PL23	Industrial pellets	Artificial polymer materials	x				x	
G113			Filament <5mm	Artificial polymer materials						x
G114			Films <5mm	Artificial polymer materials						x
G115			Foamed plastic <5mm	Artificial polymer materials						x
G116			Granules <5mm	Artificial polymer materials						x
G117			Styrofoam <5mm	Artificial polymer materials						x
G118			Small industrial spheres (<5mm)	Artificial polymer materials					x	
G119			Sheet like user plastic (>1mm)	Artificial polymer materials					x	
G120			Threadlike user plastic (>1mm)	Artificial polymer materials					x	
G121			Foamed user plastic (>1mm)	Artificial polymer materials					x	
G122			Plastic fragments (>1mm)	Artificial polymer materials					x	
G123			Polyurethane granules <5mm	Artificial polymer materials				x		
G124	48	PL24	Other plastic/polystyrene items (identifiable)	Artificial polymer materials		x	x	x		
G125	49	RB01	Balloons and balloon sticks	Rubber	x	x	x	x		
G126		RB01	Balls	Rubber		x		x		
G127	50		Rubber boots	Rubber		x	x	x		
G128	52	RB04	Tyres and belts	Rubber	x	x	x	x		
G129		RB05	Inner-tubes and rubber sheet	Rubber		x				
G130			Wheels	Rubber	x	x				
G131		RB06	Rubber bands (small, for	Rubber		x				

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Master List of Categories of Litter Items

TSG_ML General-Code	OSPAR-Code	UNEP-Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
			kitchen/household/post use)							
G132			Bobbins (fishing)	Rubber		x	x			
G133	97	RB07	Condoms (incl. packaging)	Rubber		x	x			
G134	53	RB08	Other rubber pieces	Rubber		x	x	x		
G135		CL01	Clothing (clothes, shoes)	Cloth/textile				x		
G136		CL01	Shoes	Cloth/textile			x			
G137	54	CL01	Clothing / rags (clothing, hats, towels)	Cloth/textile	x	x	x			
G138	57	CL01	Shoes and sandals (*e.g.* Leather, cloth)	Cloth/textile		x				
G139		CL02	Backpacks & bags	Cloth/textile		x				
G140	56	CL03	Sacking (hessian)	Cloth/textile		x				
G141	55	CL05	Carpet & Furnishing	Cloth/textile		x	x	x		
G142		CL04	Rope, string and nets	Cloth/textile		x	x	x		
G143		CL03	Sails, canvas	Cloth/textile		x		x		
G144	100	OT02	Tampons and tampon applicators	Cloth/textile	x	x				
G145	59	CL06	Other textiles (incl. rags)	Cloth/textile		x	x	x		
G146			Paper/Cardboard	Paper/Cardboard			x			
G147	60		Paper bags	Paper/Cardboard		x				
G148	61	PC02	Cardboard (boxes & fragments)	Paper/Cardboard	x	x	x	x		
G149		PC03	Paper packaging	Paper/Cardboard				x		
G150	118	PC03	Cartons/Tetrapack Milk	Paper/Cardboard	x	x				
G151	62	PC03	Cartons/Tetrapack (others)	Paper/Cardboard	x	x				
G152	63	PC03	Cigarette packets	Paper/Cardboard		x				
G153	65	PC03	Cups, food trays, food wrappers, drink containers	Paper/Cardboard	x	x				
G154	66	PC01	Newspapers & magazines	Paper/Cardboard		x		x		
G155		PC04	Tubes for fireworks	Paper/Cardboard		x				
G156			Paper fragments	Paper/Cardboard		x				
G157			Paper	Paper/Cardboard					x	
G158	67	PC05	Other paper items	Paper/Cardboard		x	x	x		
G159	68	WD01	Corks	Processed/worked wood		x				
G160	69	WD04	Pallets	Processed/worked wood	x	x	x	x		
G161	69	WD04	Processed timber	Processed/worked wood		x				
G162	70	WD04	Crates	Processed/worked wood	x	x		x		
G163	71	WD02	Crab/lobster pots	Processed/worked wood		x				
G164	119		Fish boxes	Processed/worked wood	x	x				
G165	72	WD03	Ice-cream sticks, chip forks, chopsticks, toothpicks	Processed/worked wood	x	x				

Tab. 41: MSFD TSG Master List - page 5

Master List of Categories of Litter Items

TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
G166	73		Paint brushes	Processed/worked wood		x				
G167		WD05	Matches & fireworks	Processed/worked wood		x				
G168			Wood boards	Processed/worked wood				x		
G169			Beams / Dunnage	Processed/worked wood				x		
G170			Wood (processed)	Processed/worked wood			x			
G171	74	WD06	Other wood < 50 cm	Processed/worked wood		x				
G172	75	WD06	Other wood > 50 cm	Processed/worked wood		x				
G173		WD06	Other (specify)	Processed/worked wood	x		x	x		
G174	76		Aerosol/Spray cans industry	Metal	x	x				
G175	78	ME03	Cans (beverage)	Metal	x	x	x	x		
G176	82	ME04	Cans (food)	Metal	x	x	x			
G177	81	ME06	Foil wrappers, aluminium foil	Metal		x				
G178	77	ME02	Bottle caps, lids & pull tabs	Metal	x	x				
G179	120		Disposable BBQ's	Metal		x				
G180	79	ME10	Appliances (refrigerators, washers, etc.)	Metal		x	x			
G181		ME01	Tableware (plates, cups & cutlery)	Metal		x				
G182	80	ME07	Fishing related (weights, sinkers, lures, hooks)	Metal		x	x	x		
G183		ME07	Fish hook remains	Metal					x	
G184	87	ME07	Lobster/crab pots	Metal	x	x				
G185			Middle size containers	Metal			x			
G186	83	ME10	Industrial scrap	Metal		x				
G187	84	ME05	Drums, *e.g.* oil	Metal		x	x			
G188		ME04	Other cans (< 4 L)	Metal		x				
G189		ME05	Gas bottles, drums & buckets (> 4 L)	Metal		x				
G190	86	ME05	Paint tins	Metal		x				
G191	88	ME09	Wire, wire mesh, barbed wire	Metal		x		x		
G192		ME05	Barrels	Metal				x		
G193			Car parts / batteries	Metal		x	x			
G194			Cables	Metal		x	x			
G195		OT04	Household Batteries	Metal		x				
G196			Large metallic objects	Metal			x			
G197			Other (metal)	Metal			x	x		
G198	89	ME10	Other metal pieces < 50 cm	Metal		x				
G199	90	ME10	Other metal pieces > 50 cm	Metal		x				
G200	91	GC02	Bottles incl. pieces	Glass/ceramics	x	x	x			
G201		GC02	Jars incl. pieces	Glass/ceramics		x	x			

Tab. 42: MSFD TSG Master List - page 6

Master List of Categories of Litter Items											
TSG_ML General- Code	OSPAR- Code	UNEP- Code	General Name	Level 1 - Materials	Core	Beach	Seafloor	Floating	Biota	Micro
G202	92	GC04	Light bulbs	Glass/ceramics	x	x				
G203		GC03	Tableware (plates & cups)	Glass/ceramics		x				
G204	94	GC01	Construction material (brick, cement, pipes)	Glass/ceramics		x				
G205	92	GC05	Fluorescent light tubes	Glass/ceramics	x	x				
G206		GC06	Glass buoys	Glass/ceramics		x				
G207	95		Octopus pots	Glass/ceramics		x				
G208		GC07	Glass or ceramic fragments >2.5cm	Glass/ceramics		x	x			
G209			Large glass objects (specify)	Glass/ceramics			x			
G210	96	GC08	Other glass items	Glass/ceramics	x	x	x			
G211	105	OT05	Other medical items (swabs, bandaging, adhesive plaster etc.)	unidentified		x				
G212			Slack / Coal						x	
G213	181, 109, 110	OT01	Paraffin/Wax	Chemicals		x			x	
G214			Oil/Tar	Chemicals					x	
G215			Food waste (galley waste)	Food waste					x	
G216			various rubbish (worked wood, metal parts)	undefined					x	
G217			Other (glass, metal, tar) <5mm	unidentified						x

Tab. 43: MSFD TSG Master List - page 7

II.h. Composition of macro-debris

Composition of beached debris

By weight

Location	Plastic [%]	EPS [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Goto Island, Japan	87	9	<1	1	<1	<3	NAKASHIMA et al. (2011)
Santos-Sao Vicente Estuary, Brazil	*26*	*0*	*6*	*0*	*0*	*68*	CORDEIRO and COSTA (2010)
South Korea	30	13	2	4	0	51	HONG et al. (2014)
Bonaire, Caribbean	31	1	3	2	0	63	DEBROT et al. (2013a)
India, Gulf of Mannar	30	11	5	2	2	50	GANESPANDIAN et al. (2011)
Port Dickson, Malaysia	24	3	0	0	24	49	KHAIRUNNISA et al. (2012)
Carteret County, USA	9	1	5	3	0	82	VIEHMAN et al. (2011)
Japan, Sea of Japan	54	3	10	5	1	27	KUSUI and NODA (2003)
Average	**36**	**5**	**7**	**4**	**5**	**49**	
Belgium, North Sea	21		2	1	0	76	VAN CAUWENBERGHE et al. (2013a)
Oman, Gulf of Oman	30		11	6	1	52	CLAEREBOUDT et al. (2004)
Lac Bay, Bonaire	39		-	-	-	61	DEBROT et al. (2013b)
Rio de la Plata estuary, Brazil	74		-	9	-	17	ACHA et al. (2003)
Anxious Bay, Australia	70		11	19	-	-	EDYVANE et al. (2004)
Tasmania	35		25	6	24	10	SLAVIN et al. (2012)
Average	**45**		**12**	**8**	**8**	43	

Tab. 44: Material composition of **beached** marine macro-debris by **weight**. Numbers in italic were corrected by the author, as the authors miscalculated the composition.

By number of items I

Location	Plastic [%]	EPS [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Jordan, Gulf of Aqaba, Red Sea	50	8	10	5	7	20	ABU-HILAL and AL-NAJJAR (2004)
Santos-Sao Vicente Estuary, Brazil	*64*	*3*	*2*	*0*	*2*	*29*	CORDEIRO and COSTA (2010)
Greater Sydney Region, Australia	74	13	1	2	5	5	CUNNINGHAM and WILSON (2003)
South Korea	50	17	8	3	2	20	HONG et al. (2014)
Lac Bay, Bonaire, Caribbean	72	16	-	-	-	12	DEBROT et al. (2013b)
Bonaire, Caribbean	70	16	1	1	0	12	DEBROT et al. (2013a)
India, Gulf of Mannar	48	16	3	3	7	23	GANESPANDIAN et al. (2011)
Goiana Estuary, Brazil	78	16	-	-	-	6	IVAR DO SUL and COSTA (2013)
Port Dickson, Malaysia	55	16	0	0	12	17	KHAIRUNNISA et al. (2012)
Taiwan	77	8	1	2	5	7	KUO and HUANG (2014)
Cijn Island, Taiwan	56	21	2	1	10	10	LIU et al. (2013)
Tern Island, Hawaii, USA	71	6	17	2	-	4	MORISHIGE et al. (2007)
Monterey Bay, USA	47	41	-	-	5	7	ROSEVELT et al. (2013)
Motupore Island, Papua New Guinea	56	34	2	1	2	5	SMITH (2012)
System of Coquimbo, Chile	76	10	1	2	2	9	THIEL et al. (2013)
Turkey, Black Sea	87	4	1	1	1	6	TOPÇU et al. (2013)
Carteret County, USA	46	32	4	4	0	14	VIEHMAN et al. (2011)
Point Pleasent Park, Canada	86	5	0	1	3	5	WALKER et al. (2006)
Japan, Sea of Japan	73	19	2	1	1	4	KUSUI and NODA (2003)
Costa do Dendê, Brazil	76	14	1	1	0	8	SANTOS et al. (2009)
Firth of Forth, Scotland	46	8	9	6	6	25	STORRIER et al. (2007)
Costa dos Coqueiros, Brazil	67	7	2	1	-	23	IVAR DO SUL et al. (2011)
Average	**65**	**15**	**4**	**2**	**4**	**12**	

Tab. 45: Material composition of **beached** marine macro-debris by **number of items**. Numbers in italic were corrected by the author, as the authors miscalculated the composition (1).

Location	Plastic [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Cassino Beach, Brazil	62	1	2	4	31	TOURINHO and FILLMANN (2011)
Salvador, Brazil	87	1	4	2	6	LEITE et al. (2014)
Volunteer Beach, Falkland Island	74	11	-	-	15	OTLEY and INGHAM (2003)
Macquerie Island, Antarctica	94	4	1	-	1	ERIKSSON et al. (2013)
Heard Island, Antarctica	95	2	0	-	3	ERIKSSON et al. (2013)
Tasmania	70	18	4	2	6	SLAVIN et al. (2012)
Charlesworth Bay, Australia	91	-	2	-	7	SMITH and MARKIC (2013)
Accra, Ghana	60	-	-	-	40	TSAGBEY et al. (2009)
Oman, Gulf of Oman	62	3	3	2	30	CLAEREBOUDT et al. (2004)
Belgium, North Sea	96	0	0	0	4	VAN CAU-WENBERGHE et al. (2013a)
Galicia, Spain	61	2	4	10	23	GAGO et al. (2014)
Average	**77**	**5**	**2**	**3**	**15**	

Tab. 46: Material composition of **beached** marine macro-debris by **number of items** (2).

Composition of floating debris

Location	Plastic [%]	EPS [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Antarctica, Southern Ocean	42		-	-	-	58	BARNES et al. (2010)
Coaster Waters Chile, Pacifc	86		-	-	-	14	THIEL et al. (2003)
Southern Chile, Pacific	47	40	-	-	-	13	HINOJOSA and THIEL (2009)
Straits of Malacca	36	63	0	0	0	1	RYAN (2013)
Bay of Bengal	82	13	2	1	0	2	RYAN (2013)
Coastal Waters SE Atlantic	98	0	0	0	2	0	RYAN (2014)
Oceanic Waters SE Atlantic	95	2	3	1	0	0	RYAN (2014)
German Bight, North Sea	65	5	-	-	-	20	THIEL et al. (2011)
Costal Waters Coquimbo, Chile, Pacific	84	5	0	0	3	8	THIEL et al. (2013)
Mediterranean Sea	82	14	-	-	-	4	SUARIA and ALIANI (2014)
British Columbia, Pacific	47	49	0	1	2	1	WILLIAMS et al. (2011)
Average	**71**	**21**	**1**	**0.5**	**1**	**5**	

Tab. 47: Material composition of **floating** marine macro-debris by **number of items**.

Composition of benthic debris

By number of items

Location	Plastic [%]	EPS [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Gulf of Aqaba, Red Sea <10m	74		8	17	0	1	ABU-HILAL and AL- NAJJAT (2009a)
Gulf of Aqaba, Red Sea	38		17	41	-	4	AL-NAJJAR and AL-SHIYAB (2011)
Greece, Mediterranean <25m	55		2	26	4	13	KATSANEVAKIS and KATSAROU (2004)
Australia, Pacific	65		2	13	-	20	SMITH et al. (2008)
New South Wales, Pacific	33		20	18	-	29	SMITH and EDGAR (2014)
Canyons off Portugal, Atlantic	67		1	6	2	24	MORDECAI et al. (2011)
Off Sanriku, Japan, Pacific	54		2	3	-	41	MIYAKE et al. (2011)
Montery Canyon, USA, Pacific	38		6	23	4	29	SCHLINING et al. (2013)
Rio de la Plata Estuary, Brazil	77		-	5	-	18	ACHA et al. (2003)
Mersin Bay, Mediterranean	73		5	10	-	12	ERYASAR et al. (2014)
Bathyal Ground, Antalya Bay, Mediterranean Sea	81		4	2	-	13	GÜVEN et al. (2013)
Western Mediterranean Sea	84		3	1	-	12	SÁNCHEZ et al. (2013)
Greek Gulfs, Mediterranean	56		11	17	-	16	KOUTSODENDRIS et al. (2008)
Malta, Mediterranean	47		12	13	-	28	MIFSUD et al. (2013)
Tokyo Bay, Pacific	54		2	36	0	8	KURIYAMA et al. (2003)
Turkey, Black Sea	90		1	2	3	4	TOPÇU and ÖZTÜRK (2010)
Belgium, North Sea	96		0	0	0	4	VAN CAUWENBERGHE et al. (2013a)
China, South China Sea	47		12	6	2	33	ZHOU et al. (2011)
Average	**63**		**6**	**13**	**2**	**17**	

Tab. 48: Material composition of **benthic** marine macro-debris by **number of items**.

By weight

Location	Plastic [%]	EPS [%]	Glass [%]	Metal [%]	Paper [%]	Other [%]	Authors
Bathyal Ground, Antalya Bay, Mediterranean Sea	28		7	3	-	62	GÜVEN et al. (2013)
Tokyo Bay, Pacific	43		12	28	0	17	KURIYAMA et al. (2003)
Average	**36**		**10**	**16**	**0**	**40**	

Tab. 49: Material composition of **benthic** marine macro-debris by **weight**.

II.i. Abundance of microplastics along a beach profile

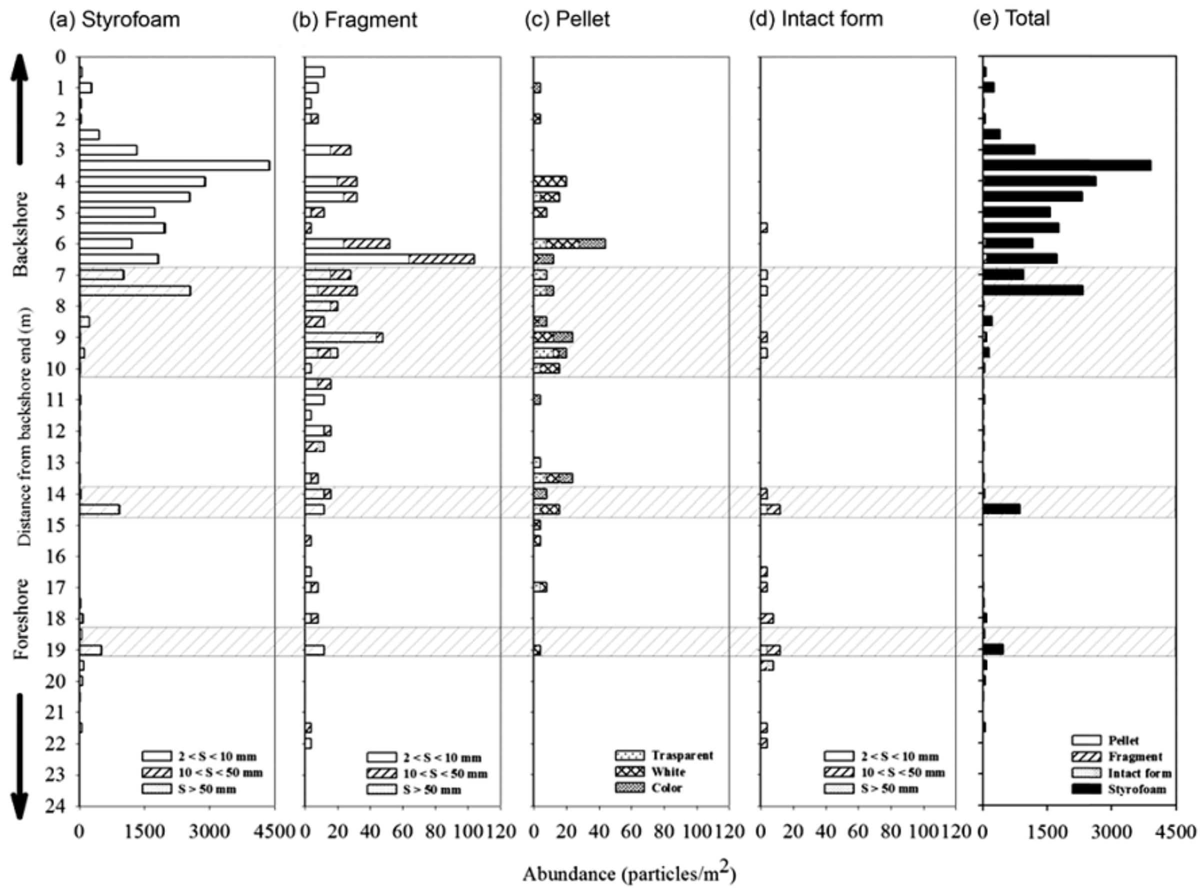

Fig. 46: Distribution of different kinds of microplastics and their total number along a transect perpendicular to the shoreline on a South Korean beach. The shaded areas indicate visible accumulations of macro-debris (strandlines) (HEO et al., 2013).

II.j. Dependence between meso- and microplastics

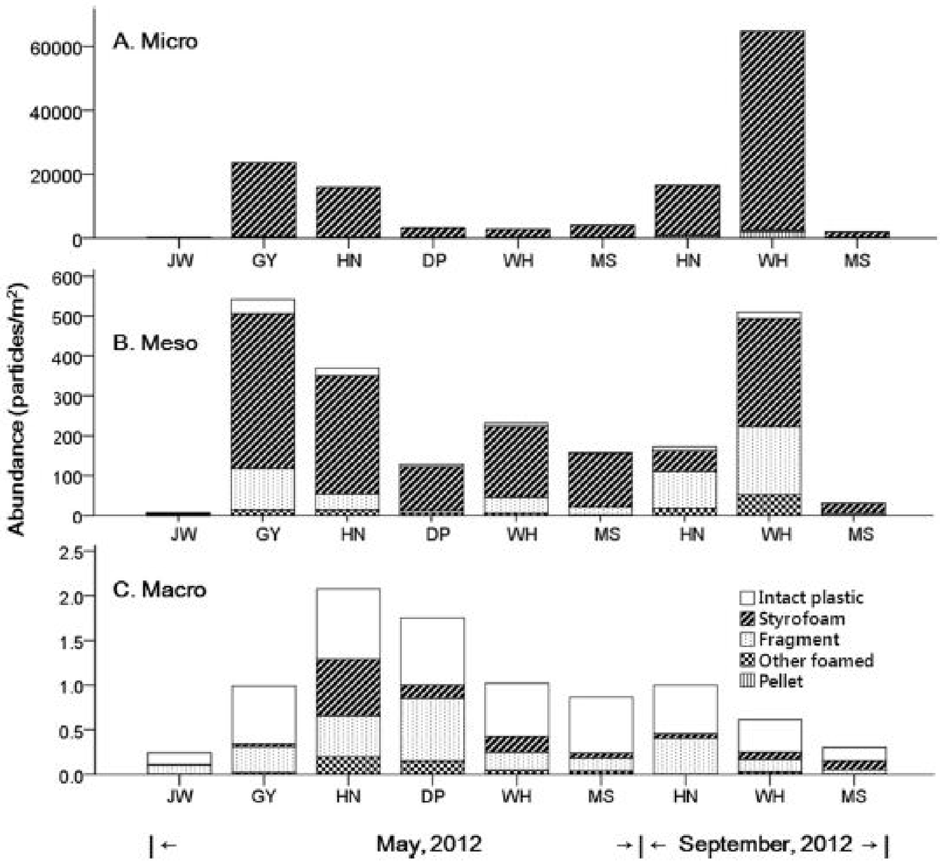

Fig. 47: Abundance of micro (1-5 mm), meso (5-25 mm) and macro litter (>25 mm) at the highest strandline of different beaches (represented by the abbreviations) and their composition (LEE et al., 2013).

II.k. Extraction methods for sediment samples

Munich Plastic Sediment Separator (MPSS) by IMHOF et al. (2012)

The MPSS is divided into three major parts, see figure 48. In the beginning only the standpipe (II) is mounted on top of the sediment container (I) and the separation liquid (they used a $ZnCl_2$ solution with a density of 1.6 – 1.7 kg/l) is poured into the MPSS to about 85% fill height and, with the help of an aerometer, adjusted to a density of 1.7 kg/l. After the rotor at the bottom is started (at 14 revolutions per minute), the sediment sample is introduced through the sediment inlet flange. The authors suggest a maximum fill height of the sediment container of four to five centimeters, which means that up to six liters of sediment can be analyzed in one run. The sediment is stirred for at least 15 minutes (can be stirred up to 12 hours) and then left to settle for one to two hours.

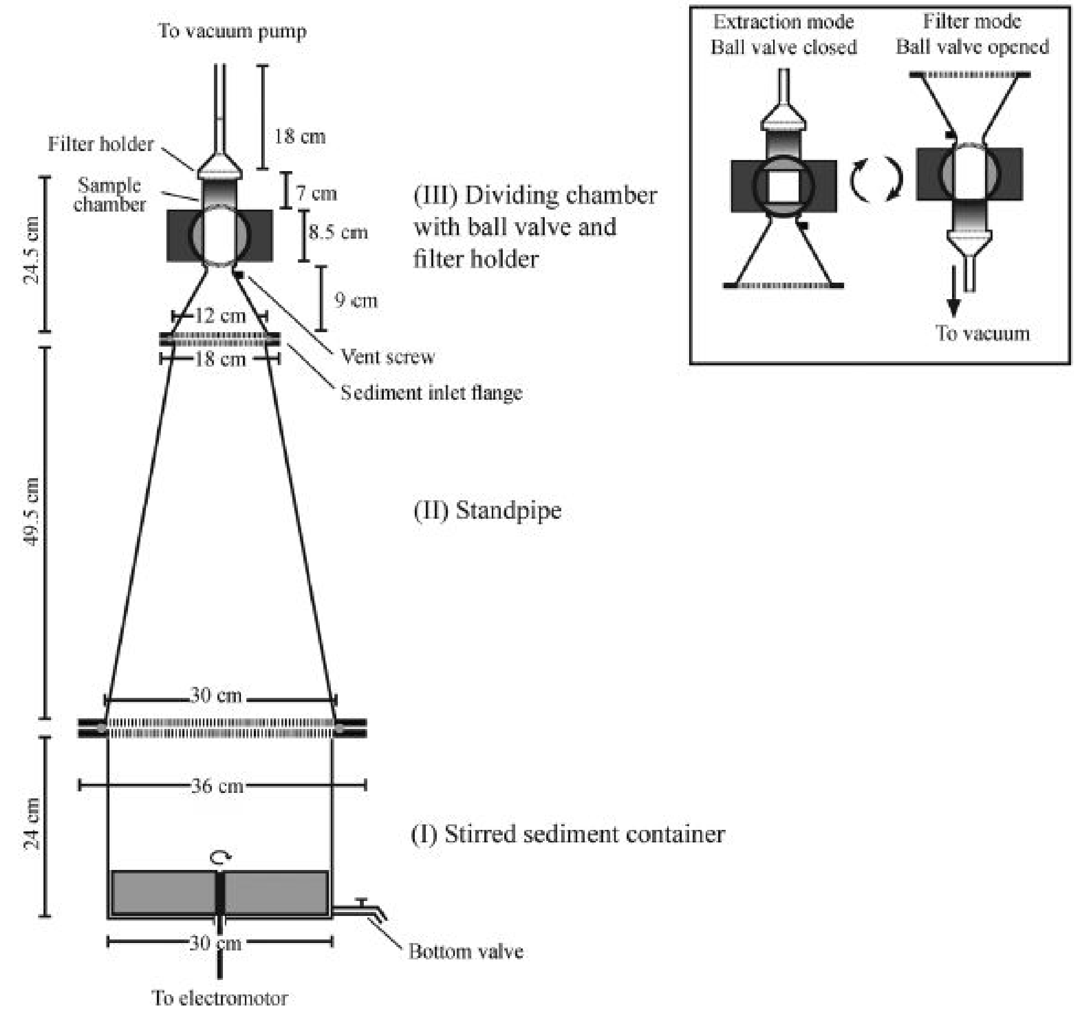

Fig. 48: Drawing of the Munich Plastic Sediment Separator and close up of the dividing chamber with ball valve (IMHOF et al., 2012).

Now the dividing chamber (III) is set up and fresh separation fluid enters through the bottom valve, thus increasing the fluid level and lifting the plastic particles through the open ball valve into the dividing chamber. When it is filled (the chamber has a volume of 68 ml), the ball valve is closed and the bottom valved opened, thus lowering the fluid level. Now the dividing chamber can be detached and by turning it upside-down and opening the ball valve and the vent screw, the included fluid can directly be vacuum filtrated through the integrated filter holder (see enlargement in figure 48). Afterwards the walls of the filter holder should be rinsed and filtered off with pure water three times, to ensure that all plastic particles are on the filter. If a lot of organic matter is present on the filters, the authors recommend the use of 30% H_2O_2 after the separation process or, if the samples are highly contaminated, the addition of sulphuric (H_2SO_4) or hydrochloric acid (HCl) to the separation fluid. In the end, the filters are dried and stored in PetriSlides™ for further analyzing. With this method the authors reached recovery rates of 100% for large microplastic particles (1-5 mm) of PC, PVC, PS, PA, PP, PE-HD and PET, and recovery rates of 95.5 ± 1.8% for small microplastic particles (<1 mm) of PC, PVC, PS, PA, PP, PE-HD and PET.

Volume reduction and density separation by CLAESSENS et al. (2013)

For the first step Claessens et al. (2013) designed a device to extract microplastics from sediment via elutriation, i.e. a process separating lighter particles from heavier ones with an upward stream of gas or liquid, that can be seen in figure 49. After a 500 ml sediment sample is washed through the 1 mm sieve on top into the column, an upward water flow is created by forcing tap water through the column from below. While the water is rising, the column is aerated from the bottom to ensure the separation of lighter from heavier particles. When the water has reached the top, it flows together with the light particles through the 38 µm sieve where the microplastics are retained. The flow rate of the water should be set at approximately 300 l/h for 15 minutes. The material retained on the sieve are then transferred in the second step to a 50 ml centrifuge tube and 40 ml of NaI solution is added. After shaking the tube manually, it is centrifuged for five minutes at 3500 g and vacuum filtered over a 5 µm membrane filter. The NaI extraction should be repeated two to three times to maximize the removal of particles from the sample. The optical analysis of the filter is then carried out with a dissecting microscope. With this method the authors reached recovery rates of 100% for PVC particles and plastic granules, and of 98% for fibers.

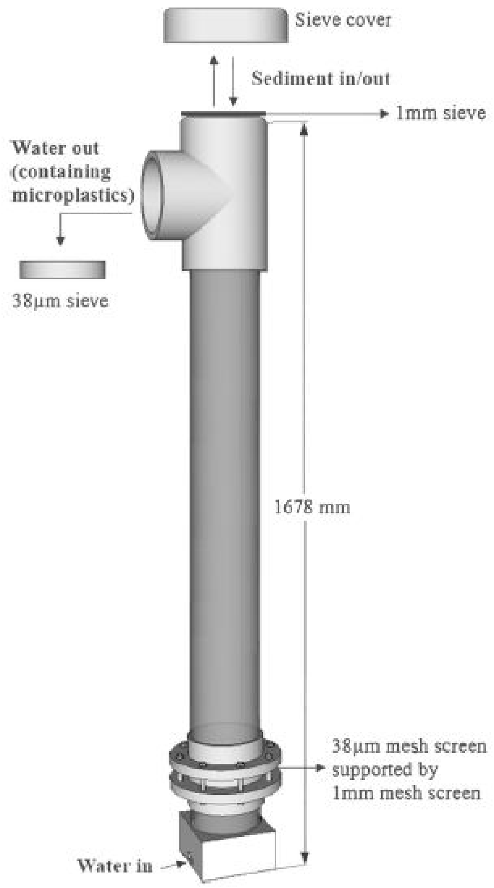

Fig. 49: Elutriation column (CLAESSENS et al., 2013).

AIO method an subsequent flotation by NUELLE et al. (2014)

Nuelle et al. (2014) created this method to increase sample volumes and thus the probability of detecting microplastics, while cutting costs at the same time. Figure 50 shows the lab set-up for the first step: a glass beaker is set inside a glass vessel and 1.5 l of saturated NaCl solution (density of 1.2 g/cm³) are pumped into it using an indoor fountain pump. After stopping the pump, moderate bubbling is generated by introducing a constant air flow (of approximately 0.1 l/s) in the NaCl solution and then the sediment sample (1 kg) is added. The pump is started again, introducing NaCl solution in the beaker with a constant flow of 2.4 l/min, thus inducing an overflow of the top layer (containing the lighter particles) of the beaker into the outer glass vessel. After 4 l of NaCl solution have been added, the air flow rate is doubled to approximately 0.2 l/s. After all NaCl solution (6.5 l) has been transferred to the beaker, everything is thoroughly rinsed. The supernatant in the outer vessel is transferred stepwise into a 25 µm stainless-steel sieve and the sieved NaCl solution stored for reuse. The sieve residue is transferred again through rinsing with distilled water in the outer glass vessel and then with NaCl solution onto a folded filter paper placed in a glass funnel. Afterwards the filter is oven-dried at 60°C for 12 hours.

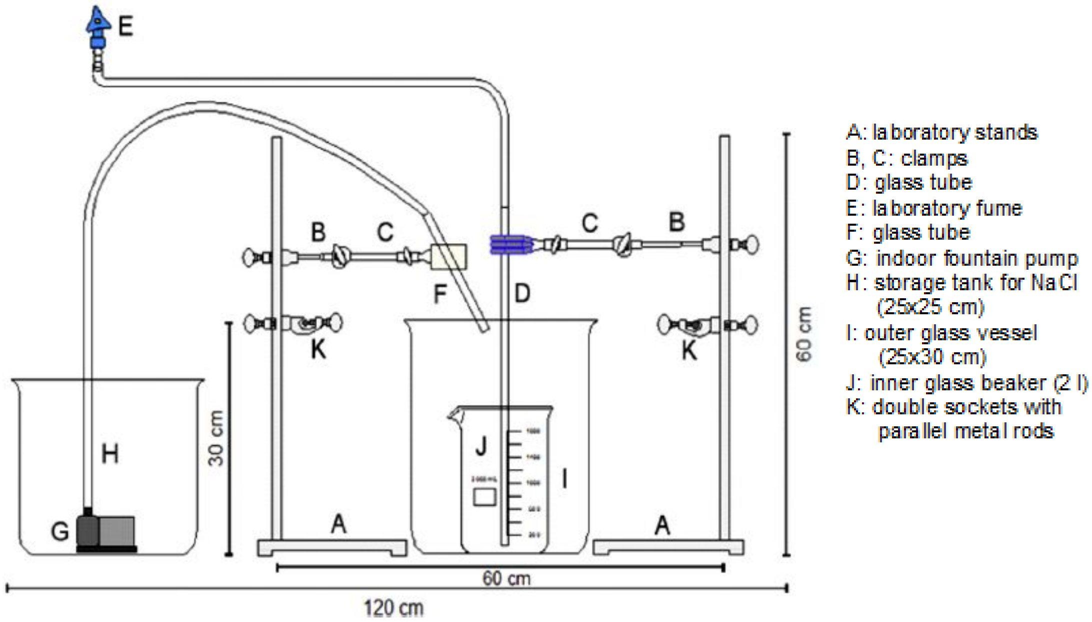

Fig. 50: Lab setup for air-induced overflow method (NUELLE et al., 2014).

For the second extraction step the sediment sample is added to a volumetric flask (which size depends on the sample size) together with a 60% (weight/weight) NaI solution (density of 1.8 g/cm³) to about three-quarters of the flask (below the angle of the flask belly). The flask is shaken by hand for about 20 seconds, filled with NaI solution to the highest calibration mark and shaken again for 10 seconds. Again, NaI solution is added up to about 1 cm below the flask's rim. The flask is left to settle for ten minutes and then the supernatant is decanted into a 200 ml glass beaker up until 1cm below the angle of the belly and shaken again for ten seconds. The procedure of repeated shaking and refilling and finally decanting is repeated five times. Afterwards the supernatant in the glass beaker is poured, and subsequently the beaker rinsed, into a vacuum filtration unit using a nitrocellulose filter (0.45 µm pore width). The filtered NaI solution is collected for reuse and the filter air-dried. If a large amount of organic matter is present on the filter, the authors recommend an oxidation step with 35% H_2O_2 solution. Therefore the filter cake is rinsed thoroughly with distilled water into the glass beaker, passed again through a new filter via vacuum filtration and washed with distilled water to remove any residues of NaI (the contact of NaI and H_2O_2 triggers an extremely exothermic reaction). Afterwards, the filter is rinsed with 20 ml H_2O_2 solution into a glass beaker and stored at room temperature for seven days. However, the authors underline that this step should only be taken, if there is a large amount of organic matter present and should thus not be included routinely in the analysis, but its use should be determined on a case-by-case basis. The optical analysis of the filter is then carried out with a stereomicroscope. With this method the authors reached mean recovery rates for PE, PP, PVC, PET, PS and PUR between 91% (PET) and 99% (PE) and 68% for EPS. They furthermore suggest to use the recovery rates as correction factors.

II.I. Densities of common polymers, minerals and floatation fluids

Polymer abbr.	Polymer name	European Demand [%]	Density [g/cm³]	Density with Additive(s) [g/cm³]	Mineral	Density [g/cm³]	Floatation fluid	Density [g/cm³]
EPS	Expanded polystyrene	3.2	0.02 – 0.03		Potassium Feldspar	2.56	Freshwater	1.0
PP	Polypropylene	18.8	0.89 – 0.91	1.04 – 1.17	Quartz	2.65	seawater	1.023
LDPE	Low-density polyethylene	17.5	0.89 – 0.94	1.18 – 1.28	Calcite	2.7	NaCl	1.2
HDPE	High-density polyethylene	12	0.94 – 0.97		Light Mica	2.80	$ZnCl_2$	1.5 – 1.7
ABS	Acrylonitrile/ butadiene/styrene	1.8	1.01 – 1.08	1.18 – 1.61	Magnetite	5.2	NaI	1.8
SAN	Styrolacrylnitrile		1.02 – 1.08					
PS	Polystyrene	4.2	1.04 – 1.08	1.2 – 1.5				
PA	Polyamide	2	1.07 – 1.08	1.13 – 1.62				
PMMA	Polymethyl-methacrylate	0.7	1.17 – 1.20					
PC	Polycarbonate	1.4	1.20					
PUR	Polyurethane	7.3	1.17 – 1.28					
PET	Polyethylene terephthalate	6.5	1.29 – 1.40					
PVC	Polyvinylchloride	10.7	1.3 – 1.58	1.3 – 1.7				

Tab. 50: Common polymers, their European demand (PLASTICS EUROPE, 2013), density and density with additives, as well as minerals and common floatation fluids and their densities (IMHOF et al. (2012), NUELLE et al. (2014)).

II.m. The effect of wind on pelagic samples

During a survey by COLLIGNON et al. (2012) for microplastics in the Mediterranean Sea, the wind conditions changed drastically in the second part of the study. At the same time, the average particle concentration was five times lower during the second part, after the strong wind event, than during the first part (the difference can be seen in figure 51). They explained these results with the changes of the wind conditions, that resulted in wind stress, thus increasing the mixing and vertical redistribution of particles in the upper layer of the water column. KUKULKA et al. (2012) support this opinion by results derived from subsurface observations and a one-dimensional theoretical model. They conclude that the total amount of plastic particles floating in the upper water column may be underestimated by up to a factor of 27 depending on the wind speed. Following this thesis, CÓZAR et al. (2014) discarded during their review of reported data all samples that were collected with wind speeds larger than five meter per second.

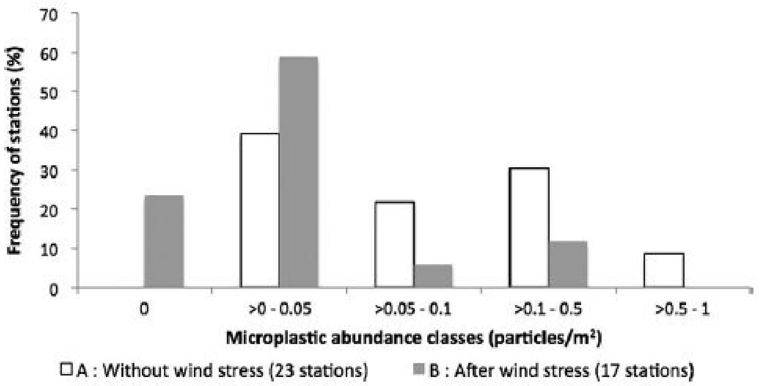

Fig. 51: Frequency of occurence of different microplastic abundance classes, before and after wind stress (COLLIGNON et al., 2012).

II.n. Enzymatic digestion by COLE et al. (2014)

Desiccated samples are placed in a 50 ml acid-washed, screw-top glass container together with 15 ml homogenizing solution (for details, see their article). They are physically homogenized with a thoroughly rinsed needle, by drawing and expelling the mixture. The samples are then incubated at 50°C for 15 minutes, 500 µg/ml of Proteinase-K are added and the samples are incubated again at 50°C for two hours. Afterwards, 5 M sodium perchlorate ($NaClO_4$) are introduced into the samples and they are shaken at room temperature for at least 20 minutes. After homogenizing the samples again with a smaller needle, they are incubated another time at 60°C for 20 minutes. In the end, the samples are vacuum filtered onto pre-weighed 50 µm mesh-filters (they mention the option of using 20 µm mesh-filters, which would slow the filtration but not yet clog the filters), flushed with purified water, covered and oven-dried at 60°C.

II.o. Recommendations by the MSFD TSG on Marine Litter

Beach macro-debris

The monitoring program for beaches debris should focus on fixed sites, chosen according to the following criteria:

- minimum length 100m,
- low to moderate slope (15-45°),
- clear access to sea (no breakwaters or jetties),
- year-round accessibility,
- ideally no other litter removing activities (if they exist, their timing must be known)
- and no impact on endangered or protected species.

Within these characteristics stratified locations including urban coasts, rural coasts and coasts close to rivers should be chosen. The representativeness of a certain number of beaches should be assessed in a pilot study. Surveys should take place at least four times a year (Mid-December to Mid-January, April, Mid-June to Mid-July and Mid-September to Mid-October) and every year at the same day at the same location. In the beginning it might be useful to survey more often to assess seasonal patterns. The TSG ML recommends to use the form provided by the OSPAR Commission (2007) to document and characterize the survey sites and to start sampling one hour after high tide. Two sections of 100 m width each should be surveyed on every beach, from the water edge (if that is not safe from the strandline) to the back of the beach, or two sections of 50 m each, if the beach is highly littered. It is furthermore advised to record at least the number of litter items, if possible also their weight and volume, although these two variables are problematic as they may differ, depending on moisture and other factors. However, the TSG ML does not establish an exact reporting unit (if per square meter or per length of coastline). Litter items larger than 2.5 cm should be collected for the survey and immediately entered in a form based on a master item list that is presented in the annex of the report (and can be seen in Annex II.g.). The employment of volunteers is encouraged but the use of a quality assurance is stressed. For this, the TSG ML recommends the quality assurance protocol of the Ocean Conservancy's National Marine Debris Monitoring Program (an US monitoring program), where a percentage of locations is independently re-surveyed right after the scheduled assessment of litter by the volunteers.

According to the MSFD TSG ML (2013), costs for monitoring programs may vary greatly, depending on the number of sites, the frequency of surveys, the price levels in the countries, whether professional surveyors are paid or volunteers are used and if the items are only counted or also weighed. It is mentioned that the Netherlands and Germany spent annually 10,000 – 20,000 € for monitoring four sites, four times a year, including data management, analysis and reporting. Table 51 illustrates the effort in hours per year for setting up and running such a monitoring program.

Task	hours/year program set-up	hours/year running the program
Contact with organisation carrying out the surveys	65	30
Setting up/Running the monitoring program	65	30
Training of surveyors (central training event)	65	40
Carrying out the surveys (4sites x 4 times/year)	-	192
Data input	-	40
Running the database	30	5
Data analysis	-	30
Reporting	8	40
(Further) development of methods	40	10
Participation on national and international workshops, working groups, etc.	50	30
Total	**323**	**447**

Tab. 51: Estimation of effort for setting up and running Beach Litter Monitoring (MSFD TECHNICAL SUBGROUP ON MARINE LITTER, 2013)

Floating macro-debris

For sighting surveys of floating debris, the MSFD TSG ML (2013) recommends to sample high and low density spots for maximum and minimum conditions. However, they should be surveyed after a minimum duration of calm sea. The lower size limit of observed items should be 2.5 cm (largest dimension). For reporting, the items should be grouped in size range classes (2.5 – 5; 5 – 10; 10 – 20; 20 – 30; 30 – 50 cm). Debris can be surveyed using ships of opportunity[13]. The average transect width should be 10 m, depending on the elevation above sea-level, the ship speed and observation conditions. The ideal location for the observer is at the bow and ideally only short transects (1h/observer) are surveyed.

Reporting unit should be items/km². Additionally, meta data incl. position and wind speed should be gathered.

The costs for sighting surveys depend mainly on the vessel and personnel used (ship of opportunity, professional or volunteer) and vary.

13 i.e. ships that travel for another purpose than the survey, e.g. other research or coast guard.

Benthic macro-debris

For the shallow sea floor (<20 m) the MSFD TSG on Marine Litter recommends the use of SKUBA divers. Items larger than 2.5 cm should be sampled in 0 – 20 m depth, skilled divers can sample in up to 40 m depth. The surveys should take place at least once a year, better every three months. For each site, two line transects, defined by a nylon line that is marked every 5 meters, shall be sampled. Items within 4 m of the line (2 m on every side) are recorded, if possible together with the line segment where they were found, their perpendicular distance from the line and their type. The length of the transect depends on the depth, the depth gradient, the turbidity, the habitat complexity and the litter density and lies between 20 and 200 m. The reporting unit should be items/m² or items/100m². Furthermore, the detection probability should be calculated. It is mentioned that DISTANCE is the standard software for this.

For sea-floor depths between 20 – 800 m the MSFD TSG on Marine Litter recommends using trawls (otter trawl) for monitoring. They stress that existing trawl surveys (which assess marine flora and fauna) should be used to gather data. Trawl surveys exist in the Atlantic Ocean, the Baltic, the Mediterranean and the Black Sea. The sampling units should be stratified according to sources (rural, urban, river) and impacted offshore areas (major current, shipping lanes, fishing, etc.). The reporting unit should be items/ha or items/km².

The MSFD TSG on Marine Litter developed a complementary protocol for the sea-floor using video cameras. They present towed video camera systems (in shallow waters) and ROVs or submersibles. For the towed camera systems they recommend using an aperture with one camera looking down to the floor and another looking forward. For ROVs/submersibles they recommend only irregular surveys using opportunistic circumstances due to the high costs. During a survey items larger than 2.5 cm should be counted along at least 0.5 km. The reporting unit should be items/ha or items/km². However, if that is not possible, items/km or items/100m can also be reported.

Intertidal sediments (Beach)

The MSFD TSG on Marine Litter recommends to take sediment samples on top of the shore (at the high tide line) of sandy shores. Different samples should be taken for particles larger and smaller than 1 mm. Particles between 20 µm – 1 mm in size should be the first to be sampled, to minimize the risk of contamination through the surveyor. For this, the top 5 cm of sand in reach at the high tide line should be collected with a metal spoon to achieve a sample of approximately 250 ml and stored in either metal or glass containers. Items between 1 – 5 mm should be sampled as an extension of the protocol to sample meso litter (5 – 25 mm) using a 1 mm sieve, preferably after the sediment has already been sieved through the 5 mm sieve (e.g. the sieves could be stacked together). To extract plastic particles from the sediment sample, the authors recommend density separation with saturated NaCl solution (1.2 g/cm^3), acknowledging that this method will not separate sediment and plastic completely. For the separation a known volume (50 ml) of sediment is added with a metal spoon to a separating funnel containing 200 ml saturated NaCl. It is then mixed for two minutes and left to settle for the same time. The supernatant is drained via buckner funnel through a 10 µm retention glass fiber filter paper (suction filtration). The filter papers are stored in sealed petri dishes and examined under a microscope. To ensure separation the procedure is repeated three times with every sediment sample. In the following, all particles smaller than 100 µm should be verified with FT-IR or Raman spectroscopy. Within the range of 100 – 500 µm at least a certain part (5-10%) should be examined. The TSG suggests, that a suitable approach would be to automatically accept any match with more than 70% similarity to the reference, individually examine 60 to 70% similarity and automatically reject any match smaller than 60% similarity.

The required reporting units are items/ml of sediment and the size of the microparticles. Additional valuable information as relative abundance of main colors and shapes, and if possible the polymer type can also be recorded.

Subtidal sediments (benthic)

The MSFD TSG on Marine Litter does not recommend a certain method to obtain sediment, as long as the approach samples relatively undisturbed surface sediment from the sea bed to a depth of approximately 5 cm. At the vessel a subsample of approximately 250 ml sediment should be acquired and stored in metal or glass container. The method for extracting microplastics is the same as for beach sediment samples.

Reporting unit should be items/ml of sediment. Furthermore the items' size, color and shape should be reported, as well as, if possible, their polymer type.

Pelagic micro-debris (floating)

Trawls

As every type of net mentioned has advantages and disadvantages, the MSFD TSG on Marine Litter does not recommend one type of net. Furthermore, the nets seem to obtain comparable results, if they have the same dimensions (preferably 333 µm mesh and 6 m length of the net for best compatibility). However, the net should always be deployed to the side of the vessel outside the wake zone, using a spinnaker book or A frame, and the vessel should maintain a steady, linear course at constant speed. During the whole trawl the net should be watched and if necessary the speed should be adjusted. The authors suggest to trawl for 30 minutes, although they mention that the duration also depends on the time of the year. Samples should be thoroughly rinsed with filtered seawater from the sides of the net and be stored in glass jars. In the lab the particles should be separated using a 5 mm-sieve. From the fraction larger than 5 mm, all recognizable debris items should be removed with forceps, rinsed with fresh water and placed in an empty vial. Afterwards, they are set aside for drying and later on the particles are typed, counted and weighed. From the fraction smaller than 5 mm, debris items should be removed using a dissecting microscope. Afterwards, the procedure is the same as for larger particles. Plastic items are size-classed and dried either for 30 minutes at 20°C in an oven or for several hours at a dry location.

Meta data that should be generated during the trawl includes record date, mesh size, aperture size, type of net, depth, distance towed, location of tow, volume of water filtered (determined best with e.g. a flowmeter), weather conditions, sea state and relevant information on plankton volume or other particulates. The authors recommend to use items/m³ as reporting unit. The particles should furthermore be separated according to size, color and shape. If possible the polymer type, their weight and their allocation to size bins should also be reported.

Sea birds

The MSFD TSG ML recommends to dissect Northern Fulmars and Shearwaters for monitoring purposes, using the procedures described above by VAN FRANEKER and MEIJBOOM (2002). The TSG ML furthermore provides information on the costs of a monitoring program using Northern Fulmars. The Netherlands hence spent about 50,000 € per year for coordinating the collection program by volunteers and groups (10,000 €), lab dissections, stomach analyses and data-analyses of 40 – 50 birds per year (20,000 €), formal report writing and production (15,000 €) and associated post reporting activities (5,000 €).

Besides using seabirds as indicator species, the authors recommend to use Loggerhead sea turtles in the Mediterranean and Black Sea. This would be a way to monitor particles in the water column and at the sea floor, as these are the areas were turtles feed. They also mention other possible indicators, for instance the stomach contents of fish or the use of plastic as building material for nests by birds. However, these protocols are not mature yet.

III. Aquatic litter

III.a. Surveys in freshwater habitats

Macro-debris

Location	Litter density [items/km^2]	Litter mass [kg/km^2]	Authors
Chicago River, USA	75,000	14,000	HOELLEIN et al. (2014)
Marine benthic macro-debris averages	87 – 3,040,000 (peak: 15,000,000)	21,000 – 860,000 (peak: 2,980,000)	see chapter 3.1.3

Tab. 52: Survey of **benthic** debris in a river. No details were given for the method used.

Micro-debris

Location	Method	Particle size	Litter density [items/m^2]	Authors
Lake Garda, Italy	5 cm, 0.04 m^2, MPSS, Raman MS	> 9 µm	108 – 1,108	IMHOF et al. (2013)
Marine beach micro-debris averages	different	>50 µm	27 – 41,000 (878,400)	see chapter 3.2.1

Tab. 53: Survey of sediment of a **lake beach**. The column Method lists depth and size of sediment sample, as well as extraction and examining methods used.

Location	Trawl details	Mesh size	Litter density [items/100 m^3]	Litter mass [mg/100 m^3]	Author(s)
Los Angeles River, USA – wet period	Manta[F] (0.15x0.9 m) for surface/center; hand nets[F] (0.46x0.25/0.43x0.22 m) for surface/edge; streambed sampler[F] (0.15x0.15 m) for mid-depth to bottom); 0.5 – 15 min	333 µm	229,800 (0 – 1,265,200)	9,330,000 (0 – 4.3x10^{7})	MOORE et al. (2011)
Los Angeles River, USA – dry period		800/ 500 µm	1,400 (0 – 4,400)	0 – 2,000,000	-“-
San Gabriel River, USA – wet period		333 µm	5,300 (0 – 15,300)	1.3x10^{7} (0 – 12.1x10^{7})	-“-
San Gabriel River, USA – dry period			100 (0 – 500)	0	-“-
Danube, below Vienna	Driftnets[F] (d: 0.5 m), stationary	500 µm	51 (0 – 14,100)	655 (0 – 69,750)	LECHNER et al. (2014)
Marine pelagic micro-debris averages	different	0.22 – 505 µm	0 – 865,500 (peak: 10,255,000)	0 – 30 (peak: 240)	see chapter 3.2.3

Tab. 54: Trawling surveys for **pelagic** micro-debris in **rivers**.

Location	Trawl details	Method	Mesh size	Litter density [items/km²]	Authors
Lake Superior, USA	Manta (0.16x0.61 m), 60 min/2 kn	seawater, SEM	333 µm	5,391 (1,277 – 12,645)	ERIKSEN et al. (2013a)
Lake Huron, USA	-"-	-"-	333 µm	2,780 (0 – 6,541)	-"-
Lake Erie, USA	-"-	-"-	333 µm	105,503 (4,686 – 466,305)	-"-
Lake Hovsgol, Mongolia	Manta (0.16x0.61 m), 60 min/3.5 kn	H_2O_2 + seawater	333 µm	20,264 (997 – 44,435)	FREE et al. (2014)
Marine pelagic micro-debris averages	different	different	200 µm – 1 mm	0 – 1,299,000 (peak: 6,530,000)	see chapter 3.2.3

Tab. 55: Trawling surveys for **pelagic** micro-debris in **lakes**. The column Method lists extraction method.

III.b. Initial categories

Nr.		Material	Subkategorie	Nicht vor Ort	Kategorie vor Ort
1	PET	Kunststoff	PET- Getränkeflaschen <= 0.5l		
2			PET- Getränkeflaschen > 0.5l		
3			PET-Sonstiges		
4	Restmüll	Kunststoff + Verbund-materialien	Kunststofftragetaschen inkl. Stücke		
5			kleine Einwegkunststofftüten (für Gemüse)	x	33 – Sonstiges aus Kunststoff
6			Lebensmittelverpackungen – Take Away		
7			Kosmetik Flaschen & Behälter		
8			Kraftstoffkanister & Motorenölflasche		
9			Getränkeverbundkartons		
10			Sonstige Kunststoffbehälter und -flaschen		
11			Kunststofffolien		
12			Tabakbeutel/Zigarettenschachtel	x	33 – Sonstiges aus Kunststoff
13			Sonstige Kunststoff- und Verbundverpackungen		
14			Autoteile		
15			Verschlüsse und Deckel	x	33 – Sonstiges aus Kunststoff
16			Zigaretten(stummel)	x	
17			Spielzeug		
18			Einweggeschirr inkl. Becher		
19			Handschuhe		
20			Verpackungsriemen/-bänder		
21			Seile und Schnüre		
22			Netze, Angelschnüre		
24			Fischbehälter		
26			Kunststoff- und Styroporstücke 0 – 2,5cm	x	Kunststoffstücke: 33 – Sonstiges aus Kunststoff; Styroporstücke: neue Kategorie
27			Kunststoff- und Styroporstücke >2,5 <10cm	x	
28			Kunststoff- und Styroporstücke >10 <50cm		
29			Kunststoff- und Styroporstücke >50cm		
30			Sanitärabfälle (Binden, Wattestäbchen, Windeln, Taschentücher,...)		
31			Medizinische Abfälle (Spritzen, Behälter)		
32			Schuhe, Rucksäche, Taschen		
33			Sonstige Kunststoff-Nichtverpackungen		
34		Gummi	Badeschlappen/Sandalen		
35			Ballons	x	XXXVIII sonst.Restmüll
36			Kondome (auch original verpackt)	x	XXXVIII sonst.Restmüll
37			Reifen		
38			Sonstiges aus Gummi		
39		Textilien	Textilien (Kleidung)		
40			Sonstige Textilien		
41		Papier und Karton	Lebensmittelverpackungen – Take Away		
42			Sonstiges Papier		
43		Holz	Korken	x	XXXVIII sonst.Restmüll <10 cm
44			Kleinteile (Eisstiel, Zahnstocher...)	x	XXXVIII sonst.Restmüll <10cm
45		Biogene Abfälle	Essensreste, etc.		
46			sonst.Restmüll > 5cm (oder 10cm?)		
47	Glas		Getränkeflaschen inkl. Stücke		
48			Sonstige Glasverpackungen		
49			Sonstige Glas-Nichtverpackungen		
50	Metall		Getränkedosen		
51			Spraydosen		
52			Ölfässer		
53			Sonstige Metallverpackungen		
54			Angelbedarf (Hacken, Gewicht...)	x	XLVII – Sonstiges aus Metall < 10cm
55			Sonstige Metall-Nichtverpackungen		
56	Baumaterial		Baurestmassen (Schäume, etc)		
57	Problemstoffe		Haushalts-Batterien		
58			Autobatterien		
59			Medikamente		
60			Sonstige Problemstoffe		
61	Sperrmüll		Elektrogeräte		
25			Eimer		
23			Bojen		
62			Holzverpackungen		
63			Sonstiges Holz <50cm		
64			Sonstiges Holz >50cm		
65			Reifen		
66			Sonstiger Sperrmüll		
67	Sonstiges / Unvorhergesehenes				

Tab. 56: Sorting categories; those that were not sorted on site are marked with an 'x' and the category they were put into during sorting at site is stated

III.c. Sorting protocol

	Material	Subkategorie	Nr. Sack	Kübel [g]	Anzahl	Masse [g]
Restmüll	Kunststoff + Verbund-materialien	Kunststofftragetaschen (ganz)	4	1680		
		Lebensmittelverpackungen – Take Away	6	520		
		Kosmetik Flaschen & Behälter	7	520		
		Kraftstoffkanister & Motorenölflasche	8	510		
		Getränkeverbundkartons	9	500		
		Sonstige Kunststoffbehälter und -flaschen >10cm	10	500		
		Kunststofffolien	11	1640		
		Sonst.Kunststoff-/Verbundverpackungen >10cm	13	530		
		Autoteile	14	520		
		Spielzeug	17	520		
		Einweggeschirr inkl. Becher	18	490		
		Handschuhe	19	520		
		Verpackungsriemen/-bänder	20	450		
		Seile und Schnüre	21	430		
		Netze, Angelschnüre	22	530		
		Fischbehälter	24	2480		
		Kunststoff- und Styroporstücke >10 <50cm	28	380		
		Kunststoff- und Styroporstücke >50cm	29	280		
		Sanitärabfälle (Binden, Watte, Taschentücher,...)	30	470		
		Medizinische Abfälle (Spritzen, Behälter)	31	280		
		Schuhe, Rucksäcke, Taschen	32	270		
		Sonstiges aus Kunststoff (v.a. <10cm)	33	280		
	Gummi	Badeschlappen/Sandalen	34	270		
		Reifen	37	270		
		Sonstiges aus Gummi >10cm	38	270		
	Textilien	Textilien (Kleidung)	39	310		
		Sonstige Textilien	40	410		
	Papier und Karton	Lebensmittelverpackungen – Take Away	41	410		
		Sonstiges Papier	42	410		
	Holz	Holzstücke <10cm	43	520		
	Biogenes	Essensreste, etc.	45	450		
Restmüll		sonst.Restmüll > 10cm	46	310		
		sonst.Restmüll < 10cm	XXXVIII	400		

Tab. 57: Sorting protocol page 1

	Material	Subkategorie	Nr.		Anzahl	Masse [g]
			Sack			
PET	Kunststoff	PET- Getränkeflaschen <= 0.5l	1	2480		
		PET- Getränkeflaschen > 0.5l	2	2300		
		PET-Sonstiges	3	2360		
			Sack			
Glas		Getränkeflaschen inkl. Stücke	47	520		
		Sonstige Glasverpackungen	48	510		
		Sonstige Glas-Nichtverpackungen	49	500		
			Sack			
Metall		Getränkedosen	50	500		
		Spraydosen	51	530		
		Ölfässer	52	2300		
		Sonstige Metallverpackungen >10cm	53	520		
		Sonstige Metall-Nichtverpackungen >10cm	55	2360		
		Sonstiges aus Metall <10cm	XLVII	410		
			Sack			
Problem-stoffe		Haushalts-Batterien	57	520		
		Autobatterien	58			
		Medikamente	59	490		
		Sonstige Problemstoffe	60	520		
Baumaterial		Baurestmassen (Schäume, etc)	56			
Sperrmüll		Elektrogeräte	61			
		Eimer	25			
		Bojen	23			
		Holzverpackungen	62			
		Sonstiges Holz <50cm	63			
		Sonstiges Holz >50cm	64			
		Reifen	65			
		Sonstiger Sperrmüll	66			
Sonstiges / Unvorhergesehenes			67			

Tab. 58: Sorting protocol page 2

III.d. Entire results

Nr.	EU	OSPAR	UNEP		Material	Subkategorie	Number Count	Weight g
1	G7	4	PL02		Kunststoff	PET- Getränkeflaschen <= 0.5l	770	37,290
2	G8	4	PL02	PET		PET- Getränkeflaschen > 0.5l	666	63,970
3						PET-Sonstiges	3	230
4	G3-5	2,3	PL07		Kunststoff + Verbund-materialien	Kunststofftragetaschen inkl. Stücke	1	10
5	G4	3	PL07			kleine Einwegkunststofftüten (für Gemüse)	0	0
6	G10	6	PL06			Lebensmittelverpackungen – Take Away inkl. Stücke	287	980
7	G11-12	7	PL02			Kosmetik Flaschen & Behälter	66	4,220
8	G14,15	8,9	PL03			Kraftstoffkanister & Motorenölflasche	7	8,500
9	G150,151	62,118	PC03			Getränkeverbundkartons	19	1,020
10	G13	12	PL02			Sonstige Kunststoffbehälter und -flaschen	121	16,250
11	G67	40	PL16			Kunststofffolien	258	4,950
12	G25					Tabakbeutel/Zigarettenschachtel	1	0
13						Sonstige Kunststoff- und Verbundverpackungen	128	1,517
14	G19	14				Autoteile	1	380
15	G20-24	15	PL01			Verschlüsse und Deckel	109	590
16	G27					Zigaretten(stummel)	0	0
17	G32	20	PL08			Spielzeug	115	6,310
18	G33-35	21-23	PL04,6			Einweggeschirr inkl. Becher	17	310
19	G39-41	25,113	PL09			Handschuhe	5	290
20	G66	39	PL21			Verpackungsriemen/-bänder	6	40
21	G48-50	31,32	PL19			Seile und Schnüre	15	1,020
22	G53-56	115/6	PL20,18			Netze, Angelschnüre	0	0
24	G57,58	34	PL17			Fischbehälter	2	400
						Styroporstücke >10 <50cm	763	16,270
						Styroporstücke >50cm	7	1,750
				Restmüll		Styroporstücke <10cm	2,896	5,230
						Kunststoffstücke 0 – 2,5cm	78	10
						Kunststoffstücke >2,5 <10cm	285	820
						Kunststoffstücke >10 <50cm	165	5,970
						Kunststoffstücke >50cm	4	660
30	G95-98	98-101	OT02			Sanitärabfälle (Binden, Wattestäbchen, Windeln, Taschentücher,...)	15	60
31	G99,100	104,103	PL12			Medizinische Abfälle (Spritzen, Behälter)	4	30
32	G71	44	CL01			Schuhe, Rucksäche, Taschen	15	3,870
33	G124	48	PL24			Sonstige Kunststoff-Nichtverpackungen	54	27,010
34	G102		RB02		Gummi	Badeschlappen/Sandalen	24	2,920
35	G125	49	RB01			Ballons	0	0
36	G133	97	RB07			Kondome (auch original verpackt)	3	10
37	G128	52	RB04			Reifen	0	0
38	G134	53	RB08			Sonstiges aus Gummi	1	470
39	G137-8	54,57	CL01		Textilien	Textilien (Kleidung)	1	350
40	G139-45	55,56,59	CL02-6			Sonstige Textilien	6	1,150
41	G153	65	PC03		Papier und Karton	Lebensmittelverpackungen – Take Away	0	0
42	G146-158	60-67	PC01-5			Sonstiges Papier	9	10
43	G159	68	WD01		Holz	Korken	0	0
44	G165	72	WD03			Kleinteile (Eisstiel, Zahnstocher...)	0	0
45					Biogene Abfälle	Essensreste, etc.	9	350
46						sonst.Restmüll	87	6,500
47	G200	91	GC02	Glas		Getränkeflaschen inkl. Stücke	178	47,040
48	G201,203		GC02,3			Sonstige Glasverpackungen	28	6,890
49	G202-210	92,95,96	GC04-08			Sonstige Glas-Nichtverpackungen	24	530
50	G175	78	ME03	Metall		Getränkedosen	66	3,560
51	G174	76				Spraydosen	117	12,920
52	G187	84	ME05			Ölfässer	1	290
53	G176-178	77,81,82	ME02,4,6			Sonstige Metallverpackungen	23	3,480
54	G182-184	80,87	ME07			Angelbedarf (Hacken, Gewicht...)	0	0
55	G185-199	83-90	ME4,5,10			Sonstige Metall-Nichtverpackungen	20	1,120
56				Baumaterial		Baurestmassen (Schäume, etc)	479	6,900
57	G195		OT04	Problemstoffe		Haushalts-Batterien	0	0
58	G193					Autobatterien	0	0
59						Medikamente	1	10
60						Sonstige Problemstoffe	3	4,120
61	G180	79	ME10	Sperrmüll		Elektrogeräte	0	0
25	G65	38	PL03			Eimer	3	2,970
23	G63	37	PL14			Bojen	4	430
62	G160-164	68-70	WD01,2,4			Holzverpackungen	0	0
63	G166-173	73,74,75	WD05,6			Sonstiges Holz <50cm	0	0
64	G166-173	73,74,75	WD05,6			Sonstiges Holz >50cm	3	2,780
65	G128	52	RB04			Reifen	3	34,540
66						Sonstiger Sperrmüll	2	17,020
67				Sonstiges / Unvorhergesehenes				
						Feuerzeuge	55	760
						Gesamt	**8,033**	**367,077**

Tab. 59: Results for all initial categories as well as new categories

III.e. Adjustment of weight (PET Drink Bottles and Tires)

In most studies for beach litter, the collected debris is weighed as it is. However, as many PET Drink bottles found along the Danube contained liquids, their weight was corrected in a second step to not overestimate the contribution of PET drinking bottles to the total weight. For this, a 0.5 l, a 0.75 l and a 1.5 l PET bottle were bought in the supermarket, emptied and weighed with a cooking balance (resolution of 0.1 g) together with the lid, as many PET bottles that were found still contained their lid. Thus, for the category “PET Drink bottles <= 0.5 l” a weight of 20 g per bottle was determined. This weight was multiplied with the number of found bottles (770). For the category “PET Drink bottles > 0.5 l” it was assumed that 60% of the found bottles had a volume of 1.5 l, and 40% of bottles 0.75 l. Thus the weight of one bottle of that category was concluded to be 32.6 g (= 0.6*37 g + 0.4*26 g), which was again multiplied with the number of bottles found (666) and rounded.

Two of the tires had rims. For them, a standard weight of 8,000 g per tire (without rim) was assumed (CONTINENTAL, 2012) and the difference to the original weight (together for both 9,130 g) was added to the category “Other metal items (non packaging)”.

III.f. SOS Mal de Seine Protocol Berville-sur-Seine 2013

OSPAR Marine Litter : Fiche de suivi (100 m)

Rivage de Berville-sur-Seine / Seine-Maritime
Organisme : S.O.S. Mal de Seine

21 bénévoles

TOTAL déchets 171kg 2,5 m3

ID	Objet	Gros	Petits & fragments	Total 2013
	Plastique / Polystyrène			
1	Serre-pack (4/6 boites)	3		**3**
2	Sac plastique (magasin, course)	0	24	**24**
3	Petit sac plastique (congélateur, etc.)	0	0	**0**
112	Souche de sacs plastiques (distribution)	2	0	**2**
4	Boisson (bouteille, fût, contenant divers)	145	20	**165**
5	Produit de nettoyage (bouteille, fût, contenant divers)	14	0	**14**
6	Alimentation (bouteille, contenant divers) incl. restauration rapide	27	1302	**1329**
7	Cosmétique (bouteille, contenant divers ; exemple : lotion, gel douche, déodorant …)	78	0	**78**
8	Huile moteur (bidon et fût < 50cm)	0	0	**0**
9	Huile moteur (bidon et fût > 50cm)	0	0	**0**
10	Jerrycan (carré, avec poignée)	7	0	**7**
11	Cartouche pour injection (silicones, etc.)	5	14	**19**
12	Autre bouteille, fût et contenant divers	0	0	**0**
13	Caisse	0	4	**4**
14	Pièces d'automobile	1	50	**51**
15	Bouchon, capsule, couvercle	0	1942	**1942**
16	Briquet	0	107	**107**
17	Crayon-feutre, stylo	0	222	**222**
18	Peigne, brosse à cheveux	2	6	**8**
19	Confiserie (emballage, bâtons, etc.)			**2859**
	Confiserie (emballage, blisters, etc.)	0	1807	1807
	batons de sucettes	0	1052	1052
20	Jouet et accessoire festif	13	213	**248**
	balles de tennis	22		
21	Gobelet plastique	13	91	**104**
22	Pailles, Couverts et plat jetables			**314**
	couverts et plats	0	15	**15**
	pailles	0	299	**299**
23	Sacs d'engrais / aliment animaux	0	3	**3**
24	Sac/filet à légumes	0	2	**2**
25	Gant (ménager)	0	0	**0**
113	Gant (professionnel)	1	0	**1**
26	Casier (pêche)	0	0	**0**
114	Marque (crustacés, poissons,...)	0	0	**0**
27	Pot à pieuvre	0	0	**0**
28	Sac/filet/poche (huîtres, moules,…) incl. lien de fermeture	0	0	**0**
29	Panier rond à huîtres (ostréiculture)	0	0	**0**
30	Tahitienne (mytiliculture)	0	0	**0**
31	Cordage (diamètre > à 1 cm)	1	2	**3**
32	Cordage (diamètre < 1 cm)	2	29	**31**

Tab. 60: Results of a survey at the Seine in 2013 - page 1 (COLLASSE, 2014)

115	Filet et morceaux de filet (< à 50 cm)	0	1	**1**
116	Filet et morceaux de filet (> 50 cm)	0	0	**0**
33	Filet et cordage emmêlés	0	1	**1**
34	Caisse à poissons	0	0	**0**
35	Bas de ligne (pêche à la ligne)	0	0	**0**
36	Bâtonnet lumineux (type cyalum)	0	1	**1**
37	Flotteur / bouée	0	0	**0**
38	Seaux	4	7	**1**
39	Feuillard / cercle d'emballage et supports	47	125	**0**
	>50cm	47		
	<50cm		125	
40	Emballage de produits industriels, film plastique	59	510	**0**
41	Résine (fibre de verre)	0	0	**0**
42	Casque de chantier	1	0	**1**
43	Cartouche et bourres (chasse)	0	98	**98**
	cartouches		4	
	bourres		94	
44	Chaussure, sandale	6	18	**24**
45	Mousse synthétique PUR	5	212	**217**
117	Morceau de plastique / polystyrène (0 - 2,5 cm)	0	0	**0**
46	Morceau de plastique / polystyrène (2,5 - 50cm)	49	6121	**6170**
47	Morceau de plastique / polystyrène (> 50 cm)	11	0	**11**
	dont un bloc de polystyrene expansé PSE de 7000 cm3 et 3kg			
48	Autre objet en plastique/polystyrène (veuillez préciser)	1400	0	**1400**
Caoutchouc				
49	Ballons (valve pastique, ruban, ficelle incl.)	0	13	**13**
50	Bottes	0	0	**0**
52	Pneus et courroies	0	0	**0**
53	morceau d'origine inconnue	0	23	**23**
Textiles				
54	Vêtement	0	0	**0**
55	Tissu d'ameublement	0	0	**0**
56	Sac en toile de jute	0	0	**0**
57	Chaussure (cuir, textile)	0	0	**0**
59	Autre textile (veuillez préciser)	0	0	**0**
Papier /	**Cartons**			
60	Sac	0	0	**0**
61	Carton	0	0	**0**
118	Boîte / Pack de lait	3	0	**3**
62	Boîte / Pack alimentaire autre	0	0	**0**
63	Paquet de cigarettes	0	0	**0**
64	Filtre de cigarette	0	0	**0**
65	Gobelet	0	0	**0**
66	Journaux, revues	0	0	**0**
67	Autre objet (veuillez préciser)	0	0	**0**

Tab. 61: Results of a survey at the Seine in 2013 - page 2 (COLLASSE, 2014)

Bois (usiné)				
68	Bouchon de liège	0	18	**18**
69	Palette	0	0	**0**
70	Cageot	0	0	**0**
71	Casier (pêche)	0	0	**0**
119	Caisse à poissons	0	0	**0**
72	Bâton de glace, pique, fourchette	0	0	**0**
73	Pinceaux (peinture)	0	0	**0**
74	Autre pièce/objet < 50 cm (planche)	1	0	**1**
75	Autre pièce/objet > 50 cm (planches)	17	0	**17**
	dont une porte de 30kg			
Métal				
76	Bombe aérosol, vaporisateur	9	1	**10**
77	Capsule & bouchons	0	15	**15**
78	Canette	0	0	**0**
120	Barbecue jetable	0	0	**0**
79	Accessoire électrique	0	0	**0**
80	Plomb/lest (pêche à la ligne)	0	0	**0**
81	Emballage aluminium	0	28	**28**
82	Boîte de conserve	0	0	**0**
83	Morceau de ferraille (industriel)	1	0	**1**
84	Fût métallique	0	0	**0**
86	Pot de peinture	2	0	**2**
87	Casier à crustacés	0	0	**0**
88	Fil de fer, grillage, fil barbelé	0	0	**0**
89	Autre pièce/objet métallique < 50 cm (veuillez préciser)	0	4	**4**
	3 boites tabac à chiquer			
	1 tube mastic			
90	Autre pièce/objet métallique > 50 cm (veuillez préciser)	0	0	**0**
Verre				
91	Bouteilles	24	0	**24**
	soit 6,7 kg			
92	ampoule / tube néon	5	0	**5**
93	Autre pièce/objet en verre (veuillez préciser)	0	**0**	**0**
Poterie / Céramique				
94	Matériaux de construction (tuiles, …)	0	0	**0**
95	Pot à pieuvres	0	0	**0**
96	Autre pièce/objet en céramique/poterie (veuillez préciser)	1	0	**1**
	1 plateau de ball-trap			
Déchets sanitaires				
97	Préservatif	0	29	**29**
98	Coton-tige	0	3488	**3488**
99	Serviette hygiénique, protège-slip	0	4	**4**
100	Tampon périodique, applicateur	0	100	**100**
101	Bloc WC	0	11	**11**
102	Autre objet sanitaire (veuillez préciser)	0	0	**0**

Tab. 62: Results of a survey at the Seine in 2013 - page 3 (COLLASSE, 2014)

Déchets médicaux				
103	Boite, bocal, tube, plaquette, unidoses			**239**
	Microlax	0	15	**15**
	Médicaments & suppositoires	0	106	**106**
	drogue / méthadone	0	1	**1**
	unidoses	0	117	**117**
104	Seringue	0	83	**83**
105	Autre objet médical (compresse, bandage, pansement, etc.) (veuillez préciser)	0	0	**0**
Fèces				
121	Sac à crotte de chien	0	0	**0**
Autres polluants				
108	Morceau de paraffine ou de cire 0 -1 cm	0	0	**0**
109	Morceau de paraffine ou de cire 1-10 cm	2	5	**7**
	5 bougies			
110	Morceau de paraffine ou de cire > 10 cm	0	0	**0**
111	Autre (veuillez préciser)	0	0	**0**

Tab. 63: Results of a survey at the Seine in 2013 - page 4 (COLLASSE, 2014)