The Mediterranean: Mare plasticum

Julien Boucher and Guillaume Billard

INTERNATIONAL UNION FOR CONSERVATION OF NATURE

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Foreword

The Mediterranean has been the birthplace of incredible civilisations – Egyptian, Hellenistic, Roman and Ottoman – but also the graveyard of plastics.

Plastic pollution is a worldwide issue; no landscape or seascape, not even the poles or remote islands, has escaped.

To effectively address the accelerated growth in plastic waste and leakage into the environment, a systems approach to addressing the problem is needed. The footprint model, and its application in the Mediterranean in this report, is an example of using a systems approach to identify actions that address the growing problem of plastic impacts on ecosystems.

This report focuses on the Mediterranean basin for several reasons. The region represents a perfect model to advance our understanding of plastic: it is a semi-enclosed sea, making the definition of plastic mass balance and the comparison between modelling approaches and field sampling approaches easier. It has also been the subject of many oceanographic field studies and thus many plastic measurements are available to help the design of local and achievable solutions. Additionally, the Mediterranean Sea is surrounded by countries with contrasting socio-economic realities and is therefore a good model to investigate and then shape a wide variety of actions related to both plastic waste and primary microplastics.

These characteristics of the Mediterranean basin make this region a perfect choice to reconcile the results of modelling with sampling approaches and provide an answer to the question, *"How much plastic is in the sea?"*

This report is part of a series of publications under IUCN's *Close the Plastic Tap* programme. The main goal of this report is to fill knowledge gaps and contribute to the triggering of preventative and remedial actions in the countries bordering the Mediterranean basin.

A first step towards action is to identify and quantify the most critical types of plastics and plastic products discharged into the Mediterranean Sea. The report refines the estimates of the quantity of plastic currently floating into the Mediterranean, based on a compilation of data from field studies and using the footprint methodology to estimate the yearly input of plastic into the Mediterranean Sea.

The report also assesses the efficiency of a series of actions currently undertaken around the Mediterranean basin and, coupled with the modelling of hotspots for priority action, recommends targeted priorities for the countries bordering the sea.

The analysis can serve as a tool to monitor the progress of current initiatives. The report also highlights some of the challenges of modelling with existing data, where disparities can result across different modelling and sampling studies. To improve both confidence in estimates of plastic waste and the application of systems-based thinking requires paying more attention to the mechanisms to collect, store and share the data required for such assessments.

The development and application of a common framework to harmonise procedures for plastics pollution monitoring is an important foundation if science-based decision-making on plastic pollution is to be mainstreamed globally.

Minna Epps
Director, IUCN Global Marine and Polar Programme

Executive summary

Widely regarded as one of the most threatened environments in the world, the Mediterranean Sea is subject to a now ubiquitous, man-made disaster: plastic pollution.

As a result of high population densities, lack of consistent waste-management schemes, and large influxes of tourists and strategic merchant navigation, this environment is under significant pressure. This study is the first of its kind to combine:

- An estimate of the plastic stock, i.e. the quantity of plastic accumulated in the sea (Part 1);
- An estimate of the plastic leakage, i.e. the yearly flux of plastic flowing into the sea (Part 2);
- An assessment of key actions that could contribute to closing the "plastic tap" in the Mediterranean Sea (Part 3).

The total plastic accumulated in the Mediterranean Sea is estimated in the order of magnitude of 1,178,000 tonnes, with a possible range from 53,500 to 3,546,700 tonnes.

There is high uncertainty in this estimate as most research undertaken so far has focused mainly on the plastic accumulated at the sea surface, which constitutes less than 0.1% of the total stock.

This study estimates a central annual plastic leakage of 229,000 tonnes (low and high leakage estimates equate to 150,000 and 610,000 tonnes year^{-1} respectively), made up of 94%

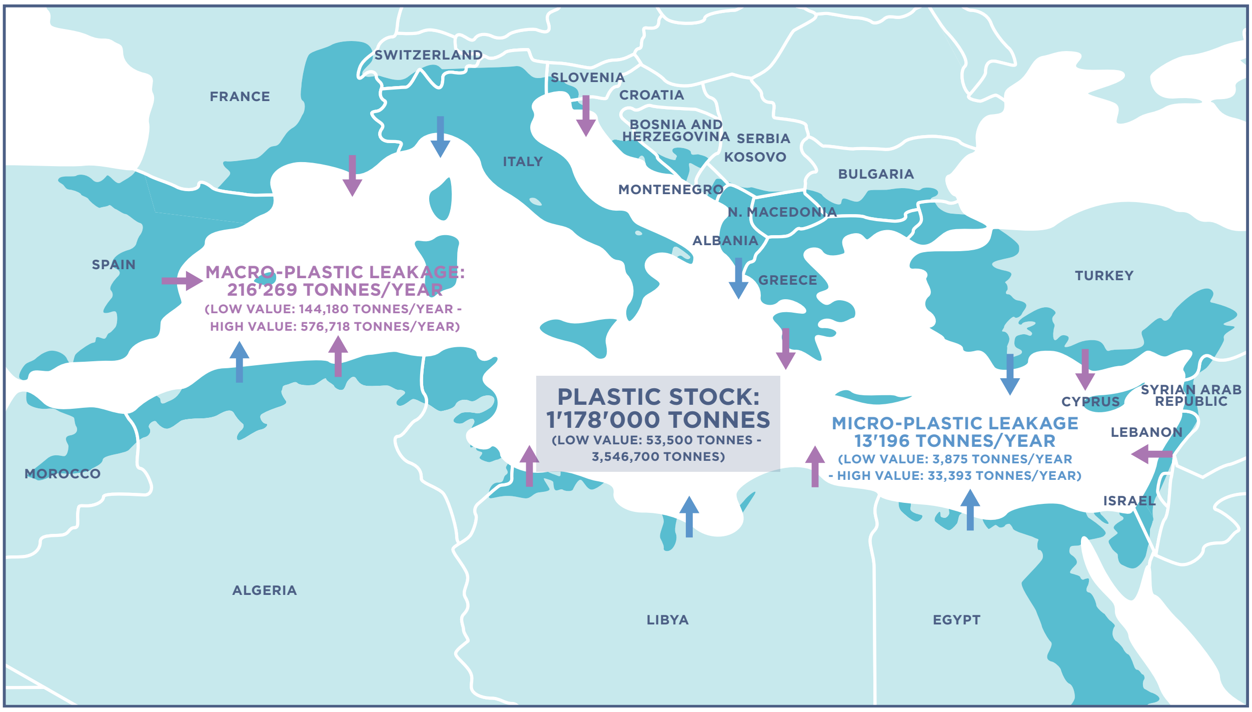


Figure 1.1: Plastic stock, reflecting 10 years of sampling across the Mediterranean Sea, compared to the annual plastic leakage from the watersheds considered in this study. The accumulated stock is in the same order of magnitude as approximately 10 years of leakage.

macroplastics and 6% microplastics. The top three countries contributing to plastic leakage are Egypt, Italy and Turkey. Plastic hotspots tend to appear near the mouth of major rivers (e.g. the Nile) and close to large cities or urban areas. These estimates are of a similar order of magnitude (though slightly smaller) as those published in a recent assessment by WWF (Dalberg Advisors, 2019).

Figure 1.2: Ubiquitous plastic pollution in the Mediterranean Sea – this is what the 21st century sailor discovers on the shoreline of any uninhabited island; here on Nisos Metopi, Greece. Photo from the author (© Julien Boucher)

1. Introduction

1.1. The Mediterranean basin

The Mediterranean Sea, originally the "*Mare Medi Terra*", literally meaning the sea surrounded by land, is is exposed to many human activities, counting approximately half a billion inhabitants when including hydrological basins (449,074,896 inhabitants considered in the present report). It is one of the busiest and most strategic navigational corridors in the world, as well as a very attractive destination with more than 342 million tourists in 2015 (UNWTO, 2015). For the purpose of this study, we have considered 33 countries (Figure 2.1), either coastal or part of a hydrological basin flowing into the Mediterranean Sea. Due to high population densities on the coast and around the rivers draining into the sea, the Mediterranean area is considered to be the most affected environment in the world in terms of plastic pollution (Cózar et al., 2015).

A semi-enclosed sea with limited exchanges with the Atlantic Ocean (Tanhua et al., 2013), it is prone to plastic accumulation (Ramirez-Llodra et al., 2013). It is composed of two basins of approximately equal size (the western basin bordered by Spain, France, Italy, Tunisia, Algeria and Morocco, and including the Adriatic Sea, and the eastern basin bordered by Greece, Turkey, the Levant, Egypt and Libya).

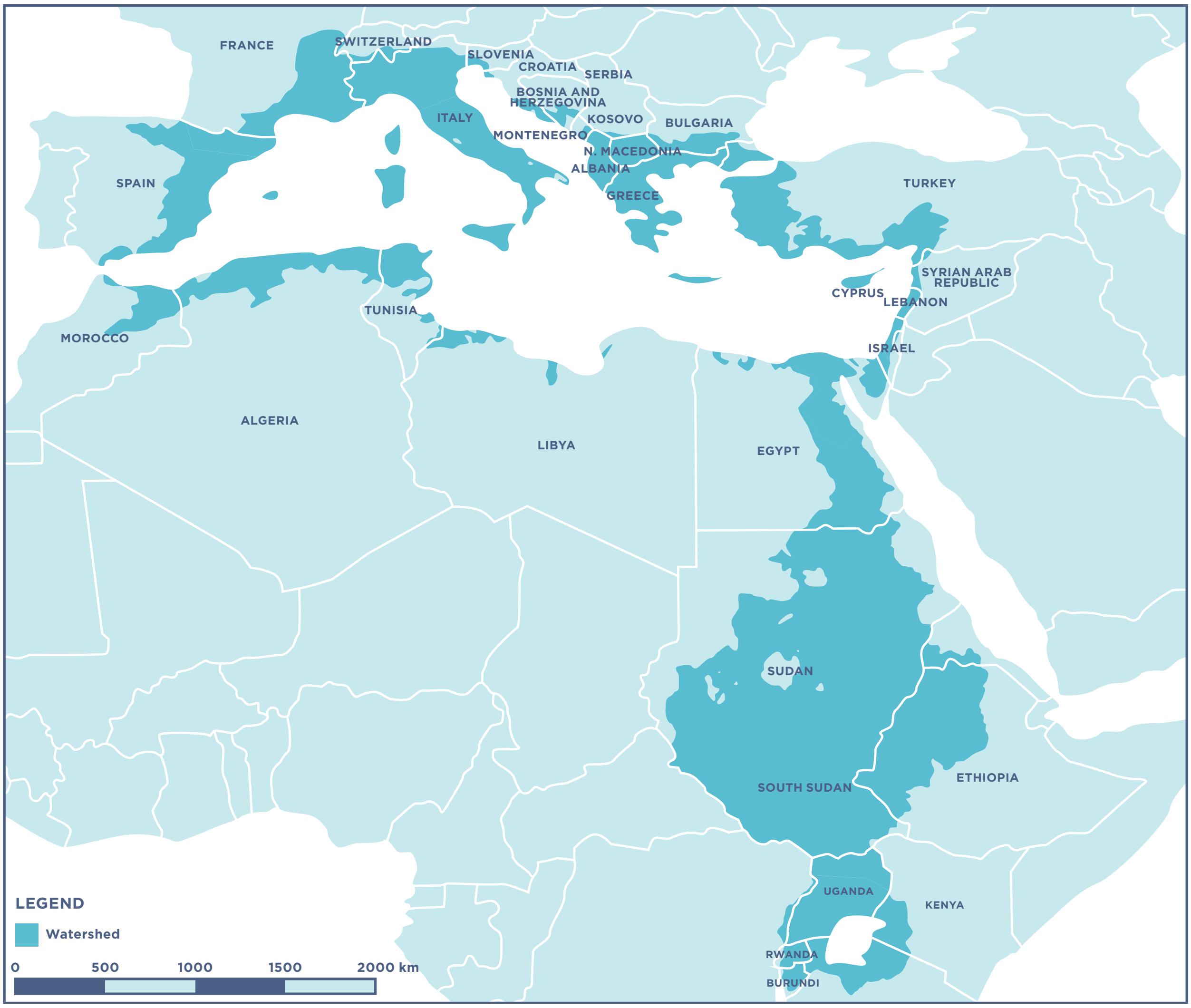


Figure 2.1: Map of the study area: the Mediterranean basin, including countries and watersheds of interest for the leakage modelling (Part 2 of the present report). Watersheds are shown in dark blue.

1.2. Study area

Fact Sheet: Mediterranean Sea

Geographic context:

- Sea area : 2,510,000 km^2
- Deepest point: -5,267 m
- Coastline considered in this study: 28,000 km
- Submarine canyons: 817
- Coastal countries: 20
- Non-coastal countries: 13
- Watersheds considered: 1,693
- Population considered: 449,074,896

Economic context:

- 10% of global shipping activity by vessel deadweight tonnes (DWT)
- Annual plastic production in the region: 38 million tonnes

1.3. Current state of knowledge

Many studies and reports have focused on the source and fate of marine plastics in the Mediterranean Sea, a subject of growing concern worldwide. Figure 2.2, showing the scientific articles and reports considered in the present study, highlights the growth in this domain.

However, despite this proliferation of literature, precise quantities leaking into the sea and accumulated within different compartments (e.g. sea surface, seafloor) are still debated, alongside the most efficient actions to mitigate this plastic pollution. As shown in Figure 2.3, both estimates of floating plastics (800–23,000 tonnes) and annual leakage (13,000–745,000 tonnes) fluctuate widely.

While other studies work towards refining and standardising both plastic leakage assessment (PLP 2019; Boucher, Kounina, et al., 2019; Boucher, Billard, et al., 2019) and field measurement protocols (GESAMP 2019), this report uses state-of-the-art research to fill the knowledge gaps and determine how much plastic has accumulated and is leaking into the Mediterranean Sea.

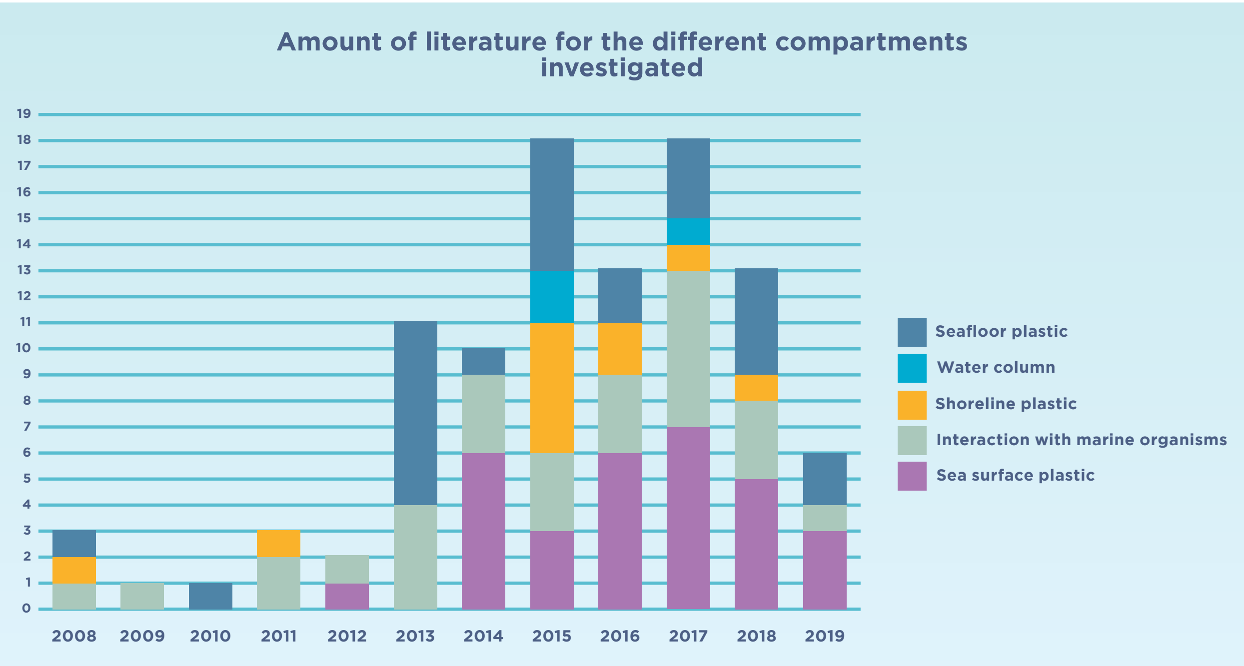


Figure 2.2: Amount of published articles considered in this study, by research area. Time period based on the publication date of each article. In 2019, many other articles published after the end of the analysis.

1.4. Aim of our work

The focus of this report is to answer three fundamental questions:

- How much plastic is currently accumulated in the Mediterranean Sea?
- How much plastic is leaking into it every year?
- What are the most efficient strategies to alleviate plastic leakage in the Mediterranean region within the next 20 years?

This report is therefore divided into three distinct parts and has three overarching objectives.

Part 1: Current situation

Using the best available data, we will extrapolate published plastic concentrations in Mediterranean sub-basins to the entire Mediterranean Sea. The report aims to advance the data and knowledge available on plastic accumulation for different sea compartments: sea surface, seafloor, water column, stranded plastics on the shoreline, and ingested in specific marine organisms.

Table 2.1: Estimated inputs of plastic litter and concentrations provided in the literature

How much plastic is currently floating in the Mediterranean Sea?		
Micro- and macroplastics (tonnes)	Comment	Source
1,000–3,000	Only floating plastic based on manta-trawl sampling, extrapolated to the entire Mediterranean Sea (1 compartment)	Cózar et al., 2015
873–2,576		Suaria et al., 2016
23,100		Eriksen et al., 2014
1,455		Ruiz-Orejón, Sardá, and Ramis-Pujol, 2016
288–1,840 with central value of 705 tonnes for the floating fraction, representing less than 0.1% of the total plastic accumulated	The present study also provides the quantities of plastic in other compartments, which largely overweight the floating fraction	Present study

How much plastic is leaking in it every year?			
Macroplastics (tonnes/year)	Microplastics (tonnes/year)	Comment	Source
150,000–500,000	70,000–130,000	Estimated for European seas, vast majority considered to enter the Mediterranean	Alessi, Eva, 2018
570,000		Updated annual leakage for the entire Mediterranean Sea	Dalberg Advisors for WWF, 2019
745,232 (Low: 447,139; High: 1,192,372)		Leakage estimates using three different release rates: low: 15%, central: 25% and high: 40%	Jambeck et al., 2015
216,269 (Low: 144,180; High: 576,718)	13,196 (Low: 3,875; High: 33,393)	Annual marine plastic footprint estimated for the Mediterranean Sea, originating from 33 countries	Present study

Part 2: Plastic Footprint

Using the model developed in the IUCN *Marine plastic footprint* report (Boucher, Billard, et al., 2019), this report will estimate macroplastic and microplastic fluxes from 33 countries. This is done by analysing data on management of waste generated in human settlements, their distance to shore, and environmental parameters such as surface water run-off.

Part 3: Drawdown scenarios

Based on the results of the two previous parts, we identify and assess potential interventions that would lead to a reduction in plastic leakage over the next 20 years.

2. Current situation

How much plastic is accumulated in the Mediterranean sea?

This section intends to answer the following question: ***How much plastic is accumulated in the Mediterranean Sea?***

To do so, we rely on scientific literature published during the last decade, complemented by proprietary data from Oceaneye[1] (132 sampling points in the Mediterranean Sea). In order to achieve a clear understanding of the problem and better articulate our results, we have divided the Mediterranean Sea into five different compartments, which together constitute our "box model" (section 3.1). Each compartment of this box model has then been populated with data using an extrapolation methodology (section 3.2). This chapter thus presents a "bottom-up" assessment of the quantity of plastic accumulated in the Mediterranean Sea, based on existing data.

Important disclaimer: *we acknowledge that our approach provides neither a precise measurement nor a statistically valid assessment of the actual quantities of plastic accumulated in the Mediterranean Sea. However, given the current knowledge gap and range of published assessments (*Figure 3.2*), this study aims to provide the best possible approximation of the quantity of plastic accumulated in five compartments of the Mediterranean Sea. Limitations of our approach and need for additional research are further discussed in section 3.4.*

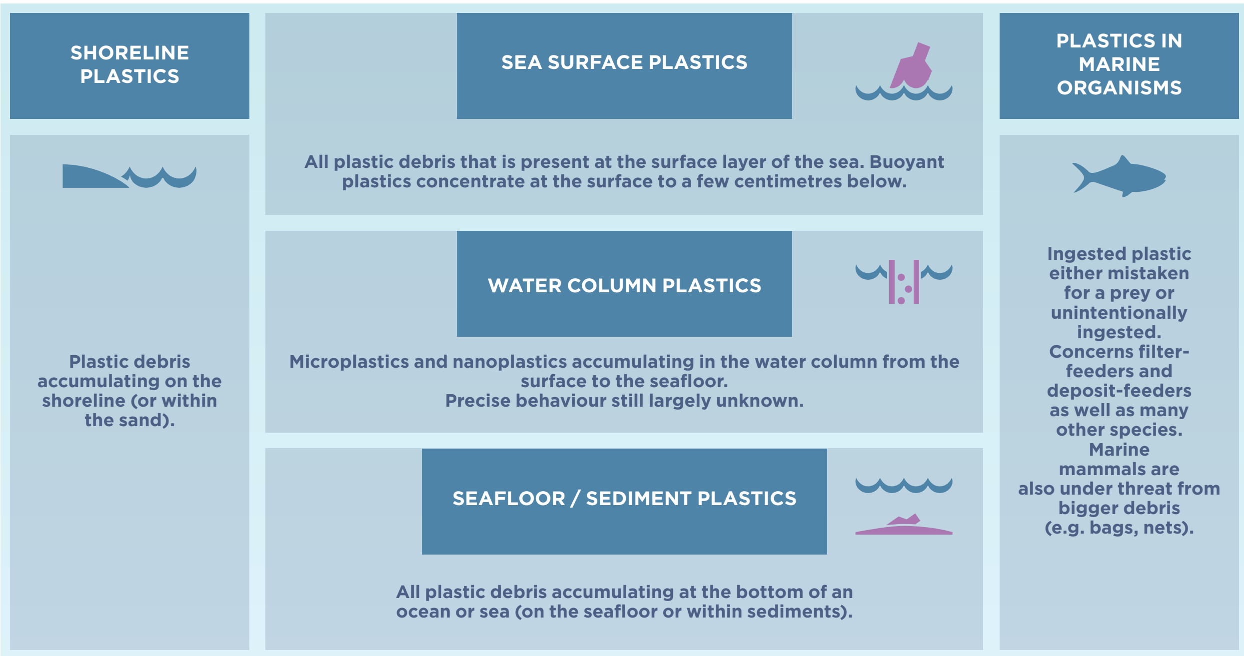


Figure 3.1: Key environmental compartments considered in this study.

1 https://www.oceaneye.ch Established in 2010, Oceaneye is a non-profit organisation, with the mission to: provide information and raise global awareness on the threats of oceans' plastic pollution; contribute to scientific research by collecting data, helping and supporting the work of the scientific community. Oceaneye has created a citizen-science approach where volunteer ships collect marine plastics and send them to the organisation for further analysis. It also provides technical and popular science for all types of audiences.

SHORELINE PLASTICS
11 articles

- What we know

Disparate assessment campaigns. North-western basin concentrates the wide majority of the research. Beaches are the main study area. Plastics are usually found at high tide / storm-level lines. Plastics of all sizes are reported. The shore acts as an emission and retention area. Monitoring protocols used: Clean Coast Index, OSPAR Commission Guidelines for Monitoring Marine Litter on the Beaches, UNEP Operational Guidelines for Comprehensive Beach Litter Assessment. Plastic is usually the main component of marine debris.

- Knowledge gaps

Degradation rates, understanding of the accumulation patterns of plastic on shoreline. General lack of data. For the Mediterranean Sea, plastic is likely to accumulate sporadically in creeks, bays or islets.

SEA SURFACE PLASTICS
31 articles + Oceaneye data

- What we know

One of the most studied compartments. Sampling areas are widely distributed across the Mediterranean Sea but the north-western sector concentrates the majority of the research effort. Highly variable concentrations reported. Prevalence of microplastics as their density usually allows them to float. Uncoordinated monitoring protocols.

- Knowledge gaps

Precise behaviour of floating micro debris. Interaction with pelagic fauna. Degradation patterns from micro- to nanoplastics and polymer degradation in seawater. Accumulation patterns following distance to shore and population densities.

WATER COLUMN PLASTICS
4 articles

- What we know

Presence of debris inside the water column, at different depths. Sinking patterns suggest that the number of microplastic particles (>300um) are mainly located at or just below the surface (air water interface).

- Knowledge gaps

One of the main knowledge gaps is the spatial distribution of plastic inside the water column. Sampling devices struggle to measure the potential concentrations of debris, mainly in the form of micro- and nanoplastics.

SEAFLOOR / SEDIMENT PLASTICS
27 articles

- What we know

Main sink for macroplastics, high concentrations reported for the Mediterranean region. Wide spectrum of plastic items (fishing gear, consumer-based plastics). Accumulation in canyons and continental shelves, potentially acting as retention areas and hotspots. High concentrations of micro debris in sediments.

- Knowledge gaps

Degradation rates due to low oxygen levels. Blanketing effects and hypoxia.

PLASTICS IN MARINE ORGANISMS
28 articles

- What we know

Presence of ingested debris in several fish species and marine mammals (red mullet, blue shark, sperm whale). Ingestion rates fluctuate depending on species and feeding behaviour. Ingestion leads to internal wounds (ulcers, clogging of gastro-intestinal tracts). Blue fragments are often recovered from commercial fish.

- Knowledge gaps

Possible transfer of particles/chemicals to humans through consumption. Implications for the wider food web. Concentration in the trophic chain?

Figure 3.2: Preliminary findings from the literature review; the total number of articles in the database is shown, however not all were used for the analysis.

2.1. The box model

The proposed box model consists of 5 compartments as presented in Figure 3.1.

There is a clear imbalance regarding the amount of data available for each compartment, with the water column being much less documented than other compartments (absence of any published article specific to the Mediterranean region, at the time of the analysis).

The goal of the present study is to estimate the likely mass of plastic accumulated in the Mediterranean Sea. However, analysis of the literature revealed that results are often stated in terms of abundance (particle counts) and thus could not be extrapolated. Such data is therefore not used. This was found to be the case for articles related to both plastics on the seafloor and ingested in organisms. Preliminary findings from the literature review are synthesised in Figure 3.2 above, which sets out the status of and main gaps in the knowledge.

2.2. Extrapolation methodology

The challenge of our approach is to extrapolate plastic quantities for each compartment of the box model based on punctual concentrations reported in the scientific literature and official reports (NGO, international organisations, etc.). This is made harder by the significant differences between the sampling and analysis methodologies used by the different authors. Due to this lack of a standardised approach in sampling plastics at sea, and an insufficient number of replicates, only a few sets of data were tested using statistical analysis (non-parametric tests).

For each of the five compartments of the box model, the extrapolation methodology follows a series of four steps, as presented in Figure 3.3.

The full database with all articles and the individual concentration data used to calculate mean concentrations per compartment (steps 1 and 2 in Figure 3.3) can be found in the appendix (page 55 onwards).

The extrapolation methodologies tested and the chosen procedure are described in Table 3.1 (expanding on step 3 in Figure 3.3). The calculations of the extrapolation made for each compartment are detailedin Section 3.3, Results.

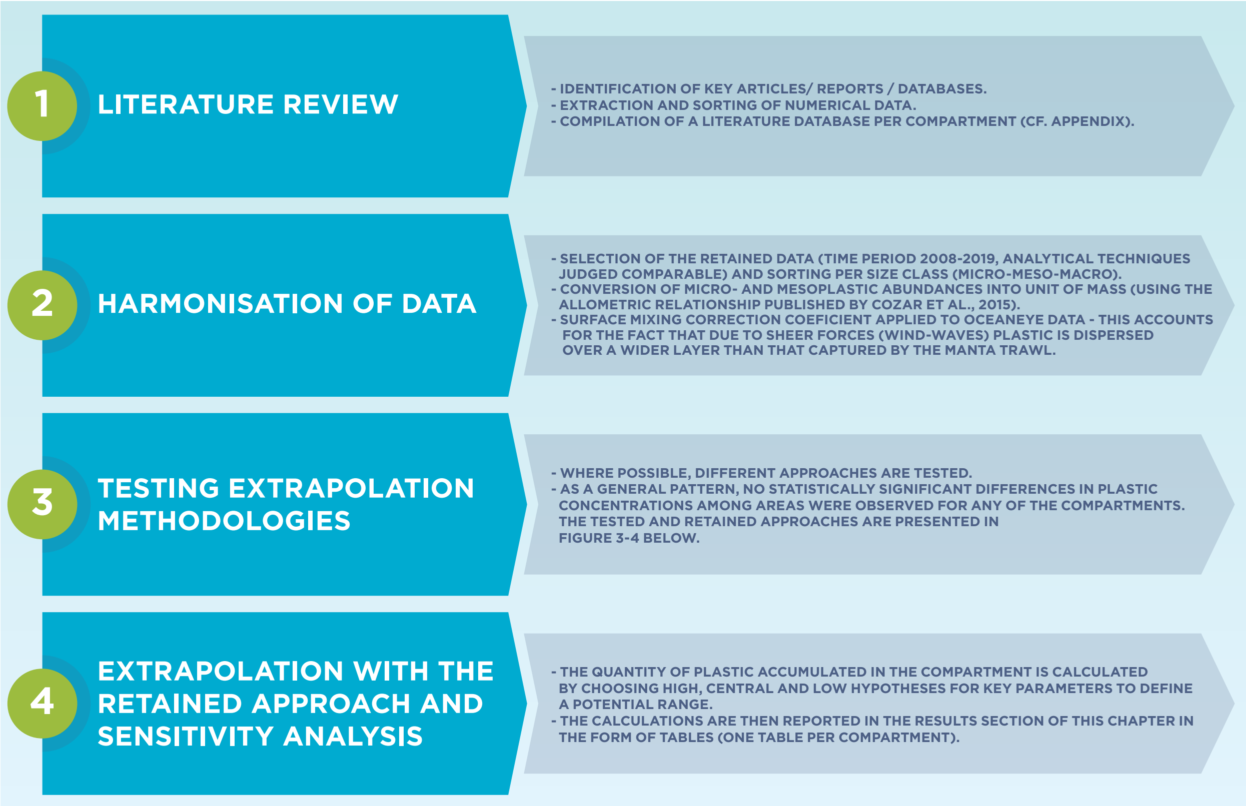


Figure 3.3: Logical steps of the extrapolation methodology

Table 3.1: Description of the harmonisation and extrapolation methodologies considered in this study and the chosen procedure for each compartment

Compartment	Harmonisation & Extrapolation Methodologies	Procedure	Justification
Surface	**FAO zones of the Mediterranean Sea:** Using the Food & Agriculture Organisation's regional grid, concentrations (items km^{-2}) are labelled with a code based on the area they were sampled in. A total of 28 areas were investigated and tested through statistical analysis to observe any significant differences in concentrations between areas. **Distance to shore:** Concentrations and their GPS coordinates are plotted together inside a Geographical Information System. Concentrations and their distance to land can be observed in order to identify whether higher concentrations accumulate in coastal waters or in the open sea. Highly variable concentrations are reported; no distinguishable pattern. **Deriving mass estimates from raw data:** Data published in items km^{-2} are transformed into grams km^{-2} using the equation for numerical concentrations to mass from Cózar et al., 2015. Because wind is responsible for the vertical distribution of debris from the surface to a few centimetres beneath it, a correction factor of 3.2 is applied by Oceaneye to its data. Concentrations reported under wind conditions of less than 9 knots were not corrected as wind does not influence plastic distribution below that threshold (Kukulka et al., 2012). Data already published in grams km^{-2} are added to the database.	Numerical concentrations to mass equation and extrapolation to the entire surface of the Mediterranean.	No significant differences in plastic concentrations across the Mediterranean. Preferred method: deriving mass estimates from raw data.
Seafloor (meso: ≥ 5 mm and ≤ 1 cm; macro: ≥1 cm)	**FAO Zones of the Mediterranean Sea:** Same approach as for sea surface concentrations. No significant differences in plastic loadings on the seafloor. Data presented in items km^{-2} and in kg km^{-2}. **Raw data extracted from the literature considering a homogeneous benthos:** Obtained a median value from the raw data in kg km^{-2}. This raw value is then extrapolated to the surface area of the seafloor of the Mediterranean, considering a homogeneous benthos regardless of submarine topography. **Raw data extracted from the literature considering submarine canyons:** Same approach as above, however considering 614 canyons with an average size of 237 km^{-2} potentially acting as retention areas. Canyon data based on the study from Harris & MacMillian-Lawler., 2015.	Raw data extracted from the literature (homogeneous benthos and considering canyons) and extrapolation to surface area of the Mediterranean Sea.	Majority of the results communicated in mass units. Extrapolated to the entire Mediterranean surface (with/without considering submarine topography).
Seafloor (micro: ≤ 5 mm)	**Data on microplastics in seafloor sediments:** This extrapolation is based on data from one article (16 data points in the Adriatic, Mistri et al., 2017) providing microplastic and mesoplastic abundances per square meter (28.5 and 11 respectively). Using the average mass of 1 microplastic and 1 mesoplastic particle (1.5 mg and 100 mg respectively) we extrapolated to the entire Mediterranean Sea regardless of submarine topography. Other articles have found high concentrations of microplastics in the Mediterranean seafloor sediments (Abidli et al., 2017; Alomar et al., 2016; Vianello et al., 2013).	Data on microplastics in seafloor sediments and extrapolation to entire surface of the Mediterranean Sea.	Only one article providing estimates in pieces.m^{-2}.

Shoreline	**Regional coastal assessments:** Disparate beach litter assessments, mainly concentrated in the north-western basin. Data usually available for one or two beaches per country. Concentrations in grams m^{-2}. **Beach clean-up data:** Data from beach litter campaigns were obtained for 11 coastal countries, with number of items collected, beach length surveyed, and number of items collected. Three hypotheses were tested: 1%, 5% and 10% of each country's coast could act as a retention area. For countries without data, the mean value of the countries with data was extrapolated to the length of their coast.	Beach clean-up data and extrapolation to countries with no data.	As a country's coastline cannot be considered equal and regular in morphology, three hypotheses were tested (see Figure 3.14).
Marine organisms	**Landing data and ingestion rates:** Plastic uptake in three commercially important fish species was investigated using official landing data from 2018. Using plastic ingestion rates obtained from the scientific literature, rates were applied to the total landings of European pilchard, anchovy and sea bogue. Plastic contamination rates: pilchard 47%; anchovy 14%; bogue 57%. Ingestion in sperm whales investigated, using the data presented in the article from de Stephanis et al. (2013). **Stock Assessment Forms:** Using regional validated stock assessment forms (SAF) from the FAO, derived a total stock estimate for the top three commercially important fish species of the Mediterranean using sub-basin regional assessments.	Landing data and ingestion rates.	Limited amount of SAFs available. Total landing data was preferred as encompassing the entire Mediterranean area.

2.3. Results

2.3.1. Overview of the plastic stock accumulated in the Mediterranean Sea: 1,178,000 tonnes (range 53,500–3,546,700)

The result of the assessment is summarised in Figure 3.4, showing that:

- The total plastic accumulated in the Mediterranean is estimated in the order of magnitude of 1,178,000 tonnes, with an uncertainty ranging from 53,500 to 3,546,700 tonnes.
- Most of the plastic seems to be accumulated on the seafloor either in the form of microplastics in the sediments, or macroplastics or mesoplastics scattered on the seafloor, with the rest being distributed in the other compartments.

2.3.2. Sea surface: 705 tonnes (range 288–1840)

Harmonisation of data

The harmonisation of data from the 20 studies, comprising 186 data points is described in Table 3.1; the granularity of the information used for further analysis is study-dependent. Presentation of results also depends on and sometimes requires transformation. To understand the potential plastic loading of the Mediterranean Sea, mass data is required.

Thus, when results are presented in average items km^{-2}, they are further transformed into grams km^{-2} using the numerical concentrations to mass equation from Cózar *et al.,* (2015). Data presented in grams. km^{-2} required no additional transformation.

Wind and sea state are responsible for the vertical mixing of debris inside the surface layer. To compensate this, a wind correction factor is required. Therefore, if the data already accounts for wind correction, no correction factor is applied, nor if sampling was conducted in low wind conditions (< 9 knots).

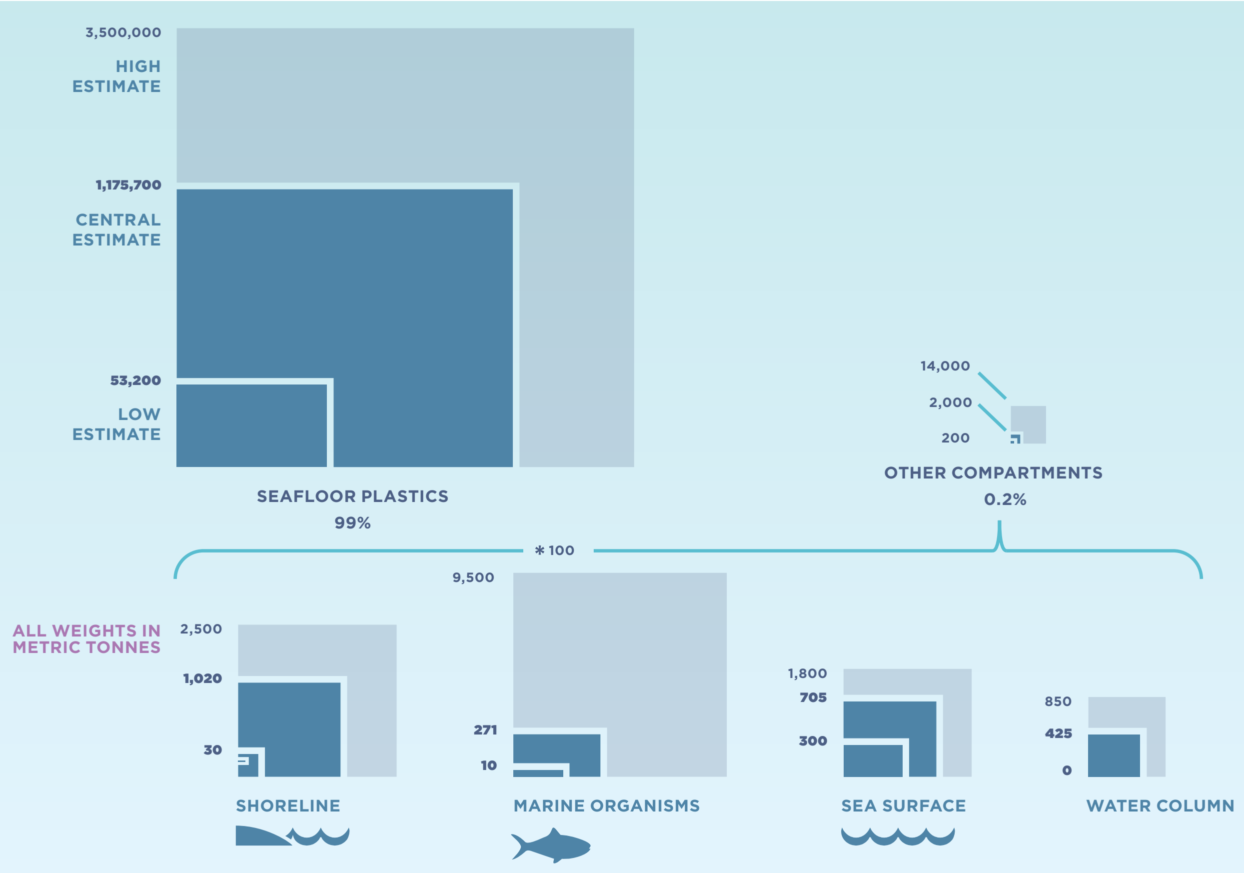


Figure 3.4: Plastic accumulated in the different compartments of the Mediterranean Sea. The three values for each box represent the low/central/high estimates. The central estimate is displayed as a full blue square and labelled with bold font. Values shown in metric tonnes. Seafloor plastic includes both the microplastics trapped in sediments and the mesoplastics and macroplastics deposited on the seafloor.

The average correction factor used by Oceaneye for the 132 net tows performed in the Mediterranean Sea is 3.2.

Throughout the sea surface analysis, only microplastics and mesoplastics were considered, with the exception of two articles studying all plastic sizes (Ruiz-Orejón et al., 2016; Eriksen et al., 2014). Therefore, macroplastic concentrations presented in grams km^{-2} in these two articles were added to the database.

Extrapolation and sensitivity analysis

The available literature presents sea surface plastic concentrations ranging from 0.3 to 10,400,000 items km^{-2}. Our analysis shows a median value of 281 grams km^{-2} corresponding to a potential loading of 705 tonnes for the whole Mediterranean Sea surface.

Additionally, taking the first quartile (Q1, 114 grams km^{-2}) and the third quartile (Q3, 733 grams km^{-2}) as low and high concentrations leads respectively to 288 tonnes and 1,840 tonnes of plastic floating at the surface of the Mediterranean Sea. Note that using the average instead of the median would yield higher values: 2,483 tonnes for the central value (989 grams km^{-2}). Although microplastics constitute the majority of the data analysed, it is likely that surface macroplastics are responsible for a higher mass balance (as also noted by Eriksen et al., 2014). Our estimate of sea surface loading is based on a limited inventory of macroplastic articles.

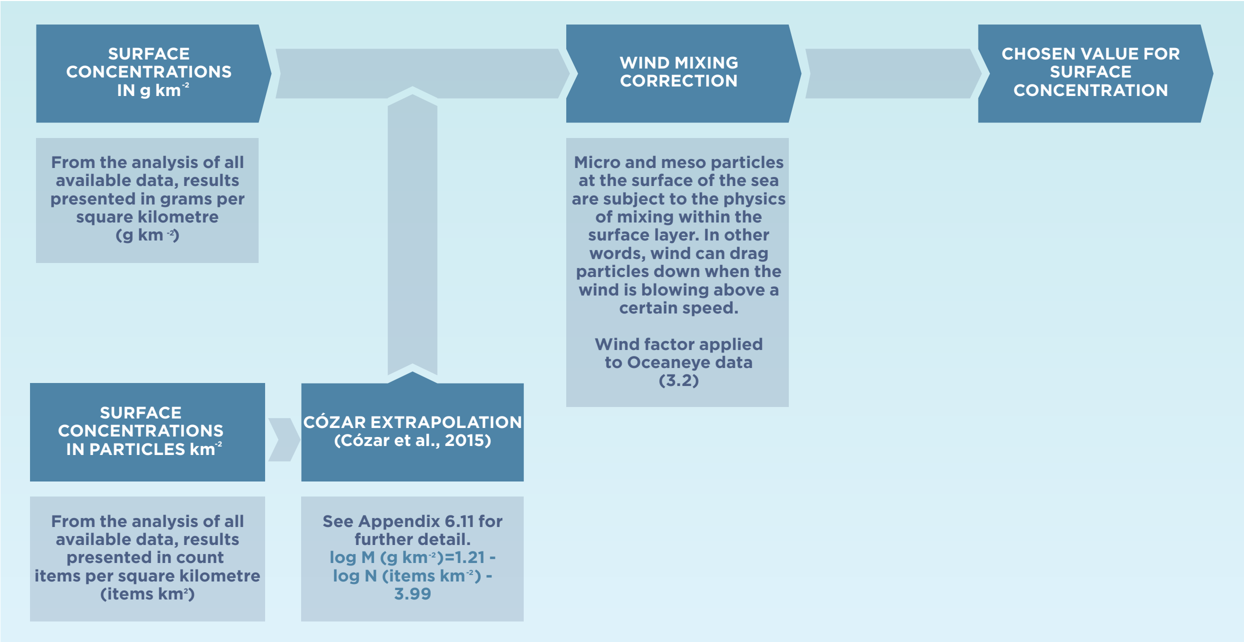
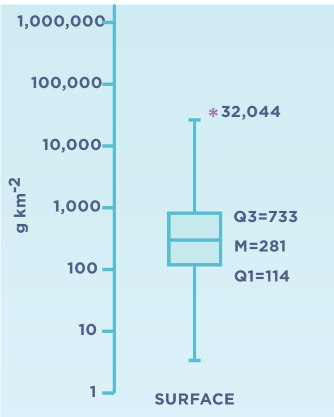


Figure 3.5: Harmonisation of the data for surface plastic concentrations



	SURFACE CONCENTRATIONS grams km-2	SURFACE OF THE MEDITERRANEAN SEA km2	AMOUNT OF PLASTIC IN THE COMPARTMENT tonnes
LOW ESTIMATE	114	2,510,000	288
CENTRAL ESTIMATE	281		705
HIGH ESTIMATE	733		1,840

Figure 3.6: Low-central-high values for the surface concentrations and extrapolation of the quantities of plastic accumulated at the Mediterranean Sea surface. The horizontal line in the middle of the box represents the median (M), the upper vertical line represents the 95th percentile, and the lower vertical line the 5th percentile. The box itself shows the interquartile range, the upper horizontal line the 75th percentile (Q3) and the lower line the 25th percentile (Q1). The red star is the outlier, the highest value reported.

2.3.3. Seafloor mesoplastics and macroplastics: 175,700 tonnes (range 50,000–186,000); microplastics in sediments: 1,000,000 tonnes (range 3,270–3,345,000)

Our assessment of the plastic accumulated on the seafloor includes both macroplastics and mesoplastics, as well as microplastics accumulated in the first centimeters of sediments and analysed separately.

Harmonisation of data

Due to the lack of allometric relationships for seafloor plastics, the data presented in units of mass per surface was only considered in our model to extrapolate a total loading. Regarding the size of debris investigated, most of the research effort is concentrated on macroplastics and mesoplastics. The database for these size spectrums includes 27 articles with only 11 presenting results in grams km^{-2}.

Extrapolation for mesoplastics and macroplastics

The available literature presents seafloor concentrations ranging from 7.5 to 1,102,000 grams km^{-2}; our analysis shows a median value of 70,000 grams km^{-2} (and Q1 and Q3 ranging from 16,800 to 146,000 grams km^{-2} respectively). Assessments using remotely operated vehicles (ROV) have also brought forward the highest mean concentrations of litter ever observed on the deep seafloor (Tubau et al., 2015).

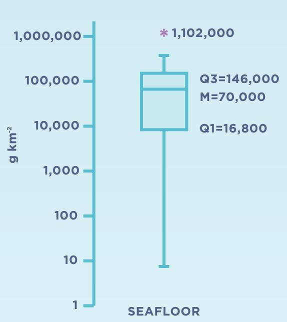
Following this study, and as pointed out by Cau et al., (2017), submarine canyons can possibly act as retention areas for macro debris (e.g. derelict fishing gear and plastic bottles). For this reason the extrapolation has been carried out by considering the extent of submarine canyons versus the rest of the seafloor (Harris and Macmillan-Lawler 2015) and associating different seafloor concentrations to both of these surfaces as described in Figure 3.7.

This approach yields a central estimate of 175,700 tonnes of plastic accumulated on the Mediterranean seafloor with an uncertainty range between 49,910 and 186,759 tonnes.

Extrapolation for microplastics

The assessment of microplastics in sediments constitutes a challenge, as there are few published data that allow for effective extrapolation and comparison between data sets. Still, sampling for microplastics in Mediterranean seafloor sediments has reported high concentrations, mainly communicated in the form of number of items (cf. Appendix 1.3): 672–2,175 items.k.g^{-1} of dry weight (DW) sediment (Vianello et al., 2013), 7,960 items.k.g^{-1} DW sediment (Abidli et al., 2017).

Therefore, because the majority of the articles provide results in *average particles* items.k.g^{-1} DW sediment, with one article in *average pieces*.m^{-2}, two approaches were then explored.



	RATIONALE OF THE EXTRAPOLATION		BOTTOM CONCENTRATIONS[1] grams km^{-2}	SURFACE CONSIDERED IN MEDITERRANEAN SEA[2] km^2	AMOUNT OF PLASTIC IN THE COMPARTMENT tonnes
LOW ESTIMATE	Central value (M) applied to submarine canyons and low concentration (Q1) applied to the rest of the seafloor.	Submarine canyons	70,000	145,518	49,910
		Rest of the seafloor	16,800	2,364,482	
CENTRAL ESTIMATE	Central value (M) applied both to submarine canyons and to the rest of the seafloor.	Submarine canyons	70,000	145,518	175,700
		Rest of the seafloor	70,000	2,364,482	
HIGH ESTIMATE	High value (Q3) applied to submarine canyons and central value (M) applied to the rest of the seafloor.	Submarine canyons	146,000	145,518	186,759
		Rest of the seafloor	70,000	2,364,482	

(1) As a result of the current literature review, with results synthesised in the boxplot presented in this figure (left) and the full data set reported in the appendix of this report.

(2) Total surface of the Mediterranean Sea: 2,510,000 km^2. Split between submarine canyons and the rest of the seafloor obtained from Harris et Macmillan-Lawler (2015), based on 614 canyons with size 237 km^2.

Figure 3.7: Low-central-high estimates for the seafloor concentrations and extrapolation of the quantities of plastic accumulated on the Mediterranean seafloor in the form of mesoplastics and macroplastics. The horizontal line in the middle of the box represents the median (M), the upper vertical line represents the 95th percentile, and the lower vertical line the 5th percentile. The box itself shows the interquartile range, the upper horizontal line the 75th percentile (Q3) and the lower line the 25th percentile (Q1). The red star is the outlier, the highest value reported.

Table 3.2: Low-central-high estimates for microplastic sediment concentrations accumulated on the Mediterranean seafloor using mass data per surface area.

Microplastics	Rationale of the extrapolation	Bottom concentrations (1)	Surface considered in Mediterranean Sea	Amount of plastic in the compartment
		kg km^{-2}	km^2	tonnes
Low estimate	Lowest value presented by Mistri et al. (2017) from 16 stations in the Adriatic	1.3	2,510,000	3,268
Central estimate	Average from the low and high values	554	2,510,000	1,390,543
High estimate	Highest value presented by Mistri et al. (2017) from 16 stations in the Adriatic	1,107	2,510,000	2,777,817

(1) Mistri et al., 'Small plastic debris in sediments from the Central Adriatic Sea: Types, occurrence and distribution'. Marine Pollution Bulletin 124, no 1 (15 novembre 2017): 435-40. https://doi.org/10.1016/j.marpolbul.2017.07.063.

Due to very limited data on mesoplastic abundances in sediments, it was decided to focus only on the presence of micro debris in sediments.

Approach 1: Using the article from Mistri et al., (2017) and the communicated results in grams m^{-2} obtained during an extensive sampling campaign in the Adriatic Sea, we derived a central estimate for microplastic concentration in the Mediterranean of 1,390,543 tonnes (within an uncertainty range between 3,268 and 2,777,817 for low and high values respectively), as presented in Figure 3.8. Because microplastics accounted for 65.1% of the debris found, the lowest and highest abundances of debris reported were multiplied by this percentage to only account for micro debris.

Approach 2: the bulk of the literature focusing on microplastics in sediments mainly present results in *items per gram of dry sediment*. To compare concentrations provided in approaches 1 and 2, the average items in dry sediments of the Mediterranean Sea were compared to concentrations found in Lake Geneva, Switzerland, reported in the article from Boucher, Faure, et al. (2019). This article provides results in pieces per gram of dry sediment, and in grams per square kilometre.

Using these findings as a basis, a ratio was obtained by dividing the mass of microplastics per m^{-2} (grams) and their corresponding concentration in *items per gram of dry sediment*. This was performed for 12 samples. Once the ratio for each of the twelve samples was obtained, the median of these twelve ratios was taken (2.33) and applied to the median *items per gram of dry sediment* in the Mediterranean (0.16).

The results of these two analyses suggest that the seafloor sediment compartment may be the main sink for the accumulation of microplastics.

With an estimate of 1,300,000 tonnes for Approach 1 and 935,000 for Approach 2 it was decided to round the microplastic sediment compartment to 1,000,000 tonnes.

Note that in both cases this extrapolation methodology has relied on the extent of the sea surface, i.e. the total area of the sea at the air-water interface. It has not considered the extent of the seafloor, which potentially makes our estimates conservative.

Table 3.3: Extrapolation based on previously obtained concentrations of microplastic (items per gram of dry sediment) and their corresponding mass per square metre.

Scenario	Ratio derived from Boucher et al., 2019	Concentrations in sediments of the Mediterranean Sea	Extrapolation	Surface of the Mediterranean Sea	Amount of plastic in the compartment
	grams m^{-2} ÷ items.g dry sediment	items.g dry sediment		km^2	tonnes
Low estimate ***Q1***	1.2	0.10	0.10*1.2	2,510,000	310,455
Central estimate ***Median***	2.33	0.16	0.16*2.33		935,561
High estimate ***Q3***	2.94	0.45	0.45*2.94		3,345,434

2.3.4. Water column concentrations: 325 tonnes (range 0–705)

Key findings from the literature

The question of whether plastic is accumulated in the water column is still being debated. There is currently no available data for this compartment in the Mediterranean region; however some recent studies have investigated the distribution of plastic of a different sizes range (from 10 μm to 5 mm) within the water column (between the surface and 1000 m depth) in the Atlantic and Pacific regions (Reisser et al., 2015; Enders et al., 2015; Choy et al., 2019). We propose to use the findings of these studies to evaluate whether the water column could be a significant accumulation compartment for plastic in the Mediterranean.

The main findings of the above-mentioned studies are summarised below:

- Macroplastics and mesoplastics that are positively buoyant concentrate on the surface.
- Microplastics with size > 300μm follow the same dynamic, as their concentration decreases exponentially with depth, with no detectable plastic below 5 m (Reisser et al., 2015).
- Small microplastics (<300μm) behaviour in the water column is more complex. It is assumed that microplastics of 100 μm and 10 μm are widely dispersed in the water column (up to 250 m according to Enders et al., 2015, and up to 1000 m according to Choy et al., 2019), with maximum abundance potentially driven by the position of the pycnocline (the layer of water in which there is a steep gradient in density with depth – International Seabed Association).

These studies discuss the potential role of the water column in concentrating the “missing plastic” i.e. the quantity of plastic estimated by models but not yet discovered in the marine environment. The number of (smaller) particles dispersed in the water column seems to largely overcome the (larger) particles present at the surface, and estimating a mass remains a very challenging endeavor.

Extrapolation and sensitivity analysis

Based on the findings from Enders et al. (2015), for both microplastic particles (in the size range 10–300 μm) and microplastic fibres (in the size range 10–2,500 μm), assuming that 40% of all microplastics identified are attributed to fibres, we derive that approximatively 30% of all particles/fibres have a size > 300 μm and mostly

Table 3.4: Estimation of plastic accumulated in the Mediterranean water column

	Plastic accumulated in the water column compartment (tonnes)
Low estimate (1)	0
Central estimate (2)	352.5
High estimate (3)	705

(1) Based on particle size distribution deduced from Enders at al. 2015
(2) Average of "low" and "high" scenarios
(3) Based on the hypothesis that the particle size in the water column increases to a power of 3 to the decreasing diameter, and thus an equivalent mass of particles in the water column as at the surface

accumulate at the surface. The rest accumulates in the water column below 300 µm in size.

Low estimate scenario: From this split, and assuming a spherical shape, with the volume (or mass) increasing to the power of three of the increasing diameter, we conclude that the mass of microplastic accumulated in the water column is negligible. Indeed, if we take the example of a 50 µm versus 1,000 µm particle, it takes 8,000 of the smaller particles to match the mass of one of the bigger particles. In other words, it seems that the number of particles is larger in the water column than at the surface, but the mass is much smaller due to the smaller size of particles.

High estimate scenario: If we take the estimate from Choy et al. (2019), assuming an average particle concentration of 1 particle.m^{-3} close to the surface (assumed to be a 1 metre layer) and reaching up to 12 particles.m^{-3} at a depth of around 200 m with a slow decrease up to 1,000 m, we can deduce that there may be 2,000 times more particles below the surface than at the surface[2]. Again, assuming that the surface particles have an average size of 1 mm and smaller particles below the surface have an average size of 50 µm and the mass of one of the bigger particle is equivalent to the mass of 8,000 of the smaller, we conclude that the maximum particles mass in the water column could be equivalent to the particle mass at the surface (2000 and 8000 being in the same order of magnitude).

We propose to use the mean of the two as the "central estimate" for this assessment, as further explained in Figure 3.4.

There are a couple of limitations to our estimates:

1. The split between the number of particles at the surface and below the surface is based on the extrapolation from only two studies that show very conflicting results. The spatial and size distribution of particles within the water column should be better understood in order to refine our findings.

2. The mass doesn't necessarily reflect the associated environmental impacts related to a higher number of smaller particles and fibres that may enter the food web.

2.3.5. Ingested plastic in marine organisms: fish, 240 tonnes (range 10–9,400); marine mammals, 31 tonnes

Investigating the contamination rate for all marine species in the Mediterranean would be impossible, and only a few species have been studied for plastic ingestion. Therefore, this study focuses on three key fish species, widely fished in the Mediterranean, representing 36% of total landings. Using the methodology described in Table 3.1 and Table 3.5, we assume that plastic loadings in the three fish species would equate to:

- European pilchard (*Sardina pilchardus*): central value of 12 tonnes on a total landing tonnage of 178,860 tonnes.
- European anchovy (*Engraulis encrasicolus*): central value of 31 tonnes on a total landing tonnage of 124,293 tonnes.
- Bogue (*Boops boops*): central value of 1 tonne on a total landing tonnage of 28,800 tonnes.

2 (200 m * 10 particles.m^{-3})/(1 m * 1 particle.m^{-3})

Using these data and contamination rates, we have derived a potential plastic concentration in marine organisms using three scenarios. These scenarios are based on the central estimate of plastic in the three species (44 tonnes) and are extrapolated to all species based on fishing effort.

From the fish stock estimation and our estimate of the plastic accumulated in the Mediterranean

Table 3.5: Estimation of plastic accumulated in the marine organisms of the Mediterranean investigated in this report

Fish species	Total landings in tonnes (1)	Estimated individuals in landings (2)	% contamination (3)	Average particle / individual (4)	Number of particles in fish stock		Particle weight (5)	Estimated plastic in stock (all species)
	Tonnes	(-)	(%)	(-)	(-)		(mg)	(tonnes)
European pilchard (sardine) (*Sardina pilchardus*)	178,860	13,758,461,538	47.2%	1.8	11,689,188,923	High estimate	(Cózar allometric relationship)	156
						Central estimate	1	12
						Low estimate	0.07	1
European anchovy (*Engraulis encrasicolus*)	124,293	24,371,176,471	14.28%	9	31,321,836,001	High estimate	(Cózar allometric relationship)	513
						Central estimate	1	31
						Low estimate	0.07	2
Bogue (*Boops boops*)	28,800	622,222,222	58%	3.75	1,348,666,666	High estimate	(Cózar allometric relationship)	11
						Central estimate	1	1
						Low estimate	0.07	0

Scenario	Estimated plastic in stock from the 3 species (sardine + anchovy + bogue)	Percentage of the fish stock (based on landings) (1)	Percentage of capture in the fish stock (6)	Estimated plastic in stock (all species)
	(tonnes)	(%)	(%)	(tonnes)
High estimate	680	36%	20%	9,442
Central estimate	44		50%	246
Low estimate	3		80%	11

(1) Landing data provided by: Mediterranean Fisheries. Stocks, Assessments and Exploitation Status, 2015 (European Institute of the Mediterranean) using the FAO-GFCM 2014 data.
(2) Number of individuals in stock was derived by obtaining the average weight of one individual, using FAO Stock Assessment Forms (sardine and anchovy), and scientific reports on the average catch size of the bogue. Once the average size was obtained, weight estimations was derived from the FishBase calculator.
(3) % contamination were derived from a meta-analysis of plastic ingestion in Mediterranean fish species. If two or more % contamination were provided, the average was taken.
(4) Same approach was adopted for the average particle / individual. Usually provided with contamination data as complementary information.
(5) Three hypotheses were tested with regard to particle weight.
The first approach relied on the mass to numerical equation provided by Cózar et al., 2015. This equation allows the transformation of a a given amount of plastic particles into a mass. Using the total amount of particle in fish stock, a mass was then derived.
Second approach: Using data provided by the article published by Romeo et al., 2016 on the plastic ingestion in lanternfish. Microplastic range (1.37 - 2.47 mm): corresponding weight range is 0.0001–0.0022 g (0.1–2.2 mg; average: 1 mg).
Based on the data provided by Gajst et al., 2016, a total number of microplastics with corresponding weight in grams was used, providing a mean microplastic weight of 0.07 mg (0.00007 g).
(6) Estimation, based on Christensen et al., *Fish & Fisheries, Hundred-year decline of North Atlantic predatory fish,* 2002.

(all compartments) we can conclude that there may be currently much more plastic in this sea (1,178,000 tonnes) than the combined annual catch of the three species of fish investigated (332,000 tonnes). For more information on plastic contamination of the three fish species investigated, refer to Appendix 1.4.

Because this plastic ingestion affects not only fish but also the wider food web, one species of marine mammal was also studied to compare the potential loading.

This extrapolation is based on the plastic ingestion in a single stranded sperm whale (*Physeter macrocephalus*). Plastic debris contained in the

Table 3.6: Estimation of plastic accumulated on the Mediterranean shoreline

		PLASTIC CLEAN-UP DATA				
		Data from Ocean Conservancy [1]				From other sources
	Country	Plastic removed during beach clean-ups	Length of coastline cleaned	Total items collected	Plastic accumulated per length of coastline	Plastic accumulated per length of coastline
		(kg)	(km)	(-)	(kg/km)	(kg/km)
1- COUNTRIES WITH DATA	Cyprus	115	4	5,347	29	
	Egypt	50	0	146	167	
	France	511	29	2,748	18	
	Greece	6,800	75	64,793	91	
	Israel	355	1	974	355	
	Italy	140	5	858	28	
	Malta	169	24	976	7	
	Morocco	35	2	175	18	33 (4)
	Slovenia	356	14	18,300	25	
	Spain	4,160	27	54,865	154	
	Tunisia	54	7	391	8	
	Turkey	747	2	12,828	374	
2- OTHER	Other countries [7]					
3- TOTAL	***TOTAL***					

(1) *Building a Clean Swell*, Ocean Conservancy, 2018 report.

(2) The coastline length of the 12 countries with data was obtained through the GIS. Total Mediterranean coastline extracted from the GIS. Due to a coarser map with less precision (e.g. number of islands), the total coastline is estimated at 28,041 km. Official length is estimated at 46,000 km. Therefore, plastic quantities can be higher.

(3) Extrapolation Methodology: three hypotheses are tested here:
Using total plastic weight removed for each of the 12 countries, we obtain a plastic weight estimate per 1 km of coastline. Then we extrapolate this weight to the entire coastline of the country. We assume that either 1%, 5% or 10% of the total plastic load extrapolated would accumulate on the coast. The rationale behind these three scenarios was that plastics do not accumulate evenly on the coastline of each country. Due to local currents and environmental parameters, we assume three scenarios, where 1%,32% and 80% of the coast would retain plastics.

gut of the animal (17.927 grams) would equate to a total stock of 31 tonnes if extrapolated to the total estimated population of sperm whales in the Mediterranean (1842 individuals - Lewis et al., 2018).

The morphology, feeding behaviour and spatial distribution of each individual will greatly influence the plastic ingestion, thus these results are an indication rather than a tangible fact.

2.3.6. Shoreline: 1,020 tonnes (range 32–2,551)

The extrapolation for shoreline plastics was based on the Ocean Conservancy "Building a Clean Swell" report. For the Mediterranean region, 12 countries were cleaned through beach clean-up campaigns, each clean up varying in size and effort. For each of these countries, the following information was provided:

	GIS DATA	EXTRAPOLATED RESULTS [3]		
Chosen value		Low estimate	Central estimate	High estimate
Plastic accumulated per length of coastline	Total coastline length [2]	Expected accumulation (1%) [5]	Expected accumulation (32%) [6]	Expected accumulation (80%) [5]
(kg/km)	(km)	(tonnes)	(tonnes)	(tonnes)
		1%	32%	80%
29	583	0.2	5.4	13.4
167	1,330	2.2	71.1	177.7
18	1,207	0.2	6.8	17.0
91	6,804	6.2	197.4	493.5
355	249	0.9	28.3	70.7
28	4,991	1.4	44.7	111.8
7	67	0.005	0.151	0.377
25	393	0.1	3.1	7.9
25	23	0.006	0.187	0.5
154	1,931	3.0	95.2	238.0
8	1,214	0.1	3.0	7.5
374	2,920	10.9	349.0	872.5
107	6,329	6.7	216.0	540.0
	28,041	32	1,020	2,551

(4) Maziane, F., D. Nachite, et G. Anfuso. 'Artificial polymer materials debris characteristics along the Moroccan Mediterranean coast' Marine Pollution Bulletin 128 (1 mars 2018): 1-7. https://doi.org/10.1016/j.marpolbul.2017.12.067.

(5) Own estimations

(6) https://earthobservatory.nasa.gov/images/92507/taking-stock-of-the-worlds-sandy-beaches

(7) Morocco, Croatia, Bosnia and Herzegovina, Montenegro, Albania, Syria, Lebanon, Libya and Algeria

- Mass of plastic removed (kg);
- Length of coast cleaned (km);
- Total items collected.

Through GIS analysis, the coast length of each of these countries was calculated. The average plastic mass per kilometre of coast was extrapolated to the entire coastline. Because litter does not accumulate evenly, we bring forward three hypotheses: 1%, 32% and 80% of the coast likely to retain plastic debris.

The 32% scenario was kept as a central value based on the proportion of sandy beaches on coastlines worldwide (Earthobservatory, 2016).

The average value for plastic accumulated per kilometre of coastline from countries with data was applied to the countries without data.

2.4. Key takeaway points from the plastic accumulation assessment and knowledge gaps

As main takeaways, the following points are to be considered:

- Most of the current research is focusing on the sub-300 μm and < 200 mm size fraction at the surface while most of the plastic seems to accumulate in other compartments of the sea.

- Some compartments – such as the water column, marine organisms and the seafloor – would require further research as they could possibly be holding the "missing fraction" of marine debris. The data regarding these compartments is still very scarce and we lack an understanding of the vertical distribution and size distribution of microplastics and nanoplastics throughout the water column, as well as mechanisms for entering the food web.

- It is obvious that the north-western section of the Mediterranean Sea concentrates most of the research effort. The eastern section urgently needs new investigations. Many studies using numerical models to predict plastic loading on the sea surface also predict higher amounts in the eastern sector. This can be attributed to very long residence time of surface waters due to lack of exchange with the North Atlantic (Van Sebille et al., 2015).

- There is a need to develop models to better understand the contribution of point sources (cities, rivers). This limitation is preventing researchers from establishing possible correlations between point emissions and concentrations recovered at sea. As a matter of fact, the inclusion of hydrological parameters (e.g. gyres or water stratification) and understanding the settling pathways governing the transport of debris towards the seafloor are the essential next steps towards better understanding the plastic pollution in the Mediterranean Sea.

We are conscious of the limitations of our approach; however, the objective is to provide orders of magnitude. It also constitutes a framework for other researchers to replicate the approach once new and more standardised data are available.

Overarching question	Level of certainty green: very likely orange: likely red: uncertain	Assertion
How much plastic is accumulated in the Mediterranean Sea?		Several tens of thousands of tonnes of plastic are currently accumulated in the Mediterranean Sea.
		The total plastic accumulated in the Mediterranean is estimated in the order of magnitude of 1,178,000 tonnes, with a possible range from 53,500 to 3,546,700 tonnes.
Where is the plastic accumulated?		Plastic has been found in the five environmental compartments studied: sea surface, water column, seafloor, shoreline and marine organisms.
		Plastic seems to be ubiquitous at the sea surface, but the quantity of floating plastic is not a significant part of the total plastic accumulated in the Mediterranean.
		The vast majority of the plastic is accumulating on the sea floor, mostly in the form of microplastics in the sediments.
		There is much more plastic in the Med (1,178,000 tonnes) than the combined annual catch of the three fish species investigated (332,000 tonnes).
		Sea surface and water column concentrations, along with plastic in marine organisms, constitute 0.0008% of the total stock.
		The water column does not seem to accumulate an significant mass of plastic although the number of particles present may be very high (these small size particles do not constitute an significant mass).
		The shoreline may be the second largest compartment in terms of accumulated plastic, although much smaller than the seafloor. This points to beach clean-up as an efficient instrument to remediate plastic leakage.

3. Plastic footprint

How much plastic is leaking into the Mediterranean sea every year?

This section intends to answer the following question:

How much plastic is leaking into the Mediterranean Sea every year?

The majority of marine plastics originate from land, reaching oceans and seas through several pathways, such as rivers and sewage systems. This leakage concerns all plastic sizes, from nanoplastic particles to macroplastic debris. Data extracted from the literature indicates that the Mediterranean Sea is widely affected by this pollution (cf. Chapter 3), with a significant stock of plastic accumulated in different compartments. Chapter 4 will focus on assessing the flows of both macroplastics and microplastics from land to sea (i.e. the leakage), using a "top-down" modelling approach based on socio-economic activity data from the countries.

This report tackles both leakage in the form of macroplastics from mismanaged waste, as well as leakage from four plastic commodities known to release primary microplastics in the environment:

- tyre dust generated during driving;
- fibre shedded during the washing of synthetic clothes;
- microbead release in cosmetics;
- industrial spills of plastic production pellets.

Primary microplastics refer to plastic entering the marine environment already in a micro format, due to the alteration of its chemical composition (marine paint, tyre abrasion) or intentionally manufactured in a sub-millimeter format (microbeads, pellets) (Boucher, Billard et al., 2019).

Beyond providing a better understanding of the plastic leakage hotspots in the Mediterranean region (essential to drive solutions), this modelling approach is complementary to the approach based on field studies presented in Chapter 3. Indeed, this complementarity of the two approaches will reinforce the argument that plastic leakage is real. This has already been demonstrated on a smaller scale in Lake Geneva, Switzerland (Boucher, Faure, et al., 2019).

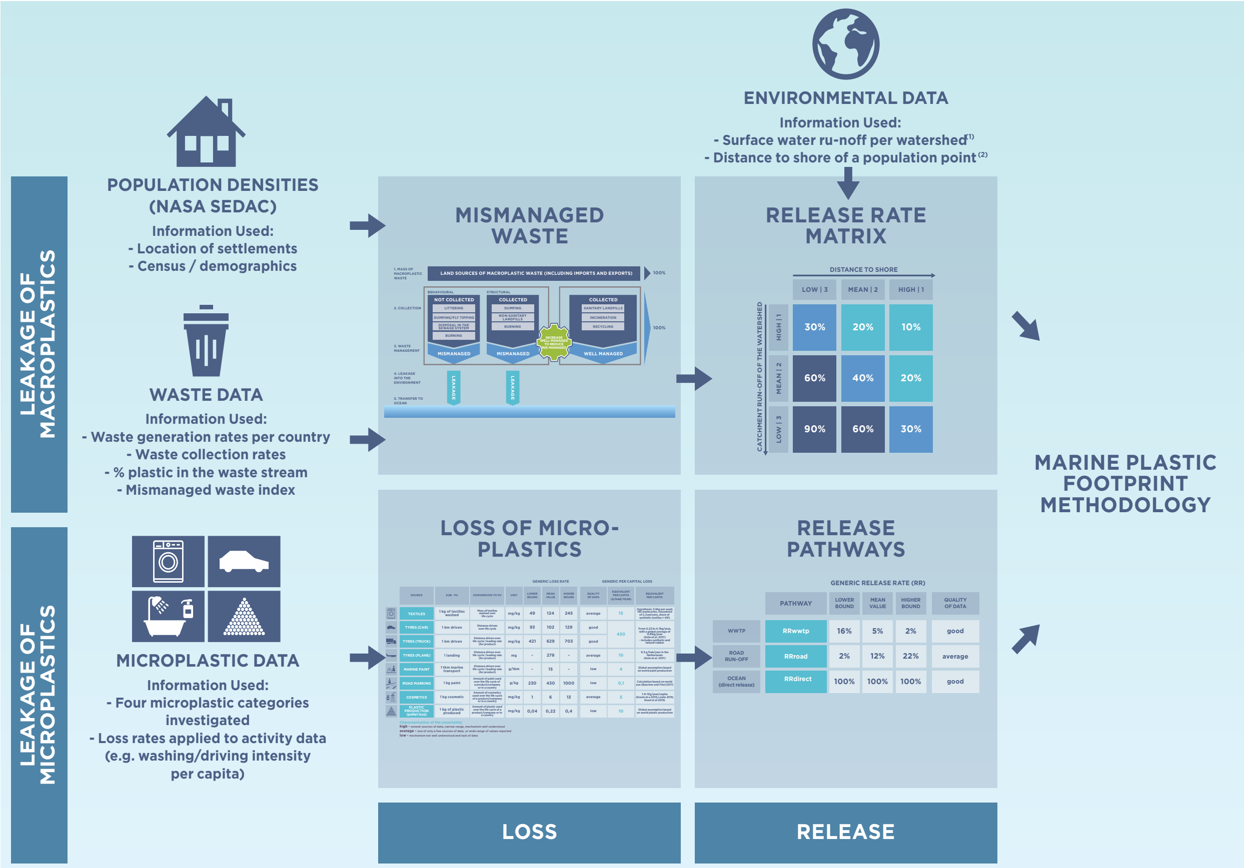
3.1. The marine plastic footprint model applied to the Mediterranean basin

This assessment is based on the newly developed methodology by the same authors previously applied to the Baltic basin, in the *Marine plastic footprint* report (Boucher, Billard, et al., 2019), for macro-sized, mismanaged plastic waste and microplastics. We thus provide here only a summary of the approach; for a more detailed description of the methodology we recommend referring to the afore-mentioned publication.

The modelling of plastic leakage into the Mediterranean Sea targets 33 countries. These countries are either coastal or part of a hydrological basin that is connected to this sea. The leakage rate of waste was calculated by applying population figures to waste data (illustrated in Figure 4.1).

For each country, plastic waste generation data as well as mismanaged waste indexes (total waste in countries with mismanaged waste problems), have been computed using data from the World Bank (Silpa et al., 2018) and population densities from the NASA *Socioeconomic Data and Application Center* (SEDAC – Gridded Population of the World - v4). Data for the distance driven by road, household washing, use of cosmetics, and plastic production pellets come from different sources as listed in Figure 4.1 and from Boucher, Billard, et al. (2019).

Using this raw data, a regionalized model has been created using geographical information systems (GIS), the catchment run-off of watersheds (derived from the article of Lebreton et al. 2017), the population densities from SEDAC, and the distance to shore (using geospatial tools in *QGIS* mapping software).



(1) For the run-off limits (refer to the Marine Plastic Footprint publication), the first quartile (Q1) and third quartile (Q3) was used set the lower and higher bounds of the leakage matrix respectively (using data for all watersheds in the Medditerranean region extracted from Lebreton et al., 2017). The maximum Release Rate (RR_{max}) was set in order to scale the global release rate at 5% for the whole Mediterranean basin.

(2) In a similar manner, the first and third quartiles of the distance to shore for all population points (extracted from the GIS based on SEDAC-Gridded Population of the World collection -v4) were used as lower and higher bounds of the release rate matrix.

Figure 4.1: Overview of the modelling approach. For further details on the modelling stages and supporting data, refer to the *Marine plastic footprint* report (Boucher et al., IUCN, 2019). The leakage is computed both for macroplastics and microplastics and accounts for a first stage of loss from a plastic source and a second stage of release to the environment through a given pathway.

The 1,693 watersheds considered can be seen in Figure 2.1, including basins ranging from 15 km^{-2} to 2,916,242 km^{-2} (Nile watershed). In addition, this approach has also relied on the demographics of the 33 countries, obtained via census and national statistics, compiled in the Gridded Population of the World dataset. The number of inhabitants is given per locality, i.e. village, town or city, and ranges from one inhabitant per locality to above a million. More than 34,000 localities were analysed, for a total of 449,074,896 inhabitants. Leakage rates are then generated and based on watershed configuration, population, and waste generation patterns.

Plastic leakage consists of a first stage of loss and a second stage of release

1. The **loss**, translated into a loss rate, is the quantity of plastics that leaves the product system, as the fraction of materials that is detached from the plastic product during manufacturing, use, or transport for microplastics, or as mismanaged waste for macroplastics. Losses are specific to sources and activities. Examples include the: processes of losing all types of plastics into the environment through abrasion, weathering or unintentional spills during production; transport, use, maintenance or recycling of products containing plastics; littered plastic packaging; etc. The probability of waste being transferred to the

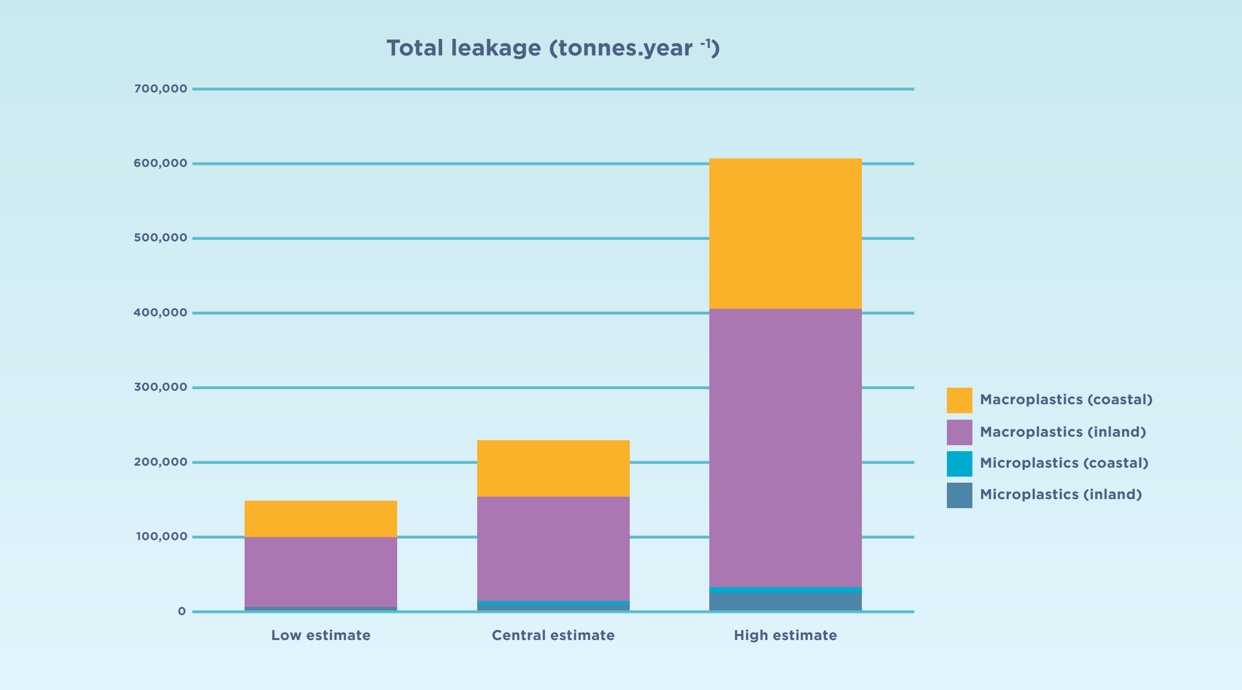


Figure 4.2: Total annual macroplastic and microplastic leakage into the Mediterranean Sea using three estimates (low, medium and high)

ocean can be calculated by applying the release rate to the overall waste loss.

2. The **release**, translated into a release rate, is the fraction of the loss that is ultimately released into the various marine compartments through different pathways. We include releases to waterways and rivers, as the plastic may be transported to the estuary (Hurley, Woodward, and Rothwell 2018).

3.2. Results

3.2.1. Overview of the plastic flows leaking into the Mediterranean Sea: 230,000 tonnes year^{-1} (range 150,000–610,000)

The result of our assessment is summarised in Figures 4.3, 4.4 and 4.5, displaying macroplastic and microplastic leakage at country level; the detailed contribution of the different sources is further presented in sections 4.2.2 and 4.2.3.

Key findings are summarised as follows:

- The quantity of plastic (macro and micro) flowing every year into the Mediterranean is estimated at 229,000 tonnes year^{-1} (central estimate) with low and high estimates of 148,000 and 610,000 tonnes year^{-1} respectively.

- The leakage is dominated by macroplastics, with only 6% stemming from microplastics in the central estimate (3% and 16% for the low and high estimates respectively). The high mean mismanaged waste index in the Mediterranean basin (67%) explains the very high leakage from this source. Note that maritime sources (e.g. lost fishing nets) have not been accounted for in this assessment.

- The countries contributing the most to the leakage are Egypt, Italy and Turkey, as a result of high quantities of mismanaged waste and/or large coastal populations. These three countries may contribute over 50% of the total leakage, and the ten countries that contribute most are responsible for almost 90% of the total leakage in the Mediterranean basin.

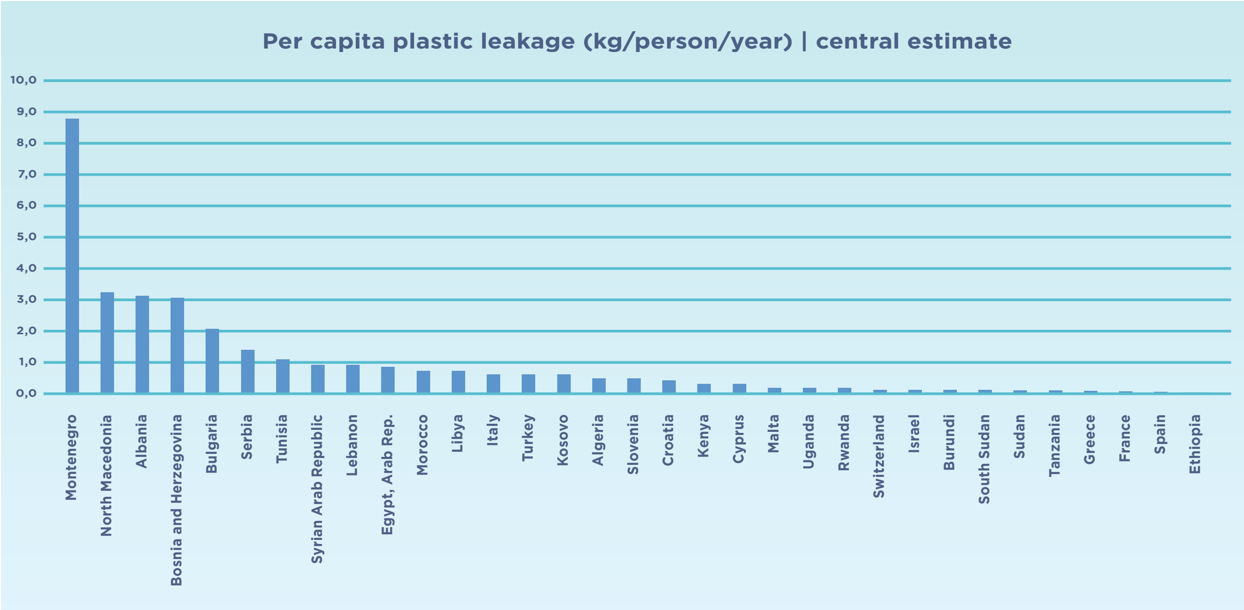


Figure 4.3: Overview of the plastic leakage in the Mediterranean basin for macroplastics and microplastics.

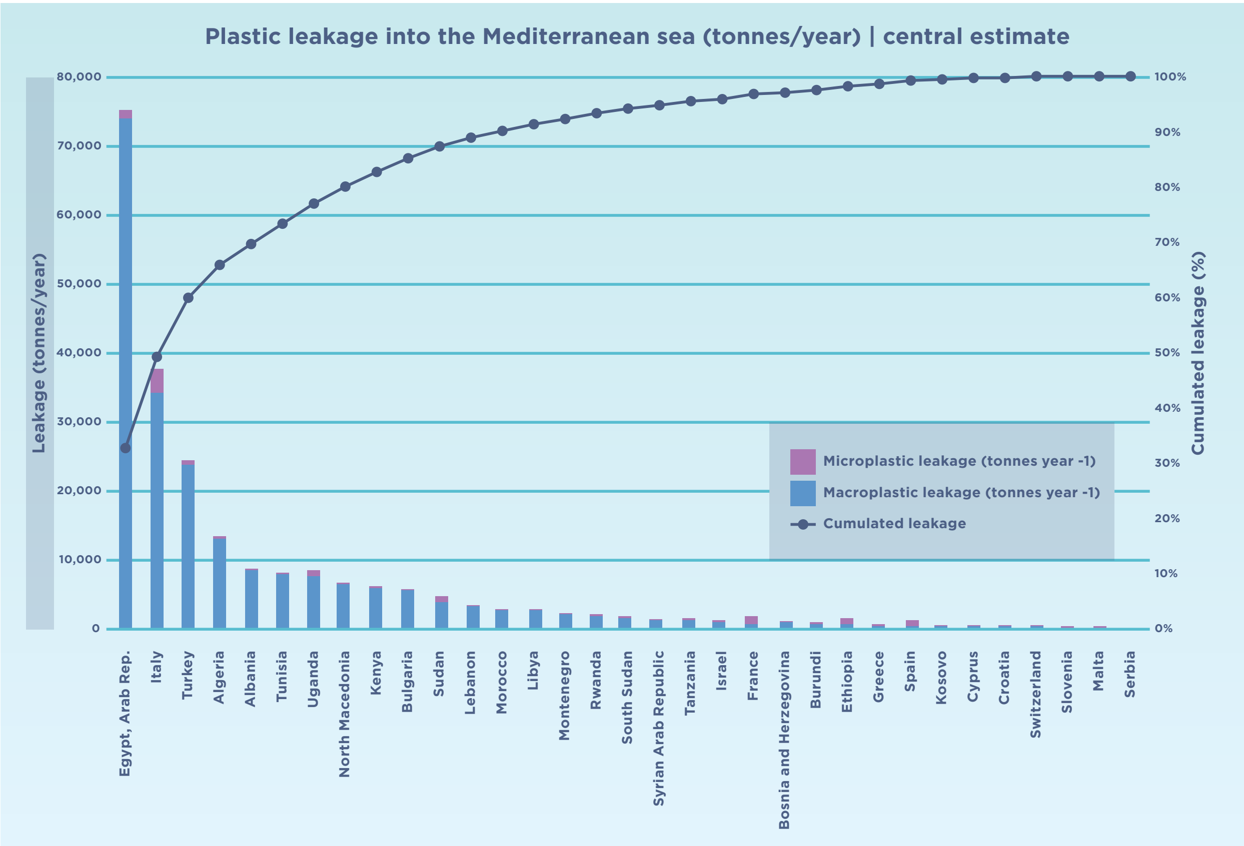


Figure 4.4: Overview of the plastic leakage in the Mediterranean basin for macroplastics and microplastics.

- The per capita leakage is greaterin countries with high proportions of mismanaged waste and a high proportion of the population living in coastal areas. Also, a high catchment run-off (e.g. rain) in a watershed combined with a high proportion of mismanaged waste will increase the probability of leakage (e.g. Montenegro). The range of annual per capita leakage is 0.02 - 8.7 kg, with an average value of 1.0 kg.

- The contribution from maritime sources has not been assessed in this report because of a lack of data. Reports from the 1990s already estimated a fishing gear loss of 3,000 tonnes year^{-1} (Golik, 1997), which is far below the order of magnitude of leakage from mismanaged waste, but close to the order of magnitude of microplastic leakage. The refugee crisis, beyond the humanitarian catastrophe, also represents another source of plastic leakage (through vessels that sink and abandoned safety flotation devices, Figure 4.10). This has not been quantified neither.

3.2.2. Annual macroplastic leakage: 216,000 tonnes year^{-1} (range 144,000–577,000)

The annual macroplastic leakage ($Leak_{waste}$) from waste is estimated at a central value of 216,269 tonnes year^{-1} (low value: 144,180 tonnes year^{-1}, high value: 576,718 tonnes year^{-1}); Each watershed contains in its vicinity dozens to hundreds of villages, towns or cities hosting

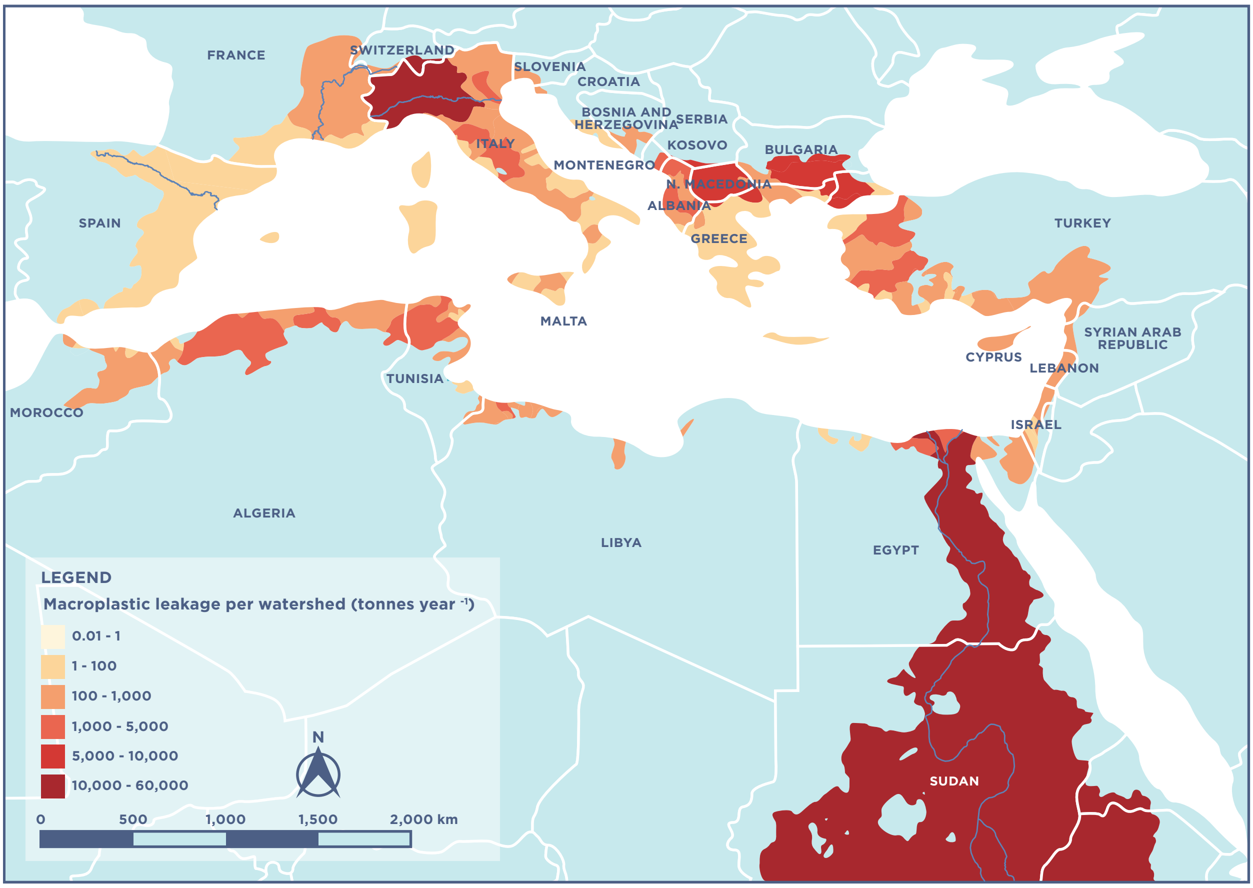


Figure 4.5: Leakage of macroplastic from mismanaged waste into the Mediterranean Sea, watershed view. For presentation purposes, the countries upstream of the Nile river are not shown. They are responsible for 9% of the total leakage.

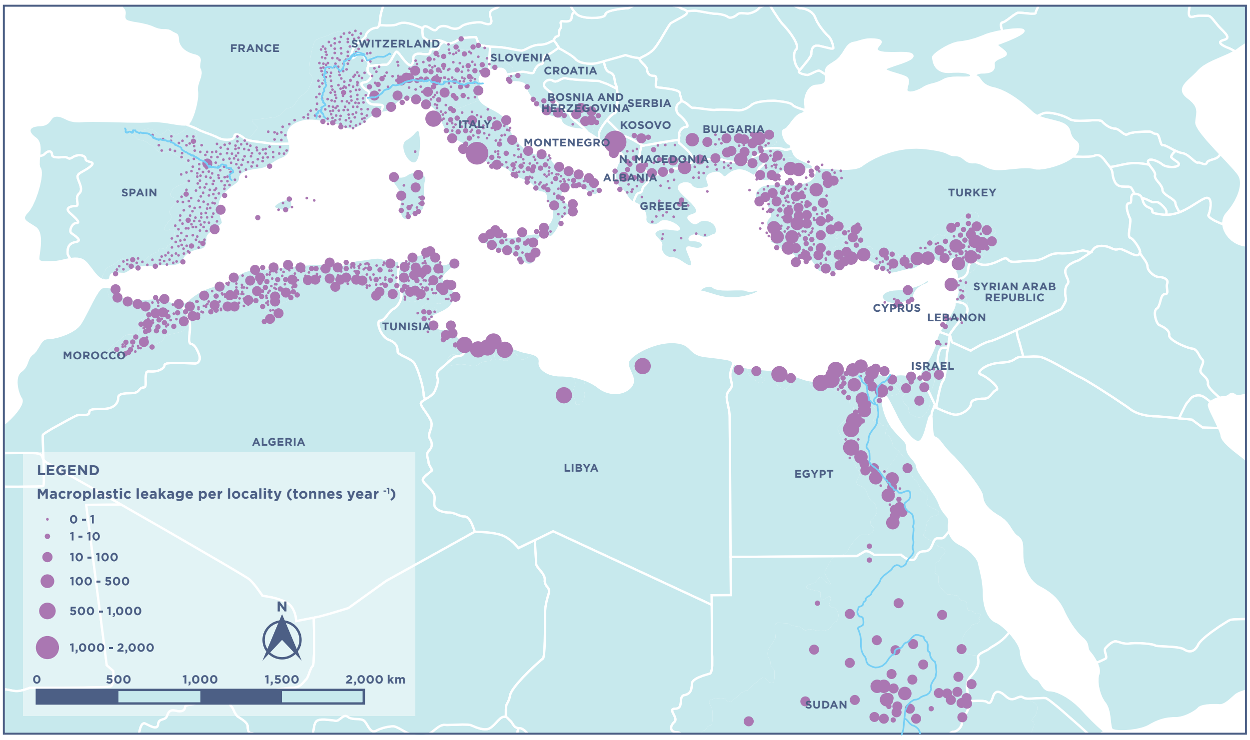


Figure 4.6: Leakage of macroplastic from mismanaged waste into the Mediterranean Sea, per locality view.

different population densities, which, in turn, consume goods and generate waste. Surface water run-off (e.g. rain) greatly fluctuates between watersheds, entailing significant differences in the total macroplastic leakage between countries. The parameters used to compute low/central/high estimates are provided in Appendix 1.7.

The top three contributors to the overall leakage are:

- Egypt: 74,031 tonnes year^{-1}
- Italy: 34,309 tonnes year^{-1}
- Turkey: 23,966 tonnes year^{-1}

Cities and towns directly located in coastal areas (defined as areas < 23 km from the coast) are responsible for 35% of the total macroplastic leakage. The remaining 65% is generated further inland and carried by surface run-off directly towards the marine environment.

Surface run-off has been identified as a key contributor density high leakage, although not in all cases. For instance, run-off rates for Egypt, averaging 0.11 mm.day^{-1}, do not explain the considerable leakage generated by this country. A high population (85 million) and a high mismanaged waste index (95%) explain Egypt's significant contribution to the overall leakage.

For a detailed presentation of the results per country, a table is available in Appendix 1.5. Detailed results, both per watershed and per locality are respectively presented in Figure 4.6 and Figure 4.7.

Watershed information: it appears that the watersheds hosting major rivers connected to the Mediterranean Sea present the highest leakage rates. The watersheds of the Nile, the Po and the Rhone rivers are responsible for macroplastic exports ranging from 900 tonnes year^{-1} (Rhone) to 55,000 tonnes year^{-1} (Nile). On a wider scale, it appears that all, watersheds export plastic debris into the marine environment in variable concentrations. In some cases, countries with a low population density present very high leakage rates per capita, i.e. emitted by each inhabitant of the country. This can be seen for Bosnia and Herzegovina and Montenegro, with an annual leakage of 3 and 8 kg per inhabitant respectively.

Table 4.1: The top 10 contributing localities and the total waste leakage into the Mediterranean Sea.

Rank	Locality	Country	Income level	$Leak_{waste}$ tonnes $year^{-1}$
1	Muntazah	Egypt	UMC	1,912
2	Roma	Italy	HIC	1,809
3	Podgorica	Montenegro	UMC	1,662
4	Tirana	Albania	UMC	1,123
5	Skopje	North Macedonia	UMC	1,029
6	Waraq	Egypt	UMC	991
7	Umraniyya	Egypt	UMC	918
8	Tripoli	Libya	UMC	885
9	Kafr Al-Dawwar	Egypt	UMC	875
10	Al-Husayniya	Egypt	UMC	871

Locality information: when compared to the watershed mapping, it appears that some localities show high leakage even though they are not in a watershed or country that otherwise ranks high in the leakage assessment.

This can be the case when a densely populated city is located within a watershed with relatively few inhabitants (e.g. Libya). Thus, representing the leakage with different levels of granularity is key in order to shape interventions. Indeed, these key localities should be made a priority for urgent remediation. The top 100 localities are responsible for 54% of the total macroplastic leakage, with 38% of them located in the coastal areas defined in this study. The list of the top 100 localities contributing to plastic leakage in the Mediterranean Sea (based on our modelling approach and its underlying assumptions) is provided in Appendix 1.8.

3.2.3. Annual microplastic leakage 13,000 tonnes $year^{-1}$ (range 4,000–33,000)

In addition to macroplastic pollution, the Mediterranean Sea is facing microplastic contamination. Of the four main sources investigated in this report, tyre dust appears as the largest contributor. Leakage in the form of microplastics ($Leak_{micro}$) is estimated at 13,196 tonnes $year^{-1}$ for the central estimate (respectively 3,875 and 33,393 tonnes $year^{-1}$ for the low and high estimates). The parameters used for computing low/central/high estimates are provided in Appendix 1.7.

For a detailed presentation of the results per country, a table is available in Appendix 1.6. Below, the results are presented both by watershed (Figure 4.8) and locality (Figure 4.9).

Watershed information: Some of the patterns already identified for macroplastic leakage can be seen for microplastic fluxes. Indeed, the watersheds hosting major rivers are still prone to considerable leakage (from 1,000 to 7,000 tonnes $year^{-1}$). However, some uncertainties remain.

The Nile river catchment is considered as one of the 10 most contributing rivers to ocean plastic leakages (Schmidt et al., 2015), yet it is not known whether the several dams along this river (11 main dams) play a role in mitigating this leakage (by preventing plastic debris from reaching the open sea).

Given the large drainage basin of the Nile River (eight countries) there is a need to prioritise the most appropriate locations for action to abate most of the leakage and to test the solutions by involving local communities. Implementing technologies/solutions to recover floating plastic upstream of dams could be an effective option

Table 4.2: Top 10 contributing localities in total microplastic leakages, per year.

Rank	Locality	Country	Income level	$Leak_{micro}$ tonnes year^{-1}
1	Roma	Italy	HIC	202
2	Milano	Italy	HIC	94
3	Torino	Italy	HIC	67
4	Tripoli	Libya	UMC	54
5	Palermo	Italy	HIC	49
6	Genova	Italy	HIC	44
7	Valencia	Spain	HIC	42
8	Zaragoza	Spain	HIC	36
9	Khartoum	Sudan	LMC	31.6
10	Malaga	Spain	HIC	31.1

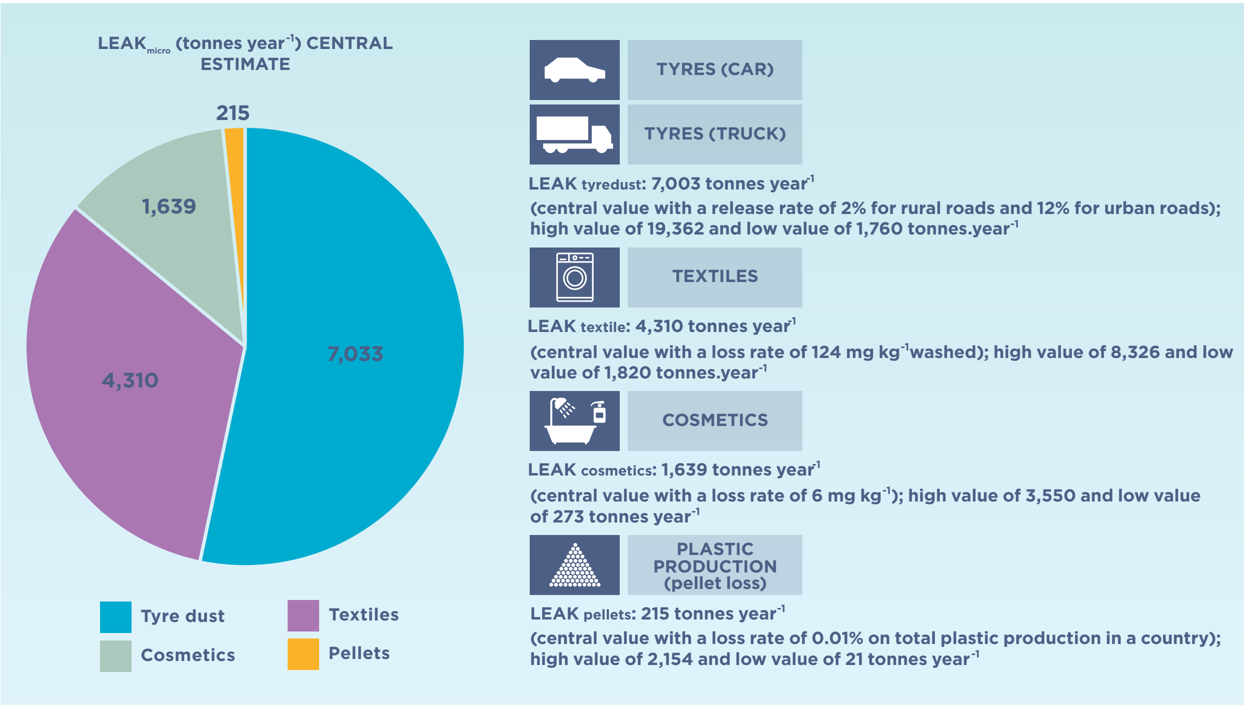


Figure 4.7: Primary microplastic leakage per type, investigated in this report.

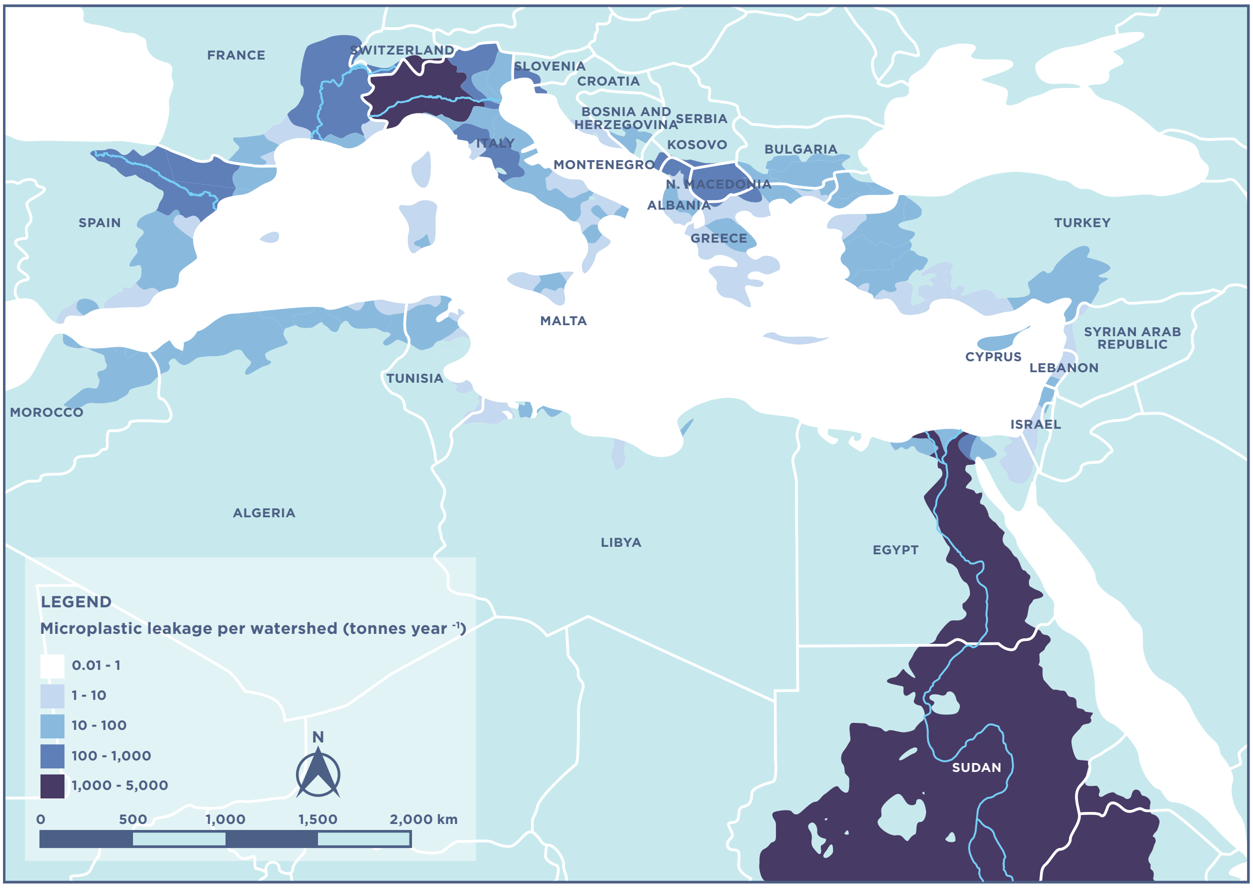


Figure 4.8: Leakage of microplastics into the Mediterranean Sea, watershed view.

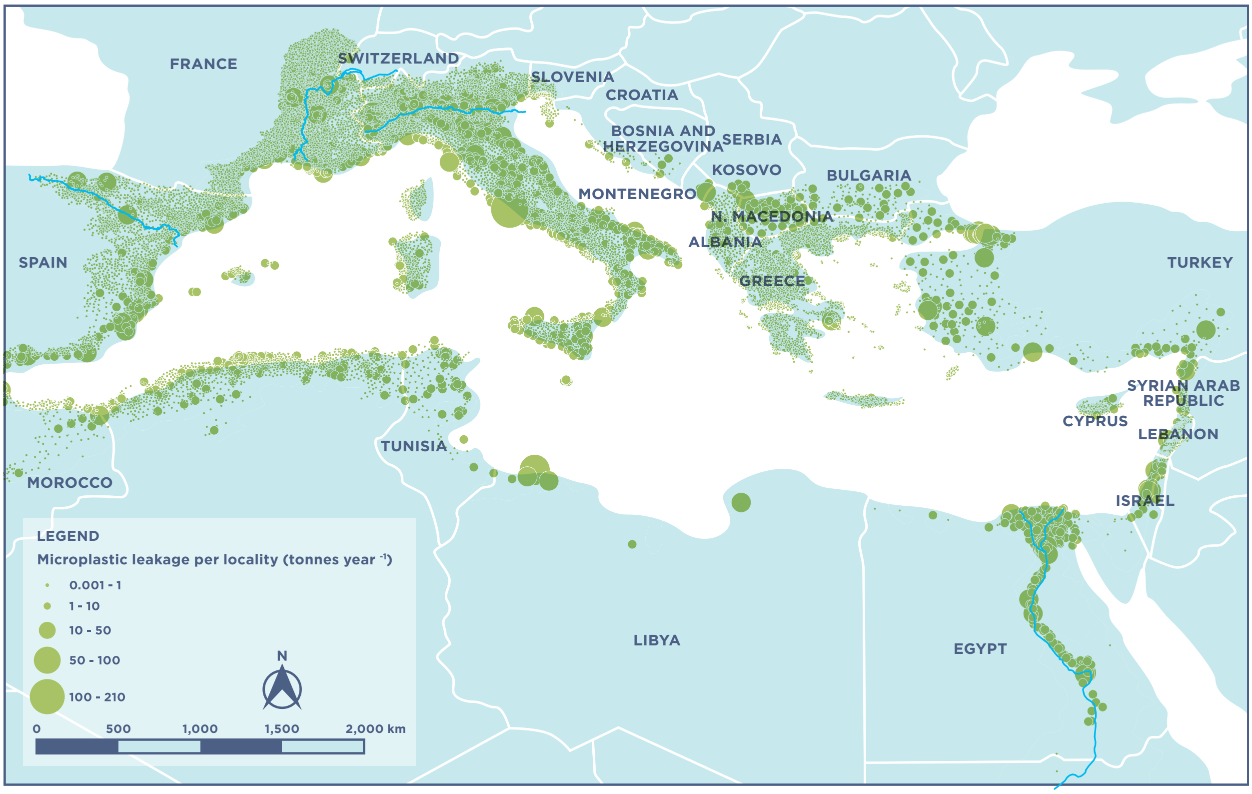


Figure 4.9: Leakage of microplastics into the Mediterranean Sea, locality view.

to mitigate ocean plastic leakage from the Nile watershed.

Locality information:

Microplastic leakages follow the same patterns as macroplastic waste fluxes: highly populated localities emit the most plastic into the sea. Areas with high levels of consumption are usually linked to significant microplastic leakage. In fact, all but two of the top ten contributing localities are located in high income countries (Table 4.2).

Libya and Sudan both lack efficient waste-water treatment (8% and 1% wastewater treatment respectively), which could explain the high fluxes of microplastics (e.g. textile and cosmetics). It is also worth noting that 35% of the 100 top contributing localities are located in coastal areas.

3.3. Key takeaway points from the plastic footprint assessment and knowledge gaps

Uncertainties underlying these conclusions stem from two main causes: the structural uncertainties and the parametric uncertainties.

The structural uncertainties in the model primarily result from three aspects:

1. Our fragmented understanding of the leakage pathways. Indeed the release rate matrix used in the model (Boucher, Billard, et al., 2019), allowing the calculation of more region-specific release rates based on distance to shore and catchment run-off, has not been calibrated and relies mainly on expert judgement.

Overarching question	Level of certainty green: very probable orange: probable red: uncertain	Assertion
How much plastic is leaking into the Mediterranean Sea every year?	green	The quantity of plastic flowing every year into the Mediterranean Sea is in the order of magnitude of 229,000 tonnes year-1, with a low and high estimate of 150,000 and 610,000 respectively.
	green	Leakage into the Mediterranean Sea is dominated by macroplastics from mismanaged waste (94%) as the average mismanaged waste fraction in the basin is very high (67%).
Where are the key plastic leakage hotspots?	orange	Based on current waste management information, the three hotspot countries for macroplastic leakage are Egypt, Italy and Turkey, together contributing over 50% of the total leakage. The ten most contributing countries are responsible for over 80% of the total leakage in the Mediterranean basin.
	orange	For primary microplastics (13,196 tonnes year^{-1}), tyre dust is the largest source of leakage (53%), followed by textiles (33%), microbeads in cosmetics (12%), and production pellets (2%). The three most contributing countries are Italy (3,000 tonnes year^{-1}), Egypt (1,200 tonnes year^{-1}) and Uganda (990 tonnes year^{-1}).
	orange	The Nile watershed represents a significant input of total leakage into the Mediterranean Sea (25% of total inputs).
	orange	The top 100 localities generate 23% of the total microplastic leakage, a key finding that could serve to prioritise action. The coastal areas are responsible for 30% and 35% of microplastic and macroplastic leakage respectively.
	orange	Per capita leakage is more significant in countries with a high proportion of mismanaged waste and with a high proportion of their population living in coastal areas (e.g. Montenegro). Mean per capita leakage of macroplastics is 1 kg year^{-1}, ranging from 0.02 kg year^{-1} for Ethiopia to 8.7 kg year^{-1} for Montenegro. Mean per capita leakage of microplastics is 40 grams year^{-1}; ranging from 10 grams (Serbia) to 200 grams year^{-1} (Malta).

2. Littering rates are considered as being constant for all countries (2%). It is known that this parameter may vary widely from one country to another (due to culture and differing street cleaning and sweeping operations), as illustrated in Figure 4.10.

3. The model does not account for maritime sources because of a lack of data. It is therefore not possible to estimate the relative importance of this source, which may influence the overall conclusions of the study.

The parametric uncertainties in the model result from the following data-related challenges:

1. The results are mainly driven by the mismanaged waste index (MWI). In general, this index is very high in the Mediterranean basin (67%), with a few countries displaying a comparatively lower index in the north-western sector. This study used waste management data provided by the World Bank (Silpa et al., 2018) extrapolated to plastic. The data rely on the information provided by each country based on its own waste generation patterns. To fine-tune this data, a case-by-case waste characterization should be conducted to see if the data reflect the reality for plastic.

2. Microplastic estimates are still uncertain. Such uncertainty applies to, for example, the loss rate of plastic pellets as the plastic industry cannot currently provide better estimates.

3. The parameters for tyre dust rely on a study that is not necessarily representative of the whole study area (Boucher, Billard, et al., 2019; Unice et al., 2018a; 2018b). As previously stated, this report has relied on the best available data and some future research is required.

To compare the predictions of the model and the concentrations reported in the literature, a measure of ground-truthing is required. As previously stated, microplastic data, as well as the parameters required to calculate the leakage (e.g. road coverage), would benefit from a higher level of precision.

This study has considered only areas with direct contact to the sea. We refer to this methodology as the *watershed approach*. Waste generation data, population numbers and environmental parameters are all factors that are input into the model to calculate plastic leakages.

As it has focused on a smaller scale, this report presents lower orders of magnitude that some

Littering in Italy | Overflowing bin in Switzerland | Refugees in Greece

Figure 4.10: Multiple examples of plastic leakage pathways: not everything can be modelled in a plastic leakage assessment (photos from the author – © Julien Boucher).

previous reports (e.g. WWF, 2019; plastic leakage into the Mediterranean Sea of 570,000 tonnes). These differences are attributed to the different scale used (such as the size of the population targeted) and release rates into the environment. Here we have created a granular matrix with fluctuating release rates based on the distance to the shore and other parameters, with a maximum release rate of 15% for our central estimate. Waste data has been based on the *What a Waste* report of the World Bank (Silpa et al., 2018). However, both reports are in the same orders of magnitude, and the conclusions remain the same with Egypt, Italy and Turkey being the three most contributing countries.

It is worth pointing out that the results of the bottom-up approach (Chapter 3) and those of the top-down approach (Chapter 4) Validate each other, as illustrated in Figure 4.11. This adds credibility to the results in spite of the embedded uncertainties discussed above. Indeed, the stock of plastic currently accumulated in the Mediterranean (1,178,000 tonnes for the central estimate), matches the order of magnitude of ten years of leakage (based on 229,000 tonnes year^{-1} for the central estimate). This comparison can only be made for a small-scale basin with limited exchanges with other water bodies. Similar results have been shown for Lake Geneva (Boucher, Faure, et al., 2019).

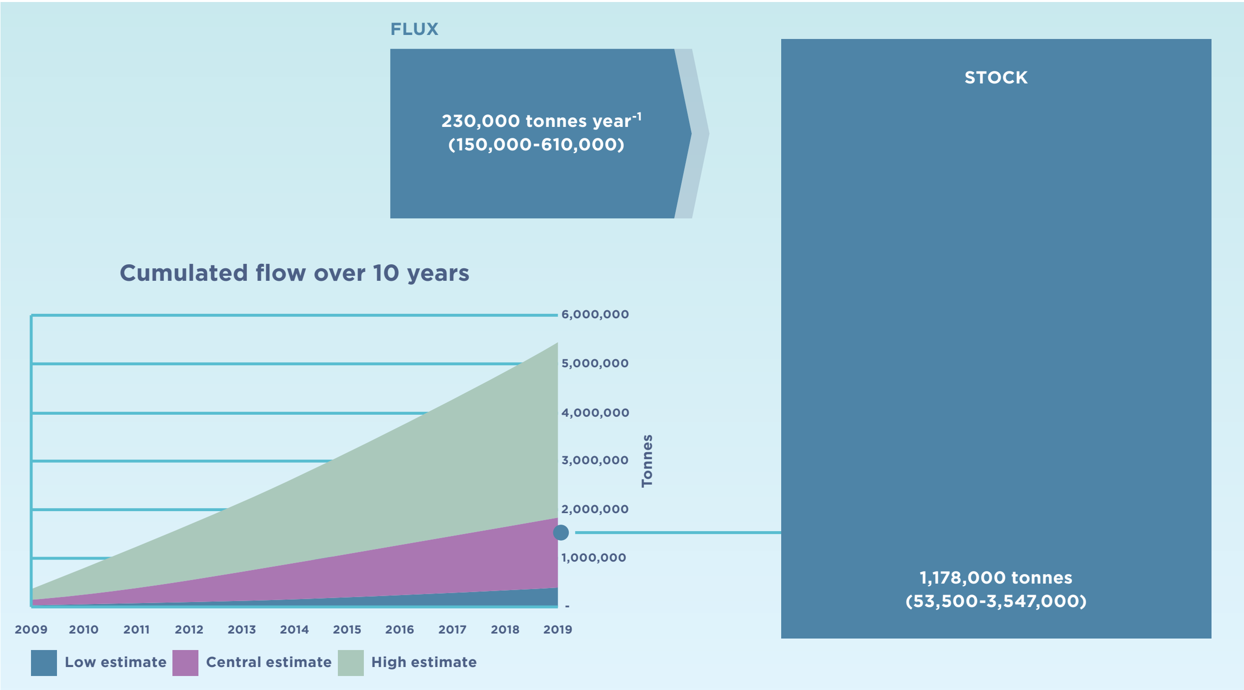
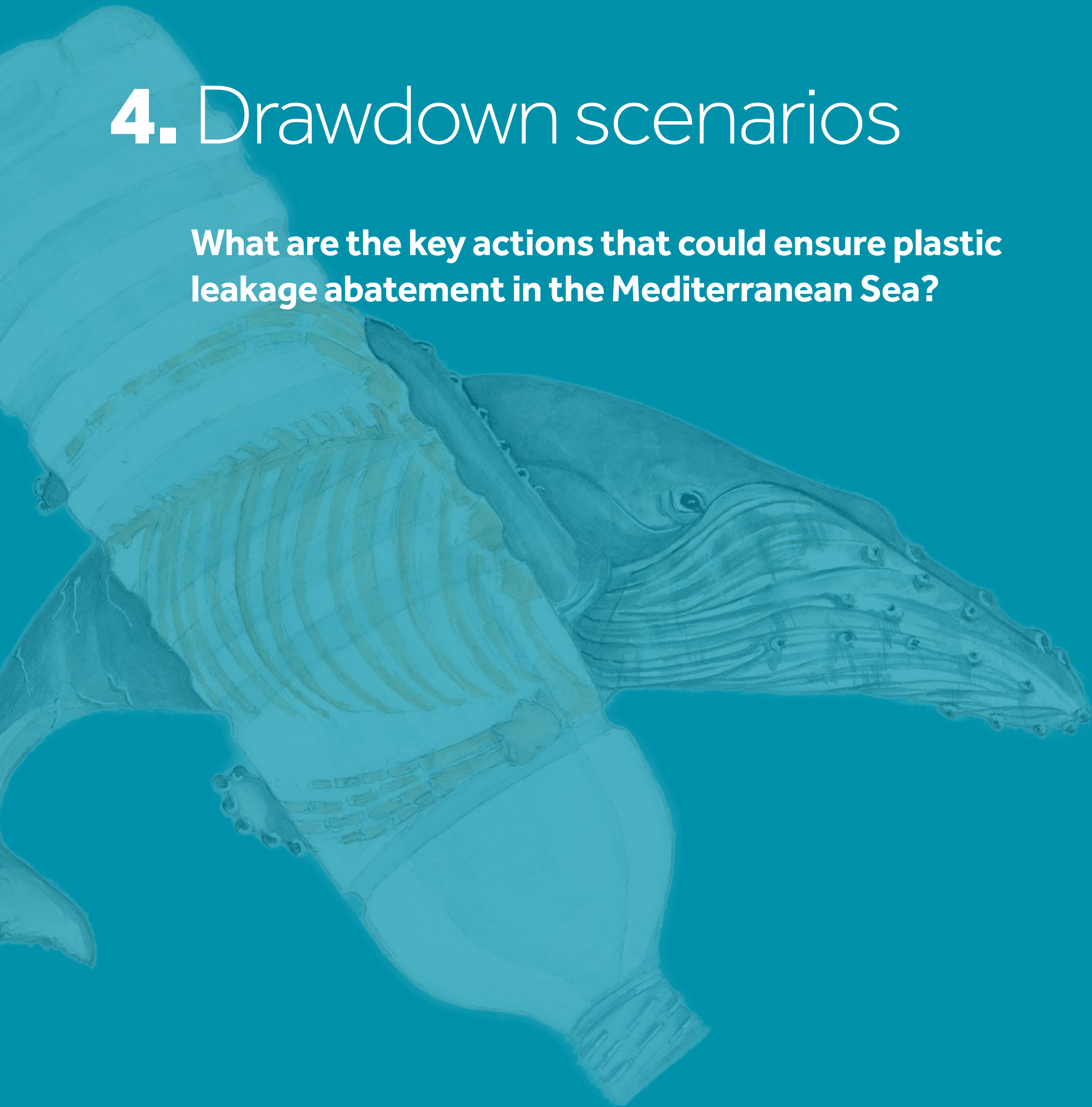


Figure 4.11: Comparison of the top-down (flux) and bottom-up approaches (stock), with a plastic production growth rate of 4%.

4. Drawdown scenarios

What are the key actions that could ensure plastic leakage abatement in the Mediterranean Sea?



4.1. Inventory and assessment of key high-level actions to mitigate plastic leakage in the Mediterranean Sea

Various solutions have been put into practice in the Mediterranean region, including bans and taxes on certain plastic goods, improvements to recycling and collection facilities, and clean-ups targeting plastic waste on beaches and in the sea (for a review see Appendix 1.10).

This section intends to model a set of these interventions that could be applied to the Mediterranean basin in order to mitigate plastic leakage. Figure 5.1 below summarises the key actions that have been studied: five actions concern bans, two actions concern lifestyles and behaviours, three actions concern waste and wastewater management, and finally one action is related to clean-up activities (post-leakage intervention). They represent high-level potential actions for the purpose of identifying orders of magnitude of potential leakage savings, and thus prioritising further research and actions. The description of these actions and the quantitative hypotheses used are provided in Figure 5.1, together with the result in terms of leakage reduction per year; detailed data sources are provided in Appendix 1.9 and Appendix 1.10.

We conclude that the most efficient actions are related to the improvement of waste management, a global ban on plastic bags, and the collection of floating debris in the Nile river (taking advantage of the presence of multiple dams on the river). Furthermore, action 9 shows that addressing the waste management in the 100 most contributing cities around the Mediterranean basin would eliminate a quarter of the total leakage. The list of these target cities is provided in Appendix 1.8.

The results also show that current planned interventions consisting of bans of some specific items are far from sufficient for solving the plastic crisis and restoring a healthy Mediterranean Sea.

4.2. Leakage drawdown scenario over the next 20 years

Plastic pollution is now global and is expected to rise in future as plastic production is forecast to increase by 4% every year (PlasticsEurope, 2017).

		ACTION	DESCRIPTION	MAIN HYPOTHESIS	CALCULATION ROUTE FOR LEAKAGE (if applicable)	RESULT Plastic use reduction per year (tonnes)	RESULT Leakage reduction per year (tonnes)
1	BANS	Ban straws	Ban plastic straws or small plastic items	N_{straw}: 26 straws per capita used (conservative asumption) | W_{straw}: 0.5 g per straw | population of the basin: 450 million inhabitants (P) | MWI 67% and	$N_{straw} * W_{straw} * P$	5,850	211
2	BANS	Ban plastic bags (current commitments)	Current commitment	Appendix 1.10	Appendix 1.11	480,642	1,453
3	BANS	Ban plastic bags (global ban)	Full ban in the watershed	Average per capita use: N_{bag}=365 bags | weight of a bag W_{bag}: 8.5 g | population of the basin: 450 million inhabitants (P) | MWI 67% and RR=5.4%	$N_{bag} * W_{bag} * P$	1,396,125	50,315
4	BANS	Ban microbeads (current commitment)	Full ban in the watershed	Bans in all EU countries	(based on the GIS model)		488
5	BANS	Ban microbeads (global ban)	Full ban in the watershed	Average per capita use: $Q_{microbeads}$=6 g | population of the basin: 450 million inhabitants (P) | Share of wastewater treatment in the watershed	$Q_{microbeads} * P * ((1-SWT) + (SWT * RR_{WWTP}))$	2,700	1,597
6	PLASTIC-FREE LIFESTYLE & CITIZEN BEHAVIOUR	Decrease of the growth rate of the plastic production as a result of relying society prelying less on plastic	Reduce plastic production (by reducing consumption)	Plastic production growth rate reduced from 4% to 2%, assuming a linear reduction of leakage, based on annual leakage of 216 269 tonnes	(based on the GIS model)		4,325
7	PLASTIC-FREE LIFESTYLE & CITIZEN BEHAVIOUR	Campaigns to reduce littering	Reduce littering by 80%	Set littering rate to 0.4% instead of 2%	(based on the GIS model)		5,165
8	WASTE AND WASTEWATER MANAGEMENT	Improve waste collection and management by 10%	Improve waste collection and management on average by 10%	MWI reduced from 67% to 57% as the average in the Mediteranean basin	(based on the GIS model)		32,279
9	WASTE AND WASTEWATER MANAGEMENT	Improve waste collection and management in 100 key cities	Achieve the waste management standards of high income countries in the 100 most polluting cities	MWI reduced from an average of 67% to 6% in the Mediterranean basin	(based on the GIS model)		52,779
10	WASTE AND WASTEWATER MANAGEMENT	Improve waste collection and management (up to best in class standard)	General improvement across all countries so that the average mismanagement index reaches that of high income countries	MWI reduced from 67% to 6% as average in the Mediteranean basin	(based on the GIS model)		196,902
11	WASTE AND WASTEWATER MANAGEMENT	Improve wastewater collection and treatment	95% of water treated throughout the basin	Share of wastewater treated SWT=95%	(based on the GIS model)		522
12	CLEAN-UPS	Waste capture at Nile river dams	The Nile, a big contributor to leakage, has 13 dams that offer great potential for recovery of floating waste	Recovery of 80% of plastic waste floating on the Nile river	(based on the GIS model)		44,023

Figure 5.1: Key actions for reducing the plastic leakage into the Mediterranean Sea and quantification of the associated annual benefits (baseline 2018).

This will inevitably influence waste production and increase the fraction released into the environment if nothing is done to turn the tide on plastic pollution. For this reason, the efficiency of the interventions must be considered over time, considering different growth rates of the plastic industry.

Figure 5.2 and Figure 5.3 show the drawdown analysis from 2018 to 2040 of the different scenarios for annual growth rates of plastic production of 4% and 1%, respectively. Improving waste management by 4% in the entire Mediterranean basin would greatly contribute to the reduction of plastic leakage.

The purpose of the analysis is not to compare one scenario against another, but rather to lay down all possible solutions to closing the plastic tap. These measures would have the greatest impact if combined and implemented together. Doing so would constitute a challenge and would not produce results overnight: marine plastic pollution has high inertia, and only by acting now will we have the ability to reduce this inertia to its minimum before environmental thresholds are exceeded.

The figures show that:

- with a growth rate of 4%, the only action shown to deliver an improvement on

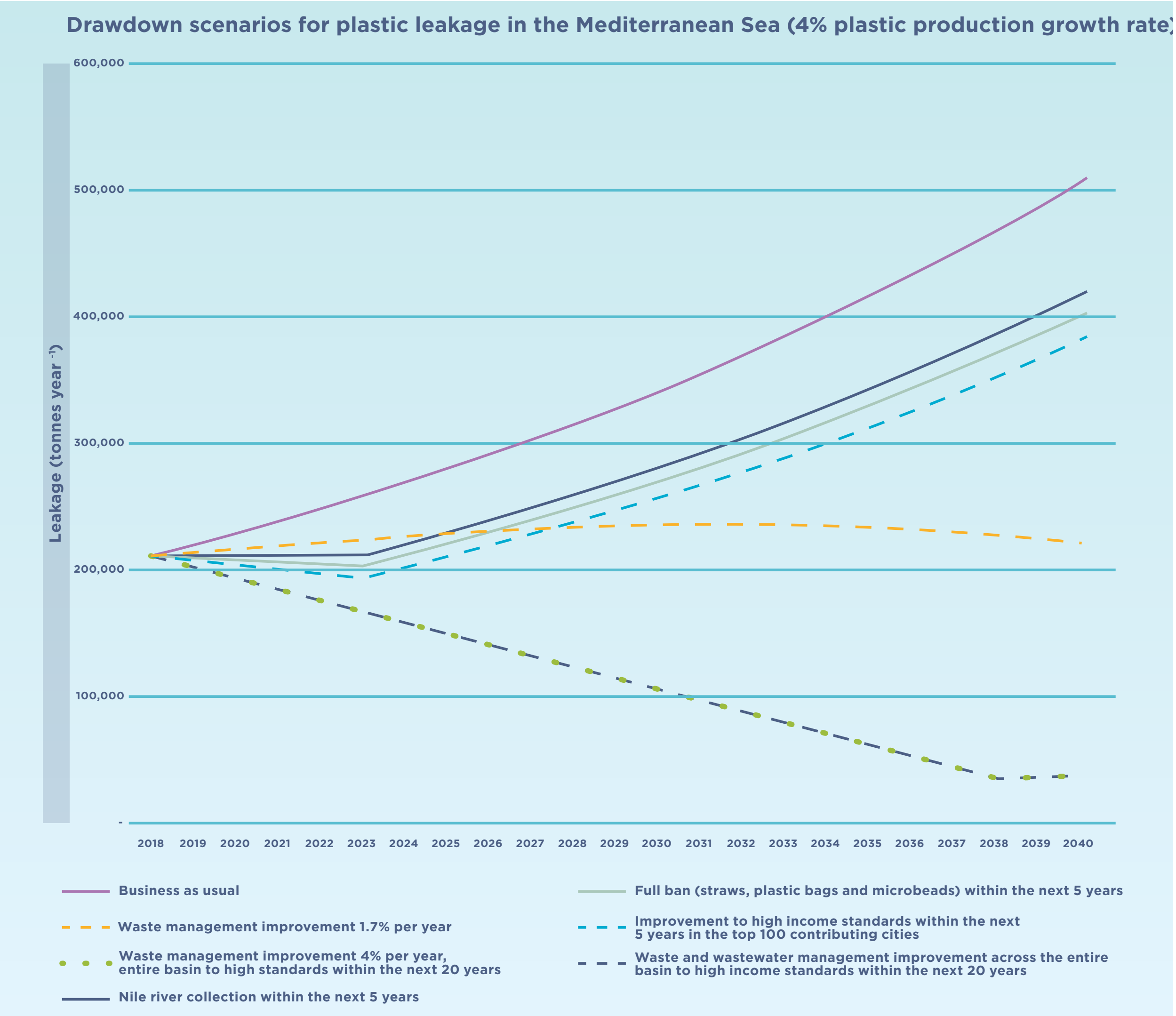


Figure 5.2: Drawdown analysis from 2018 to 2040 of the different scenarios and using a 4% annual growth rate for plastic production.

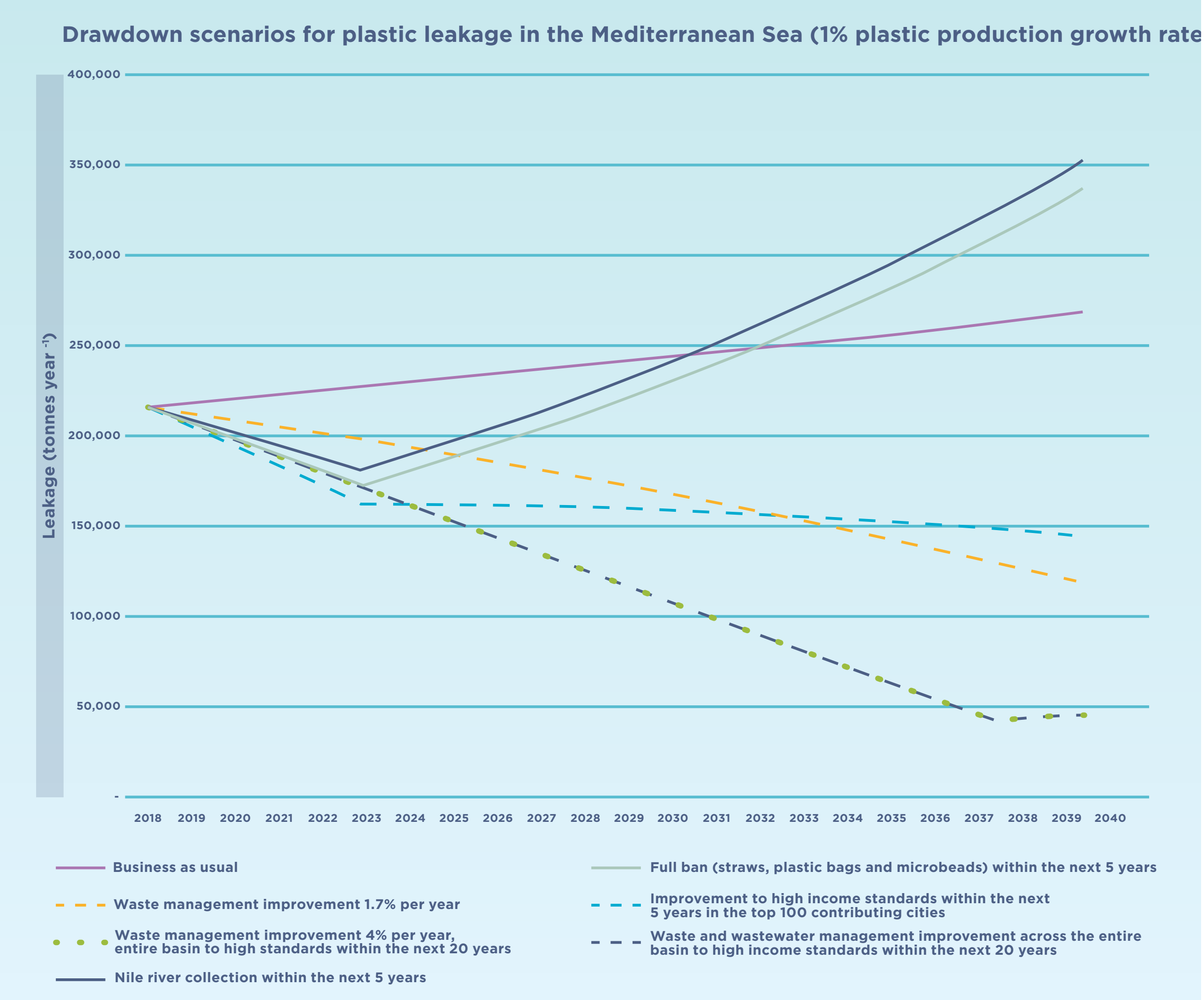


Figure 5.3: Drawdown analysis from 2018 to 2040 of the different scenarios and using a 1% annual growth rate for plastic production.

the baseline leakage (2018) is a radical improvement in waste collection and management in all countries bordering the Mediterranean Sea. With the same growth rate in plastic production and use, stabilising the leakage with respect to the 2018 baseline would require decreasing the level of mismanagement by 1.7% per year throughout the Mediterranean basin.

- When considering a growth rate of 1% for the production and use of plastic, the situation is more favourable, with six of the tested scenarios showing an improvement with respect to the 2018 baseline.
- Without radical intervention, the leakage will easily double and reach over 500,000 tonnes per year by 2040.

4.3. Keytake away points from the drawdown assessment and knowledge gaps

The key findings of our assessment are summarised in the table below.

Uncertainties related to our assessment of the drawdown scenarios stem from the plastic footprint model and the underlying data; they are listed in section 4.3.

Overarching question	Level of certainty green: very probable orange: probable red: uncertain	Assertion
Is the current effort enough to reduce the leakage?	green	Current and planned measures are not significantly reducing plastic leakage into the Mediterranean Sea.
	green	Reducing the leakage level in 20 years to below current levels requires implementing a set of ambitious interventions on the downstream side (waste management and post-leakage collection), as well as reducing the growth rate of plastic production and use in the Mediterranean basin.
	green	Without radical intervention the annual leakage is expected to double over the next 20 years.
What are the most efficient interventions?	green	Improving waste management, starting with waste collection, should be the priority as this is the intervention showing the greatest leakage abatement over time.
	orange	Considering a growth rate of 4% for plastic production and use, stabilising the leakage to the 2018 level would require reducing the mismanaged waste index by 1.7% per year.
	orange	Bans can be effective as interventions if widely implemented – a full plastic ban in the basin would reduce plastic leakage by 23%.
	orange	Improving waste management in the top 100 contributing cities would deliver a reduction of 25% in the plastic leakage in the Mediterranean basin.
	red	Post-leakage management in rivers can be an efficient intervention, with the Nile river alone representing a potential abatement of 20%.

Appendices

Appendix 1.1 Sea surface data

Sea surface concentrations extracted from the literature. Other concentrations in this table labelled as "Oceaneye" are courtesy of Oceaneye, a Swiss non-profit organisation collecting citizen science data across the Mediterranean Sea. The level of detail regarding sampling methodologies and sea-state conditions vary between studies. No concentration is corrected for wind if the study does not provide information on sea-state/wind conditions during sampling.

Surface concentrations (grams km^{-2})	Surface concentrations (items km^{-2})	Wind mixing correction applied	Numerical abundances to mass transformation equation (Cózar et al., 2015)	Only sampled during low wind conditions (< 9 knots)	Chosen value for surface concentrations	Author (et al.)	Title
	116,000	No	137.4	Not stated	137.4	Collignon	Neustonic microplastic and zooplankton in the North Western Mediterranean Sea
	470,000	No	746.9	Not stated	746.9	Fossi	Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (*Balaenoptera physalus*)
	310,000	No	451.4	Not stated	451.4	Fossi	Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (*Balaenoptera physalus*)
	150,000	No	187.5	✓	187.5	De Lucia	Amount and distribution of neustonic microplastic off the western Sardinian coast (Central-Western Mediterranean Sea)
	62,000	No	64.4	✓	64.4	Collignon	Annual variation in neustonic micro- and mesoplastic particles and zooplankton in the Bay of Calvi (Mediterranean–Corsica)
	69,197	Yes	73.5	No	73.5	Eriksen	Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
	22,592	Yes	19	No	19	Eriksen	Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
	10,563	Yes	7.6	No	7.6	Eriksen	Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
88	2.7	Yes	0	No	88	Eriksen	Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
26	0.3	Yes	0	No	26	Eriksen	Plastic Pollution in the World's Oceans: More than 5 Trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea
	103,000	No	119	✓	119	Pedrotti	Plastic fragments on the surface of Mediterranean waters
62	129,682	Yes	157.2	No	62	Faure	An evaluation of surface micro- and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea
	5,700	Yes	3.6	No	3.6	Faure	An evaluation of surface micro- and mesoplastic pollution in pelagic ecosystems of the Western Mediterranean Sea

Surface concentrations (grams km^{-2})	Surface concentrations (items km^{-2})	Wind mixing correction applied	Numerical abundances to mass transformation equation (Cózar et al., 2015)	Only sampled during low wind conditions (< 9 knots)	Chosen value for surface concentrations	Author (et al.)	Title
468	820,000	Yes	1,464.6	No	468	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
351	840,000	Yes	1,507.9	No	351	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
691	790,000	Yes	1,400	No	691	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
400	950,000	Yes	1,750	No	400	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
1,320	3,980,000	Yes	9,905.1	No	1,320	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
408	1,200,000	Yes	2,321.7	No	408	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
2,614	3,130,000	Yes	7,406.4	No	2,614	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
969	2,340,000	Yes	5,209	No	969	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
115	870,000	Yes	1,573.3	No	115	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
335	930,000	Yes	1,705.5	No	335	Suaria	The Mediterranean Plastic Soup: synthetic polymers in Mediterranean surface waters
	144,098	No	178.6	✓	178.6	Pedrotti	Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land
	113,460	No	133.8	✓	133.8	Pedrotti	Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land
	77,176	No	83.9	✓	83.9	Pedrotti	Changes in the Floating Plastic Pollution of the Mediterranean Sea in Relation to the Distance to Land
	370,000	No	559.1	✓	559.1	Gundogdu	Micro- and mesoplastics in Northeast Levantine coast of Turkey
	1,518,340	No	3,086.4	Not stated	3,086.4	Van Der Hal	Exceptionally high abundances of microplastics in the oligotrophic Israeli Mediterranean waters
	96,000	No	109.3	Not stated	109.3	Schmidt	Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea)
	212,000	No	285	Not stated	285.0	Schmidt	Occurrence of microplastics in surface waters of the Gulf of Lion (NW Mediterranean Sea)

Surface concentrations (grams km^{-2})	Surface concentrations (items km^{-2})	Wind mixing correction applied	Numerical abundances to mass transformation equation (Cózar et al., 2015)	Only sampled during low wind conditions (< 9 knots)	Chosen value for surface concentrations	Author (et al.)	Title
	140,418	No	173.1	✓	173.1	Guven	Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish
	1,067,120	No	2,014.4	Not stated	2,014.4	Gundogdu	High level of microplastic pollution in the Iskenderun Bay, NE Levantine
41	69,161	Yes	73.5	✓	41	Baini	Abundance and characterization of microplastics in the coastal waters of Tuscany (Italy): The application of the MSFD monitoring protocol in the Mediterranean Sea
298	875,466	Yes	1,585.3	No	298	Ruiz Orejon	Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain)
161	23,299	Yes	19.7	No	161	Ruiz Orejon	Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain)
706	2,897	Yes	1.6	No	706	Ruiz Orejon	Now, you see me: High concentrations of floating plastic debris in the coastal waters of the Balearic Islands (Spain)
	300,000	No	433.8	✓	433.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	100,000	No	114.8	✓	114.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	1,040,0000	No	3,1667.2	✓	31,667.2	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	2,100,000	No	4,569.7	✓	4,569.7	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	4,300,000	No	10,876.7	✓	10,876.7	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	300,000	No	433.8	✓	433.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	200,000	No	265.6	✓	265.6	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	100,000	No	114.8	✓	114.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea

Surface concentrations (grams km^{-2})	Surface concentrations (items km^{-2})	Wind mixing correction applied	Numerical abundances to mass transformation equation (Cózar et al., 2015)	Only sampled during low wind conditions (< 9 knots)	Chosen value for surface concentrations	Author (et al.)	Title
	100,000	No	114.8	✓	114.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	300,000	No	433.8	✓	433.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	100,000	No	114.8	✓	114.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	200,000	No	265.6	✓	265.6	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	100,000	No	114.8	✓	114.8	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	600,000	No	1,003.6	✓	1,003.6	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
	300,00	No	26.7	✓	26.7	Vianello	First evaluation of floating microplastics in the Northwestern Adriatic Sea
290	110,000	Yes	128.9	No	290	De Haan	Floating microplastics and aggregate formation in the Western Mediterranean Sea

+ 132 data points from Oceaneye
Median: 281 grams km^{-2}
Total sea surface loading: 705 tonnes

Appendix 1.2 Seafloor data

The data presented below has been extracted from the literature, targeting mainly macroplastics and mesoplastics on the seafloor. Microplastics have not been included, and indeed a specific database for microplastics sampled within seafloor sediments was created and extrapolated. We believe that extrapolating the three size spectrums together would not reflect a true picture, as the mass of debris would greatly vary.

Average items km^{-2}	Total items	Total weight (kg)	Average weight (g/km^2)	Author (et al.)	Title
		362.81	25,530	Loulad	Quantity and spatial distribution of seafloor marine debris in the Moroccan Mediterranean Sea
		56.8	0	Garcia Riviera	Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor
			25,000	Garcia Riviera	Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor
			3,000	Garcia Riviera	Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor
			8,000	Garcia Riviera	Spatial and temporal trends of marine litter in the Spanish Mediterranean seafloor
860			75,000	Tunca Olgunera	Distribution and composition of benthic marine litter on the shelf of Antalya in the eastern Mediterranean
2,568			180,000	Tunca Olgunera	Distribution and composition of benthic marine litter on the shelf of Antalya in the eastern Mediterranean
1,491			158,000	Tunca Olgunera	Distribution and composition of benthic marine litter on the shelf of Antalya in the eastern Mediterranean
1,309			134,000	Tunca Olgunera	Distribution and composition of benthic marine litter on the shelf of Antalya in the eastern Mediterranean
92.4			7.5	Koutsodendris	Benthic marine litter in four Gulfs in Greece, Eastern Mediterranean; abundance, composition and source identification
1,438.5	253		1,102,000	Guven	Benthic Debris Accumulation in Bathyal Grounds in the Antalya Bay, Eastern Mediterranean
			8,600	Ramirez Llodra	Effects of natural and anthropogenic processes in the distribution of marine litter in the deep Mediterranean Sea
			60,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			400,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			110,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins

			120,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
40			70,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			180,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			120,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			170,000	Pham	Marine Litter Distribution and Density in European Seas, from the Shelves to Deep Basins
			5,800	Garcia Riviera	Composition, spatial distribution and sources of macro-marine litter on the Gulf of Alicante seafloor (Spanish Mediterranean)
			34,000	Strafella	Spatial pattern and weight of seabed marine litter in the northern and central Adriatic Sea
706	810.4		65,600	Pasquini	Seabed litter composition, distribution and sources in the Northern and Central Adriatic Sea
35.15	522		7,350	Alvito	Amount and distribution of benthic marine litter along Sardinian fishing grounds (CW Mediterranean Sea)

Appendix 1.3 Seafloor sediment microplastic data

Compared to macroplastic and mesoplastic pollution assessment, datasets for sediment microplastic are scarce and harder to extrapolate. The calculations in this report are based on the article by Mistri et al. (2017).

Because results are provided in mass per surface area (and not by average number of particles per kg of dry sediment), the average mass was extrapolated to the entire surface of the Mediterranean Sea. Low and high values were also derived.

Area	Average items km^{-2}	Average mass items grams m^{-2}	Average mass items kg km^{-2}	Average items.g dry sediment	Title	Author (et al.)
Balearic Islands				0.2	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Balearic Islands				0.1	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Balearic Islands				0.1	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Balearic Islands				0.1	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Balearic Islands				0.9	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Balearic Islands				0.2	Microplastics in the Mediterranean Sea: Deposition in coastal shallow sediments, spatial variation and preferential grain size	Alomar
Northern Adriatic				1.4	Microplastic particles in sediments of Lagoon of Venice, Italy: First observations on occurrence, spatial patterns and identification	Vianello
Malta Island				0.006	Environmental quality assessment of Grand Harbour (Valletta, Maltese Islands): a case study of a busy harbour in the Central Mediterranean Sea	Romeo
Northern Tunisia				7.96	The First Evaluation of Microplastics in Sediments from the Complex Lagoon-Channel of Bizerte (Northern Tunisia)	Abidli
Ligurian and North Tirrenian Sea				0.1	Plastic litter in sediments from the coasts of south Tuscany (Tyrrhenian Sea)	Cannas
Ligurian and North Tirrenian Sea				0.3	Plastic litter in sediments from the coasts of south Tuscany (Tyrrhenian Sea)	Cannas
Adriatic			153	0.2	Plastic litter in sediments from the Croatian marine protected area	Blaskovic
Ligurian and North Tirrenian Sea				0.5	Plastic litter in sediments from the coasts of south Tuscany (Tyrrhenian Sea)	Cannas
Northern Adriatic	28,430,000	1.1	1,107		Small plastic debris in sediments from the Central Adriatic Sea: Types Occurrence and distribution	Mistri
Northern Adriatic		0.001	1.3		Small plastic debris in sediments from the Central Adriatic Sea: Types Occurrence and distribution	Mistri
Northern Adriatic	11,220,000				Small plastic debris in sediments from the Central Adriatic Sea: Types Occurrence and distribution	Mistri
Northern Adriatic	2,500,000				Small plastic debris in sediments from the Central Adriatic Sea: Types Occurrence and distribution	Mistri
Northern Adriatic	87,500,000				Small plastic debris in sediments from the Central Adriatic Sea: Types Occurrence and distribution	Mistri

Appendix 1.4 Data on marine organisms investigated, with corresponding contamination rates as reported in the literature

Title	Author	Area	% contamination	Total items	Total weight (g)	Average item. ind^{-1}	Number individuals	Species
Ingestion of microplastics and natural fibres in *Sardina pilchardus* and *Engraulis encrasicolus* along the Spanish Mediterranean coast	Compa et al., 2018	Alboran Sea	14.28					*Engraulis encrasicolus Sardina pilchardus*
Microplastics in mussels and fish from the Northern Ionian Sea	Digka et al., 2015	Northern Ionian	47.2			1.8	36	*Sardina pilchardus*
High levels of microplastic ingestion by the semipelagic fish bogue *Boops boops* (L.) around the Balearic Islands	Nadal et al., 2016	Balearic Islands	57.8	731		3.75	337	*Boops boops*
As main meal for sperm whales: Plastics debris	De Stephanis et al., 2013	Northern Alboran Sea			17,927		1	*Physeter macrocephalus*

Appendix 1.5 Detailed results for macroplastic leakage per country

Country	Population considered	Plastic waste generation	Mismanaged plastic waste	Average RR	*Leak*$_{waste}$ in the sea (total)	*Leak*$_{waste}$ in the sea (from coastal areas)	*Leak*$_{waste}$ per capita
	(-)	(kg/hab/ year^{-1})	(tonnes)	(%)	(tonnes year^{-1})	(tonnes year^{-1})	kg/hab/ year^{-1})
Albania	2,775,059	38	80,403	11%	8,625	4,449	3.1
Algeria	24,968,872	52	288,844	5%	13,111	5,531	0.5
Bosnia and Herzegovina	299,126	39	9,077	10%	901	254	3.0
Croatia	712,728	90	3,143	10%	329	298	0.5
Cyprus	1,049,892	69	7,265	5%	332	299	0.3
Egypt, Arab Rep,	85,389,137	31	2,544,351	3%	74,031	18,114	0.9
Greece	7,412,979	70	10,438	6%	592	465	0.1
Israel	7,620,772	116	24,376	4%	1,009	833	0.1
Italy	53,903,276	56	409,453	8%	34,309	15,477	0.6
Montenegro	245,458	98	22,911	9%	2,146	252	8.7
France	14,824,564	45	13,508	7%	959	249	0.1
Lebanon	3,635,015	42	46,615	7%	3,321	2,939	0.9
Libya	3,703,229	26	74,386	4%	2,777	885	0.7
Malta	170,076	75	788	5%	35	35	0.2
Morocco	3,711,400	16	43,422	7%	2,824	1,536	0.8
Slovenia	145,647	49	615	12%	72	53	0.5
Spain	16,898,683	39	13,196	4%	570	405	0.0
Syrian Arab Republic	1,449,687	15	19,771	7%	1,357	1,290	0.9
Switzerland	1,879,377	109	40,78	8%	319	0	0.2
Kosovo	803,278	19	5,459	9%	491	0	0.6
North Macedonia	2,062,598	53	109,492	6%	6,632	0	3.2
Kenya	16,985,586	25	396,952	2%	5,954	0	0.4
Tanzania	11,295,978	8	84,908	2%	1,274	0	0.1
Burundi	6,274,984	10	54,216	2%	813	0	0.1
Sudan	34,028,098	9	260,869	2%	3,913	0	0.1
South Sudan	12,279,361	10	104,716	2%	1,571	0	0.1
Bulgaria	2,661,652	51	101,198	6%	5,566	0	2.1
Ethiopia	38,161,363	2	51,038	2%	766	0	0.0
Uganda	38,761,285	15	516,235	2%	7,744	0	0.2
Turkey	37,769,569	12	307,949	8%	23,966	17,354	0.6
Rwanda	9,724,007	15	127,235	2%	1,909	0	0.2
Serbia	12,570	33	414	4%	17	0	1.4
Tunisia	7,459,590	27	192,238	4%	8,034	5,794	1.1
Average		***41***		***5%***			***1.0***
Total	***449,074,896***		***5,929,558***		***216,269***	***76,511***	
					Contribution of coastal areas (%)	***35%***	

Appendix 1.6 Detailed results for microplastic leakage per country

Country	Population considered	Tyre dust	Textile	Cosmetics	Pellets	$Leak_{micro}$ in the sea (total)	$Leak_{micro}$ in the sea (from coastal areas)	$Leak_{micro}$ per capita
	(-)	$tonnes.year^{-1}$	$tonnes.year^{-1}$	$tonnes.year^{-1}$	$tonnes.year^{-1}$	$tonnes.year^{-1}$	$tonnes.year^{-1}$	$kg/hab.year^{-1}$
Albania	2,775,059	75	17	6	2	101	43	0.04
Algeria	24,968,872	276	108	41	0	425	183	0.02
Bosnia and Herzegovina	299,126	6	4	2	1	13	2	0.04
Croatia	712,728	8	7	2	2	19	17	0.03
Cyprus	1,049,892	24	7	3	2	36	30	0.03
Egypt, Arab Republic	85,389,137	98	760	292	58	1,208	185	0.01
Greece	7,412,979	173	24	9	5	212	173	0.03
Israel	7,620,772	139	10	4	2	154	134	0.02
Italy	53,903,276	2,950	308	118	38	3,413	1,465	0.06
Montenegro	245,458	32	3	1	1	37	3	0.15
France	14,824,564	779	57	22	14	871	306	0.06
Lebanon	3,635,015	74	50	19	7	149	132	0.04
Libya	3,703,229	53	54	21	0	127	55	0.03
Malta	170,076	34	0	0	0	34	34	0.20
Morocco	3,711,400	39	28	11	0	77	39	0.02
Slovenia	145,647	8	1	0	0	10	7	0.07
Spain	16,898,683	790	28	11	6	835	523	0.05
Syrian Arab Republic	1,449,687	5	19	7	0	32	29	0.02
Switzerland	1,879,377	110	3	1	0	114	0	0.06
Kosovo	803,278	46	13	5	1	64	0	0.08
North Macedonia	2,062,598	130	32	12	5	181	0	0.09
Kenya	16,985,586	64	247	95	0	406	0	0.02
Tanzania	11,295,978	4	175	67	0	246	0	0.02
Burundi	6,274,984	30	97	37	3	167	0	0.03
Sudan	34,028,098	123	527	202	16	867	0	0.03
South Sudan	12,279,361	46	192	74	6	317	0	0.03
Bulgaria	2,661,652	58	15	6	1	79	0	0.03
Ethiopia	38,161,363	86	591	227	3	908	0	0.02
Uganda	38,761,285	164	578	222	28	993	0	0.03
Turkey	37,769,569	474	112	43	7	637	445	0.02
Rwanda	9,724,007	53	194	58	7	312	0	0.03
Serbia	12,570	0	0	0	0	0	0	0.01
Tunisia	7,459,590	83	51	20	0	154	104	0.02
Average								0.0
Total	449,074,896	7,033	4,310	1,639	215	13,196	3,909	
						Contribution of coasts (%)	30%	

Appendix 1.7 Key data for the transportation distances (leakage due to tyre dust)

	Average distance per capita (car km)	Average distance per capita (truck km)	Loss rate car ($mg.km^{-1}$)	Loss rate truck ($mg.km^{-1}$)
Albania	2,076	677	55	340
Algeria	2,082	47	55	340
Serbia	408	277	55	340
Bosnia and Herzegovina	347	555	55	340
Croatia	694	261	55	340
Cyprus	4,210	114	55	340
Egypt, Arab Rep.	90	20	55	340
Greece	2,704	237	55	340
Israel	2,082	223	55	340
Italy	9,659	128	55	340
Montenegro	126	3,126	55	340
France	8,378	255	55	340
Lebanon	2,082	320	55	340
Libya	2,082	305	55	340
Malta	4,002	4,182	55	340
Morocco	2,082	54	55	340
Slovenia	9,617	782	55	340
Spain	5,389	404	55	340
Syrian Arab Republic	22	107	55	340
Turkey	2,688	24	55	340
Tunisia	2,082	169	55	340
Switzerland	8,000	220	55	340
Kosovo	2,082	1,063	55	340
North Macedonia	3,807	934	55	340
Bulgaria	895	387	55	340
Kenya	2,082	39	55	340
Tanzania	0	34	55	340
Burundi	2,082	179	55	340
Sudan	2,082	48	55	340
South Sudan	2,082	155	55	340
Ethiopia	1,440	19	55	340
Uganda	2,082	45	55	340
Rwanda	2,082	159	55	340

Appendix 1.8 Parameters used for the sensitivity analysis (low/central/high estimates for the plastic footprint calculation)

Parameter		Chosen Value	Low	Centre	High
$LR_{textiles}$	Loss rate from textiles (mg/kg)	124	49	124	245
$LR_{cosmetic}$	Loss rate from cosmetics (mg/kg)	6	1	6	13
$LR_{pellets}$	Loss rate from pellets	0.01%	0.001%	0.01%	0.10%
$RR_{TyreRural}$	Release rate from tyres in rural areas	2%	2%	2%	22%
$RR_{TyreUrban}$	Release rate from tyres in urban areas	12%	2%	12%	22%
RR_{max}	Release rate maximum	15%	10%	15%	40%

Appendix 1.9 List of the top 100 contributing localities to the exports of plastic fluxes (macroplastics)

Country	Administrative region/area	Locality name	Leakage (tonnes)
Egypt	Alexandria	Muntazah	1,912
Italy	Lazio	Roma	1,809
Montenegro	Podgorica	Podgorica	1,662
Albania	Tirana	Tirana	1,123
North Macedonia	Skopje	Skopje	1,029
Egypt	Giza	Waraq	991
Egypt	Giza	Umraniyya	918
Libya	Tripoli	Tripoli	885
Egypt	Behera	Kafr Al-Dawwar	875
Egypt	Sharkia	Al-Husayniya	871
Italy	Lombardia	Milano	846
Egypt	Alexandria	Al Amreia	833
Egypt	Cairo	Basatin	812
Egypt	Giza	Imbaba	756
Bulgaria	Plovdiv	Plovdiv	755
Egypt	Dakhlia	Bilqas	730
Egypt	Sharkia	Zaqaziq	728
Egypt	Giza	Bulaq Al-DakrUr	719
Egypt	Monoufia	Ashmun	709
Egypt	Behera	Abu Hummus	686
Egypt	Garbia	El Mahalla El Kobra	670
Egypt	Sharkia	Minya al-Qamh	666
Italy	Sicilia	Palermo	663
Egypt	Sharkia	Bilbis	662
Egypt	Giza	Kardasa	646
Egypt	Helwan	Hilwan	641
Egypt	Kaliobia	Shubra Al-Khayma 2	626
Turkey	Antalya	Kepez	620
Egypt	Alexandria	Kesm than Al Raml	606
Italy	Piemonte	Torino	598
Italy	Liguria	Genova	592
Egypt	Garbia	Tanta	588
Egypt	Dakhlia	Shirbin	579

Country	Administrative region/area	Locality name	Leakage (tonnes)
Egypt	Dakhlia	Mit Ghamr	571
Egypt	Alexandria	Al Dikhila	560
Egypt	Kafr El Shiekh	Sidi Salim	559
Egypt	Sharkia	Faqus	555
Turkey	Bursa	Osmangazi	542
Egypt	Cairo	Al Salam	541
Turkey	Istanbul	Bağcılar	532
Egypt	Menia	Markz Bani Mazar	521
Egypt	Cairo	Ain Shams	518
Egypt	Dakhlia	El Mansora	517
Egypt	Dakhlia	Sinbillawin	517
Libya	Banghazi	Banghazi	515
Egypt	Kaliobia	Shubra Al-Khayma 1	512
Egypt	Damietta	Kafr Sad	512
Egypt	Kaliobia	Tukh	507
Egypt	Garbia	Zifta	506
Libya	Al Jifarah	Al Jifarah	501
Syrian Arab Republic	Lattakia	Lattakia	501
Egypt	Cairo	Marg	500
Egypt	Cairo	Nasr City	495
Egypt	6 October / Giza	Imbaba	494
Egypt	Behera	Damanhur	493
Egypt	Cairo	Al Matariyya	492
Egypt	Menia	Markz Maghagha	489
Egypt	Alexandria	Muharam Bik	488
Egypt	6 October /Giza	Badrashain	485
Egypt	Kaliobia	Al Khanka	484
Egypt	Dakhlia	Dikirnis	482
Turkey	Istanbul	Küçükçekmece	471
Egypt	Kaliobia	Shibin al-Qanatir	470
Turkey	Izmir	Buca	465
Egypt	Dakhlia	Aga	461
Egypt	Behera	Kum Hamada	460
Egypt	Behera	Abu-l-Matamir	458
Turkey	Istanbul	Pendik	448
Egypt	6 October/Gizah	Ayat	445
Albania	Durrës	Durrës	443
Egypt	Behera	Kafr Al-Dawwar	440
Turkey	Bursa	Yıldırım	438
Egypt	Kafr El Shiekh	Al Hamul	434
Egypt	Dakhlia	Manzala	432
Egypt	Kaliobia	Qanatir Al-Khayriyya	425
Egypt	Monoufia	Quwisna	424

Country	Administrative region/area	Locality name	Leakage (tonnes)
Egypt	Behera	Itay Al-Barud	423
Egypt	Garbia	Santa	422
Turkey	Antalya	Muratpaşa	419
Egypt	Damietta	Dumyat	418
Egypt	Kaliobia	Banha	417
Egypt	Alexandria	Mina Al-Basal	415
Egypt	Garbia	Kafr Al-Zayyat	414
Turkey	Istanbul	Bahçelievler	410
Turkey	Istanbul	Ataşehir	409
Egypt	Beni Suef	Al Wasta	406
Egypt	Kaliobia	Qalyub	406
Egypt	Kafr El Shiekh	Mitubas	398
Egypt	Beni Suef	Al Fashn	397
Egypt	Dakhlia	Minya Al-Nasr	397
Egypt	Sharkia	Dyarb Nigm	393
Egypt	Monoufia	Shibin al-Kum	391
Egypt	Sharkia	Abu Hammad	388
Egypt	Kafr El Shiekh	Kafr Al-Shaykh	385
Egypt	Giza	Al-Ahram	383
Turkey	Istanbul	Ãœmraniye	377
Egypt	Monoufia	Minuf	373
Egypt	Beni Suef	Biba	373
Egypt	Kafr El Shiekh	Disuq	370
Egypt	Behera	Al-Mahmudiyya	369

Appendix 1.10 Plastic bag quantification

Morocco

- In 2016, ban on production, import and distribution of plastic bags[3]
- 26 billion bags used each year (800 bags per person)[4]
    - Moroccan authorities seized more than 420 tonnes of plastic bags per year since ban (July 2016-July 2017)[4]. First three months of 2017, 36 tonnes of plastic bags seized
- 2.96 tonnes of plastic bags seized in Tangier (March 2018)[5]
    - Monitoring appears to be done by the Ministry of Industry, Trade, Investment and Digital Economy (www.mcinet.gov.ma)
- Production capacity of substitutes to plastic bags: 4.6 billion paper bags, 100 million woven bags, 120 million non-woven bags[6]
    - Not entirely clear if this is a direct indicator of a reduction in actual plastic bag consumption
    - Within first six months of ban (July 2016-Jan 2017) 19 tonnes of plastic bags seized at the border and total of 6,800 tonnes of illegal plastic bags incinerated

Tunisia

- 1 March 2017 ban on supermarkets distributing single-use plastic bags[7]
    - Tunisia consumes 1 billion plastic bags per year (10,000 tonnes of waste) – 315 million distributed by supermarkets (should be none after ban comes into effect)
    - Implemented by the Ministry of Local Affairs and Environment with support from Carrefour and Monoprix (major supermarket chains in the area)
    - Still using heavy duty plastic bags (>50 microns) – sold rather than distributed freely
    - Doesn't affect smaller retailers

France

- Single-use bags: 79 bags per person per year in 2010[8]
- 17 billion lightweight plastic bags used in France in 2015[9]
    - Ban effective since 1 Jan 2017
    - Implemented by the French Ministry of Sustainable Development
- 8 billion plastic bags discarded in nature – Ministry for Environment[10]

3 https://www.aljazeera.com/news/2016/07/green-morocco-bans-plastic-bags-160701141919913.html
4 https://www.news24.com/Africa/News/morocco-seizes-420-tons-of-plastic-bags-in-year-since-ban-20170428
5 https://www.moroccoworldnews.com/2018/03/242171/nearly-3-tons-banned-plastic-bags-seized-tangier/
6 http://www.mcinet.gov.ma/en/content/ban-plastic-bags-positive-results-six-months-after-law-entered-force
7 https://www.treehugger.com/environmental-policy/tunisia-bans-disposable-plastic-shopping-bags.html
8 https://s3-eu-west-1.amazonaws.com/europarl/plastic_bags/plastic_bags_en.html
9 https://www.planete-energies.com/en/medias/close/france-s-single-use-plastic-bag-regulation
10 https://www.thelocal.fr/20160701/what-does-frances-ban-on-plastic-bags-actually-mean

- Bags >50 micron thickness still allowed if they are labelled as reusable. But 50 microns may still be flimsy and not reused[11]
- Estimated 122 million plastic bags pollute 5,000 km of the coast[12]

Italy

- Ban on non-biodegradable plastic bags in shops and retail points since January 2011[13] Previous usage >300 per person per year (data from Legambiente)[14]
- In 2010, 181 single-use plastic bags per person per year[7]
- Ban not fully implemented due to disputes with EU trade laws[17]
- After five years of ban of plastic bags below 100 micron, the consumption of PE has been reduced by 55%, from more than 200,000 tonnes year^{-1} to 90,000 tonnes year^{-1} with a positive transition to compostable bags, necessary to develop and improve the separate collection of food waste.[15]

Israel

- 2016 legislation to introduce USD 0.03 levy per plastic bag[18]
- Israel had reduced plastic bag leakage into the sea by half one year after the introduction of the levy (unsure how data was calculated as sources not given)[16]
    - Consumption of plastic bags reduced by 80%
    - All supermarkets required to report statistics on sales of plastic bags to government for monitoring purposes
    - Money raised is reserved for air pollution control
    - Total annual consumption of plastic bags in 2016 was 2.7 billion (average 325 bags per person per year)
    - 25% of plastic bags immediately thrown away without being reused
- Unintended consequences, such as an increase in purchases of other forms of plastic bag, may have occurred[17]
    - Increase in the purchase of plastic bin liners
    - Sales of all plastic bag categories increased by 56% in 2017 (just after the law had been passed)

11 https://reporterre.net/Ils-sont-interdits-Mais-pourquoi-trouve-t-on-encore-des-sacs-en-plastique-chez

12 https://www.euractiv.com/section/sustainable-dev/news/eu-to-halve-plastic-bag-use-by-2019/

13 https://www.environmentalleader.com/2011/01/italy-carries-out-plastic-bag-ban/

14 http://www.dw.com/en/italian-shoppers-get-used-to-life-without-plastic/a-14749347

15 https://oceanconference.un.org/commitments/?id=15599

16 https://www.switchmed.eu/en/news/news-1/israel-halves-plastic-bag-waste-in-the-sea-one-year-after-new-law-on-supermarket-distribution

17 http://www.jewishpress.com/news/israel/the-knesset/israels-anti-plastic-bag-law-increased-the-sale-of-plastic-bags/2017/11/10/

Greece

- EUR 0.04 fee for plastic bags introduced 1 January 2018, which rose to EUR 0.09 in January 2019[18]
    - Kiosks and market stalls are exempt from the fee
- Estimated 4 billion plastic bags used per year in Greece before the fee was implemented[19]
    - Plastic bags reported to make up 50% of waste in Greek waters – Greek Environment Ministry
    - The fee is to be used for raising money to support production of eco-friendly bags
- Greece uses an estimated 4.5 billion bags per year – 400 per person[20]
    - Two thirds of bags used by Greeks come from supermarkets
    - The estimate was 242 per person in 2010[7] – large increase in 5 years
- Use of plastic bags expected to drop by 30-50% in 2018 as compared to 2017[21]
- January 2018: 75-80% drop in use of lightweight plastic bags in supermarkets compared to January 2017 (research carried out by the Research Institute of Retail Consumer Goods (IELKA))[22]
    - 5,000% rise in usage of reusable plastic bags
    - Fashion sector choosing paper bags to avoid being taxed for plastic
    - Across whole economy, estimated 65-70% drop in plastic bag use (lower implementation in rural areas)
    - 70% reduction in use of plastic bags means 110 bags per person per year, still above EU target of 90 per person per year

Malta

- Plastic bag tax implemented: 1 March 2009[23]
    - In 2008, 40 million plastic bags used per year
    - Shopkeepers required to track all plastic bags received in store and sold on. Implementation of large fines if the policy is not respected
    - Tax: EUR 0.15 per bag
- 2010, 107 single-use bags per person per year[7]

18 http://www.ekathimerini.com/224613/gallery/ekathimerini/in-images/greek-shoppers-face-plastic-bag-charge
19 http://www.keeptalkinggreece.com/2018/01/02/greece-plastic-bags-tax/
20 https://www.thenationalherald.com/173467/fee-will-drive-greek-shoppers-away-plastic-bags/
21 http://www.ekathimerini.com/221993/article/ekathimerini/community/decade-long-war-on-plastic-bags-fails-to-yield-results
22 http://greece.greekreporter.com/2018/02/06/greek-shoppers-responding-to-plastic-bag-tax/
23 https://www.timesofmalta.com/articles/view/20090129/local/eco-tax-on-plastic-bags-from-march-1.242668

Appendix 1.11 Actions to reduce plastic waste in the Mediterranean region (blue = proactive; yellow = reactive)

For the purpose of this report, actions have been classified as either proactive or reactive. Proactive actions are those taken to stem the flow of plastic waste into the Mediterranean and surrounding waterways. Reactive actions are those that try to reduce pollution by removing plastics from in and around the sea.

Action	Country	Details	Date	Source
Plastic bag legislation	France	France plastic bag ban covering bags <10L and <50 micron thickness	Jul-16	(The Local, 2016)
		Plastic bags for fruit and vegetable banned	Jul-17	
		Charge on remaining bags	Jul-16	
	Morocco	Single-use plastic bags banned	Jul-16	(Alami, 2016)
	Israel	Ban on plastic bags with thickness <20 micron. Tax on bags >20 microns	Jan-17	(Udasin, 2017)
	Italy	Ban on non-biodegradable plastic bags	Jan-11	(Bardelline, 2011)
		Charge on biodegradable and compostable plastic bags	Jan-18	(Povoledo, 2018)
	Tunisia	Ban on distribution of single-use plastic bags	Mar-17	(Martinko, 2017)
	Greece	Charge of 4 cents on plastic bags in grocery stores	Jan-18	(Anon, 2018)
	Malta	Minimum charge of 15 cents per single-use plastic bag	Mar-09	(Xuereb, 2009)
	Spain	Charge on single-use plastic bags until 2020 when bags will be banned entirely	Sometime in 2018	(Gerrard, 2018)
Other plastic legislation	EU	All plastic packaging must be recyclable by 2030	Jan-30	(European Commission, 2018b)
	France	Ban on single-use plastic plates, cups, cutlery and cotton swabs	Jan-20	(Eastaugh, 2016)

Motivating recycling	France	Increase in taxes on landfill and incineration of waste		(EEA, 2016)
	Italy	Mandatory separation of waste in certain states		
		Pay as you throw policy in certain states		
	Greece	Pay as you throw policy		
	Slovenia	Pay as you throw policy		
	Malta	Deposit return scheme aiming at 70% recycling rate by 2019	Jan-18	(Carauna, 2017; Pace, 2018)
	Croatia	Deposit return scheme on glass, plastic and aluminium. 90% returns in 2015	Jan-06	(CM Consulting, 2017)
	Israel	Deposit return scheme operated by ELA recycling corporation (PET, glass, aluminium). 77% return rate in 2015.	Jan-01	(CM Consulting, 2017)
Port reception facilities	EU	Mandatory declaration and disposal of waste into port reception facilities	Jan-18	(European Commission, 2018a)
	Cyprus	Free port reception facilities to motivate proper disposal of waste		
Clean-ups	EU	Clean-ups conducted by civil society and individual organisations		
	Croatia	Collecting waste through trawling and diving. State funded		(Arroyo Schnell, et al., 2017)

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