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UNIVERSITY OF PIRAEUS
DEPT. OF MARITIME STUDIES
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MSc sustainability and quality in marine industry

RIVER WATER AND SEA WATER QUALITY MONITORING IN KIFISSOS RIVER AND ESTUARIES (MAINLY, USE OF A PORTABLE SPECTROPHOTOMETER)

(EXAMINING THE FATE OF MICROPLASTICS IN AQUATIC ENVIRONMENTS)

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CONTENTS

ASTRACT

Nowadays, widespread use of microplastics , mostly in everyday products, has resulted in mass accumulation worldwide. In this thesis information about sampling , separation , identification/quantification, sources as well as concentration and fate of microplastics in marine environment are cited. Microplastics are categorized in primary and secondary. First category , contains plastics with size 5mm or less , while secondary consist a result of degradation of larger plastics. Due to insufficient management , microplastics are entering the environment mostly through waste treatment plants. In order to be able to study accumulation of microplastics it is essential to use precise methods of separation , identification & quantification . The more data we can collect from sampling , identification & quantification , the better we will be able to comprehend distribution , accumulation and fate of microplastics in the environment.

Microplastics can be found in urban rivers , oceans , soil , lakes , even polar regions . However , numerous & different methods can create knowledge gaps and provoke when comparing scientific studies.

In order to achieve a precise assessment on the effects of microplastics on human beings and the environment , we need to deal with scientific gaps and at the same time take drastic measures since microplastics are invading more and more in the environment.

INTRODUCTION

Mediterranean Sea is a vital ecosystem that supports numerous coastal communities. As time goes by, Mediterranean is faced up with an escalating environmental threat due to relentless accumulation of microplastics. Microplastics can be defined as particles smaller than 5 mm (Andrady, 2017), and have created a global concern due to their widespread distribution and potential adverse effects on marine life and ecosystems.

They emanate from various sources, including primary microplastics that are released directly into the environment and secondary microplastics as well that are generated because of degradation of larger plastic fragments (Gewert et al., 2015). Considering Mediterranean Sea's significance as a major transportation route as well as its significance regarding human activities will help us comprehend the size of production, transport, and impact of microplastics in the region. All above are vital for effective environmental management and conservation efforts.

Primary microplastics are a result of human activities such as coastal tourism, fishing, and maritime transport (De Lucia et al., 2020). These activities provoke direct release of microplastics into the marine environment through multiple sources like wastewater discharge, littering, and accidental spills (Deudero et al., 2019). Furthermore, Mediterranean Sea serves as a repository for secondary microplastics formed from the fragmentation and degradation of larger plastic debris, including bottles, bags, and fishing gear (Li et al., 2016).

The ever increasing presence of microplastics in the Mediterranean has lead to several ecological challenges, physically , chemically etc. Physically, microplastics can harm marine organisms through entanglement, ingestion, and habitat alteration (Browne et al., 2008). Chemically, they may carry toxic chemicals such as persistent organic pollutants (POPs) and heavy metals, which may accumulate in marine organisms and to end up in the human food chain (Bakir et al., 2016). Moreover, microplastics can act as vectors for the transport of harmful microorganisms and invasive species, exacerbating ecological impacts (Zettler et al., 2013).

Efforts to assess the extent and distribution of microplastics in the Mediterranean Sea have adopted different and sampling methods, including surface water and depth-specific sampling at sea, as well as sediment sampling in order to evaluate microplastic deposition and accumulation in coastal and benthic environments (Compa et al., 2018).

However, separation, identification, and quantification of microplastics can lead to unique challenges. Analytical techniques such as spectroscopy (e.g., infrared and Raman spectroscopy), scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDS), and pyrolysis gas chromatography-mass spectrometry (Pyr-GC-MS) are used for identification & qualification of microplastics' existence in environmental samples (Lambert & Wagner, 2016).

Understanding the fate of microplastics in the water environment is crucial for effective management and mitigation strategies. Dispersion and transport mechanisms play a significant role in the movement of microplastics throughout different environmental compartments, including marine, terrestrial, and atmospheric (Suaria & Aliani, 2014).

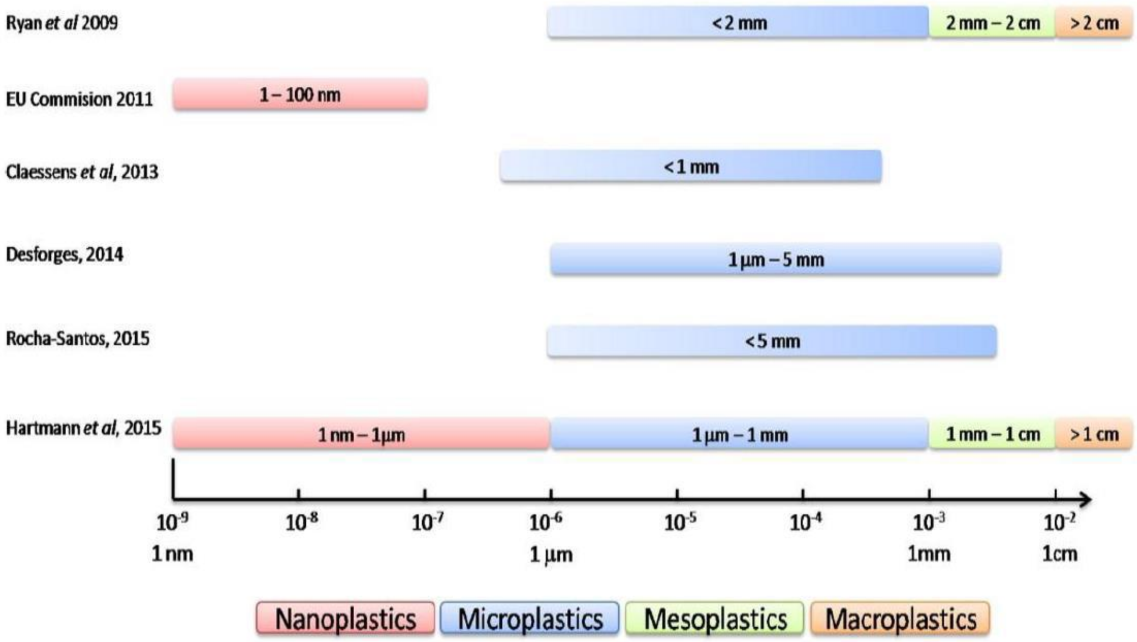
Institutional arrangements and programs have been established globally and at a national level also , in order to protect water environment from microplastic pollution . Focusing , at the same time, on prevention, limitation, and consolidation measures, as well as development of legislative frameworks regarding limitation/ confrontation of microplastics. (GESAMP, 2020).

Main cause of this thesis is to examine production, ways of transport, and impact of microplastics in the Mediterranean region. It is essential of course to define the term "plastic" as a subset of polymers, with polymers being large molecules composed of repeating units known as monomers (GESAMP 2015).

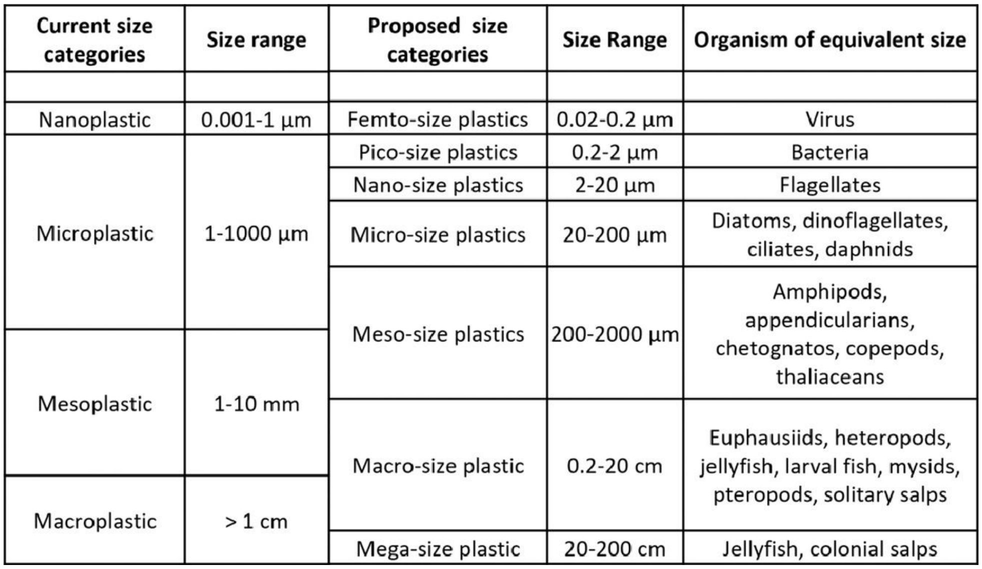
Barnes et al. (2009), in their publication on "Accumulation and fragmentation of plastic debris in global environments," analyzed how plastics accumulate in marine environments and how they may cause severe damage to marine organisms through ingestion, among other mechanisms. They also emphasized the vital need for managing and monitoring microplastics to prevent further harm to marine ecosystems.

Microplastics, can be defined as small particles not visible to the naked eye. As a result , microscopic analysis for detection is necessary. In 2019, European Chemical Agency (ECHA) introduced a new definition for microplastics: "Microplastics are defined as synthetic solid particles with regular or irregular shape and size below 5mm in at least one dimension, which are not soluble in waters."

Taking into consideration all different definitions of microplastics, in present thesis we will adopt the one of Desforges et al. (2014), as described in "Ingestion of microplastics by zooplankton in the Northern Pacific Ocean." Therefore, microplastics are considered as particles with size ranging approximately from 1μm to 5mm.

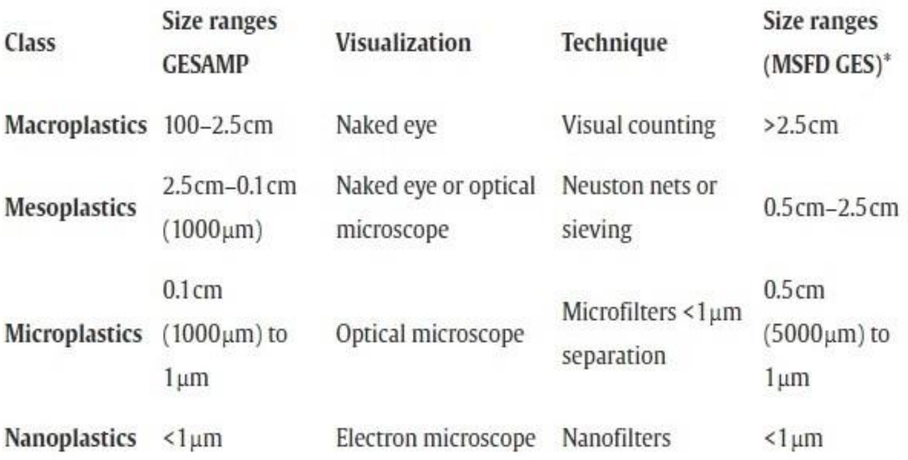


Picture 1.1 : Microplastics' definition based on their size according to different scientific reaserches (Rodriguez-Seijo et al.,2017)



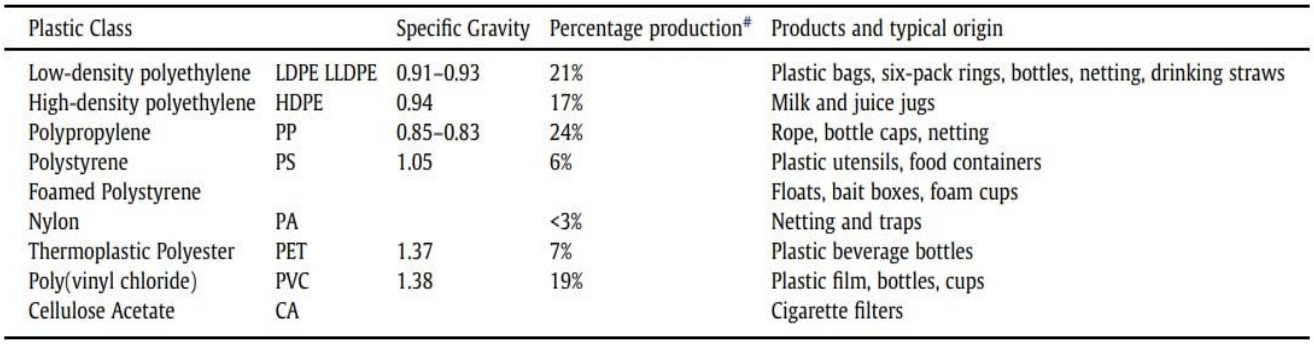
<table>
<tr><th>Current size categories</th><th>Size range</th><th>Proposed size categories</th><th>Size Range</th><th>Organism of equivalent size</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nanoplastic</td><td>0.001-1 µm</td><td>Femto-size plastics</td><td>0.02-0.2 µm</td><td>Virus</td></tr>
<tr><td rowspan="4">Microplastic</td><td rowspan="4">1-1000 µm</td><td>Pico-size plastics</td><td>0.2-2 µm</td><td>Bacteria</td></tr>
<tr><td>Nano-size plastics</td><td>2-20 µm</td><td>Flagellates</td></tr>
<tr><td>Micro-size plastics</td><td>20-200 µm</td><td>Diatoms, dinoflagellates, ciliates, daphnids</td></tr>
<tr><td rowspan="2">Meso-size plastics</td><td rowspan="2">200-2000 µm</td><td rowspan="2">Amphipods, appendicularians, chetognatos, copepods, thaliaceans</td></tr>
<tr><td rowspan="2">Mesoplastic</td><td rowspan="2">1-10 mm</td></tr>
<tr><td rowspan="2">Macro-size plastic</td><td rowspan="2">0.2-20 cm</td><td rowspan="2">Euphausiids, heteropods, jellyfish, larval fish, mysids, pteropods, solitary salps</td></tr>
<tr><td rowspan="2">Macroplastic</td><td rowspan="2">> 1 cm</td></tr>
<tr><td>Mega-size plastic</td><td>20-200 cm</td><td>Jellyfish, colonial salps</td></tr>
</table>

Picture 1.2: Classification of MP's (Hartman et al.) compared to organisms with equivalent size of the environment



Class	Size ranges GESAMP	Visualization	Technique	Size ranges (MSFD GES)*
Macroplastics	100–2.5 cm	Naked eye	Visual counting	>2.5 cm
Mesoplastics	2.5 cm–0.1 cm (1000 μm)	Naked eye or optical microscope	Neuston nets or sieving	0.5 cm–2.5 cm
Microplastics	0.1 cm (1000 μm) to 1 μm	Optical microscope	Microfilters < 1 μm separation	0.5 cm (5000 μm) to 1 μm
Nanoplastics	< 1 μm	Electron microscope	Nanofilters	< 1 μm

Picture 1.3 : Classification of plastic debris in the environment , based on GESAMP (2015) MSFD GES Technical Subgroup on Marine Litter (2013) Monitoring Guidance for Marine Litter in European



Plastic Class		Specific Gravity	Percentage production#	Products and typical origin
Low-density polyethylene	LDPE LLDPE	0.91–0.93	21%	Plastic bags, six-pack rings, bottles, netting, drinking straws
High-density polyethylene	HDPE	0.94	17%	Milk and juice jugs
Polypropylene	PP	0.85–0.83	24%	Rope, bottle caps, netting
Polystyrene	PS	1.05	6%	Plastic utensils, food containers
Foamed Polystyrene				Floats, bait boxes, foam cups
Nylon	PA		<3%	Netting and traps
Thermoplastic Polyester	PET	1.37	7%	Plastic beverage bottles
Poly(vinyl chloride)	PVC	1.38	19%	Plastic film, bottles, cups
Cellulose Acetate	CA			Cigarette filters

Picture 1.4: Classes of plastics encountered in marine environment Andrady (2011)

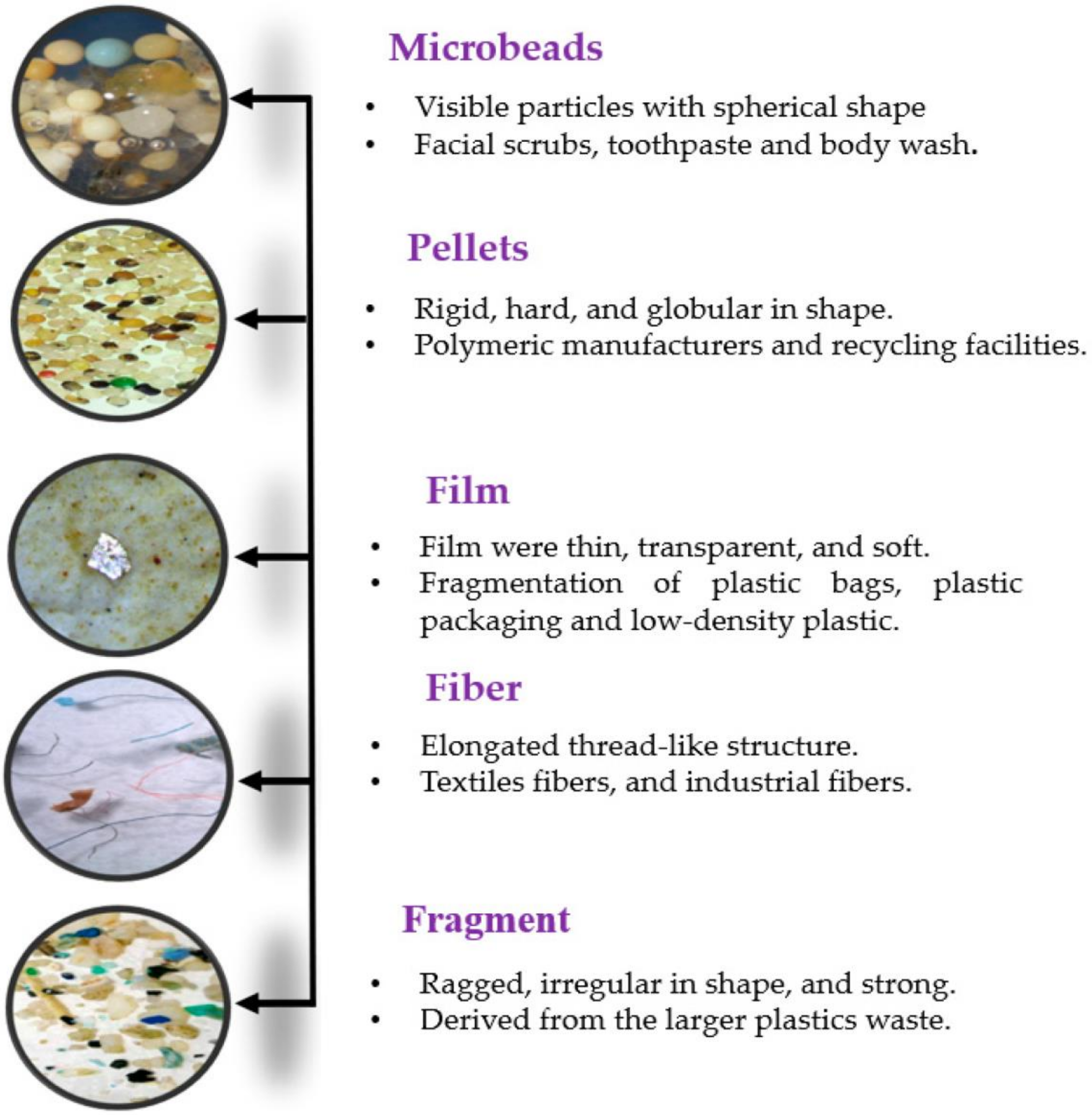
Table 1.1 : Characteristics of plastics and effects on their behavior (Andrady A.,2017)

Characteristic	**Influence on behavior of Microplastics**	**Comments**
1. Density	The buoyancy of microplastics determines at what depth in the water column they will be found	The density of each polymer is known, but it can be altered by additives as well as surface accumulators
2. Crystallinity	The degree of crystallinity determines the ease of oxidative degradation and fragmentation during aging	General ranges of values are available for different plastics but these can change
3. Oxidative resistance	Chemical structure determines how easily the plastic will be oxidized in the environment. Fragmentation is a consequence of extensive oxidative degradation	The ease of oxidation suggested by the chemical structure may vary significantly in compounded plastics that incorporate stabilizers and additives.

4. Biodegradability	Determines the rate of mineralization and the potential partial removal of plastics from the water column or sediment	Common plastics are generally bio-inert, although exceptions exist in both synthetic plastics and biopolymers
5. Residual Monomer	Toxicity of leaching residual monomers in microplastics to marine organisms that ingest plastics.	Both residual monomer levels in common plastics as well as their toxicities are reliably known
6. Transport Properties	Bioavailability of residual monomers, additives and POPs sorbed by the MPs depends on their leaching rates in the gut environment	The characteristics mentioned are well-established for resins, although they can be modified due to variations in the crystallinity index
7.Additives	Concentration and toxicity of additives in MPs may contribute to the adverse impacts on ingesting species.	The chemistry, levels of use in plastics, and toxicities are generally known, but the levels

		for endocrine disruptors are not reliably known
8. Surface Properties	The rate of fouling on floating debris determines the rates of weathering and sinking of microplastics.	Surface properties and fouling rates for common plastics are known.

Knowing the shape of microplastics provides additional information about their hydrodynamic characteristics. For instance, microplastics shaped like fibers exhibit higher buoyancy and slower settling speeds compared to spheres with equivalent density and volume. Additionally, microplastics characterized by significant surface areas relative to their volume (such as fibers and foam) experience a faster rate of colonization by organic matter, leading to quicker settling (Ryan, 2015).



Microbeads

- Visible particles with spherical shape
- Facial scrubs, toothpaste and body wash.

Pellets

- Rigid, hard, and globular in shape.
- Polymeric manufacturers and recycling facilities.

Film

- Film were thin, transparent, and soft.
- Fragmentation of plastic bags, plastic packaging and low-density plastic.

Fiber

- Elongated thread-like structure.
- Textiles fibers, and industrial fibers.

Fragment

- Ragged, irregular in shape, and strong.
- Derived from the larger plastics waste.

Picture 1.5 : Microplastics' categories based on their shape (Barducci et al. ,2020

CHAPTER 1- ORIGINS OF MICROPLASTIC PRODUCTION AND TRANSPORT

1.1 Introductory information

Microplastics , defined as plastic particles smaller than 5mm , have emerged as a pervasive environmental issue , given their widespread presence in diverse ecosystem , especially aquatic environments (Bergmann et al. , 2017) . The production and transport of microplastics involve complex processes influenced by both primary and secondary sources.

1.2 Sources of primary microplastics

Primary microplastics, are result of human manufacture. Considered as small plastic particles that are used in a variety of products, such as personal care items, cosmetics, and industrial abrasives (Hidalgo-Ruz et al., 2012). These primary microplastics can enter the environment through different pathways, including improper disposal of plastic waste, direct release during manufacturing processes, and the shedding of microfibers from textiles (Jambeck et al., 2015; Ziajahromi et al., 2016).

On the other hand, secondary microplastics originate from the fragmentation and degradation of larger plastic particles due to environmental factors such as UV radiation, mechanical forces, and chemical weathering (Gewert et al., 2015). This process of physical breakdown can occur in various environments, including oceans, rivers, and coastal areas

(Cózar et al., 2014). As plastic debris continues to degrade, it gradually breaks down into smaller and smaller particles, ultimately forming microplastics (Andrady, 2017)." Microplastics can be transferred by a combination of mechanisms, such as water currents, wind, and the movement of organisms as well (Wright et al., 2013). Microplastics have the potential to traverse extensive distances in aquatic environments, facilitated by ocean currents, resulting in their broad dissemination across marine ecosystems (Lebreton et al., 2012). Wind is another factor influencing their movement, particularly in terrestrial settings, where airborne microplastics can be transported significant distances and ultimately settle in water bodies (Allen et al., 2019). Furthermore, the actions of organisms, such as ingestion and excretion, play a role in the internal circulation of microplastics within ecosystems (Browne et al., 2008).

Understanding the production and transport of microplastics is essential for developing effective strategies to mitigate their environmental impact. By investigating both primary and secondary sources of microplastics, as well as different transportation mechanisms, the scientific community can gain valuable insights into the factors influencing their distribution and accumulation in various environments.

1.3 Formation of secondary plastics

As we have already mentioned ,secondary plastics are microplastics that are formed through degradation and fragmentation of larger particles. The process encompasses a collaboration of physical, chemical, and biological elements that collectively play a role in breaking down plastics into smaller particles

Degradation is primarily provoked by exposure to environmental stressors, such as sunlight (UV radiation), temperature fluctuations, and mechanical forces (Gewert et al., 2015). When plastics are exposed to UV radiation, the polymer chains undergo photodegradation, resulting in the breakdown of the material into smaller fragments (Lambert & Wagner, 2016). Temperature fluctuations, including freeze-thaw cycles and heat exposure, can also accelerate the degradation process by causing expansion and contraction of the plastic, leading to subsequent fragmentation (Chae et al., 2018). Chemical weathering, another important factor, involves the interaction of plastics with chemicals present in the environment. Plastics can absorb various organic pollutants, such as polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), which can act as catalysts for degradation (Ziajahromi et al., 2016). The presence of water and moisture can also facilitate hydrolytic degradation, wherein water molecules break down the polymer chains of the plastic (Rochman et al., 2013).

Biological processes can lead to further creation of secondary plastics. Biofouling, the colonization of plastics by microorganisms and marine organisms, can destabilize the material and as as result to increase its susceptibility to fragmentation (Barnes et al., 2009). Biodeterioration by microorganisms, such as bacteria and fungi, produces enzymes that degrade the polymer structure of plastic (Webb et al., 2013). The behavior of marine organisms, including the abrasion caused by grazing or burrowing creatures, can also result in the physical breakdown of plastics into smaller particles (Rillig, 2012).

All these factors combined lead to the generation of secondary plastics, including microplastics, which can persist in the environment for extended periods and contribute to plastic pollution within ecosystems.. Comprehending the processes that contribute to formation of secondary plastics is vital if we want to develop effective mitigation strategies.

Table 1.3: Examples of Primary and Secondary Microplastics.

Primary Microplastics
Specific products in personal care, such as toothpaste, shower gels, creams, shaving cream, and sunscreen, contain microplastics for exfoliation
Everyday use products
Chemically enhanced with plastic microbeads for detection in gas and oil.
Secondary Microplastics
Loss of plastic waste from landfills and recycling facilities
Disintegration of plastics over time due to physical factors.
Utilization of plastics in fertilizers for agricultural activities
Application of synthetic materials to improve soil quality.
Fibers released from the wear and tear of synthetic fabrics during washing.
Abrasion from car tire wear
Presence of synthetic polymers in paints.
Discharge of plastic organically in effluent.
Discarding and rejecting plastic equipment from fishing boats.
Disposal of plastic merchandise from commercial ships.
Loss of plastic materials from construction activities.
Degradation of artificial spaces (wear of artificial carpets).

1.4 Points of entrance

Microplastics can enter aquatic ecosystems through diverse avenues, including intentional discharge, runoff, atmospheric deposition, and wastewater effluent. These pathways contribute to the extensive dispersion of microplastics in water bodies, posing significant challenges for their management and mitigation.

Direct release occurs when plastic particles are deliberately introduced into aquatic environments, involving the intentional disposal of plastic waste in rivers, lakes, and oceans (Cózar et al., 2014). It can also arise from the dumping of plastic debris from ships or offshore activities (UNEP, 2016), initiating the initial introduction of microplastics into aquatic ecosystems.

Runoff from land represents another crucial path for microplastics entering water bodies. Rainwater and snowmelt transport microplastics from the land surface, including those originating from urban areas, agricultural fields, and industrial sites (Guzzetti et al., 2018). Runoff carries microplastics through stormwater drains, rivers, and streams, eventually depositing them into lakes, reservoirs, and marine environments (Koelmans et al., 2017).

Atmospheric deposition is emerging as a significant route for microplastics to infiltrate water bodies. Airborne microplastics, originating from sources like road dust, industrial emissions, and degraded plastic debris, can be transported over long distances by wind and deposited into aquatic environments (Allen et al., 2019). This atmospheric pathway underscores the potential for microplastics to be transported to remote and pristine areas, contributing to their ubiquity in water bodies.

Wastewater effluent represents another critical pathway for microplastic entry. Microplastics can be discharged into water bodies through the release of treated or untreated wastewater from domestic, industrial, and agricultural sources (Hernandez et al., 2018). Wastewater treatment plants are not designed to effectively remove microplastics, resulting in their discharge into receiving waters (Ziajahromi et al., 2017). Additionally, microplastics can be present in agricultural runoff and irrigation water, further contributing to their entry into water bodies (Wagner et al., 2014).

Understanding all possible entry points of microplastics is crucial for developing effective strategies to mitigate their release and prevent their accumulation in aquatic ecosystems. Recognizing these entry pathways empowers policymakers, researchers, and stakeholders to work towards minimizing the introduction of microplastics into water bodies, thereby maintaining the balance and health of aquatic environments. Image 2.1 below illustrates the main points of microplastic entry into the environment and potential transport mechanisms.

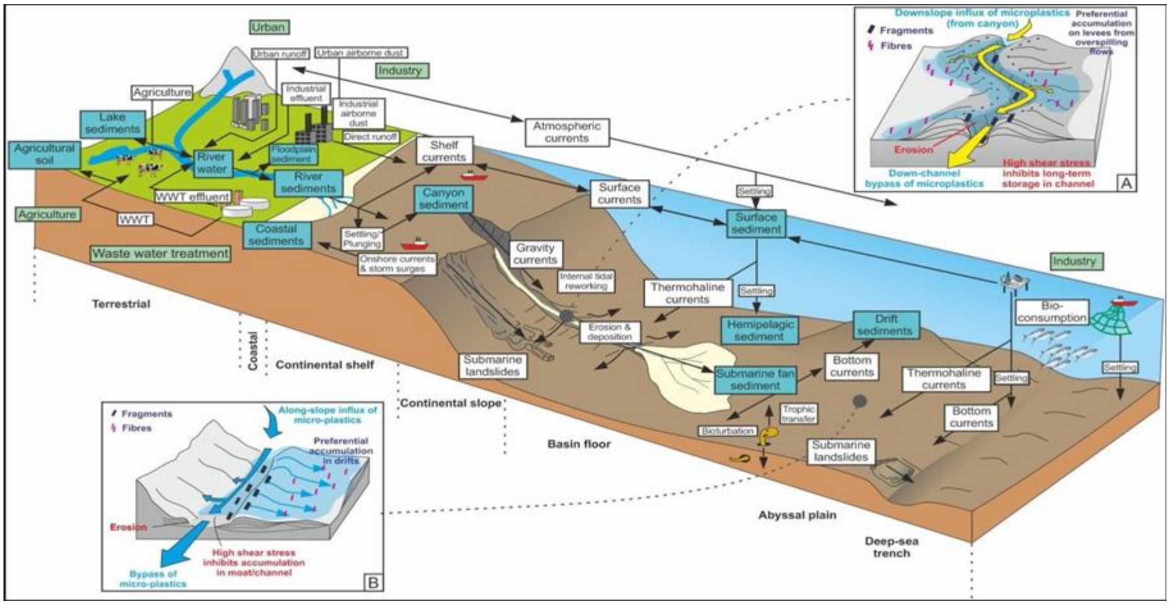


Image 2.1: Entry points and transportation routes of microplastics. Green boxes symbolize entry points, blue boxes represent permanent and temporary concentrations, white boxes indicate transport mechanisms, and arrows depict the transportation pathways. Pictures A and B illustrate the potential movement of microplastics in the canal-dam system and trench, respectively. (Source: Kane and Clare, 2019).

CHAPTER 2 - IMPACTS ARISING FROM THE PRESENCE OF MICROPLASTICS IN AQUATIC ECOSYSTEMS.

The existence of microplastics in aquatic settings presents notable challenges and potential consequences for ecosystems, organisms, and human health. These concerns fall into categories encompassing both physical and chemical effects, along with the role of microplastics as carriers of harmful substances.

2.1 Physical effects

Microplastics can physically impact aquatic organisms. Due to their small sizes and various shapes, marine animals, including fish, seabirds, and marine mammals, can ingest them along with their food, leading to negative effects on their feeding, digestion, and overall health (Wright et al., 2013; Rochman et al., 2015). The bioaccumulation of microplastics in the digestive system can cause blockages, significantly reduce nutrient absorption, and impair reproductive processes (Lusher et al., 2017).

Furthermore, microplastics can cause physical harm to marine organisms through abrasion and entanglement. For instance, plastic fibers and fragments may entangle and suffocate marine animals such as turtles and seals, resulting in severe injuries, reduced mobility, and eventual death (Gall & Thompson, 2015; Hall et al., 2015).

2.2 Chemicals effects

Microplastics possess the capability to adsorb and accumulate various chemical pollutants from the surrounding water, including persistent organic pollutants (POPs), heavy metals, and other harmful substances. Acting as a repository for these pollutants, microplastics can concentrate them to higher levels compared to the surrounding water (Rochman et al., 2013; Koelmans et al., 2017). When organisms ingest microplastics loaded with pollutants, they can experience toxicological effects, such as disruption of hormone regulation, impaired reproduction, and compromised immune systems, among other impacts (Teuten et al., 2009; Browne et al., 2013).

2.3 Microplastics as carriers

Microplastics can act as carriers for various organisms, including bacteria, algae, and invasive species. The rough surfaces of microplastics provide a conducive environment for microorganisms to attach and form biofilms on the plastic particles (Zettler et al., 2013). These biofilms can alter interactions between microplastics and their surrounding environment and may be responsible for transferring organisms across different habitats and ecosystems (Dussud et al., 2018). Moreover, microplastics can facilitate the transport of harmful algae and pathogens, contributing to the spread of harmful algal blooms and the transmission of diseases (Lusher et al., 2017; Cai et al., 2018).

The proliferation of microplastics in aquatic environments emphasizes the urgent need to address pollution. All efforts should focus on restricting the production and release of plastics, improving waste management practices, and promoting sustainable alternatives to plastic materials. Addressing these issues will ensure the health, security, and integrity of aquatic ecosystems.

CHAPTER 3- SAMPLING METHODS

Accurate and reliable sampling methods are essential for assessing the widespread presence of microplastics in aquatic environments. Various techniques have been developed to collect water samples from different locations, including surface waters, medium depths, bottom sediments, and other water compartments.

3.1 Introductory information

When conducting sampling, it is vital to ensure proper handling and control contamination. The use of clean and sterilized equipment, including gloves, sampling containers, and filters, is essential to prevent the introduction of external microplastics during the sampling process.

A critical aspect of collecting information about microplastic concentration in the environment is selecting the most appropriate sampling method. This decision primarily depends on the area we intend to examine. Even neighboring areas can exhibit variations, leading to differences in sampling methods. In conclusion, the choice of equipment used during sampling can result in variations in the concentration, shape, and other characteristics of existing microplastics.

3.2 Sampling at sea

The distribution of microplastics in the ocean is influenced by factors like density, size, shape, and bioaccumulation, along with environmental factors such as wind, waves, and ocean currents. Consequently, the choice of sampling method Impacts the collected samples up to a certain degree, with methodologies and tools varying based on the desired sampling depth.

3.2.1 Surface water sampling

Surface water sampling involves collecting water samples from the uppermost layer of the water column. This can be done using various techniques, such as plankton nets, surface trawls, or grab samplers. Devices like manta trawls, which are towed behind boats, can also be used to collect larger volumes of water for microplastic analysis (Cauwenberghe & Janssen, 2014).

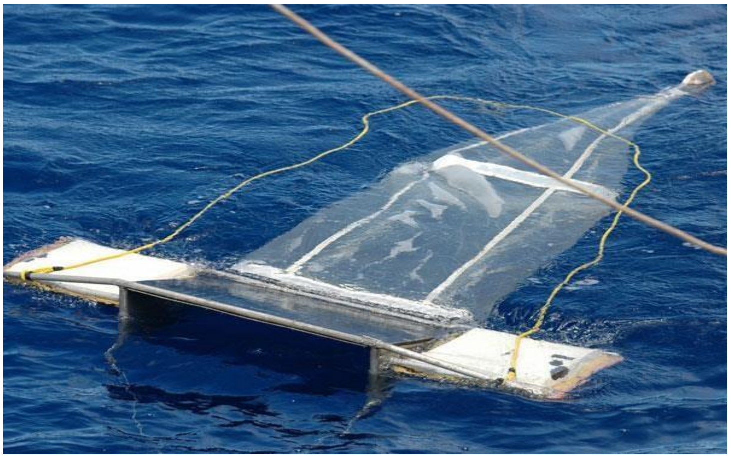


Image 3.1: Manta net

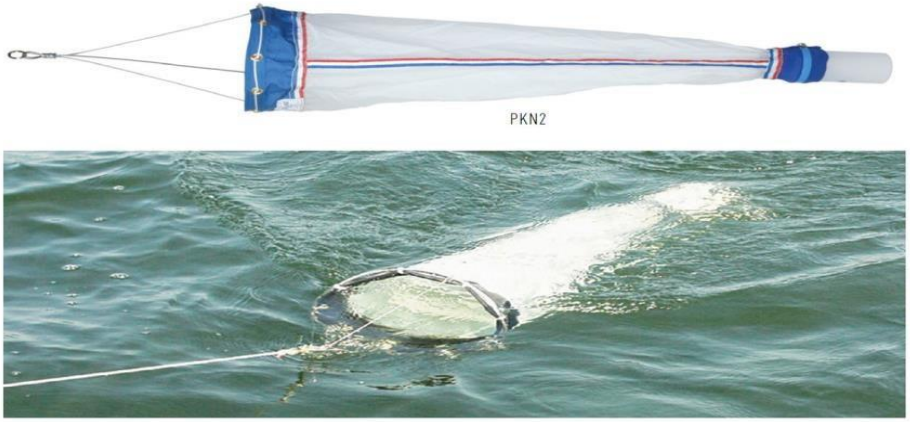


Image 3.2: Net Plankton

The selection of net size directly influences the detected concentration of microplastics. For example, employing nylon nets with a 0.1 mm diameter may lead to concentrations up to a hundred times higher than those obtained with a manta net featuring a standard opening of 0.333 mm (Vermaire et al., 2016). However, manta nets can effectively collect larger water volumes compared to nylon nets, which tend to clog quickly and need regular cleaning for continuous operation.

Research indicates that water samples typically comprise 52% microfibers and 29% fragments, with minimal amounts of other morphologies such as microspheres and foams. Nevertheless, some studies suggest that microfibers can make up to 80% of the microplastic content in specific cases (Constant et al., 2019; Carr et al., 2016). The use of standard 0.333 mm diameter nets might overlook these microfibers, leading to underestimated microplastic concentrations and, consequently, a diminished understanding of the severity of the issue

3.2.2 Sampling at medium depths and the seabed

Sampling at medium depths and the seabed requires distinct methodologies. To collect bottom sediments, corers or sediment grabs can be employed, enabling the retrieval of sediment cores or surface sediments. These samples can undergo various extraction methods to isolate microplastics (Hidalgo-Ruz et al., 2012). For water sampling at different depths, techniques like Niskin bottles or CTD (conductivity, temperature, and depth) rosettes can be utilized to gather water samples at specified depths (Zobkov & Esiukova, 2017). Subsequently, these samples can be filtered to separate microplastics from the water matrix.

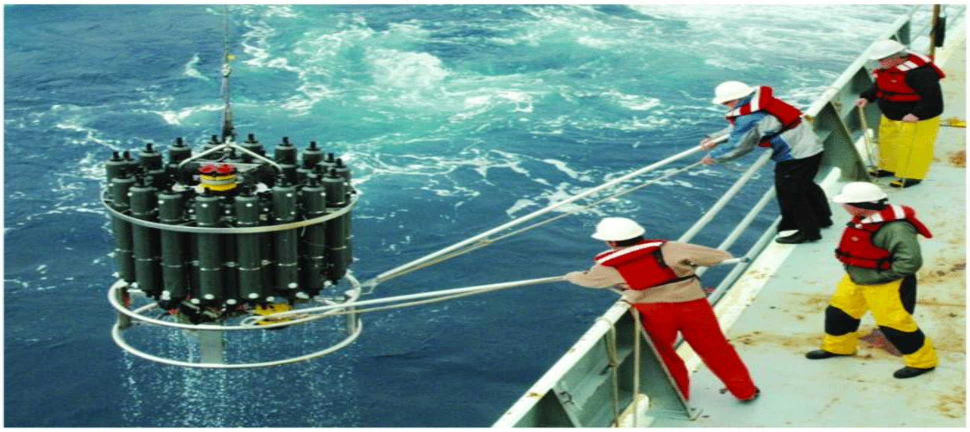


Image 3.3: A rosette sampler with Niskin bottles. The conductivity, temperature, depth (CTD) sonde is inside the ring near the bottom (not visible) (Photo credit: Sabine Mecking, University of Washington).

3.3 Sampling in the sediment

Sampling sediments is essential due to the tendency of microplastics to accumulate in the benthic environment. The use of coring devices or sediment grabs facilitates the collection of sediment samples, allowing for the retrieval of sediment cores or surface sediments (Eriksen et al., 2013). Following collection, various techniques such as sieving, density separation, or others can be employed to extract microplastics from the sediment matrix (Löder & Gerdts, 2015).

It's crucial to highlight that the selection of a sampling method relies on the research objectives, the specific water compartment under investigation, and the available resources. Each method comes with its own set of advantages and limitations, and a combination of techniques may be required to obtain a comprehensive understandingof microplastic contamination in aquatic environments.

A summary of these methods, including their respective advantages and disadvantages, is presented in Table 3.1 below.

Mechanism	**Points Application**	**Advantages**	**Disadvantages**
Nets manta-neuston	Shallow waters	Easy use Sampling larges volumes of water Broad use	Possible pollution from the boat and the ropes Boat use Restriction of samples 330μm
Nets plankton	Shallow waters Medium Depths (Net bongo)	Easy use Sampling up to 100 mm	Possible pollution from the boat and the ropes Use of boat Clogging Sampling small volumes of water

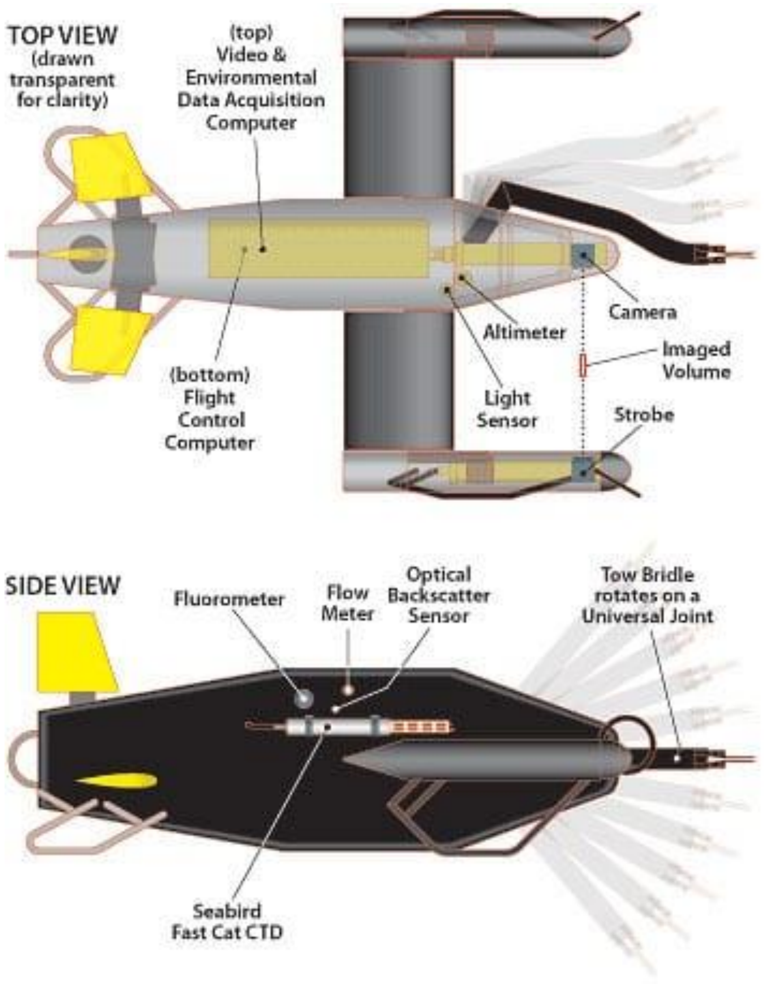
Sieves	Shallow waters Medium Depths Sediment	Easy use Doesn’t require special equipment or vessel	Time consuming Low volume Samples
Pumps	Shallow water Medium depths	Sampling large volumes water	Specific equipment
Nucleator - Specialized Sampler	Bottom Sea	Easy use	Expensive Equipment Boat use Variations according to depth and area
Plankton recorder	Medium Depths (10 m)	Sampling large volumes water Easy use	Boat use Expensive Equipment
Epi-benthic Sledge	Bottom Sea	Low cost construction Sampling large	Use boat

		volumes water Safe use even in about powerful winds	Weakness sampling in uphill flat

Table 3.1 : Sampling methods in water and seabed

Picture 3.4: Epibenthic Sledge on the deck of a research vessel. (Southampton Oceanographic Centre)

Picture 3.5 : Nucleator



Picture 3.6 : Plankton recorder is underwater video microscope that images plankton and particles in the size range from 0.1mm to 1 cm . (Jayne Daucette's illustration , Woods Hole Oceanographic institution)

CHAPTER 4- MICROPLASTIC SEPARATION, IDENTIFICATION, AND QUANTIFICATION

4.1 Introductory information

Accurate and reliable methods are crucial for separating, identifying, and quantifying microplastics in environmental samples. Various techniques and analytical tools have been developed to meet these challenges, offering valuable insights into the presence and abundance of microplastics in aquatic environments.

The analysis of microplastics provides information not only about the material's morphological, physical, and chemical characteristics but also about its concentration in the environment. Armed with this comprehensive information, we can derive meaningful conclusions regarding the origins of microplastics, their sources of production, entry points into ecosystems, dispersion patterns within the environment, the extent of their pollution, and potential environmental impacts.

4.2 Separation

The initial stage of microplastic analysis entails the separation of microplastics from the environmental matrix. Different separation techniques can be applied based on the sample type and the desired size range of microplastics.

4.2.1 Sample Cleaning

Cleaning the sample typically involves several steps aimed at eliminating organic matter, inorganic particles, and other debris while preserving the microplastics of interest. Common cleaning methods include rinsing, filtering, and digestion processes.

Rinsing the samples with filtered water or solvents helps eliminate loose particles and organic matter present on the surface of microplastics. This step is crucial for obtaining a clean sample and minimizing potential contamination (Browne et al., 2010).

Filtering the samples through a clean filter further aids in removing larger particles and debris, ensuring that only microplastics are retained for subsequent analysis (Claessens et al., 2013).

Digestion processes, such as enzymatic or chemical digestion, may also be employed to eliminate organic matter and facilitate the separation of microplastics from complex matrices, such as sediments (Eriksen et al., 2013).

It's important to note that the choice of the cleaning method depends on the sample type and research objectives, and careful consideration should be given to avoid introducing additional contaminants during the cleaning process.

4.2.2 Filtering

Filtering is a widely employed separation method where water is passed through a filter with a specified pore size, typically ranging from 0.2 to 1.0 micrometers. This allows the retention of microplastics while permitting smaller particles and dissolved substances to pass through (Hidalgo-Ruz et al., 2012). Subsequently, the filter is meticulously examined under a microscope to identify the presence of microplastics.

4.2.3 Density separation

Density separation techniques, such as density flotation, can be utilized to segregate microplastics from sediment samples. In this method, a solution with a predefined density is introduced to the sediment sample. Microplastics, being less dense, float to the surface, while heavier materials sink, facilitating the separation and retrieval of microplastics for subsequent analysis (Löder & Gerdts, 2015).

Table 4.1: Density separation for each category of microplastic using water and sodium chloride (NaCl).

Types of Plastic	**Density(g/cm ^{3})**	**Water (1.015 g/cm ^{3})**	**NaCl(1.4 g/cm ^{3})**
Polypropylene	0.9-0.91	Yes	Yes
Polyethylene	0.92-0.97	Yes	Yes
Nylon	1.02-1.05	No	Yes
Polystyrene	1.04-1.1	No	Yes
Acrylics	1.09-1.20	No	Yes
Polyethyl acrylic	1.17-1.20	No	Yes
Polyurethane	1.2	No	Yes
Polyvinyl chloride	1.16-1.58	No	Maybe
Polyvinyl alcohol	1.19-1.31	No	Maybe
Alkyd Rytin	1.24-2.10	No	No

Polyester	1.24-2.3	No	No
Terephthalate **Polyethylene**	1.37-1.45	No	No
Polyoxymethylene	1.41-1.65	No	No

4.3 Quantification

4.3.1 Infrared Spectroscopy

Infrared spectroscopy is a potent analytical technique widely employed for identifying and characterizing microplastics. It operates by assessing the interaction between infrared radiation and the chemical bonds present in the analyzed samples, providing crucial insights into their molecular structure and composition.

The process involves irradiating the sample with infrared light and measuring the energy absorbed at various wavelengths. The resulting unique spectrum, known as an infrared spectrum, corresponds to the different chemical bonds within the sample. Comparing this spectrum with reference spectra of known compounds enables the identification of various plastic polymers (Zhang et al., 2012).

In the realm of microplastics, infrared spectroscopy is particularly useful for identifying polymer types like polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and others. This technique allows researchers to distinguish between different plastic materials and estimate their relative abundance in environmental samples (Rochman et al., 2013).

Various instrument setups, including Fourier-transform infrared (FTIR) spectrometers, can be used for infrared spectroscopy. FTIR spectroscopy, characterized by high-resolution spectra and the ability to rapidly analyze large sample numbers, has gained widespread adoption in microplastic research due to its accuracy, sensitivity, and non-destructive nature (Zhang et al., 2012).

By employing infrared spectroscopy, researchers can gain valuable insights into the types and abundance of microplastics in environmental samples, contributing to our understanding of microplastic pollution and its potential impacts. The choice of the method depends directly on the sample's species and characteristics. Samples with significant thickness yield more precise results when measured using the Attenuated Total Reflectance (ATR) method, while for minute samples, the reflection method is suitable, especially for those smaller than 10 µm in size.

Method	**Advantages**	**Appropriateness Sample**	**Characteristics Microplastic**
Transmission	Established method Good spectral Information Kaliya quantification	Samples at who it can to pass the infrared Ray Minutes polymers Thermoplastics powders	Fine fibers Powders
Reflection	Minimal preparation sample	Samples where they can to are converted in minute powder Soft powders Tablets	Minutes microplastics<1μm Irregular shape

Mirror Reflection	Non destructive analysis	Samples with large and flat surfaces Metallic surfaces Surfaces from silicone	Smooth and thick film
ATR	Minimal preparation sample	Thick samples with good absorption	Thick fibers Powders
	Non destructive analysis Ideal for fat and samples with good absorption infrared light	Plastics, Rubbers, Paints	Irregular shape

Table 4.2 : Methods of analysis of samples with FTIR

4.3.2 RAMAN Spectroscopy

Raman spectroscopy stands out as a valuable analytical technique extensively utilized for identifying and characterizing microplastics. This method furnishes molecular details regarding the chemical composition and structure of the examined samples by assessing the scattering of monochromatic light.

In Raman spectroscopy, a laser beam is directed onto the sample, and the scattered light is scrutinized to discern the vibrational and rotational modes of the molecules present. The resultant Raman spectrum serves as a unique fingerprint, facilitating the identification of distinct plastic polymers (Löder et al., 2017)

Raman spectroscopy boasts several advantages in microplastic analysis. It is non-destructive, necessitates minimal sample preparation, and delivers swift and accurate identification of microplastic particles. Moreover, it can analyze microplastics across various environmental matrices, including water, sediments, and biological tissues (Löder et al., 2017).

A key strength of Raman spectroscopy lies in its capability to differentiate between different plastic polymers, even within intricate mixtures. Each polymer exhibits characteristic Raman peaks corresponding to its distinctive molecular structure, enabling the identification of polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and other commonly found microplastics (Löder et al., 2017; Zhang et al., 2017).

The coupling of Raman spectroscopy with microscopy techniques adds spatial resolution to the analysis of microplastic particles. This integration allows for the visualization and examination of microplastics at the individual particle level, enhancing our understanding of their morphology and distribution in environmental samples (Löder et al., 2017).

In summary, Raman spectroscopy proves to be an invaluable tool for the identification and characterization of microplastics, offering swift, non-destructive, and precise analysis of plastic polymers in diverse environmental samples.

4.3.3 SEM-EDS

Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDS) is a powerful analytical technique commonly used for the characterization of microplastics. It combines high-resolution imaging capabilities with elemental analysis to provide valuable information about the morphology, size, and chemical composition of microplastic particles.

SEM-EDS works by scanning a focused electron beam over the sample surface, which generates secondary electrons and backscattered electrons. These electrons are then detected and used to construct high-resolution images of the sample, revealing details about its surface morphology and structure. Additionally, an EDS detector attached to the SEM allows for elemental analysis by measuring the characteristic X-rays emitted when the electron beam interacts with the sample (Käppler et al., 2016).

The EDS component of SEM-EDS is particularly valuable for identifying the chemical composition of microplastics. It can detect and quantify the presence of various elements, including carbon (C), oxygen (O), nitrogen (N), and other elements commonly found in plastic polymers. By analyzing the elemental composition, researchers can identify specific types of microplastics and differentiate them from other particles present in the sample (Lassen et al., 2015).

SEM-EDS offers several advantages for microplastic analysis. It provides high-resolution imaging, allowing for detailed examination of microplastic particles, including their shape, surface features, and potential surface coatings. The combination of imaging and elemental analysis provides comprehensive characterization of microplastics, aiding in their identification and understanding of their sources and fate in the environment (Käppler et al., 2016; Lassen et al., 2015).

Furthermore, SEM-EDS can be used for quantitative analysis, enabling the determination of the relative abundance of different plastic types in environmental samples. This information is crucial for assessing the extent of microplastic pollution and understanding its potential environmental impacts (Lassen et al., 2015).

In summary, SEM-EDS is a valuable technique for the characterization and identification of microplastics, offering high-resolution imaging and elemental analysis capabilities for comprehensive analysis of microplastic particles.

4.3.4 Pyr-GC-MS

Pyrolysis-Gas Chromatography-Mass Spectrometry (Pyr-GC-MS) is a widely employed analytical method for the identification and characterization of microplastics, combining pyrolysis, gas chromatography (GC), and mass spectrometry (MS). This technique provides essential insights into the chemical composition and thermal degradation products of the analyzed samples.

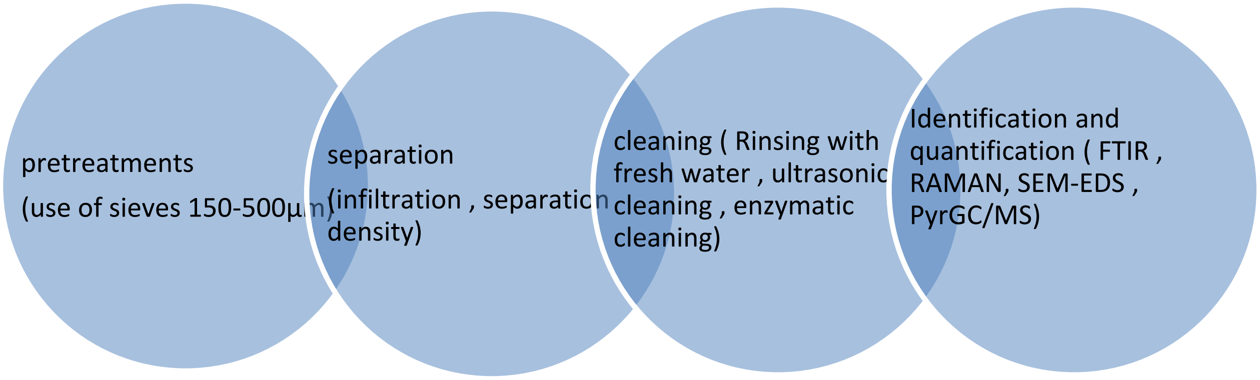
In Pyr-GC-MS, the microplastic sample undergoes exposure to elevated temperatures in a pyrolysis unit, causing the breakdown of polymer chains into smaller fragments. The resulting pyrolysis products are then separated through gas chromatography and detected by mass spectrometry, revealing information about their molecular structure and composition (Zarfl et al., 2011).

The key strength of Pyr-GC-MS lies in its ability to analyze the thermal degradation products of microplastics, offering information about their polymer type and potential additives. Through a comparison of the obtained pyrolysis products with reference databases, researchers can identify the specific polymer types present in the sample (Hirai et al., 2011).

Pyr-GC-MS enables the identification of various plastic polymers, such as polyethylene (PE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC), and others. Additionally, it can detect the presence of additives like plasticizers, flame retardants, and antioxidants commonly used in plastic formulations (Hirai et al., 2011; Rochman et al., 2014).

This technique provides crucial information about the chemical composition of microplastics, aiding in the assessment of their sources, environmental fate, and potential impacts. By understanding the polymer types and additives associated with microplastics, researchers can gain insights into their potential toxicity and environmental risks (Zarfl et al., 2011).

In summary, Pyr-GC-MS stands out as a powerful technique for the identification and characterization of microplastics, delivering valuable information about their chemical composition and thermal degradation products



Picture 4.1: Schematic representation of laboratory sample processing procedure

CHAPTER 5- INVESTIGATING THE FATE OF MICROPLASTICS IN AQUATIC ENVIRONMENT

5.1 Fate of microplastics in Aquatic environments

The accumulation of microplastics in aquatic environments has emerged as a significant concern due to potential impacts on ecosystems and human health. Microplastics, defined as small plastic particles with sizes typically less than 5 millimeters, originate from diverse sources such as the breakdown of larger plastic items, intentional release of microbeads in personal care products, and shedding of fibers from textiles.

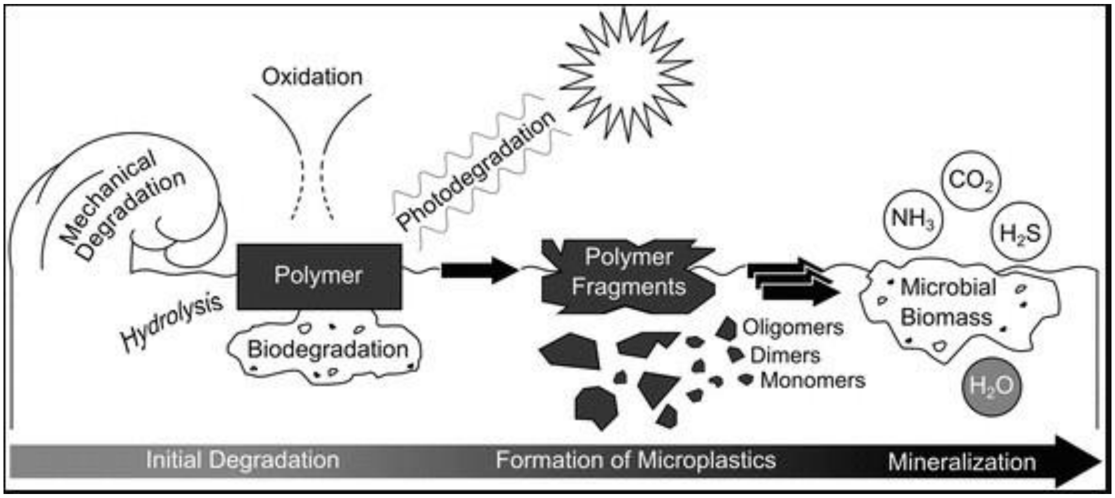
The presence and distribution of microplastics in aquatic ecosystems are influenced by factors like proximity to pollution sources, hydrodynamic conditions, and the nature of the water body, including rivers, lakes, and oceans. Research indicates that microplastics are pervasive in various aquatic settings, encompassing freshwater rivers and lakes, coastal regions, and even remote locations like polar and deep-sea environments.

Microplastics enter aquatic environments through multiple pathways. Primary microplastics, deliberately produced in small forms for specific applications, can enter water bodies through industrial processes or the use of consumer products. Secondary microplastics result from the breakdown of larger plastic items and can enter water bodies through runoff, wastewater discharge, or atmospheric deposition.

Once introduced, microplastics undergo processes influencing their transport and fate, such as vertical settling, horizontal transport by currents, river flows, and sediment deposition. Microplastics can interact with aquatic organisms, potentially causing bioaccumulation and biomagnification in the food chain through ingestion.

Concerns arise from the potential adverse effects of microplastics on marine organisms and ecosystems. Physical harm, including ingestion and entanglement, can lead to internal injuries, reduced feeding efficiency, and impaired reproduction. Microplastics also serve as carriers for harmful chemicals, such as persistent organic pollutants (POPs) and heavy metals, which can adsorb onto their surfaces and be transferred to organisms upon ingestion.

Understanding the occurrence, distribution, and fate of microplastics is essential for developing effective mitigation strategies. Ongoing research focuses on enhancing monitoring techniques, evaluating ecological risks, and implementing measures to reduce the release of microplastics into aquatic environments.



Picture 5.1: Main pathways of degradation of synthetic polymers in the aquatic environment and degradation processes (Source: Klein et al., 2018)

5.2. Dispersion and Transport of Microplastics

The dispersion and transport of microplastics in the environment are crucial factors that significantly influence their distribution and potential impacts. An understanding of these processes is essential for evaluating the fate of microplastics and their potential exposure to different ecosystems. Various pathways contribute to the dispersion and transport of microplastics, such as marine currents, atmospheric deposition, and sedimentation.

These processes are intricate and are influenced by numerous factors, including physical forces, environmental conditions, and the characteristics of microplastic particles. Ongoing research aims to comprehend the mechanisms and pathways involved in the transport of microplastics, with the goal of developing predictive models and effective mitigation strategies.

5.2.1 Marine Environment

In marine settings, microplastics have the capacity to be conveyed through the movement of ocean currents and surface waves, covering extensive distances from their origins. This can result in their potential aggregation in specific regions, often attributed to oceanic gyres and convergence zones (Lebreton et al., 2018). Coastal areas are especially prone to the accumulation of microplastics, given the interplay among marine currents, inputs from rivers, and nearshore processes (Kooi et al., 2017). The dynamics and transportation of microplastics within the marine environment are subject to various factors, including particle dimensions, density, buoyancy, and interactions with organic substances and marine organisms.

5.2.2 Fresh Water

As mentioned earlier, when the density of plastic is less than that of freshwater, microplastics follow the course of the river and eventually reach oceans or both artificial and natural lakes (Lebreton et al., 2017). In cases where the density is higher, microplastics will either submerge into the water or continue to be transported if the river's flow is robust. The irregular shape of microplastics differs from the hydrodynamic characteristics described in classical theories for spherical particles (Chubarenko and Stepanova, 2017), rendering their movement in the aquatic environment unpredictable. According to Ballent et al. (2013), particles with highly irregular shapes have a greater tendency to sink than those with a spherical shape.

Once the particles sink, they may follow one of two paths: settling to the river or lake bottom or resurfacing on the water's surface with the assistance of high-speed flow.

5.2.3 Marine environment

Research on microplastic transport in seas and oceans is more extensive compared to that in freshwater environments. A study by Cozar et al. (2014) estimated that approximately 7,000 to 35,000 tons of plastic float in open oceans, while Eriksen et al. (2014) suggested the existence of over five trillion pieces and more than 250,000 tons of plastic globally in oceans. The consensus is that microplastics, once they enter aquatic ecosystems, eventually reach the oceans. Around 70% of the waste settles at the ocean bottom, 15% floats on the surface, and the remaining 15% ends up on coasts (UNEP, 2005).

In oceans, microplastics exhibit a behavior similar to that in freshwater environments, where particles with higher water density form colonies of microorganisms and sink, while less dense particles float and travel on the ocean surface. In 2012, Engler estimated that approximately 50% of urban waste has a density capable of sinking. Microplastics that do not sink are transported to regions where they are collected, driven by currents and waves. The combination of large and small currents, along with the influence of Coriolis strength, forms five major marine currents where microplastics accumulate (Arthur et al., 2009). Each of the five oceans has areas of microplastic accumulation, but only the Atlantic and Pacific oceans maintain such accumulations for extended periods (van Sebille et al., 2012).

Changes in temperature and salt concentration in water cause marine currents to transfer from the surface to the interior, carrying microplastics with them. After a few hours in saltwater, biofilms composed of biopolymeric bacteria form on microplastics (Urbanek et al., 2018). The creation of biofilms marks the beginning of more extensive particle colonization, with a gradual increase in density, leading to an increase in vertical speed and an acceleration of sinking to the ocean floor. For many years, it was believed that larger colonies sank faster to the ocean floor (Ye and Adrandy, 1991; Adrandy, 2011), but Kooi et al. (2017) demonstrated that as microplastics move deeper, colonies are destroyed faster due to the lack of light. This results in the particles becoming lighter and resurfacing

Marine organisms also play a role in horizontally transporting microplastics. Organisms that have a direct relationship with both marine and terrestrial environments, such as seabirds and seals, can carry microplastics back to land (GESAMP, 2015).

5.2.4 Terrestrial Environment

Terrestrial Environment: Microplastics can be transported from land to aquatic environments via terrestrial pathways. Runoff originating from urban areas, agricultural fields, and rivers has the potential to carry microplastics into water bodies, where they may travel downstream (Carr et al., 2016). Wind can facilitate the long-distance transport of microplastics, resulting in their deposition in distant aquatic systems such as lakes and oceans (Dris et al., 2015). The observation of atmospheric transport of microplastics in various regions suggests their widespread distribution through airborne routes.

5.2.5 Atmospheric Environment

Atmospheric Environment: Microplastics have the capacity to travel through the atmosphere and subsequently settle in terrestrial and aquatic environments. They can be directly released into the air from various sources, including industrial activities, vehicle emissions, and resuspension from soils and water surfaces (Gewert et al., 2015). Once present in the atmosphere, microplastics can undergo long-distance transport facilitated by wind and then be deposited through dry or wet deposition processes (Zhang et al., 2020). The deposition of microplastics from the atmosphere has been identified in diverse settings, encompassing urban areas, remote mountainous regions, and marine ecosystems.

5.3 Concentrations of Microplastics in the aquatic environment

Microplastics in aquatic environments have the propensity to accumulate and aggregate in specific regions or habitats, driven by diverse processes and factors. These aggregation mechanisms encompass physical, biological, and environmental aspects. For instance, hydrodynamic conditions such as ocean currents and tides play a pivotal role in causing the accumulation of microplastics in particular areas like coastal zones, estuaries, or nearshore regions (Browne et al., 2011). The accumulation in these areas can be attributed to the buoyancy, size, and interactions of microplastics with water currents.

Biological elements also play a significant role in the gathering of microplastics. Microorganisms and biofilms have the capacity to colonize and aggregate around microplastics, giving rise to biofouling communities (Zettler et al., 2013). These biofouling communities contribute to the enhanced aggregation and sinking of microplastics, potentially leading to their accumulation in sediments.

Moreover, natural or anthropogenic debris serves as gathering sites for microplastics. Floating debris, including seaweed, driftwood, or plastic items, acts as traps or aggregators for microplastics, resulting in their accumulation and concentration in specific locales (Cózar et al., 2014).

It is crucial to emphasize that the gathering or aggregation of microplastics in the aquatic environment is a multifaceted process influenced by numerous factors, encompassing hydrodynamics, biological interactions, and environmental conditions. Understanding these intricate mechanisms remains an active area of research, necessitating further studies to comprehensively investigate gathering patterns and their implications.

5.3.1 Microplastics in the Oceans

The accumulation of microplastics in the oceans poses a significant environmental challenge. These minute plastic particles, measuring less than 5 millimeters, find their way into the ocean through various channels, presenting the risk of persistence and build-up in marine ecosystems.

Sources of microplastics in the oceans encompass direct releases resulting from land-based activities like coastal littering, improper waste disposal, and industrial discharges (GESAMP, 2015). Furthermore, microplastics can be conveyed from rivers and other water bodies to the oceans, further contributing to their prevalence in marine ecosystems (Lebreton et al., 2017).

Once in the oceans, microplastics can be carried across long distances by ocean currents and wind-driven processes (Koelmans et al., 2017). They can disperse throughout the water column or aggregate in specific zones, such as coastal areas, gyres, and convergence zones (Lebreton et al., 2018). These aggregation areas, often termed "plastic patches" or "garbage patches," represent regions with elevated concentrations of floating microplastics due to current convergence and the accumulation of marine debris (Lebreton et al., 2018).

The repercussions of microplastics on marine ecosystems raise significant concerns. They can be ingested by a diverse range of marine organisms, including fish, seabirds, turtles, and marine mammals, potentially causing harm to their health and well-being (Wright et al., 2013; Rochman et al., 2015). Additionally, microplastics can interact with marine sediments, influencing benthic organisms and potentially entering the food web (Hidalgo-Ruz et al., 2012).

Addressing the issue of microplastics in the oceans involves the implementation of waste management strategies, the reduction of plastic pollution at its source, and the development of technologies for the removal and cleanup of marine debris (GESAMP, 2019). Global collaborations and initiatives, such as the United Nations' Sustainable Development Goals and the Global Partnership on Marine Litter, aim to combat marine plastic pollution and encourage sustainable practices.

5.3.2 Pacific Ocean

is crucial to highlight that microplastics present a significant menace to the well-being of the ocean ecosystem. Marine organisms can ingest microplastics, leading to their accumulation in sediments and integration into the food chain, potentially causing harm to marine life and ecosystems. Moreover, microplastics can serve as carriers of harmful chemicals, affecting water quality and the overall health of the marine environment.

Global endeavors are underway to tackle the microplastics issue in the ocean, encompassing research initiatives, awareness campaigns, and policy measures. The emphasis is on mitigating plastic pollution at its source, enhancing waste management systems, and advocating for sustainable practices to prevent further microplastic accumulation in the ocean.

Table 5.1 : Concentrations of Microplastics in the Pacific Ocean

Location	**Equipment**	**Measured prices of particles concentration**	**Concentration of Mp's (number/m)**	**Source**
Bering Sea	Ring net	80/km2	0.000016	Day and Shaw (1987)
Bering Sea	Neuston net	1/km2	0.0000002	Day et al. (1990)
Subarctic North Pacific	Neuston net	61.4/km2	0.000012	Day et al. (1990)
North-East Pacific	Plangton net	21.290 ton appr.		Law et al. (2014)
North-East Pacific	Manta net	279/m3		Desforges et

				al. (2014)
Central Pacific Gyre	Manta net	334.271/km2	2.23	Moore et al. (2001)
Central Pacific Gyre	Manta net	85.184/km2	0.017	Carson et al. (2013)
Subtropical Pacific Gyre	Plangton/Neuston/Manta nets	0.116/m3 (on average)	0.12	Goldstein et al. (2012)
Subtropical Pacific Gyre	Neuston/Manta nets	678.000/km2	0.1356	Lebreton et al al. (2018)
Southern California	Manta net	0.011-0.033/m3 (on average)	0.011-0.033	Gilfillan et al al. (2009)
Santa Monica Bay	Manta net	3.92/ m3	3.92	Latin et al.(2004)
Santa Monica Bay	Manta net	7.25/m 3	7.25	Moore et al al.(2002)
Subtropical Northern Pacific Gyre	Ring net	96,100/ km2	0.019	Day and Shaw (1987)
Subtropical Northern Pacific Gyre	Neuston/Ring nets	535.1/ km2	0.00011	Day et al. (1990)
Subtropical Northern Pacific Gyre	Manta net	0.02-0.45/m 2	0.0042-0.089	Goldstein et al. (2013)
Japan	Neuston/Ring nets	128.2/km2	0.000026	Day et al. (1990)

Yang che estuaries	Neuston net	4137.3/m3	0.00085	Zhao et al. (2014)
Subtropical South Pacific Gyre	Manta net	26898/km2	0.0054	Eriksen et al. (2013)
Australian Coast	Neuston/Manta nets	4.256,3/km2	0.00085	Reisser et al.

5.3.3 Atlantic Ocean

Surveys conducted in the Atlantic Ocean (Table 5.2) may not be as extensive as those in the Pacific, but some of them have a longer duration. Investigations by Law et al. (2010) and Moret-Ferguson et al. (2010) revealed the existence of a large-scale convergence zone in the northern Atlantic, created by surface currents and wind patterns.

Table 5.2 : Microplastics' concentration in Atlantic Ocean

Location	**Equipment**	**Measured prices of particles concentration**	**Concentration of Mp's (number/m)**	**Source**
North Atlantic Gyre	Plangton net	20328/km2	0.0041	Law et al. (2010)

Northern Atlantic	Plangton Recorder	1960-1980: 0,01/m3 1980-2000: 0.04/m3	1960-1980: 0,01 m-3 1980-2000: 0.04 m-3	Thompson et al. (2004)
North-east Atlantic	Pumps	2.46 ±2.43/m3	2.46 ±2.43	Lusher et al. (2014)
North-east Atlantic	Neuston net	490/km2	0.00098	Wilber (1987)
Atlantic's ocean oceanic bottom (1176-4843m)	Seabed sampling	0.5/25cm2		VanCauwenberghe et al. (2013)
Atlantic's ocean oceanic bottom (1000-3500m)	Seabed sampling	13.4/50ml		Woodall et al. (2014)
Gulf of Maine	Plangton net	153/ km2	0.00031	Law et al. (2010)
Ney England , USA	Plangton net	0,00-2,58/m3	0-2.58	Carpenter et al. (1972)
USA's West Coast	Neuston net	2.773/km2	0.00056	Colton et al. (1974)
Sargasso Sea	Neuston net	3.537/km2	0.00071	Carpenter and Smith (1972)
Caribbean	Plangton net	60.6-180/ km2	0.000012-0.000036	Colton et al.
Caribbean	Ring net	1,414/ km2	0.00028	-1974

Ireland	Pumps	2.46/m3	2.46	Lusher et al. (2014)
English Channel , UK	Plangton net	0,27/m3	0.27	Cole et al. (2014)
Portugal Coast	Neuston net	0.02-0.036/m3	0.02-0.036	Frias et al. (2014)
Archipelagos Saint Peter and Saint Paul, Brazil	Plangton net	0,01/m3	0.01	Ivar do Sul et al. (2013)
Basin Cape	Neuston Sled	1.874,3/km2	0.00037	Morris (1980)
Province Caper	Neuston net	3.640/km2	0.00073	Ryan (1988)
Brazil	Manta net	0.03/m3	0.03	Ivar do Sul et al. (2014)
North-West Atlantic	Plangton net	0.01-14.1/m3	0.01-14.1	Carpenter et al.(1972)

5.3.4 Indian Ocean

The concentration of microplastics in the Indian Ocean, much like in other marine environments, is subject to variability influenced by factors such as proximity to sources, oceanographic conditions, and human activities. While I don't have access to the latest data for specific concentration values, I can offer general insights into the matter.

Research indicates the presence of microplastics in diverse regions of the Indian Ocean, encompassing coastal areas, open ocean expanses, and even remote, less populated locations. Studies conducted in the Indian Ocean have identified microplastics in water samples, sediments, and marine organisms, underscoring their widespread distribution within the marine ecosystem (e.g., Chatterjee et al., 2020; Fok et al., 2017; Nayar et al., 2020).

Coastal and nearshore regions, where human activities and urban centers are concentrated, often exhibit higher concentrations of microplastics compared to offshore areas. The elevated concentrations in these areas are attributed to inputs from coastal cities, rivers, and other sources of plastic pollution (Chatterjee et al., 2020; Fok et al., 2017).

In the Indian Ocean, ocean currents, including the South Equatorial Current, the Agulhas Current, and the Somali Current, play a significant role in the transport and dispersion of microplastics. These currents can carry microplastics over substantial distances, potentially leading to their accumulation in specific areas or influencing downstream coastal regions (Lavender Law et al., 2019).

It is crucial to acknowledge that microplastic concentrations can vary both temporally and spatially. Further research is imperative to gain a more comprehensive understanding of the specific patterns and levels of microplastics in different parts of the Indian Ocean.

Table 5.3 : Microplastics’ concentration in Indian Ocean

Shipyard , Alang-sosiya India	Fragments	St. Steel Shovel	81 mg/kg	Reddy et al. (2006)
Mumbai India	Pellets	St. Steel Tweezers		Ogata et al. (2009)
Singapore	Fibers/Fragments	St. Steel Spatula	36.8±23.6/kg	Mohammed Nor et Obbard (2014)
Lang Kawi, Penang and Borneo, Malaysia	Pellets	St. Steel Tweezers		Ogata et al. (2009)
Rayong Thailand	Pellets	St. Steel Tweezers		Ogata et al. (2009)
Jakarta Bay Indonesia	Pellets	St. Steel Tweezers		Ogata et al. (2009)
Mozambique	Pellets	St. Steel Tweezers		Ogata et al. (2009)
Gulf of Oman	Pellets	Hands	>50-200/m2	Khordagui και abu-Hilal (1994)
Persian Gulf	Pellets	Hands	>50-80.000/m2	Khordagui και abu-Hilal (1994)

5.3.5 Microplastics in the Arctic Ocean and Antarctica

Microplastics have been identified in both the Arctic Ocean and Antarctica, underscoring the global scope of this issue. The following information provides insights into the presence of microplastics in these regions:

- **Arctic Ocean:**

Research indicates the existence of microplastics in various areas of the Arctic Ocean, encompassing surface waters, sea ice, sediments, and even remote locations such as the Arctic deep sea. Local sources, including shipping activities, coastal communities, and tourism, contribute to microplastic pollution in the Arctic, alongside long-range transport from more densely populated regions. Ocean currents and atmospheric deposition facilitate the transportation of microplastics to the Arctic (Kedzierski et al., 2018; Obbard et al., 2014). The melting of sea ice releases microplastics previously trapped within, adding to the overall microplastic burden in the Arctic Ocean (Bergmann et al., 2017). The presence of microplastics in the Arctic ecosystem raises concerns regarding potential impacts on marine organisms and the ecological balance in this fragile region.

- **Antarctica:**

Microplastics have been identified in the waters surrounding Antarctica and in Antarctic sediments. Human activities, including research stations, tourism, and fishing, are the primary sources of microplastics in Antarctica. These microplastics can reach Antarctica through ocean currents and atmospheric deposition from distant locations (Barnes et al., 2018). The presence of microplastics in Antarctic waters and sediments raises concerns about their potential effects on marine organisms, particularly filter-feeding species such as krill, which play a crucial role in the Antarctic food web.

The remote and pristine nature of the Arctic Ocean and Antarctica amplifies the concern about the presence of microplastics. While the impacts on these sensitive polar environments are still under investigation, it is evident that measures must be implemented to mitigate further pollution and safeguard these unique ecosystems.

5.4 Microplastics in the Seas

5.4.1 Microplastics in European Seas and the Mediterranean Sea.

Microplastic pollution in European seas and the Mediterranean Sea is a growing concern due to its potential impact on marine ecosystems. The following information provides an overview of the situation in these regions:

European Seas: Various European seas, such as the North Sea, Baltic Sea, and Mediterranean Sea, are affected by microplastic pollution. Studies have identified the presence of microplastics in different components of these seas, including surface waters, sediments, and marine life. The primary sources of microplastics in European seas are linked to land-based activities like urban runoff, industrial discharges, and inadequate waste management practices (Claessens et al., 2011; Gago et al., 2018). Rivers also serve as conduits, transporting microplastics from inland areas to the seas (Lebreton et al., 2017). The combination of high population density and industrial activities in Europe contributes to the accumulation of microplastics in these marine environments.

Mediterranean Sea: The Mediterranean Sea faces unique challenges concerning microplastic pollution due to its semi-enclosed nature, high tourism levels, and dense coastal population. Microplastics have been identified in various parts of the Mediterranean, including surface waters, sediments, and marine organisms (Suaria & Aliani, 2014; Collignon et al., 2012). The sources of microplastics in the Mediterranean are diverse, encompassing urban and industrial discharges, tourism-related activities, maritime transport, and coastal littering (Cózar et al., 2014; Fossi et al., 2012). The Mediterranean Sea also receives microplastics transported from other regions through ocean currents, contributing to its pollution levels (Suaria et al., 2016).

The presence of microplastics in European seas and the Mediterranean underscores the urgency of increased efforts to mitigate and prevent further pollution. Several initiatives and regulations at the European Union level, including the EU Plastics Strategy, the Single-Use Plastics Directive, and the Marine Strategy Framework Directive, aim to reduce plastic waste, enhance waste management practices, and safeguard marine ecosystems. The next panel provides information on microplastic concentrations in European Seas and the Mediterranean Sea (Table 5.4).

Table 5.4 : Microplastics' concentration in EU and Mediterranean sea

Location	**Equipment**	**Measured prices of particles concentration**	**Concentration of Mp's (number/m3)**	**Source**
Denmark	Sieve	0.0324g/L		Strand et al. (2013)
Mediterranean Seafloor (1000-3500 m)	Seafloor Sampler	13,4/50mL		Woodall et al. (2014)
Mediterranean Seafloor (1176-4843m)	Seafloor Sampler	0,5/25cm2		VanCauwenberghe et al. (2013)
Italy (Mediterranean)	Neuston net	1.25/m2	0.25	Suaria et al. (2016)
North-west Mediterranean	Manta net	0.116/m2	0.0232	Collignon et al. (2012)
Medirerranean Sea	Neuston net	890.000/km2	0.178	Eriksen et al. (2014)
West Coast of Sweden	Manta net (80μm & 450μm)	150-2.400/m3 & 0.01-0.14/ m3	150-2400 & 0.01-0.14	Noren (2007)
Skagerrak Sweden	Pumps	102,000/m3	102,000	Noren και Naustvoll (2011)
Gulf of Oristano , Sardinian Sea Italy	Manta net	0.15/m3	0.15	De Lucia et al. (2014)

Northern Sea Finland	Manta net	0-0.74/m3	0-0.74	Magnusson (2014)
Gulf of Crete Greece	Plangton net	119±250 g/km2		Kornilios,Drakopoulos και Dounas (1998)
Western Mediterranean , Ligurian sea & Sardinian sea	Neuston/plangton net	0.62±2.00 /m3	0.62-2	Fossi et al. (2012)
Western Mediterranean , Gulf of Calvi	Neuston net	6.2/100 m2	0.0124	Collignon et al. (2014)
Western Mediterranean	Manta net	0.26±0.33/m3	0.26±0.33	Baini et al. (2018)
Medirerranean Sea	Neuston net	243.853/km2	0.0487	Cozar et al. (2015)
Western Mediterranean	Manta net	82.000±79.000/km2	0,0164±0.0158	Fossi et al. (2018)
Aegean - Middle East Sea	Manta net	16.339-520.213/km2	0.00327-0.1040	Guven et al. (2017)
Aegean - Middle East Sea	Manta net	7.68±2.38/m3	7.68±2.38	Van der Hal et al (2017)
Aegean - Middle East Sea	Manta net	0.376/m3	0.0752	Gundogdu and Cevik (2017)
Northeast	Manta net	1.067.120/km2	0.213	Gundogdu (2017)

Middle East Sea, Turkey				

*Results from studies that were not published in microplastics per m3 were converted as follows: km-2 to m-2 by multiplying by 10-6, and then m-2 to m-3 by multiplying by 0.20. The 20 cm approximates the typical sampling depth in surface waters.

5.4.2 Microplastics in Fresh Waters

Microplastics are not confined to marine environments but are also prevalent in freshwater ecosystems, encompassing rivers, lakes, and streams. The following information sheds light on the presence of microplastics in freshwater or sweet waters:

- **Freshwater Systems**: Research indicates the widespread contamination of freshwater systems globally by microplastics. Sources of these particles in freshwater environments include urban runoff, industrial discharges, effluents from wastewater treatment plants, agricultural activities, and atmospheric deposition (Besseling et al., 2017; Wagner et al., 2014). Microplastics enter freshwater systems through various means such as surface runoff, direct littering, and transportation by rivers from upstream areas. Recreational activities and tourism can also contribute to the introduction of microplastics into freshwater ecosystems (Khan et al., 2019). Once in freshwater systems, microplastics can accumulate in sediments, be ingested by aquatic organisms, and potentially enter the food web.

- **River Systems:** Rivers play a pivotal role in transporting microplastics from land to freshwater ecosystems and eventually to oceans. Studies demonstrate that rivers act as significant pathways for microplastic transport, carrying them downstream and contributing to the overall contamination of marine environments (Lebreton et al., 2017). Sources of microplastics in rivers are often linked to urban and industrial areas characterized by high levels of plastic waste and inadequate waste management practices.

- **Lakes and Reservoirs**: Microplastics have been identified in lakes and reservoirs, vital freshwater resources. The presence of microplastics in these systems is attributed to inputs from surrounding land, atmospheric deposition, recreational activities, and boat traffic (Free et al., 2014; Zhang et al., 2017). The accumulation of microplastics in lake sediments poses risks to benthic organisms and can impact the overall ecological balance of these ecosystems.

The contamination of freshwater, or sweet waters, with microplastics raises significant concerns due to potential ecological and human health implications. Addressing this issue necessitates improved waste management practices, effective wastewater treatment, and heightened public awareness to reduce plastic releases into freshwater system

5.4.3 Rivers

Microplastic pollution in rivers has become a focal point of concern in recent times due to its potential ecological and environmental repercussions. Here is information regarding microplastics in rivers:

Rivers receive inputs of microplastics from diverse sources, primarily including urban runoff, industrial discharges, wastewater treatment plant effluents, agricultural activities, and atmospheric deposition (Lechner et al., 2014; Horton et al., 2017). Urban areas and densely populated regions serve as major contributors to microplastic pollution in rivers, with urban runoff carrying plastics from streets, storm drains, and sewage systems into waterways (Koelmans et al., 2017). Industrial activities, particularly those related to plastic production and processing, can also release microplastics into rivers through direct discharges or accidental spills.

Rivers play a pivotal role in the transportation and dispersion of microplastics from inland areas to coastal regions and the ocean. Microplastics can be transported downstream by river currents, with larger particles settling in riverbeds and smaller particles remaining suspended in the water column (Collard et al., 2017). Besides downstream transport, microplastics can be temporarily retained in river sediments, acting as both sinks and potential sources for microplastic re-entrainment (Hurley et al., 2018). Flood events can mobilize microplastics stored in river sediments, transporting them to downstream areas and contributing to further dispersion.

Microplastics in rivers can have diverse ecological impacts. Aquatic organisms may ingest them, leading to physical harm, intestinal blockage, and potential transfer through the food chain (Koelmans et al., 2017). Microplastics can also serve as vectors for chemical pollutants, absorbing and releasing harmful substances into the water, potentially affecting the health of aquatic organisms (Gouin et al., 2015). Furthermore, microplastics can alter the physical and chemical properties of river sediments, influencing benthic organisms and overall ecosystem dynamics (Eerkes-Medrano et al., 2015).

Ongoing monitoring and research endeavors aim to assess the extent and impacts of microplastic pollution in rivers. Techniques such as sediment sampling, water sampling, and biota analysis are employed to quantify and characterize microplastic contamination in river systems (Horton et al., 2017). These studies contribute to understanding the sources, transport pathways, and potential risks associated with microplastics in rivers, guiding future management and mitigation strategies.

Table 5.5 Concentration of Microplastics in rivers worldwide

Location	**Equipment**	**Measured prices of particles concentration**	**Concentration of Mp's (number/m3)**	**Source**
Urban Rivers (USA)	Manta net	Maximum: 12,932/m 3 Minimum: 10/m 3	10-12,932	Moore et al. (2011)
Rhine river (Germany)	Manta net	Average: 892,777/km 2	0.178	Mani et al. (2015)

Danube river (Austria)	Net	Average: 0.3168/m 3	0.3168	Lechner et al. (2014)
Yang Che river (China)	Manta net	Average: 8,465,600/km 2	1.69	Zhang et al al. (2015)
Seine river (France)	Plangton net / Manta net	3-106/m 3 (Net plankton) 0.28-0.47 (Net Manta)	3-106 0.28-0.47	Dris et al. (2015)
St. Lawrence river (Canada)	Sieve	13,759/m 2	2,752	Castaneda et al. (2014)
Thames river (UK)	St. steel laddle	Maximum: 660/kg		Horton et al. (2017)
Los Angeles river	Hand net/ Manta net	Total Number:12,933/m 3 (1-4.75mm) 820/m 3 (>4.75mm)		Moore et al. (2005)
San Gabriel river (California)	Hand net/ Manta net	Total Number: 411/m 3 (1-4.75mm) 125/m 3 (>4.75mm)		Moore et al. (2005)
Marne river (France)	Manta net	100.6±99.9/m 3	100.6±99.9	Driss et al al. (2018)

Pearl river (China)	Seabed sampling	2724/m 3	2724	Lin et al. (2018)
29 rivers (Japan)	Plangton net	0.44/ m3	0.44	Kataoka et al. (2019)
Wei river (China)	Pumps/Sieves	0.918 gr/l		Ding et al. (2019)
Maribyrnong and Yarra rivers (Australia)	Manta net	2.5803 gr/l		Kowalczyk et al. (2017)

According to table 5.5 , the concentrations of microplastics vary significantly across different regions. This variation can be attributed to factors such as population density, economic and urban development, hydrological phenomena, and waste management practices. Additionally, the absence of a standardized procedure for the collection and analysis of data is noteworthy, contributing to the lack of comparability between various research studies.

5.4.4 Lakes

Lakes can be influenced by various sources of microplastic pollution, including urban runoff, stormwater drainage, wastewater treatment plant effluents, recreational activities, atmospheric deposition, and inputs from surrounding land areas (Koelmans et al., 2017; Free et al., 2014). Urban areas and densely populated regions play a significant role in introducing microplastics into lakes, with runoff from urban surfaces being a major contributor. Recreational activities, such as boating and fishing, also contribute to microplastic pollution in lakes through the use of plastic-based equipment and littering.

Spatial variations in the distribution and accumulation of microplastics are observed in lakes. Microplastics can accumulate in lake sediments, persisting over extended periods. Sediment cores from lakes reveal layers enriched with microplastics, indicating historical inputs and gradual accumulation (Espinosa et al., 2020). Additionally, microplastics can be present in the water column, where currents can transport them to specific areas or disperse them throughout the lake.

Microplastic contamination in lakes poses risks to aquatic organisms and the overall ecosystem. Various organisms, including zooplankton, fish, and benthic invertebrates, can ingest microplastics, leading to physical harm, reduced feeding efficiency, and potential transfer through the food chain (Castañeda et al., 2020; Mani et al., 2015). The presence of microplastics can also alter the physical and chemical characteristics of the water, impacting water quality, light penetration, and nutrient cycling, thereby influencing the entire ecosystem.

Ongoing monitoring programs and research endeavors aim to assess the extent and impacts of microplastic pollution in lakes. Sampling techniques, such as sediment coring, water filtration, and biota collection, are employed to quantify and characterize microplastic contamination (Espinosa et al., 2020; Free et al., 2014). These studies contribute to understanding the sources, transport dynamics, and potential ecological risks associated with microplastics in lakes, facilitating the development of effective management and mitigation strategies.

Table 5.6 Concentration of Microplastics in lakes worldwide

Location	**Equipment**	**Measured prices of particles concentration**	**Concentration of Mp's (number/m3)**	**Source**
Laurentian Lakes (Canada)	Neuston net	43.000-466.000 km2	0.0086-0.0932	Eriksen et al. (2013)
Poyang Lake (China)	Sieve/Seabed sampling	0.2034gr/l		Yuan et al. (2019)
Winnipeg Lake (Canada)	Manta net	193.240±115.567/km2	0.0386±0.0231	0.0386±0.0231 Anderson et al. (2017
Vembanad Lake (India)	Sieve/Seabed sampling	252.80±25.76/m2		Struthy and Ramasamy (2017)
Remote lakes in Thibet (China)	Shovel	0.5067g/l		Zhang et al. (2016)
Chuisi & Bolsena Lakes (Italy)	Manta net	2,765/m3	2,765	Fischer et al. (2016)
Geneva lake (Austria)	Manta net	48.146/km2	0.096	Faure et al. (2012)
Huron lake (USA/Canada)	St. Steel Spatula	3.209/85m2	7.55	Zbyszewski and Corcoran (2011)
29 Big lakes' estuaries (USA)		1.9/m3	1.9	Baldwin et al. (2016)

*Results from studies that were not published in microplastics per m3 were converted as follows: km-2 to m-2 by multiplying by 10-6, and then m-2 to m-3 by multiplying by 0.20. The 20 cm approximates the typical sampling depth in surface waters.

Once again, it is important to highlight that the absence of a standardized research protocol for assessing microplastic concentrations hinders the ability to compare findings across studies, thereby impeding a more realistic and precise representation of the situation.

CHAPTER 6- INSTITUTIONAL ARRANGEMENTS FOR MARINE ENVIRONMENT PROTECTION

Institutional arrangements possess a significant role reffering to protection of aquatic environments, along with mitigation of microplastic pollution. These arrangements involve the development and implementation of policies, programs, and regulations at multiple levels. To be more specific :

- International Level: Internationally, numerous organizations and agreements are dedicated to water protection and mitigating microplastic pollution. The United Nations Environment Programme (UNEP) coordinates global efforts & initiatives targeting marine pollution, including microplastics. The UNEP's Global Partnership on Marine Litter actively strives to diminish marine litter, including microplastics, by fostering cooperation and exchanging knowledge among nations (UNEP, n.d.). Furthermore, the United Nations Convention on the Law of the Sea (UNCLOS) establishes a structure for the preservation and sustainable utilization of marine resources, incorporating measures to address pollution issues..

- National Level: Many countries have established national strategies and regulations to protect their aquatic environments. These may include laws and regulations for plastic waste management , wastewater treatment, and prevention of plastic pollution. National environmental agencies or departments are responsible for overseeing these efforts and enforce regulations. Additionally, some countries have implemented programs for monitoring and assessing microplastic contamination in water bodies too.
- Regional and Local Level: Regional entities and local governments also have a crucial role in water protection and addressing microplastic pollution. Regional agreements and organizations, such as the European Union's Marine Strategy Framework Directive (MSFD), aims to achieve good environmental status of marine waters by addressing various pressures, including microplastic pollution. Local authorities frequently enact measures related to waste management, stormwater management, and the promotion of sustainable practices to diminish plastic pollution in aquatic environments.
- Collaborative Initiatives: Collaboration among different stakeholders is essential for effective water protection as well. This includes collaboration among governments, research institutions, non-governmental organizations (NGOs), industries, and the general public. Collaborative initiatives may involve exchange of effective strategies, joint research endeavors, implementation of awareness campaigns, and development of innovative solutions to prevent and manage microplastic pollution.
- Research and Innovation: Research institutions and academic institutions play a

crucial role in advancing our knowledge and comprehension of microplastic pollution in aquatic environments. They actively contribute to the creation of monitoring techniques, risk assessment frameworks, and cutting-edge technologies for the detection and removal of microplastics. The insights gained from their research significantly influence policy and decision-making across various levels.

6.1 Treatment programs for Microplastics' pollution

6.1.1 Worldwide level

Several programs and initiatives focus on treatment and mitigation of microplastics' pollution . These programs intend to raise awareness, promote research, develop guidelines, and implement strategies to reduce release of microplastics into the environment.

For instance :

- United Nations Environment Programme (UNEP): UNEP plays a significant role on a global scale. Through initiatives such as the Global Partnership on Marine Litter and the Clean Seas campaign, UNEP collaborates with governments, businesses, and civil society to promote the reduction of marine litter, including microplastics. The UNEP also promotes research and the exchange of knowledge to create effective strategies for preventing and managing microplastic pollution.
- International Maritime Organization (IMO): The IMO, a specialized agency of the United Nations, focuses on the prevention and reduction of pollution from ships. It

has implemented regulations, such as the International Convention for the Prevention of Pollution from Ships (MARPOL), which incorporates measures to prevent the release of plastics, including microplastics, into the sea. The IMO strives to encourage adherence to these regulations and supports research and the advancement of innovative technologies aimed at reducing microplastic emissions from shipping operations.

- Global Plastics Action Partnership (GPAP): GPAP, a collaboration between the World Economic Forum and numerous stakeholders, works to diminish the global plastic pollution crisis. GPAP works with governments, businesses, and civil society organizations to develop and implement strategies that reduce plastic waste and prevent its entry into the environment. This includes efforts to minimize the generation of microplastics and promote the circular economy approach for plastics.
- G20 Action Plan on Marine Litter: The G20 countries have recognized the issue of marine litter. The G20 Action Plan on Marine Litter outlines strategies to prevent and reduce marine litter, improve waste management systems, promote sustainable production and consumption patterns, and enhance international cooperation and coordination.
- International Union for Conservation of Nature (IUCN): The International Union for Conservation of Nature (IUCN) is a global organization committed to nature conservation and sustainable development. They address marine plastic pollution through initiatives like the Global Programme on Marine Plastics and the Plastic Waste-Free Islands project. These efforts aim to reduce plastic waste by advocating

for policies and raising awareness.

These programs and initiatives, among others, contribute to global efforts in treating pollution from microplastics by promoting policy development, research, and collaboration among stakeholders to find effective solutions for reducing microplastic emissions and for environmental protection.

6.1.2 National level

Nowadays, lots of countries have implemented programs and initiatives in order to address pollution from microplastics. These programs focus on different aspects, research, regulation, waste management, and public awareness among others.

More specifically:

- United States - Microplastics Initiative: The United States Environmental Protection Agency (EPA) has launched the Microplastics Initiative to identify sources, fate, and impacts of microplastics in the environment. The initiative includes research projects, collaborations with stakeholders, and development of best management practices to reduce microplastic pollution.

- United Kingdom - Microplastics Research Strategy: The UK government has developed a Microplastics Research Strategy to guide research efforts on microplastics. Its main target is to improve understanding of the sources, pathways, and impacts of microplastics and to develop effective mitigation measures. It also emphasizes collaboration between government agencies, academic field, and industry.

- Canada - Plastics Science Agenda: Canada has established the Plastics Science Agenda, which focuses on advancing scientific knowledge to address plastic pollution. This agenda supports research on the impacts, sources, and fate of microplastics, as well as the development of innovative solutions for their prevention and removal.

- Germany - Plastics Strategy: Germany has developed a comprehensive Plastics Strategy to reduce plastic waste and address microplastic pollution. This strategy promotes recycling and sustainable production methods, the enforcement of more stringent regulations concerning plastic products,, and supporting research and innovation in the field of microplastics.

- Australia - National Plastics Plan: Australia has launched the National Plastics Plan, which sets out the government's approach to addressing plastic pollution, including microplastics. The plan aims to reduce plastic waste generation and recycling infrastructure improvements . It also includes initiatives to raise awareness and educate the public about the impacts of microplastics.

These national-level programs demonstrate the commitment of governments to tackle microplastic pollution through research, regulation, and stakeholder collaboration. By implementing these initiatives, countries intend to reduce the release of microplastics into the environment and protect aquatic ecosystems.

6.2 Prevention and Restriction measures for Microplastics' pollution

6.2.1 Prevention measures

While trying to address pollution from microplastics, various preventive measures and strategies have been developed at different levels, including implementation of actions and measures. Main purpose of these acts is to reduce release of microplastics into the environment and alleviate their negative effects.

Some of the main prevention measures are :

1. Source Reduction: It is essential to reduce the production and use of microplastics at their source. This involves measures such as phasing out the of microbeads in personal care products, promoting eco-friendly alternatives, and promote the implementation of environmentally-friendly production practices in industries involved in the use or generation of microplastics.

2. Product Labeling and Certification: Labeling and certification schemes can help consumers make more consious choices and opt for products that are microplastic-free or have reduced microplastic content. These schemes provide transparency and

promote the use of environmentally friendly alternatives. They can also encourage manufacturers to embrace practices that reduce microplastic pollution.

3. Waste Management and Recycling: Effective waste management systems play a crucial role . Implementing proper waste collection, sorting, and recycling programs can help capture microplastics before they enter water bodies. This includes improving infrastructure for plastic waste management, promoting recycling initiatives, and encouraging responsible disposal practices.

4. Wastewater Treatment: Advanced wastewater treatment technologies can help remove microplastics from domestic and industrial wastewater before been discharged into the environment. Treatment processes such as membrane filtration, activated carbon adsorption, and advanced oxidation have high effectiveness regarding removal of microplastics from wastewater effluents.

5. Best Management Practices in Industries: Industries that are major sources of microplastic pollution, such as textile manufacturing and plastic production, must adopt best management practices to prevent and control the release of microplastics. This may involve implementing filtration systems, optimizing production processes, and adopting recycling and waste reduction measures.

6. Public Education and Awareness: Raising public awareness about the issue of microplastic pollution is crucial for prevention. Educational campaigns, workshops,

and outreach programs can inform individuals about sources, impacts, and prevention acts related to microplastics. This can lead to behavioral changes, such as the reduction of plastic consumption, proper waste disposal, and supporting microplastic-free products.

By implementing prevention measures and actions, we can reduce release of Microplastics into the environment and minimize their negative effects.

6.2.2 Restriction measures

In addition to prevention measures, restriction measures are implemented to regulate the use of specific materials or products that contribute to microplastic pollution and limit their environmental impact.

For instance :

1. Ban on Microbeads: Many countries and regions have enforced prohibitions on the use of microbeads in personal care and cosmetic products. Microbeads are tiny plastic particles found in products like facial scrubs and toothpaste, pose a threat to the aquatic ecosystems as they can easily enter water bodies. These bans regulate and limit the manufacturing , sale, and import/export of such products containing microbeads.

2. Bans on plastic bags.: Numerous jurisdictions have implemented prohibitions and restrictions on the use of plastic bags to reduce plastic waste and its associated environmental impacts. These measures discourage the use of single-use plastic

bags, which can fragment into microplastics over time. Instead, reusable bags or biodegradable alternatives are promoted as more sustainable options.

3. Single-Use Plastics Regulation: To address the issue of plastic pollution, certain countries have implemented regulations to limit or gradually eliminate specific single-use plastic items. These items comprise plastic straws, cutlery, plates, and beverage stirrers, whose improper disposal can contribute to microplastic pollution. The regulations are designed to promote the adoption of reusable alternatives and encourage sustainable consumption practices.

4. Fishing Gear and Aquaculture Regulations: Regulations are being implemented to address the release of microplastics from fishing gear, such as nets and ropes, as well as aquaculture operations. These regulations focus on promoting responsible fishing practices, including the use of gear that minimizes the shedding of microplastics and the proper disposal of worn-out or damaged gear.

5. Industrial Discharge Regulations: Regulations are developed to control and limit the discharge of microplastics from industrial activities into the environment. These regulations may include restrictions on the release of microplastics from manufacturing processes and the implementation of filtration systems to prevent their entrance into water bodies.

6. International Agreements: International agreements and conventions are being

established focusing on marine pollution and microplastic pollution. For example, he United Nations Environment Assembly (UNEA) has played a role in adopting resolutions to tackle marine litter and microplastics. These resolutions typically encourage member states to implement measures aimed at reducing the discharge of microplastics into the oceans. This reflects a global effort to address the environmental challenges associated with plastic pollution in marine ecosystems.

The restrictions are designed to decrease the introduction of microplastics into the environment and encourage a shift towards more sustainable alternatives. Through the control of specific materials and products, these measures play a role in the broader initiative to safeguard water ecosystems and alleviate the consequences of microplastic pollution.

6.2.3 Consolidation measures

Consolidation acts and measures involve the implementation of strategies to reinforce existing regulations, policies, and actions pertaining to microplastic pollution. These efforts prioritize improving coordination, collaboration, and enforcement to ensure the effective execution of strategies, leading to more successful outcomes in addressing microplastic pollution

- Integrated Approaches involves coordinating efforts across diverse sectors, including waste management, industry, agriculture, and consumer behavior, to address the various pathways through which microplastics enter the environment.

- Policy Harmonization: Is a critical component of consolidation measures, involving the alignment of policies and regulations across regional, national, and international levels. This process includes standardizing standards, definitions, monitoring methods, and enforcement mechanisms to ensure consistency and effectiveness in addressing microplastic pollution. This harmonization facilitates collaboration and information sharing among countries and regions.
- Research and Monitoring: Elevated research and monitoring initiatives are integral to consolidation measures. This involves conducting thorough studies to evaluate the sources, distribution, and impacts of microplastics in various environments. The implementation of standardized monitoring protocols contributes to the generation of reliable data for informed decision-making and enables the assessment of the effectiveness of mitigation measures.
- Stakeholder Engagement: Engaging stakeholders, including government agencies, industries, NGOs, research institutions, and the public, is essential for meters consolidation. Collaboration and dialogue among different stakeholders can foster knowledge sharing, capacity building, and the development of innovative solutions to address microplastic pollution. It also helps raise awareness and promote behavior change.
- Capacity Building: A fundamental element of meters consolidation is the investment in capacity building. This involves providing training and resources to relevant stakeholders, such as policymakers, scientists, waste management professionals,

and enforcement agencies, to enhance their understanding of microplastic pollution and their ability to implement and enforce regulations effectively.

- Enforcement and Compliance: Ensuring proper enforcement and compliance with regulations is critical for meters consolidation. This may involve establishing inspection programs, strengthening penalties for non-compliance, and promoting transparency and accountability in the monitoring and reporting of microplastic pollution. Cooperation between regulatory agencies, law enforcement, and judicial systems is necessary to effectively enforce regulations.

By consolidating meters and actions, it is possible to strengthen the overall response to microplastic pollution and improve the protection of water ecosystems.

6.2.4 Legislative Measures

Legislative measures or laws are enacted to address the issue of microplastic pollution. These measures provide a legal framework to regulate, control, and mitigate the release of microplastics into the environment. They have an important role in setting standards, defining responsibilities, and establishing enforcement mechanisms.

- Bans and Restrictions: Legislative measures may encompass complete bans or limitations on specific products or materials identified as significant contributors to microplastic pollution. Examples include prohibitions on single-use plastics, microbeads in personal care items, or particular types of plastic packaging. The objective of these measures is to inhibit the production, sale, and utilization of materials that play a substantial role in microplastic pollution.

- Extended Producer Responsibility (EPR): Legislation has the capacity to institute extended producer responsibility schemes, assigning producers responsibility for the entire lifecycle of their products, encompassing the management of microplastic pollution. This may involve specifications for product design, labeling, collection, recycling, and appropriate disposal to mitigate the release of microplastics.
- Water Quality Standards: Legislation can set water quality standards with specific limits or thresholds for microplastic concentrations in water bodies. These standards provide a basis for monitoring and assessing the levels of microplastic pollution and serve as a guideline for regulatory actions and enforcement.
- Waste Management Regulations: Legislations can include guidelines on how to deal with plastic waste properly to prevent small pieces of plastic, known as microplastics, from entering the environment. This involves regulations about proper collection, sortin, recycling, and disposal of waste, ensuring that plastic waste is managed in a way that reduces the production and spreading of microplastics.
- Environmental Impact Assessments (EIAs): Legislation may mandate the conduct of environmental impact assessments for projects with the potential to create microplastic pollution. This guarantees that the possible environmental risks linked to microplastic release are evaluated and addressed before approving or permitting such projects.
  - Monitoring and Reporting Requirements: Legislation has the capacity to set

forth mandates for monitoring and reporting on microplastic pollution. This might involve obligatory monitoring programs, data collection, and reporting responsibilities for industries, water utilities, and other pertinent stakeholders. These requirements play a crucial role in evaluating the effectiveness of mitigation measures and facilitating well-informed decision-making.

Legislative measures are crucial for establishing a legal framework and regulatory conditions that foster the reduction and prevention of microplastic pollution. They furnish the essential tools and enforcement mechanisms necessary to ensure compliance and instigate positive changes in the management of microplastic pollution.

CHAPTER 7- CONCLUSIONS

Main subject of this thesis is to explore fate of microplastics in aquatic settings, particularly emphasizing the marine environment. The study involved reviewing numerous publications to examine methods for identifying and analyzing microplastics in water environments, along with the associated processes. Finally, an assessment of the concentrations of microplastics in various water areas was carried out. The conclusions of the study are summarized as follows:

- ➢ The extensive use of microplastics leads to accumulation of both primary and secondary microplastics in aquatic ecosystems through various sources. A major concern involves the secondary microplastics already present in the environment, which, due to their physicochemical traits, they biodegrade with difficulty, making their removal quite difficult. Despite recent efforts to decrease plastic consumption, this is not reflected in recent records of their presence in the aquatic environment, where an increase is noted Problems from the Presence of Microplastics: The presence of microplastics in the Mediterranean Sea poses significant physical and chemical risks to marine organisms and ecosystems. It can lead to physical harm, ingestion, and bioaccumulation of toxic chemicals, disrupting the delicate balance of the marine environment.

- The concern regarding water pollution caused by microplastics has grown significantly in recent years. This has resulted in the creation of innovative techniques for collecting samples and identifying microplastics. Concurrently, existing methods are undergoing updates and modernization. These advancements facilitate broader research, even in regions that were previously difficult to investigate
- Primary sampling methods in studies used by researchers, including nets (such as manta, neuston, and plankgton nets), pumps, and seabed After the preprocessing and cleaning of samples, the identification and quantification of microplastics occur. This analysis primarily involves FTIR and RAMAN spectroscopy, the SEM-EDS method, and the Pyr-GC/MS method. Improving modern analysis methods for both the physical and chemical characteristics of microplastics, as well as their quantity, is crucial for accurately assessing

the issue and understanding the potential risks to both the aquatic environment and human health. Equally important is the exploration of the movement of different types of microplastics in the aquatic environment to enable the determination of their fate within it.

- A significant issue observed across all research studies is the substantial variability in their findings, which can be attributed to two primary factors. First and foremost there is not a global common accepted definition for microplastics, describing their dimensions and composition. As a result , this lack of standardization enforces reasearchers from different institutions all around the world to use different criteria , which will lead to disparate and non- comparable results. In addition to the above , there is no standardized procedure for collecting, identifying, quantifying, and assessing samples from the environment. Consequently,the outcomes are dependent on the equipment used during sample collection, the identification method applied, and the model used for quantification, rendering comparisons across studies impossible. Nonetheless, based on the data we have collected until now regarding the high concentrations of microplastics in all regions of the world, from the most densely populated to the most isolated, and taking into account the estimation of an increase in these concentrations d due to factors like fragmentation, resilience to environmental conditions, abundant production sources,, , their ease of movement from one medium to another, and their widespread use at all stages of human activity, the for adopting eco-friendly management approaches becomes evident. This applies both at a global and national level, to avoid exceeding the critical concentration limit that could lead to an irreversible problem.

- Water Protection Institutional Frameworks: Recognize the significance of initiatives, legal frameworks, and enforcement actions in addressing and averting microplastic pollution.
- To sum up microplastic pollution emerges as a notable issue in the Mediterranean Sea. Implementing effective management strategies and fostering collaborative endeavors are imperative to diminish the influx of microplastics and alleviate their repercussions on the marine ecosystem. Recommendations include the development of comprehensive policies, improved waste management practices, public awareness campaigns, and further research to fill knowledge gaps.In summary, this thesis contributes to the understanding of microplastic pollution in the Mediterranean Sea and provides insights into the potential risks and mitigation measures. The findings emphasize the urgency of taking action to protect the marine environment and promote sustainable practices to minimize microplastic pollution.

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