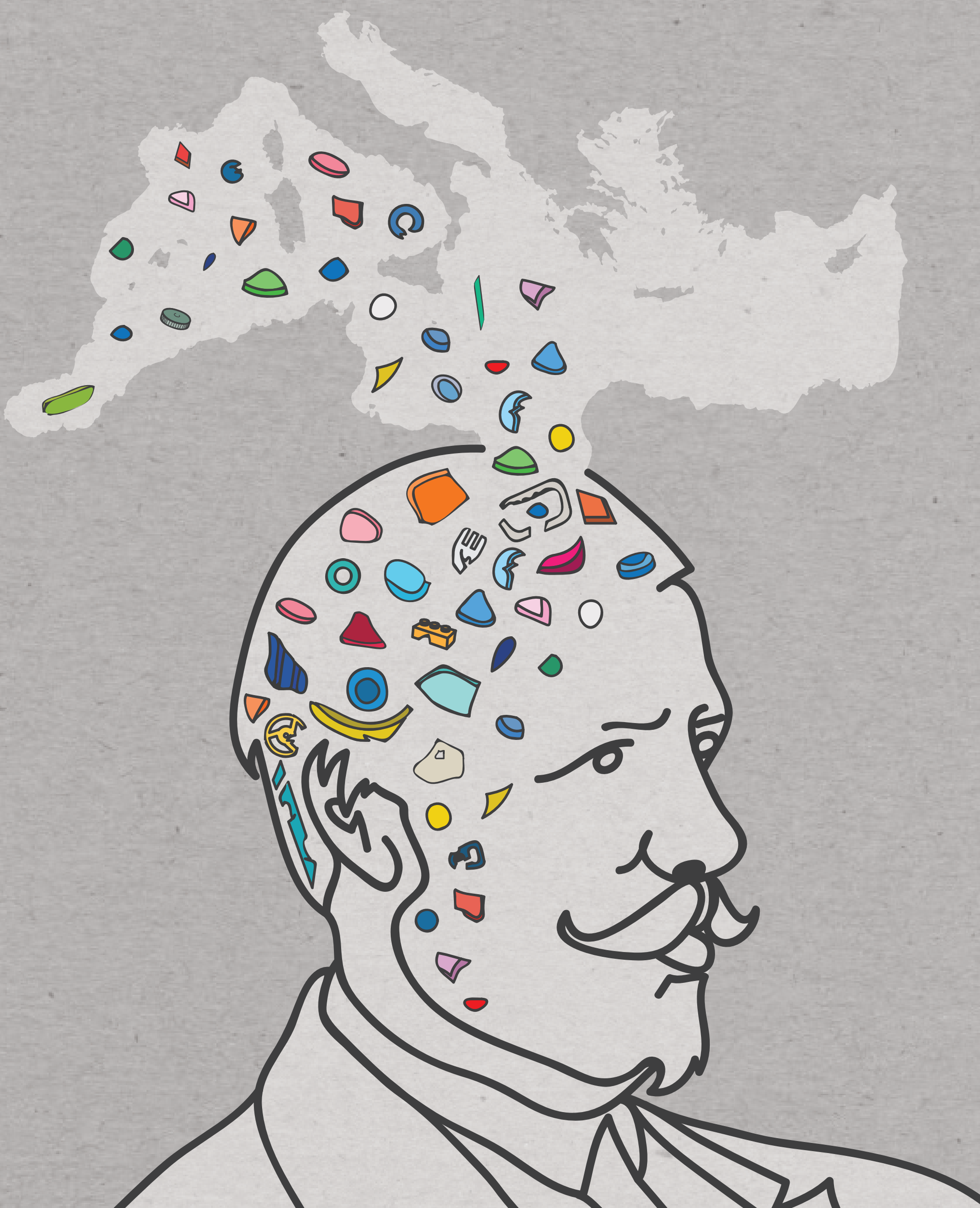
Floating plastic debris in the Central and Western Mediterranean Sea:

current status and its social perception

Luis Francisco Ruiz-Orejón Sánchez-Pastor



Floating plastic debris in the Central and Western Mediterranean Sea:
current status and its social perception

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Dedicated to

All those people who have always supported me,
Both family and friends.

Inspirational quotes

"All men dream - but not equally. Those who dream by night in the dusty recesses of their minds wake in the day to find that it was vanity. But the dreamers of the day are dangerous men, for they may act their dreams with open eyes, to make it possible. This I did."

T.E. Lawrence

"It is a curious situation that the sea, from which life first arose, should now be threatened by the activities of one form of that life. But the sea, though changed in a sinister way, will continue to exist: the threat is rather to life itself."

Rachel Carson

"El mar sigue cantando cuando pierde una ola"

José Ángel Buesa

"People ask: Why should I care about the ocean? Because the ocean is the cornerstone of earth's life support system, it shapes climate and weather. It holds most of life on earth. 97% of earth's water is there. It's the blue heart of the planet — we should take care of our heart. It's what makes life possible for us. We still have a really good chance to make things better than they are. They won't get better unless we take the action and inspire others to do the same thing. No one is without power. Everybody has the capacity to do something."

Sylvia Earle

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Abstract

Plastics are currently one of the most widely distributed litter in marine ecosystems worldwide. The floating fraction of these debris are estimated to represent about 1% of the plastics that enter into the marine environment where subtropical ocean gyres are considered to be the main convergence zones of floating plastics. The dense social system around the Mediterranean Sea pressures this environment being aggravated due to its semi-enclosed condition. Concern about plastic waste has been increasing in recent years due to the adverse effects it can cause on the Mediterranean ecological systems, its persistence in the environment and the consequences for social systems.

The problem of plastic pollution has a profound social origin. In this context, our work is aimed to assess the current state of the problem of floating plastic debris in the Central and Western Mediterranean in both environmental and social systems. From the ecological point of view, the surface of the Mediterranean was sampled on three different spatial scales; a regional macro scale in the Northwestern-Central Med. Sea, a regional micro scale in the Balearic Islands (Spain) and a local scale focused on the current MPA of the Menorca Channel (Balearic Islands). In addition, a pilot seasonal study was carried out in the local scale. The distribution and concentrations observed along the sea surface confirmed the omnipresence and persistence of plastic waste in marine ecosystems, resulting in maximum concentrations of particles off the NW coast of Ibiza Island (Spain) and concentration by weight near to the Gulf of Taranto (Italy). The results of the 139 samples analyzed in total confirm the significant superiority of microplastics over other particle sizes observed in the Mediterranean surface. In general, the concentration of plastic waste was higher in the areas near the coast,

with concentrations significantly higher in the Balearic Islands than in the rest of the Mediterranean. However, the seasonal distribution of plastic concentrations seems to be influenced by multiple factors in which particles appear to be directed by oceanographic variables, while the weight by social variables.

From a social point of view, the perception and awareness of three key stakeholders in the decision-making processes (experts, public administrators and business agents) and beach users on the island of Mallorca were assessed. Perceptions of the plastic issue were explored by applying a mixed methodology in three focus groups formed by Mallorcan stakeholders. The participants' broad view of plastic problems was demonstrated, in which topics covering most of the material's life cycle were developed. The main problems detected were centered within the social systems, where the excess of plastic used in the production and consumption processes was considered the main problem of plastic by the three groups. However, its approach to the definition of the problem was limited to the areas in which stakeholders were defined. Through a questionnaire distributed on the beaches, the perception and awareness of its users was analyzed. The result showed that users perceived plastics as an important environmental problem whose main causes are plastic excess and lack of public awareness, as well as, present a rejection attitude to the waste found on the beaches that influences the user's selection.

The results presented in this doctoral thesis contribute to the development and application of knowledge of the state of plastic pollution in the Mediterranean Sea in the context of social-ecological systems.

Resumen

Los plásticos son actualmente uno de los residuos más ampliamente distribuido en los ecosistemas marinos a nivel mundial. La fracción flotante de estos residuos se estima que representan alrededor de 1% de los plásticos que entran en los ambientes marinos y los giros oceánicos subtropicales son considerados como las principales zonas de convergencia de los plásticos flotantes. Los densos sistemas sociales alrededor del Mar Mediterráneo presionan este ambiente que se ve agravado debido a su condición de mar semi-cerrado. La preocupación por los residuos plásticos ha ido aumentando en los últimos años debido a los efectos adversos que pueden causar en los sistemas ecológicos del Mediterráneo, por su persistencia en el medio y las consecuencias para los sistemas sociales.

El problema de la contaminación por plásticos tiene un profundo origen social. En este contexto, nuestro tiene por objetivo valorar el estado actual de la problemática de los residuos plásticos flotantes en el Mediterráneo Central y Occidental en ambos sistemas, el ambiental y social. Desde el ámbito ecológico, se muestreó la superficie del Mediterráneo en tres diferentes escalas espaciales; una de ámbito macro regional en el Noroeste-Centro del Mediterráneo, otra de ámbito micro regional en las Islas Baleares y una local centrada en el actual Área Marina Protegida del Canal de Menorca (Islas Baleares – España). Además, en esta última escala se incluyó un estudio piloto estacional. La distribución y concentraciones observadas a lo largo de la superficie marina confirmaron la omnipresencia y persistencia de los residuos plásticos en los ecosistemas marinos, resultando los valores máximos concentración de partículas frente a la costa NW de la isla de Ibiza (España) y de concentración por peso en las proximidades del Golfo de Taranto (Italia). Los resultados de las 139 muestras analizadas en

total, confirma la significativa superioridad de microplásticos sobre el resto de tamaños de partícula observados en la superficie del Mediterráneo. En general, la concentración de los residuos plásticos fue superior en las zonas cercanas a costa, siendo las concentraciones significativamente superiores en las costas de las Islas Baleares que en el resto del Mediterráneo. Sin embargo, la distribución estacional de las concentraciones de los plásticos parece estar influenciada por múltiples factores en la que las partículas parece estar dirigidas por las variables oceanográficas, mientras que el peso por las variables sociales.

Desde el punto de vista social, se evaluaron la percepción y concienciación de tres stakeholders clave en los procesos de toma de decisiones (expertos, administradores públicos y agentes de empresa) y de los usuarios de la playa en la isla de Mallorca. Se exploraron las percepciones sobre la problemática del plástico aplicando una metodología mixta en tres "focus groups" formados por stakeholders mallorquines. Se demostró la amplia visión de los participantes en relación con los problemas del plástico, en los que se desarrollaron temas que abarcaron la amplia mayoría del ciclo de vida del material. Los principales problemas detectados estuvieron centrados dentro de los sistemas sociales, donde el exceso de plástico utilizado en los procesos de producción y consumo fue considerado el principal problema del plástico por los tres grupos. Sin embargo, su aproximación a la definición del problema se limitó a los ámbitos en los que stakeholders estuvieron definidos. A través de un cuestionario repartido en las playas, se analizó la percepción y concienciación de sus usuarios. El resultado mostró que los usuarios percibieron los plásticos como un importante problema ambiental cuyas causas principales son el exceso de plástico y la falta de concienciación pública, así mismo, presentan una actitud de rechazo ante los residuos encontrados en las playas que influye en la selección del usuario.

Los resultados presentados en esta tesis doctoral contribuyen al desarrollo y aplicación del conocimiento del estado de la contaminación por plásticos en el Mar Mediterráneo en el contexto de los sistemas socio-ecológicos.

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Acronyms and abbreviations

°C: Celsius degrees.

μm: micrometer (10^{-6} m).

A_0**:** turbulent exchange velocity near surface.

ABS: Acrylonitrile-butadiene-styrene.

AW: Atlantic Waters.

B.C.: Before Christ.

BR: Butadiene rubber.

C_D**:** drag coefficient.

CEO: Chief executive officer.

CMEMS: Copernicus Marine and Environment Monitoring Service.

CSPE: chlorosulfonated polyethylene.

d**:** manta trawl's immersion depth.

DW: Dry weight.

ENP: European Neighborhood Policy countries.

EP: Epoxy resin.

ePTFE: expanded polytetrafluoroethylene.

EtOH: Ethanol.

EU: European Union.

EU-PRF: European Union Port Reception Facilities directive.

FAO: Food and Agriculture Organization.

FIAyC: Fundación Innovación, Acción y Conocimiento.

G7: Group of seven major advanced nations.

GEnS: Good Environmental Status.

GMA: Glycidyl methacrylate.

GPA: Global Programme of Action for the Protection of the Marine Environment from Land-based Activities.

HDPE: High-density polyethylene.

H_S**:** significant wave height.

IIR: Butyl rubber.

IOC: Intergovernmental Oceanographic Commission.

IR: Isoprene rubber.

L: Litre.

LC: London Convention.

LDPE: Low density polyethylene.

LLDPE: Linear low-density polyethylene.

LP: London Protocol.

M cells: microfolds cells.

MARPOL: International Convention. for the Prevention of Pollution from. Ships (Marine pollution).

MPA: Marine Protected Area.

MAP: Mediterranean action plan.

mPPE: Modified Polyphenylene Ether.

MSFD: Marine Strategy Framework Directive.

MSW: Municipal Solid Waste.

MT: metric ton (1,000 kilograms).

N: adjusted plastic particle concentration.

NASA: National Aeronautics and Space Administration.

Ndi: Relative normalized distribution

NEMO: Nucleus for European Modelling of the Ocean.

NGO: Non-governmental organization.

NOAA: National Oceanic and Atmospheric Administration.

N_{tpw}: plastic particle concentration obtained in the surface layer.

OSPAR: Convention for the Protection of the Marine Environment of the North-East Atlantic.

PA: Polyamides.

PAES: Polyarylene ether sulfone.

PAN: Polyacrylonitrile.

PBT: Polybutylene terephthalate.

PBZ: Polybenzoxazine.

PC: Polycarbonate.

PCL: Polycaprolactone.

PE: Polyethylene.

PEEK: Polyether ether ketone.

PES: Polyethersulphone.

PET: Polyethylene terephthalate.

PF: Phenol-formaldehyde.

PHA: Polyhydroyalkonoate.

PHB: Polyhydroxybuterate.

PHV: Polyhydroxyvalerate.

PLA: Polylactic acid.

PMA: Polymethylmethacrylate.

Podaac: Physical Oceanography Distributed Active Archive Center.

POM: Polyoxymethylene.

POP: Persistent organic pollutant.

PP: Polypropylene.

PPE: Polyphenylene ether.

PPO: Polyphenylene oxide.

PPP: Poly(p-phenylene).

PPS: Polyphenylene sulphide.

PPSF: Polyphenylsulfone.

PPy: Polypyrrole.

PS: Polystyrene.

PSU: Polysulfone.

psu: practical salinity units.

PTFE: Polytetrafluoroethylene (Teflon).

PUR: Polyurethane rubber.

PVC: Polyvinyl chloride.

R/V: Research Vessel.

SBR: Styrene butadiene rubber.

SF: Shape factor.

SST: Sea Surface Temperature.

U: Zonal vector.

U_{10}: Wind speed adjusted to a 10m reference level.

UF: Ureum-formaldehyde.

UHMWPE: Ultra-high-molecular-weight polyethylene.

UNCLOS: United Nations through the Convention on the Law of the Sea.

UNEP: United Nations Environment Programme.

USA: United States of America.

UV: Ultraviolet.

V: Meridional vector.

VLDPE: very low-density polyethylene.

VOC: Volatile organic compound.

u_{*a}: frictional air velocity.

u_{*w}: Friction velocity in water.

w_b: buoyant rise velocity.

ρ_{air}: air density.

ρ_w: water density.

σ: wave age.

$\varkappa$: von Karman constant.

τ: wind stress.

Foreword

Nowadays it is practically impossible to imagine a society that is not dependent on plastic. Even many of the already scarce traditional societies, such as those described by Jared Diamond[1], are gradually 'acquiring' this aspect of modern society, almost irretrievably distancing themselves from yesterday.

Plastic has provided many advantages to society since its origin; however, the consequences of its excessive use are now being observed. It is inevitable to think about the possible causes that could have led to the current situation in the context of the great acceleration produced by human activities, which are reflected in social-economical trends and changes in ecosystems. The growing trends in many economic sectors would probably not have evolved in the same way without the existence of a material with the properties and advantages of plastic over others. In this sense, one of the most explicit examples is the evolution of processed food and non-food products and their association with the plastic packaging, which today reach values close to half of the annual production of plastics in the case of Europe. Unfortunately, many of these plastics are designed for single-use despite the inherent durability of many of the polymers and additives used.

Global production continues to rise steadily, only decelerating during the most challenging years of the global economic crisis of the early 21st century. Also, the volume of production is accompanied by an increasing number of new or modified plastic 'recipes', which increase the complexity of management

[1]**Diamond, J. (2013).** ***The world until yesterday: What can we learn from traditional societies?.*** **Penguin.**

processes when transformed into waste. However, for convenience, ease or pure ignorance, we continue to simplify under the umbrella of the word 'plastic' a set of materials that have adverse consequences on natural ecosystems and the organisms that inhabit them but also transfer to socio-economic systems. Although, it is true that these management processes have undergone improvements in recent decades, and that international and national authorities are beginning to become aware of them. Even so, these measures are still insufficient when confronted with the continuous scientific evidence of the environmental problem caused by plastic waste.

It should not be forgotten either that plastic pollution also has a strong social and behavioral origin, which requires an analysis to promote solutions that can achieve higher efficiency than those purely subscribed to from a 'top-down' directionality. The near horizon brings together the figures of producer and consumer, known as the 'prosumer', with the arrival of new technologies; where beyond the advantages they can provide, there is still no widespread debate about the foreseeable consequences that may emerge.

This work is intended to facilitate an initial approach to the current state of the problem of plastic pollution in the Mediterranean Sea without underestimating the importance of the social aspects of it.

Luis F. Ruiz-Orejón

Blanes, May 2018

Chapter 1

General introduction

1. Introduction

United Nations Environment Programme (UNEP) defines marine debris as "*any persistent, manufactured or processed solid material discarded, disposed of, or abandoned in the marine and coastal environment*"[1] and marine litter as such "*items that have been made or used by people and deliberately discarded into the sea or rivers or on beaches*"[2] where plastics are the major proportion on this environment (GEF, 2012). The presence of such debris in marine waters is considered today a vast problem affecting all the world's seas and oceans, consisting mainly of plastics and another type of synthetic materials (e.g. Galgani et al., 2015; Wright et al., 2013). Its presence in the seas is considered unacceptable but as plastic production in the world is exponentially increasing mirroring our modern societal growth, it is thought that the entering of plastics into the ocean will continue; a huge problem that needs to be solved as soon as possible.

Nearly all aspects of our daily lives involve plastic materials. Plastics are versatile, light, durable, and inexpensive and can be shaped to almost any form imaginable (e.g. Andrady, 2015; Andrady and Neal, 2009; Barnes et al., 2009). While these are valuable traits, the "disposable" use of plastics

1. Key messages. Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel—GEF (2012). Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, pp. 8.

2. UNEP, 2009. Marine Litter: A Global Challenge. Nairobi: UNEP. pp. 13.

in recent decades is now clearly visible in the majority of Earth's ecosystems. Plastics have been found in the atmosphere, soils, fresh water, oceans, seas, and polar regions (e.g. Cincinelli et al., 2017; Cózar et al., 2017, 2014; Wagner et al., 2014). They are even recognized as new habitat for organisms, called the Plastisphere (Zettler et al., 2013). As they become increasingly prevalent in ecosystems, concerns about plastics are mounting due to their unknown effects at the organismal level and potential consequences for ecosystem functioning (Lanzarote's Declaration, 2016).

Starting at the 30's last century, world plastic production has been growing steadily for more than 70 years, estimating a total of 8,300 million metric tons (MT) of new plastic produced to date (Geyer et al., 2017). 322 million metric tons of plastics were produced in 2015, representing a 3.5% increase over 2014 (PlasticsEurope, 2016). Nowadays, the average of plastics consumed by a person living in Western Europe or North America reaching 100 kilograms each year, mostly in the form of packaging; Asia uses just 20 kilograms per person, but this figure is expected to grow rapidly as economies in the region will continue to expand (Gourmelon, 2015).

From all the plastic waste, between 22% and 79% of the plastic used worldwide is disposed of in landfills (Geyer et al., 2017; UNEP, 2014). Although recycling and incineration rates have increased in two of the largest plastic producers (Europe and China), it is estimated that approximately 4.8 – 12.7 million tons of plastic end up in the oceans each year (Jambeck et al., 2015). However, a recent study conservatively estimated that 5.25 trillion plastic particles weighing a total of 268,940 tons are currently floating in the world's oceans (Eriksen et al. 2014). Obviously, there is still an unknowledge of the real proportions corresponding to flows and accumulations of plastics. Most plastics are considered persistent material and accumulate in the environment since they cannot be mineralized, even coming to assume as a new predictor of a new geological age: the Anthropocene (Waters et al., 2016; Zalasiewicz et al., 2016). Over time we find increasing numbers of fragments of decreasing size, with diverse negative externalities and loss of welfare for human people.

Although in the early 70s, the first laws and/or treats on marine debris were developed [Oslo Convention (February 15, 1972), London Convention

(November 13, 1972) and the Barcelona Convention (February 16, 1976) in the Mediterranean] establishing the basis for controlling these residues, it was not until late seventies when the Captain Charles Moore, founder of Algalita Marine Research & Education, discovered an accumulation of marine litter, mainly composed by plastics, in the North Pacific Central Gyre (Moore & Philipps, 2012). This discovery revealed the global problem of a material created a few decades earlier. Based on the obtained evidences many other regional, national, and international efforts [the MARPOL Convention (1978); the East Asian Seas Action Plan (1981); the Abidjan Convention (1984); the Cartagena Convention (1986); Bâle Convention (1989); the OSPAR Convention (1992/1998/2002/2005/2006/2007); the Northwest Pacific Action Plan (1994); the Nairobi Convention (1996); EU Water Framework Directive (2000); the Teheran Convention (2003); EU Marine Strategy Framework Directive (2008); the Honolulu Commitment (2011); the Manila Declaration (2012); the Mediterranean Regional Plan on Marine Litter (2014); and the G7 Leaders' Declaration (2015)] have been launched as a recognition of the problem and to deal with it.

Social concern about the marine debris problem is also increasing. Even though the social perception of this problem is still lower than other environmental worldwide problems such as climate change, deforestation or others, it is also true that all stakeholders in the value chain of these products are reacting and, particularly, the plastic industry is accelerating the way in which solutions need to be developed. In a recent speech, the CEO of PlasticsEurope in 2016 set the scene "*Marine litter is a global challenge that needs a global solution. We want to find the right answers to marine litter because our aim is for zero plastics entering the oceans. The plastics industry is an important industry to Europe. We have a key role to play in providing leadership and best practice. We all share the same goal: to protect the environment*"[3]. It is time to find solutions. Everyone can contribute. Thus, it is crucial to create awareness about the marine debris problem, invest in educational projects, enhance individual responsibility and keep products and waste where they belong. With this aim, the present work is presented as a contribution to know about the problem and its perception in the Mediterranean Sea.

3. Patrick Thomas (CEO PlasticsEurope). PolyTalk 2016: Towards Zero Plastics to the Oceans. Brussels on March 16th -17th, 2016.

At the end of the 19th Century, the steam-yacht Nixe, property of Archduke Ludwig Salvator of Austria was navigating the Mediterranean. Archduke Ludwig Salvator was also a naturalist, traveler, artist, and a clear unconventional aristocrat that loved the Balearic Island and spent there, a large part of his life. During most of this life he showed great interest for Mediterranean societies, cultures, landscapes and flora and fauna that carefully detailed along several monographs. He spent many years studying the Mediterranean and he wrote more than 70 books (mostly anonymously and in German language) in which described numerous sites and landscapes he met through his travels. From his descriptions, it is also extracted man-made changes in the placed that he visited; however, he rarely specified impacts on the marine environment because most of these adverse changes had not yet been expressed or had not even been produced. During his explorations, he never saw plastics floating in the Sea because at that time plastic had not yet expanded commercially.

To celebrate the 100-year anniversary of the death of Archduke Ludwig Salvator, the Nixe III Project (www.nixe3.com) was initiated in 2010. The main objective of this project was to make a comparison between the Archduke monographs carried out 100 years ago and new documents obtained by revisiting the original sites that he visited. The Nixe III project lasted five years and during this time several campaigns were carried out throughout the Mediterranean Sea. As the original monographs from the Archduke were done on land, it was thought that we could make use of the navigational time of these expeditions to sample for floating debris, so as a second objective of the Nixe III project was initiated a research for plastic debris in the Mediterranean Sea.

In this introductory chapter, we will focus on the description of: (1) the relationship between Archduke Ludwig Salvator, the NIXE III project and the Mediterranean Sea; (2) plastic as marine litter and the importance of society on the effects of plastic waste; (3) its distribution and effects in the environment; (4) International, regional and national instruments and the Marine Strategy Framework Directive (MSFD) in Europe and (5) to present the aim and the outline of the thesis.

1.1. Archduke Ludwig Salvator of Austria, the NIXE III project and the Mediterranean Sea

1.1.1. Archduke Ludwig Salvator of Austria (1847-1915)

The Archduke Ludwig Salvator was born, under the ruling House of Habsburg-Lorraine, in the Pitti Palace, Florence (August 4, 1847). At the age of twenty years, the Archduke (Figure 1.1) first visited the island of Mallorca (Spain) where shortly afterwards established his habitual residence. There, he cultivated his curiosity about habits, culture, nature and its conservation when the concept was barely used. These interests led him to go across the Mediterranean Sea through his steamboat "The Nixe".

As a consequence of the Archduke trips, more than seventy monographs are attributed to him and a large number of other works remain anonymous. Due to his enormous interest in science, he and other authors developed the systematic model "*Tabulae Ludovicianae*" for obtaining information for his books that distributed to majors, botanists, zoologists, engineers, priests, etc. of each place visited. According to this methodology, data from local sources

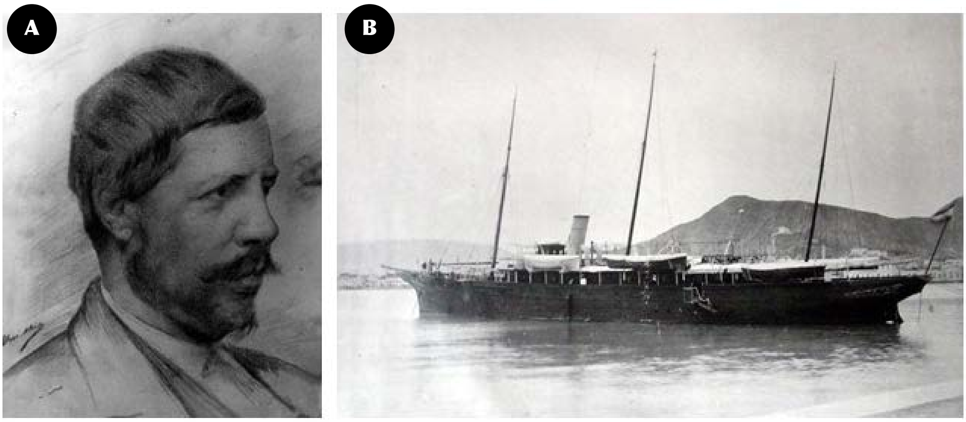


Figure 1.1. Archduke Ludwig Salvator of Austria (A) and his second steamboat the Nixe II (B). *(image attributions: Chapter 10 – References).*

and original documents of the period were collected in order to write ethnography (sayings, habits, among others), history, portolan charts, but also data and graphs from landscapes, flora and fauna (Ramis-Pujol, 2011).

After long years of study in which travelled along the Mediterranean Sea from Alboran Sea to shores of Syria and form Tunisia to Venetia, initially with his steamboat The Nixe until its sinking and then continued with the Nixe II (Figure 1.1), he died in Brandeis (Czech Republic, October 12, 1915) far from his beloved Mallorca.

1.1.2. The NIXE III Project

The NIXE III Project began its journey in 2010 with the main objective to compare the works of the Archduke with the current reality; the idea was to travel back again into the past to repeat the trips of the Archduke and to establish centurial long-term comparison about social-ecological transformations in the Mediterranean region. The project selected twenty-nine works of the Archduke to carry out during four consecutive years. After the first year travelling throughout the Mediterranean Sea we noticed that man-made particle floating on the sea was something different of what the Archduke could have seen 130 years ago. Then, the project adopted the floating plastic assessment as a second objective to be done during the trips. The goal behind was to perform an assessment of the state of the Mediterranean concerning this problem.

For the 21st Century, United Nations launched the necessity to incorporate an ecosystem approach framework when managing public natural goods inside a large social-ecological paradigm "*a worldview recognizing the mutual inter-associations between human activities and ecological processes dependences that may be necessary for the survival of both*"[4]. The NIXE III project did not want it to escape from this responsibility moreover when the project itself was based on social developments. Following these ideas, the assessment of floating debris in the Sea was developed in conjunction with a social study about the perception of the problem by society.

4. COP 9 (UNEP) - Ninth meeting of the Conference of the Parties to the Convention on Biological Diversity Bonn, Germany, 19 - 30 May 2008

1.1.3. The Mediterranean Sea

Geographical and environmental characteristics

The Mediterranean is a semi enclosed sea that extends roughly from 30°N to 45°N and from 6°W to 36°E, covers 2,500,000 km^2 and laps the shores of three continents (Africa, Asia and Europe) accounting 46,000 km of coast-lines through 22 countries. The average estimated deep is 1,500 m. and Calypso Deep is the deepest point (5,267 m.), located in the Ionian Sea (Barale, 2008). Connections to other bodies of water are carried through the Strait of Gibraltar to the Atlantic Ocean, the union with the Black Sea across the Sea of Marmara through the Straits of the Dardanelles and the Bosphorus and finally, the artificial connection to the Red Sea through the Suez Channel. The climate of the region is characterized by alternating mild winters, autumns and springs where it receives the contributions of rainfall and hot and dry summers (Barale, 2008).

The surface temperature varies between 14 – 16 °C to 20 – 26 °C and 12.8 °C in average for the entire body of water with an increase of 0.12 °C in the last 40 years (Barale, 2008; Laubier, 2005). The salinity shows an increase over the Atlantic reaching 39 psu and an average of 38.2 psu. Due to the high evaporation rate, the limited precipitation and river runoffs a deficit of 2,500 m^3 per year of freshwater is estimated, only compensated by the input from the Atlantic Ocean (Barale, 2008; Laubier, 2005). In order of importance the major rivers flowing into the Mediterranean are: Rhone (France), Po (Italy), Nile (Egypt), Ebro (Spain); with a significant reduction of discharges over time in these last two rivers (Laubier, 2005).

Approximately between 10,000 – 12,000 marine species turn the Mediterranean into a sea with high biodiversity, without considering bacteria, where the western basin presents much diversity richness than the eastern (Laubier, 2005). The 28% of such marine species represent endemic organisms (Barale, 2008). The monk seal (*Monachus monachus*) together with some chondrichthyans species (e.g. Angel shark, *Squatina squatina*; Maltese skate, *Leucoraja melitensis* or Smallthooth sawfish, *Pristis pectinata*) and the Leatherback turtle (*Dermochelys coriacea*) are some of the critically endangered species in the Mediterranean in addition with other organisms as the Loggerhead (*Caretta caretta*) and Green (*Chelonia mydas*) turtles, Short-beaked common dolphin (*Delphinus delphis*), Sperm whale (*Physeter macrocephalus*) or the Great white shark (*Carcharodon carcharias*) that are listed as endangered species (Barale, 2008; Cavanagh and Gibson, 2007; IUCN, 2012).

Social characteristics

Within the Mediterranean region a positive trend is estimated in the growth of most of the economic activities present in it (Figure 1.2). This region has one of the highest global tourism rates, which is expected to increase to 550 million of arrivals by 2030, while one-third of the world's merchant fleet sails its waters (EEA, 2016; Piante and Ody, 2015; Ruff and Bellver, 2016). The energetic industry expects a strong increase and expansion of their activities in the face of new oil reserve estimates of around 9,400 million toe (Plan Bleu, 2011),

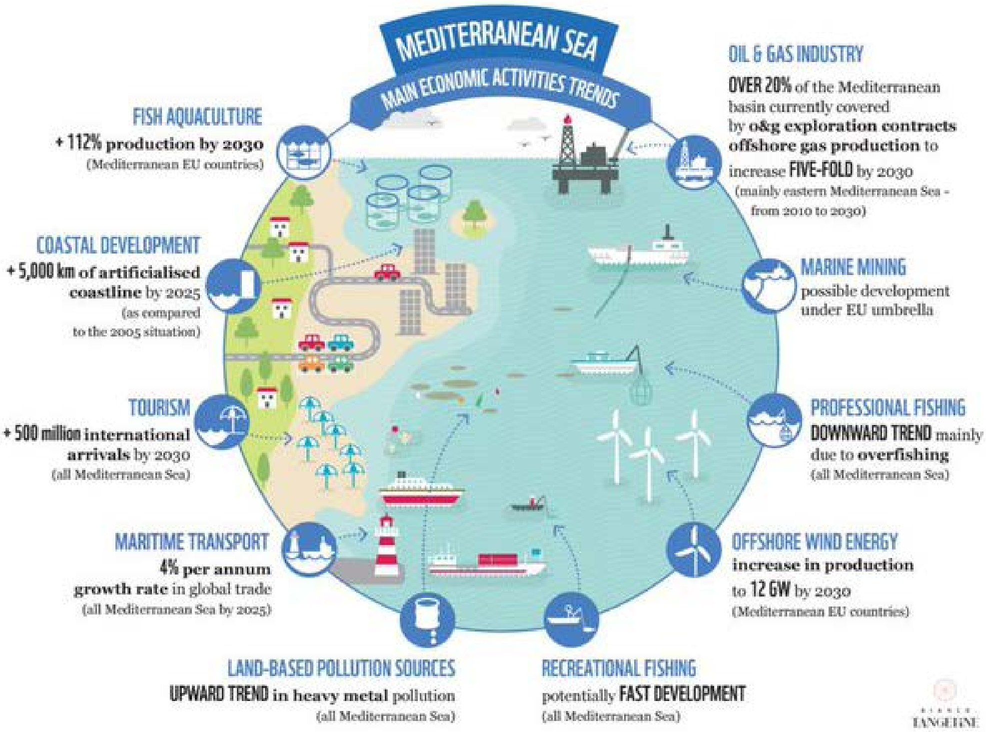


Figure 1.2. Main economic activities and their expected trends in the Mediterranean region. *(Source: Med Trends Report, WWF, 2016)*

while the professional fishing is expecting to decrease due to the overfishing and its substitution for the fish aquaculture (Piante and Ody, 2015).

Moreover, this region is populated by around 460 million people, of which, 250 million reside in its coastal areas (EEA, 2016; UNEP/Map-Plan Bleu, 2009). In the last years due to the economic and political instability in the north and south of the Mediterranean, an unprecedented economical and humanitarian crisis is also occurring (Ruff and Bellver, 2016). Overall, economic activities and population density are creating a high anthropogenic pressure in the region and therefore, it is also expected to increase waste from land-based sources, resulting in a loss of biodiversity and deterioration of the Mediterranean ecosystems.

1.2. Plastic and the importance of society on the effects of plastic waste

1.2.1 The plastic

Currently, plastics are defined as semi-synthetic or synthetic material based on diverse polymers and that can contain different additives (Shashoua, 2008; Vegt, 2005). The polymers are structured through the polymerization process through which the unit molecules or monomers establish links between them forming long chains (Crawford et al., 2017a). It is estimated that more than six thousand plastic formulations based in approximately fifty basic types of polymers (Frias, 2015; Shashoua, 2008), which are divided into three main categories:

- *Thermoplastics*: are non-cross linked or linear set of long polymer chains that flow at high temperature and pressure but returning to their solid state when cooled. They could be remolded and recycled easily. The most common thermoplastics are: Polyethylene (PE), Polypropylene (PP), Polyvinyl chloride (PVC), Polystyrene (PS), Polyamides (PA) or Acrylonitrile-Butadiene-Styrene (ABS). (Frias, 2015; Vegt, 2005).

- *Synthetic elastomers*: are in a softened condition which allow them to flow. When networks are formed they lose their softened condition but retain the shape given to them. Some authors unify this group with the following, thermosets. The most common compounds in this group are the rubbers: styrene butadiene rubber (SBR), Butadiene rubber (BR), Isoprene rubber (IR), Butyl rubber (IIR) or Polyurethane rubber (PUR), among others. (Vegt, 2005).

- *Thermosets*: are characterized by the formation of a network (cross-linked chains of polymers) at elevated temperature and pressure. These materials are usually very strong due to their tighter structure, however show flows unless heat is applied to them. Examples of these materials are Epoxy resin (EP), Phenol-formaldehyde (PF) or Ureum-formaldehyde (UF).

1.2.2. History

Epistemologically, plastic derives from the Greek word *plastikos* "able to be molded" (due to its mechanical properties) however, to establish the origin of the use of plastic materials by humans is complex to determine. Ancient Mesoamerican civilizations, such as Mayans and Olmecs, used a nature polymer (latex) obtained from the Panama rubber tree (*Castilla elastica*) and processed with an extract of the moonflower plant (*Ipomoea alba*) to produce rubber around 1600 B.C. (Hosler, 1999) (Figure 1.3). Even though, there are discrepancies in locating the origin of the continued use of these materials, situating this point from the investigations carried out by La Condomine in the middle of the XVIII century (Crawford et al., 2017a).

Despite the occasionally use of plastics by humans, it was not until 1839 when Thomas Hancock and Charles Goodyear invented the vulcanized rubber, eventually patenting it in 1843 and 1844 respectively. This invention was followed by important discoveries until the end of the century as polystyrene, polyvinyl chloride (PVC), celluloid or rayon, most of them based in semi-synthetic polymers (Andrady and Neal, 2009; Crawford et al., 2017a) (see Figure 1.4). In New York in the year 1907, a Belgian chemist named Leo Hendrik Baekeland discovered the first entirely synthetic plastic, the Bakelite. The discovery of the Bakelite marked the great revolution on the plastic materials observed during the 20th century.

At the beginning of the modern plastic era the raise of the Cellulose acetate, a thermoplastic that was developed about the same time as the urea-based

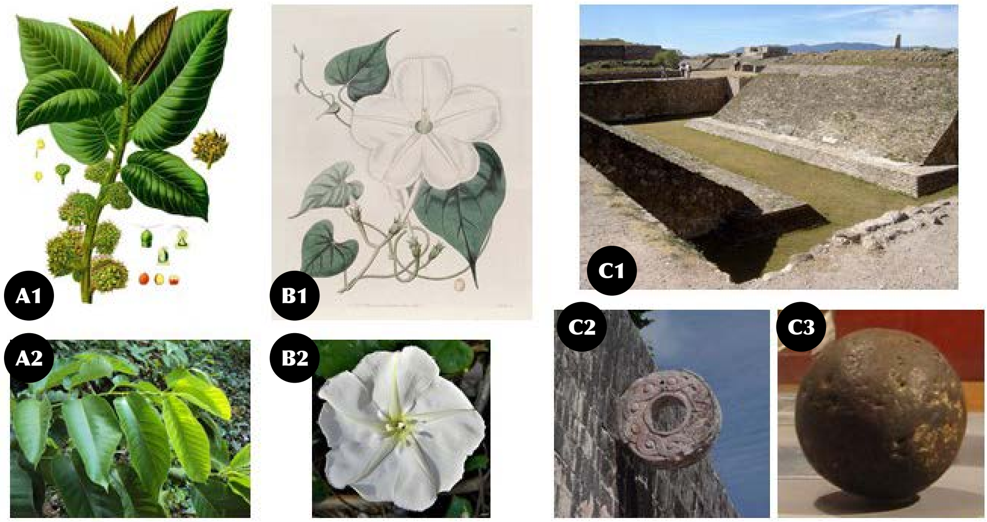


Figure 1.3. Origin and use of the first plastics dated from natural polymers. *(A1) and (A2) representations of (Castillia elastica), from which the latex was extracted. (B1) and (B2) (Ipomoea alba), the sulfur of this specie was used to cross-link the rubber (vulcanization). (C1) the Ancient ball court of Monte Alban (Oaxaca, Mexico). (C2) one of the goal in the ball court of Chichén Itzá (Yucatán, Mexico). (C3) example of rubber ball from the natural polymers extracted from (Castilla elastica) and procesed with (Ipomoea alba), similar to those used in the Mesoamerican ballgame. (image attributions: Chapter 10 - References).*

resins, constituted a significant contribution. Similar in structure to cellulose nitrate, it was found to be safer to process and use. Cellulose acetate was introduced as a molding compound in 1927 (introduced by P. Schützenberger in 1869). During the period 1930-1940, we saw the initial commercial development of today's major thermoplastics: polyvinyl chloride (PVC), low density polyethylene (LDPE), polystyrene (PS), and polymethylmethacrylate (PMA) (Crawford et al., 2017a). The starting of the World War II in 1939 brought plastics into great demand, largely as substitutes for materials in short supply, such as natural rubber. In the United States, the crash program leading to large-scale production of synthetic rubbers resulted in extensive research into the chemistry of polymer formation and, eventually, to the development of more plastic materials. After World War II, the development of polypropylene, high-density polyethylene and the growth of the new plastics in many applications occurred. Linear low-density polyethylene was introduced in 1978 and made it possible to produce diverse density polyethylenes (Crawford et al., 2017b). From 1990 there was a great revolution with the commercialization and research of biobased and biodegradable polymers, until the last years with the self-healing polymers (Rekondo et al., 2014) (see Figure 1.4).

The evolution of these materials was favoured due to their characteristics respect that other existing materials, as can be observed during 1955-1990 (Figure 1.4). The lightweight and a high strength to weight ratio of plastics facilitates transport, and energy saving compared to other materials like glass or metal, even in their own manufacturing (Andrady and Neal, 2009; Hocking, 1994; TNO, 2007). In addition to their properties, they were useful to preserve the health and safety of users in product consumption or use of medical equipment (Andrady and Neal, 2009). The large-scale production of these materials reduced their cost dramatically allowing to compete with the older plastics and even with the more traditional materials such as wood, paper, metal, glass, and leather. Since then, plastics have become an important part of our daily life.

1.2.3. Plastic production

World production of plastics yielded 322 million tons in 2015 (PlasticsEurope, 2016) and a compound annual growth rate of 8.47% since the 1950 , but this value would increase to 383 MT if synthetic fibres were taken into account (Lusher et al., 2017). Excluding this type of fibers, Europe contributed 58 million tons (Figure 1.5-A) to the total of that year with an annual growth rate similar to worldwide (8.33%) for the same period, reaching the 2nd world producer. Although these values, plastic production in Europe is still in lower than pre-crisis levels (before 2008), with a production stabilized (PlasticsEurope, 2016). The polymers with highest demand in Europe is possible to observe in Figure 1.5-B.

1.2.4. From Plastic waste material to marine pollutants

Plastics materials are used in a wide variety of objects from daily life. Notably, it has been increased the use of hardy plastic material for single-use items (Gold et al., 2014), reaching 39.9% of European production only in packag-

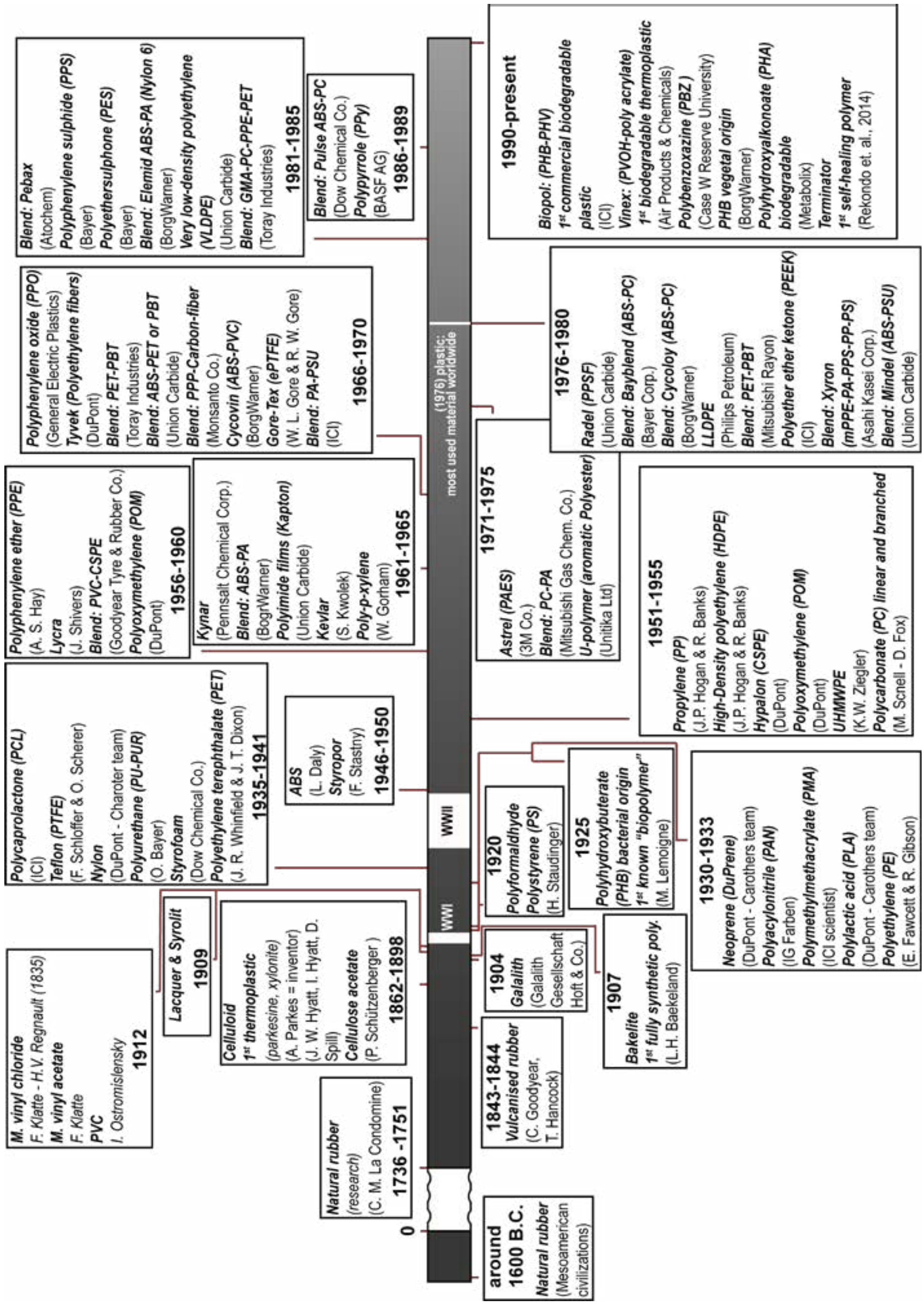


Figure 1.4. Timeline of Plastics. *Main plastic polymers throughout history. The improvements of each individual polymer have not been considered. Figure is not in scale. Based on information from:(Andrady and Neal, 2009; Crawford et al., 2017a, 2017b; Rekondo et al., 2014)*

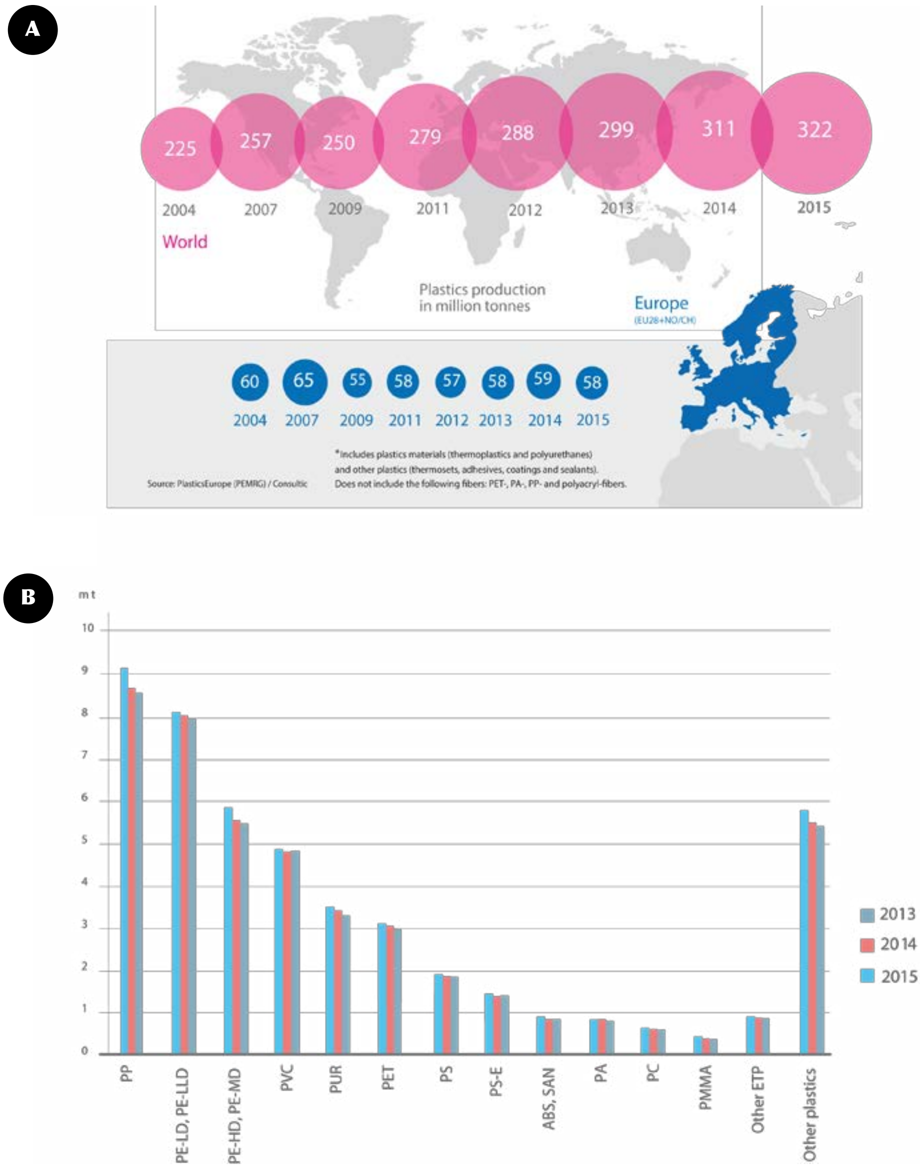


Figure 1.5. *World and European plastic production (A). Polymer demands (million tons) in Europe. (Modified from: PlasticsEurope, 2016)*

ing (PlasticsEurope, 2016). However, alongside with the rise of demand of these products, it is usually followed by the generation of an extensive amount of waste. According to the World Bank (Hoornweg and Bhada-Tata, 2012), the global generation of Municipal Solid Waste (MSW) produced in 2012 reached 1.3 billion tons per year and it is estimated to reach 2.2 billion tons in 2025; where around the 10% in weight is plastic (Thompson et al., 2009a). In Europe (EU-27), the average of MSW produced per inhabitant in the year 2013 was approximately 485 kg (Figure 1.6). Although the declining trend of waste generation between these years, it might be an effect of the economic crisis and consumption patterns when differences among countries are observed (Eurostat, 2015). On the other hand, the ENP-South region (Algeria, Egypt, Israel, Jordan, Lebanon, Libya, Morocco, Palestine and Tunisia) in the Mediterranean Sea accounted 272 kg of waste per inhabitant in 2010 (European Environment Agency, 2014).

After collecting waste, the conventional treatment over time has been transferring to landfills (Hopewell et al., 2009). However, this management method has drawbacks such as the risk of soils and groundwater contamination (e.g. leaching of plasticizers) (Hopewell et al., 2009; Teuten et al., 2009; Thompson et al., 2009a), in addition to their finite capacity (Defra, 2006). The use of landfill has been reduced between treatments used in Europe since 1995 to 2013 (Figure 1.7; EU27), increasing the proportion of the incineration and recycling but nevertheless, in the EPN-South region, approximately the 58% of MSW were placed in open dumps and 31% in sanitary landfills (European Environment Agency, 2014).

Packaging waste is a part of the MSW, where the percentage of plastics by weight accounted for 19% in the European Union (EU-28) in 2013 (Eurostat, 2015). However, in the EPN-South countries approximately the 12.9% were plastics (European Environment Agency, 2014). Considering the total of recycled plastic (excluding fiber plastic), Europe (30%) and China (25%) had the highest recycling rates in 2014, even though, it is estimated that the recycling rate of the rest of the world was around 9% (Geyer et al., 2017). Even so, there was usually a mismanaged plastic fraction that ends up to ecosystems, of which, in the year 2010 between 4.8 to 12.7 million metric tons entering the oceans (globally) with an increasing projection for 2025 of approximately 100 to 250 million tons (Jambeck et al., 2015).

However, the pathways to marine ecosystems occur from diverse points of origin (Figure 1.8). Direct discharges from the coastlines (e.g. beach users, coastal industry), boats or offshore platforms, together with the plastic particles transported by river water channels and the transport effect of the wind on the abandoned plastics in the land environments, have been the traditionally considered entrance routes to marine ecosystems (e.g. GEF, 2012; Veiga et al., 2016). In the last decade, the entrance through the sewage systems has also been verified due to the untreated water or deficiency in these systems for the removal of the plastic waste (e.g. Mahon et al., 2016; Morritt et al., 2014; Napper and Thompson, 2016).

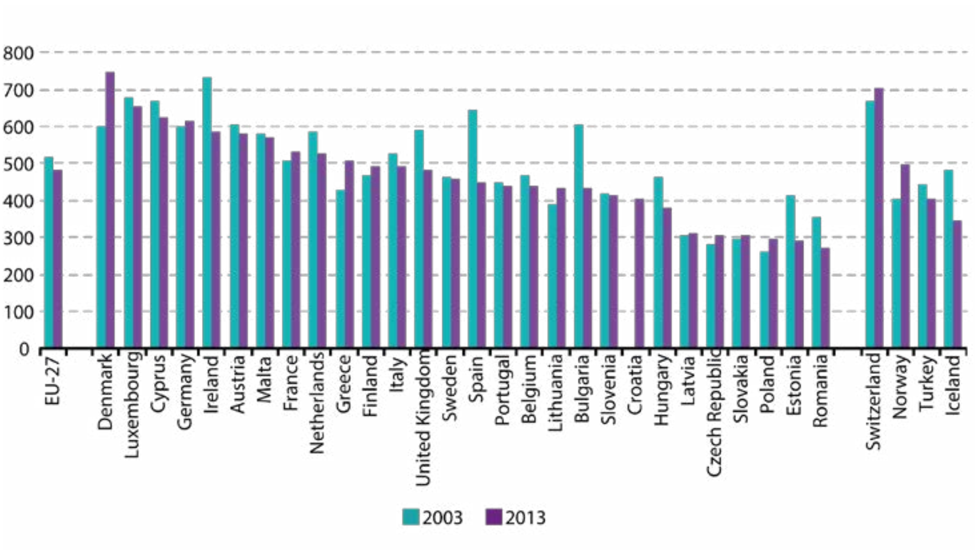


Figure 1.6. Municipal waste generated, by country, 2003 and 2013 (kg per inhabitant). *EU-27 + Croatia, Switzerland, Norway, Turkey and Iceland. (Extracted from: Eurostat, (2015)).*

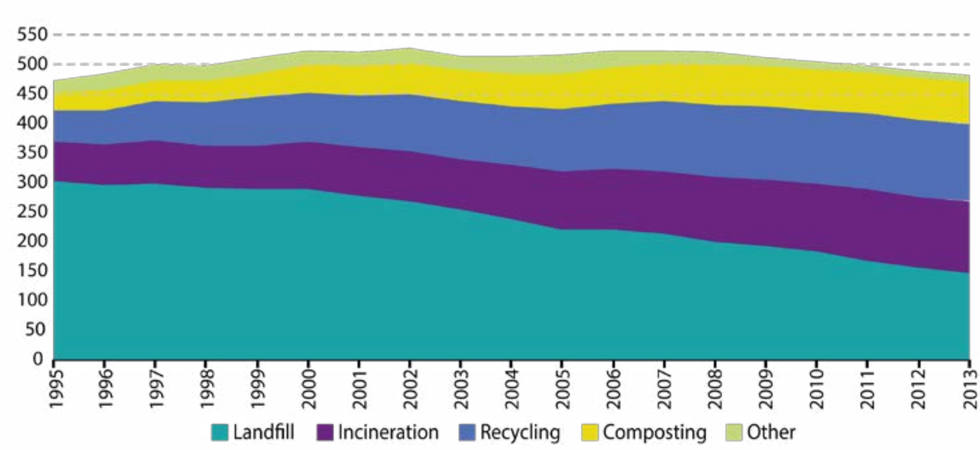


Figure 1.7. Municipal waste treatment, EU-27, 1995-2003 (kg per inhabitant). *(Extracted from: Eurostat, (2015)).*

The process of degradation of plastics begins from the moment they are discarded in the environments. Ultraviolet (UV) radiation is the principal degradative agent acting on the majority of common plastics; together with oxidation constitute the main mode of its degradation, the process of photo-oxidation (Andrady, 2015). Furthermore, hydrolysis and biodegradation routes ending the principal degradation modes; however, the first acts effectively in a small fraction of plastic types (e.g. PLA) and has the second rates slower degradation (Andrady, 2015; Höglund et al., 2012). These processes result in the breakdown of plastics in increasingly smaller particles (fragmentation), nevertheless, under marine conditions where light and oxygen are limited, degradative processes are prolonged over the time (Andrady, 2003). Although there is no standardized classification for the size of plastics, especially microplastics, due to the limitation of sampling methods and the lack of agreement in the research community (GESAMP, 2015), after the first international research

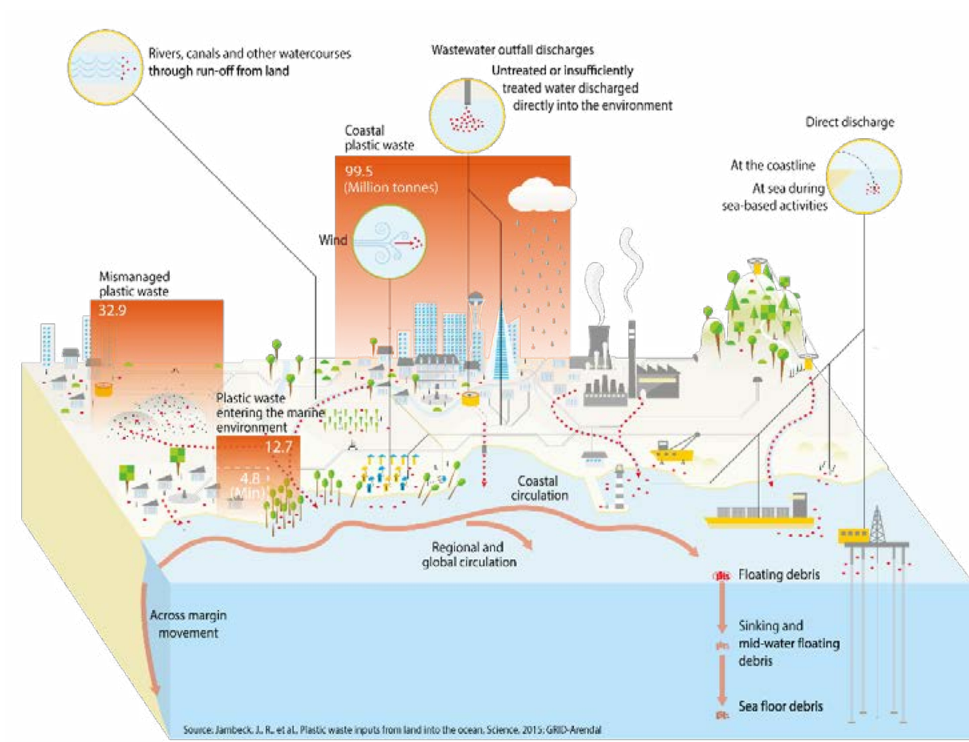


Figure 1.8. *Plastic routes, from production to the environment. (Extracted from: UNEP and GRID-Arendal, (2016))*

workshop of microplastic debris in 2008 (Tacoma, WA, USA), the participants suggested that the following size scale could be applied elsewhere: mega (>1 m), macro (1 m – 2.5 cm), meso (2.5 cm – 5 mm), micro (5 mm – 1 µm) and nano (<1 µm) (Lippiatt et al., 2013).

1.3. Distribution and impacts of plastic in the environment

The first news of plastic material in the gut of seabirds came for the early 1960s and the first reports of plastics in the environment were published in the 1970s (Thompson et al., 2009b). The awareness of the threats posed by waste plastics to marine ecosystems developed gradually through the 1960s and 1970s and most of the environmental impacts of plastic litter were identified in the 1970s and 1980s, resulting in numerous policy discussions and recommendations to decrease the amount of waste plastic entering the environment (Chen, 2015). There was a lull in research activity in the 1990s, but the confirmation that microplastics were a ubiquitous marine pollutant in the early 2000s (e.g. Barnes et al., 2009; Cózar et al., 2014; Eriksen et al., 2014; Shim and Thomposon, 2015), coupled with publicity around the formation of mid-ocean garbage patches, has stimulated renewed research interest and increased public awareness of the marine litter problem. Figure 1.9 shows how exponentially is growing the numbers of papers on different aspects of the marine litter issue published in five-year intervals over the last 50 years (based on a Web of Science search and unpublished bibliography).

1.3.1 Distribution of plastics in the environment

Floating plastic debris is the proportion of such debris that is found in the surface layer of the oceans and seas and that is driven by the winds and currents (e.g. Carson et al., 2013; Galgani et al., 2015; Moore et al., 2005; Zambianchi et al., 2017). Spatial variability, in great scales, are controlled by the Ekman transport and geostrophic flow forming convergences zones that act as retention areas; however, eddies and fronts have greater relevance at lower scales (Maximenko et al., 2012; van Sebille et al., 2012). Despite the existence of several data sets, differences between the methodologies used,

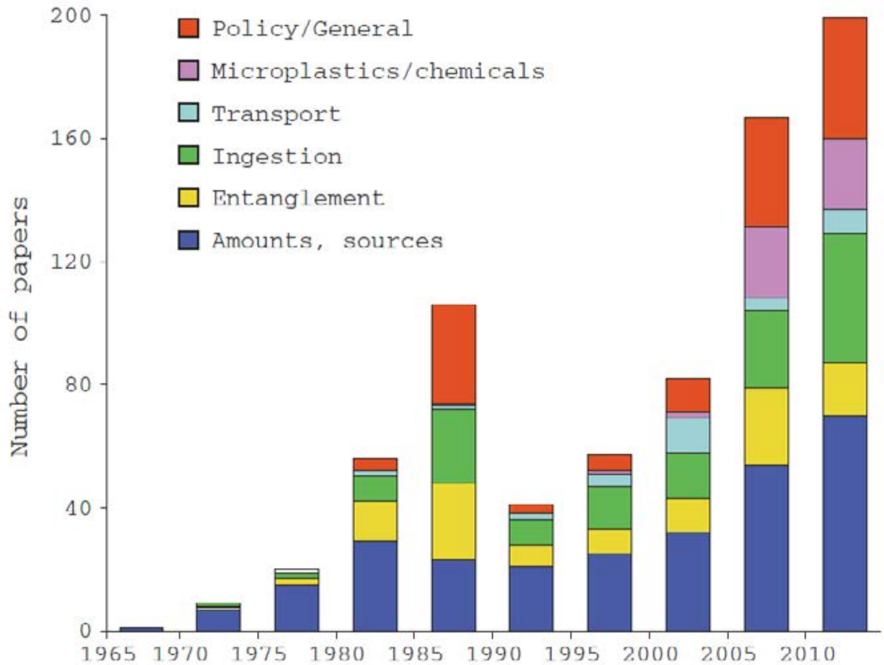


Figure 1.9. Numbers of papers on different aspects of the marine litter issue published in five-year intervals over the last 50 years (based on a Web of Science search and unpublished bibliography). *(Extracted from Ryan et al., 2015) [* note that the final column only covers three years, 2011–2013].*

coverage and limited periods of monitoring, increases the difficulty of comparing results. There is a general debate about the total estimation of global load of plastics in surface waters with a range of values from 6.6 to 268.9 thousand tons (6.6 – 35.2 thousand metric tons by Cózar et al., 2014; 236 thousand metric tons by van Sebille et al., 2015 model (only accounted for microplastics) and 268.9 thousand metric tons by Eriksen et al., 2014 model). Similar situation appears when comparing the oceans individually although, the North Pacific is considered to have the higher total concentration (Table 1.1). Nevertheless, plastic pollution is ubiquitous to marine ecosystems with observations in remote places like the Arctic and the Antarctic (e.g. Cincinelli et al., 2017; Cózar et al., 2017; Obbard et al., 2014).

A lower amount of studies has been conducted on seafloors; however, according to Galgani et al., 2015, "*Deep-sea surveys are important because*

Table 1.1. Total weight estimations of floating plastic debris in the oceans. *Data are in thousand tons. Data extracted from: (1) Cózar et al. (2014); (2) Eriksen et al. (2014) and (3) van Sebille et al. (2015)*

	North Pacific	South Pacific	North Atlantic	South Atlantic	Indian Ocean
Cózar estimations¹	2.3 – 12.4	0.8 – 5.6	1 – 6.7	1.7 – 5.4	0.8 – 5.1
Eriksen model²	96.4	21.0	56.5	12.8	59.1
van Sebille microplastic model³	155.2	3.7	17.7	14.2	15.0
Maximenko microplastic model³	62.8	1.0	5.1	6.2	13.3
Lebreton microplastic model³	108.2	3.7	3.6	15.5	5.5

c.a. 50 % of plastic litter items sink to the seafloor..."[5], and also, an abundance of up to four orders of magnitude higher than those found in the surface subtropical gyres is estimated (Woodall et al., 2014). The litter distribution is usually directed by the geomorphology (e.g. slope, canyons, shelf platforms, sandy or rocky bottom), hydrodynamics and human factors affecting the environment although, sampling limitation restricts to infer accumulation patterns and their temporal trends (Galgani et al., 2015; Pham et al., 2014). Plastic abundances seem to be higher in coastal and estuarine areas due to the proximity of human activities (e.g. Galgani et al., 2015; Lee et al., 2006; Wei et al., 2012). Despite the need for further analysis and the variability of the data already reported, the Mediterranean Sea and North Atlantic Ocean has showed the highest concentrations (Sánchez et al., 2013; Woodall et al., 2014).

Beaches have been one of the most widely studied ecosystems in terms of plastic waste due to the proximity of the sources and the ease of sampling. The composition of the plastics is highly variable spatial-temporally and usu-

5. Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In *Marine Anthropogenic Litter*. pp. 41.

ally concentrate mainly on the high-tide and storm lines (Claereboudt, 2004; Oigman-Pszczol and Creed, 2007). However, numerous variables affect the degree of accumulation of these residues in beaches such as vegetation (Turra et al., 2014), marine dynamics and morphology of the beach (e.g. Galgani et al., 2000; Kataoka et al., 2013; Turra et al., 2014; Yoon et al., 2010), tourism (e.g. Ariza et al., 2008; Martinez-Ribes et al., 2007) or the beach clean-up (Galgani et al., 2015).

In recent years, growing concern about plastic pollution has led to the exploration of inland aquatic ecosystems although they are still limited (e.g. Lebreton et al., 2017; Wagner et al., 2014). The emissions generated by rivers worldwide that finally ends in the oceans have been estimated between 1.15 – 2.41 millions of tons yearly (Lebreton et al., 2017). The transport of plastic particles has been reported both in rivers and in their tributaries (e.g. Lechner et al., 2014; Mani et al., 2015; Moore et al., 2011; Morritt et al., 2014; Rech et al., 2015,2016; Yonkos et al., 2014), as well as, lacustrine systems (Eriksen et al., 2013; Free et al., 2014), where the highest concentration of 4,123 items·m^{-3} was found on the Yangtze River (China) (Zhao et al., 2014). The concentrations have shown high temporal variability related to the human activities as well as by the fluvial dynamics (Moore et al., 2011; Vianello et al., 2013; Yonkos et al., 2014), which could influence in the flux of particles entering in the marine ecosystems, but also the retention zones or structures (i.e. dams or vegetation) (Aguilera et al., 2016; Mani et al., 2015).

1.3.2. Plastic impacts on wildlife

The ubiquitous of plastics debris in marine ecosystems, as described above, increases the potential on availability for organism that inhabit them. Direct and indirect deleterious effects of plastics, particularly microplastics, had been reported from the 60s (Clark et al., 2016; Kühn et al., 2015; Lusher et al., 2017; Ogunola and Palanisami, 2016). In the last decade, it has been growing awareness about the effects when plastics enter in the food chain (Figure 1.10), producing processes of bioaccumulation and/or biomagnification until the final consumer (Clark et al., 2016; Koch and Calafat, 2009; Kühn et al., 2015; Lusher et al., 2017). Entanglement, suffocation, ingestion or as dispersal vector are the main effects of plastics on marine organisms.

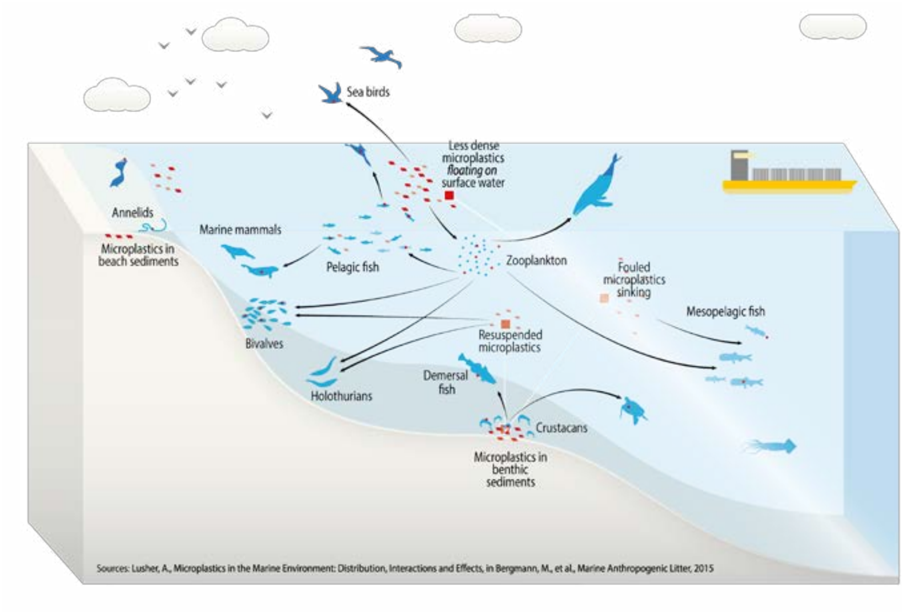


Figure 1.10. *Routes of plastics in through the food chain in marine environments. (extracted from: UNEP and GRID-Arendal, (2016))*

In general, the effects of entanglement are often related to plastic sizes larger than microplastics; especially with the issue of ghost nets and synthetic lines (Derraik, 2002). Sea turtles are particularly affected by this fact (Kühn et al., 2015), but also marine mammals attracted by their own behavior, e.g. fur seals (Derraik, 2002) or whales (e.g. de Stephanis et al., 2013; Galgani et al., 2014), seabirds (Derraik, 2002; van Franeker and Law, 2015) and elasmobranch (e.g. Alomar and Deudero, 2017; Anastasopoulou et al., 2013; Cliff et al., 2002); however, so far, the effect of "ghost fishing" on fish and invertebrate organisms are underestimate (Browne et al., 2015). The principal effect of entanglement is the limitation of movement of organisms that, on numerous occasions, resulting in a restriction or impossibility to acquire food (Laist, 1997). Causing wounds that might lead to infections, deformities, amputations (Barreiros and Raykov, 2014; Orós et al., 2005) and or even cause mortality (Antonelis et al., 2011; Cho, 2011; Kühn et al., 2015; Matsuoka et al., 2005). However, these effects not only affect to mobile organisms but also to the sessile (e.g. corals, gorgonians or some bivalves), which can be covered by plastics debris causing starvation, breakage or necrotic processes (Asoh et al., 2004; Chiappone et al., 2005; Fabri et al., 2014; Kühn et al., 2015; Lamb et al., 2018; Pham et al., 2013; Richards and Beger, 2011; Smith and Edgar, 2014; Yoshikawa and Asoh, 2004).

Impacts produced by the ingestion of plastic are being broadly reported since the last decades (Kühn et al., 2015); especially the smallest fractions that might be available to a greater number of organisms. However, the first reports of plastic ingestions date from the last years of the 60s decade (Thompson et al., 2009b). Particles of plastics can be ingested in a directed manner or accidental. Firstly, directed ingestion usually occurs as result of the confusion of particles with preys (Kühn et al., 2015; Laist, 1997; Ryan, 2016; Schuyler et al., 2014; Tourinho et al., 2010) or the curiosity produced by the plastic waste (Cadée, 2002; Kühn et al., 2015; Laist, 1987), where the color of particles might be an influence in the ingestion (Boerger et al., 2010; Casale et al., 2016; Eriksson and Burton, 2003; Lavers and Bond, 2016; Lusher et al., 2013; Moser and Lee, 1992; Santos et al., 2016; Schuyler et al., 2014; Tourinho et al., 2010). Secondly, accidental ingestion usually occurs on the marine filter-feedings organisms (Baulch and Perry, 2014; De Pierrepont et al., 2005; Fossi et al., 2014, 2012; Laist, 1997; Van Cauwenberghe and Janssen, 2014) however, it is also happens as a consequence in capturing prey with surrounding plastics (Beck and Barros, 1991; Bravo Rebolledo et al., 2013; Di Beneditto and Ramos, 2014; Frick et al., 2009; Kühn et al., 2015; McCauley and Bjorndal, 1999) or as a result of feeding on an organism that previously had ingested plastic (Boerger et al., 2010; Eriksson and Burton, 2003; Laist, 1987; Perry et al., 2013). Once ingested the residue by any of the routes discussed above, the impacts within the organism begins to occur.

The total blockage of the digestive tract or the damage resulting in the process of ingestion, causing direct mortality of organisms; as Kühn et al., (2015) explains. Nevertheless, partial blockage of this tract may lead to reduced food intake necessary for the development or the efficiency of digestive processes of the individual (Hoss and Settle, 1990; Lavers et al., 2014). Plastic particles ingested can carry chemicals compounds added during manufacture, but also may have been adsorbed within the fragment from those compounds present in the marine environment (Ashton et al., 2010; Holmes et al., 2012; Martin et al., 2014; Mato et al., 2001; Rochman, 2015) and even some monomers from the polymer chains can be released to the environment (Rochman, 2015). Many of these compounds, added or acquired, and monomers have shown adverse effects on various species. Where the most common reported effects are related to carcinogenic effects (Lithner et al., 2011; Oehlmann et al., 2009; Vasseur and Cossu-Leguille, 2006; Zhuang et al., 2009), act as endocrine disruptors (Darnerud, 2003; Kawahata et al., 2004; Kim et al., 2002; Rochman, 2015; Talsness et al., 2009; Wagner and Oehlmann, 2009), neurobehavioral effects (Darnerud, 2003; Talsness et al., 2009; Verma et al., 2016), reproductive diseases (Brown et al., 2004; Cole et al., 2015; Kim et al., 2002; Meeker et al., 2009; Verma et al., 2016) and may even cause mortality (Brown et al., 2004).

Although the entanglement and ingestion have been reported more deeply, other impacts, as suffocation, cause deleterious effects just as important as the previous ones. Suffocation affects both fauna and flora (Kühn et al., 2015). On one hand, choking by cover with plastic usually occurs as secondary consequence of entanglement when the respiratory track is clogged externally (Sazima et al., 2002; Wabnitz and Nichols, 2010). On the other hand, anoxic sediment is another effect produced by smothering affecting to infaunal invertebrates (Goldberg, 1997; Kühn et al., 2015; Mordecai et al., 2011). However, anoxic sediments produced by plastics debris also affect the flora (Kühn et al., 2015), but also decreasing photosynthetic rates and a possible reduction of biomass (Uhrin and Schellinger, 2011; Uhrin and Fonseca, 2005).

Plastic can act as dispersion vectors a might act as a potential vehicle for initiating invasive processes. In words of Kiessling et al., (2015), "*floating litter can facilitate the dispersal of associated organisms when moved across the ocean surface by winds and currents*"[6]. Generally, latitudes between 0 – 15° have colonization rates of around 50 % which decreases with increasing latitude (Barnes and Milner, 2005; Kiessling et al., 2015). However, it is true that in order to be considered an invasive species have to overcome numerous barriers, starting to survive in the particle, reproductive processes or the ability to form populations, i.a. (Kiessling et al., 2015); where colonial organisms have a greater potential to success (Winston, 2012).

The entrance of plastics into the animal life through ingestion is just the starting point for the processes of bioaccumulation and biomagnifica-

6. Kiessling, T., Gutow, L., & Thiel, M. (2015). Marine litter as habitat and dispersal vector. In *Marine Anthropogenic Litter*. pp. 155

tion of chemicals associated with plastics. However, there is still a need for studies that explore the transfer of these compounds through the food chain (Lusher, 2015).

1.3.3. The effects of plastic on human health

Plastic pollution affects not only marine organisms but through the trophic web or directly can reach humans. Although polymers themselves might be considered inert, nonstructural monomers and the large quantity of additives added to plastics could produce deleterious effects on organisms (Galloway, 2015; Lithner et al., 2011). Despite this, there is some controversy as to whether the particles can be absorbed through the tissues. Micro and, particularly, nano-particles could cross some lymphoid tissues in the gut (M cell) or through enterocytes as an alternative route (Galloway, 2015). However, there is not extensive information on the transfer of particles through the food chain, although an estimation of 90 particles per meal on consumption of mussels in Belgium (Van Cauwenberghe and Janssen, 2014).

Additives added to plastics are, perhaps, those who have warned of the impact of this material to human health. Bisphenol A, bisphenone, flame retardants, organotins, phthalates or triclosan are some of these compounds that could migrate from the particle as a result of leaching (Galloway, 2015; Verma et al., 2016). As result, some additives acting as hormone disruption (Moriyama et al., 2002), promoting obesity and cardiovascular diseases (Cipelli, 2013; Lang, 2008; Melzer et al., 2012, 2010), alter reproductive functions and their development (Rochester, 2013), reducing the gut flora, changes in the biomolecules structure or interact with them (Galloway, 2015). Also, it should be added the effects of adsorbed pollutants such as POPs (Persistent Organic Pollutants) or metals (Rochman, 2015; Verma et al., 2016).

Although undoubtedly it has paid less attention to the toxic plastics from inadequate management. Incomplete combustion, due to thermal utilization or combustion in landfills, of some polymers can release carbon monoxide, dioxins, aromatics, bromide, volatile organic compounds (VOCs) and noxious emissions, in addition with color pigments that on numerous occasions incorporate heavy metals (Verma et al., 2016). Some of the potential risks to human health from the previous premise is summarized in the impact to the central nervous system, carcinogens effects, damage to the respiratory and endocrine systems and organs (e.g. liver) (Verma et al., 2016). However, it is necessary to broaden the knowledge of both the pathways and sublethal and lethal effects.

1.3.4. The effects of plastic on economic activities

Waste produced from plastics has a cost associated; however, the complexity, the spread of these wastes, their impact and the lack of knowledge, make it difficult to determine their economic cost. In addition, studies that try to assess the costs tend to underestimate them or not take social-ecological impacts (McIlgorm et al., 2011; Newman et al., 2015). Even so, the economic impacts may be classified into three categories according to Newman et al., (2015): direct costs, marginal or alternative costs and welfare costs.

Direct costs refer to those that can be attributed directly to the consequences of plastic pollution. Among those highlighted those caused to key sectors for the economy, especially those related to the marine environment, such as: fisheries with the costs of damage to the vessels and their gears (up to 19,000 € per year and vessel in the Scottish fishery; Mouat et al., 2010), the aquaculture with impacts caused mainly by blockage of the pipes (around 160,000 € per year to Scotland aquaculture producers; Mouat et al., 2010) or the shipping and yachting (e.g. blockage of pipes, valves, propeller or the cleaning of ports and harbors). However, the mainly direct cost is produced in the economy of the coastal municipalities derived from the cleaning of beaches. The estimated cost depended on many variables (e.g. coastal population, cleaning intensity or km of beach), although the estimated cost of cleaning in countries like UK is set to 18-19 € million per year and 10.4 € per year million in Belgium and The Netherlands (Mouat et al., 2010). Nevertheless, there is evidence of economic impacts related to human health or impacts on agriculture, although there is little information concerning them.

Secondly, the marginal or alternative costs are mainly related with the loss of revenue (Newman et al., 2015). Tourism is the sector most affected by this kind of impact, but so far has not taken into account. Despite the few studies on the subject, the example of a small island in South Korea that lost 500,000 tourists in one year, resulting in 23-29 € million less than the previous year (Newman et al., 2015). However, it also results in a loss of opportunity as in the case of Orange County (California, USA) where the reduction of 75 % of marine litter generated around 40 € million in just three months (Leggett et al., 2014). Fisheries are one of the sectors affected due to the potential loss of catches due incidental catches of plastic or competition against the effect called "ghost fishing" (Antonelis et al., 2011; Bilkovic et al., 2014; Newman et al., 2015).

Thirdly, the welfare costs are mainly related to the different impacts to human health (outlined in the previous section) and recreation. Nevertheless, other intangible and/or opportunity costs could also be accountable.

1.4. International, regional and national instruments and the Marine Strategy Framework Directive (MSFD) in Europe

The high value of marine ecosystems and their resources have not gone unnoticed by the public and political opinion when they can be related to the exposure of marine pollution. Due to the increase number of reports about the impacts of marine litter in the environment, public health or its impact on the economy (Newman et al., 2015), it has been creating numerous treaties and laws in order to deal with the growing problem. In view of the complexity of this issue, this section will attempt to summarize the main instruments affecting the Mediterranean Sea.

1.4.1. International instruments

In 1975 the first protocol, called London Convention (LC), comes into force. This protocol dealing with dumping of wastes at sea and subsequently reinforced, under London Protocol (LP) name since 2006. LP prohibit disposal of persistent plastics and other materials (e.g. sewage sludge, fish wastes or incineration residues) except possessing a permit of waste listed in Annexes I and II (Chen, 2015; UNEP and GRID-Arendal, 2016). During the same period, The International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) was adopted (1978); however, it did not be in force until 1983. The revised Annex V of MARPOL, which it came into force in 2013, bans the disposal of all kinds of garbage into the sea from ships (except by some circumstances regulated in the Annex V, reg. 3) (Chen, 2015; UNEP and GRID-Arendal, 2016). Also, for large vessels (more than 400 gross tonnage or certified to carry more than 14 persons), a garbage record book and adequate reception facilities are needed that may be revised by the competent authority at port (Chen, 2015). It was not until 1994 when the United Nations through the Convention on the Law of the Sea (UNCLOS) entered into force. The UNCLOS together with the MARPOL 73/78 are the major instruments to regulate the use of the oceans and seas (Chen, 2015). Although the UNCLOS does not specify issues relating to plastic waste, Part XII is dedicated to protection and preservation of the marine environment and it is used as a basis for regulation of waste (Chen, 2015; UNEP and GRID-Arendal, 2016). Finally, in 2006 the International Maritime Organization (IMO) was approved the Action Plan on Tackling the Inadequacy of Port Reception Facilities (PRFs) to contribute to the correct implementation of MARPOL 73/78 in the areas of ports and harbors.

Nonetheless, these agreements focus solely on the oceans and seas, and until 1995 the Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) was not established. The GPA is the first regulation that which takes into account the connection between ecosystems (from terrestrial to marine ecosystems) in relation to contaminants, especially those who can reach the sea (UNEP and GRID-Arendal, 2016). Subsequently the GPA was supported by the United Nations Environment Programme (UNEP) through the Regional Seas Programme in order to achieve its implementation.

Despite the previous regulations, various agencies including UNEP, a large number of guidelines have been developed to address the plastic waste impact. Some of the most important are the UNEP/IOC Guidelines on Surveying and Monitoring of Marine Litter, with the main focus on provinding a platform for scientific monitoring; UNEP Guidelines on the Use of Market-Based and Economic Instruments, in order to provide support to decision makers to implement and apply tools to reduce the impacts from the economic system; UNEP/FAO Abandoned, Lost or Otherwise Discarded Fishing Gear, whose main function is to investigate and propose new recommendations to avoid abandonment or discarding of fishing gear; UNEP/NOAA Honolulu Strategy, as a global framework to act against marine pollution and, UNEP Global Partnership of Marine Litter, acts as stakeholder coordination tool to management marine litter problems. (Chen, 2015; Macfadyen et al., 2009; NOAA and UNEP, 2011; UNEP and GRID-Arendal, 2016).

1.4.2. Regional instruments

The UNEP Regional Seas Programme launched in 1974, is currently the main regional instrument for the protection of marine ecosystems through the participation of neighboring countries to an adjacent marine body. Nowadays, there are 18 regional conventions and action plans of which 13 are under the UNEP program: Black Sea, Caspian, Wider Caribbean, East Asian Seas, Eastern Africa, South Asian Seas, ROPME Sea Area, Mediterranean, North-East Pacific, North-West Pacific, Red Sea and Gulf of Aden, South-East Pacific, Pacific, and Western Africa. For the purpose of this paper the analysis will focus on the Mediterranean region.

In 1975, sixteen Mediterranean countries adopted the Mediterranean Action Plan (MAP), the first Regional Seas Programme. One year later, these countries approved the Barcelona Convention that in 1995 adopted the amended version and extending the area of action to marine and coastal environments, finally calling it "Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. (Barcelona Convention)". Among its main objectives are the evaluation and control of marine pollution and the prevention, reduction and elimination of pollution from land and sea-based sources.

In the European Union, there are several instruments which mostly stem from the transposition of international regulations ratified. Due to the high intensity of port activity in the European Union, one of the first directives transposed was the EU PRF Directive that came into force in 2002, and has some requirements as the waste and handling reception or the requirement for delivery of waste to ships, among others. Furthermore, the Waste Framework Directive, aimed at management and revaluation of waste (EU, 2008a); the Landfill Directive, establishes the uses, operation and limits of landfills (EU, 1999); and the Packaging and Packaging Waste Directive, adopted by the member states to prevent and reduce the impact on the environment of packaging (specifically about the use of bags in its latest revision of 2015) (EU, 2015). Concerning legal measures for the protection of the water environment, both the Water Framework Directive and the Marine Strategy Framework Directive (MSFD) are considered integral instruments for the development of a visioning status, the good ecological status and the good environmental status respectively.

1.4.3. EU Marine Strategy Framework Directive (MSFD Directive 2008/56/EC)

The Marine Strategy Framework Directive (MSFD) is the main holistic integral policy instrument for the protection of the marine environment in the European Union (EU, 2008b; Sardá et al., 2015). The directive was adopted on 17th June 2008 to establish the necessary measures and following an ecosystem-based management on the human activities that have an impact on the marine environment, to achieve and maintain the Good Environmental Status (GEnS) by 2020 (Chen, 2015; EU, 2008b; Sardá et al., 2015). This Directive establishes a framework within which Member States shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest. Following this statement, each member state was required to transpose and develop its strategy for their marine waters and coastal areas to address the objectives of the MSFD.

Achieving Good Environmental Status (GEnS) is the key target of the environmental marine policy in Europe and should be considered its desired vision for the future of its marine waters. GEnS means "*the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and* *future generations*"[7] (MSFD, 2008). As it has been pointed out in the Commission Decision 2010/477/EU (September 1st), the criteria for the achievement of GEnS is the starting point for the development of coherent approaches in the preparatory stages of marine strategies, including the determination of characteristics of GEnS and the establishment of a comprehensive set of environmental targets, to be developed in a coherent and coordinated manner in the framework of regional cooperation.

The criteria of Good Environmental Status (GEnS) build on existing legal obligations and it depicts the pathway to move from the present "status quo" of our Social-Ecological System (SES) until its ultimate desired vision is reached. The Member States in Europe, for each marine region or sub-region, are aimed today to establish environmental targets and indicators based on the COM 2010/477/EU (Figure 1.11). It is clear that these targets and indicators constitute legal obligations but it is also advisable that, due to the fact that probably large masses of water should be included together to develop GEnS, a particular area (Social-Ecological System, SES) could try to get better targets if GEnS have been reached. A total of eleven qualitative descriptors have been described in the MSFD to help each member state to reach the GES (Figure 1.11).

- Descriptor 1: Biological diversity is maintained. The quality and occurrence of habitats and the distribution and abundance of species are in line with prevailing physiographic, geographic and climate conditions.

- Descriptor 2: Non-indigenous species introduced by human activities are at levels that do not adversely alter the ecosystem.

- Descriptor 3: Populations of all commercially exploited fish and shellfish are within safe biological limits, exhibiting a population age and size distribution that is indicative of a healthy stock.

7. MSFD, 2008. DIRECTIVE 2008/56/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). Art. 3.

- Descriptor 4: All elements of the marine food webs, to the extent that they are known, occur at normal abundance and diversity and levels capable of ensuring the long-term abundance of the species and the retention of their full reproductive capacity.

- Descriptor 5: Human-induced eutrophication is minimized, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algal blooms and oxygen deficiency in bottom water.

- Descriptor 6: Sea-floor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected.

- Descriptor 7: Permanent alteration of hydrological conditions does not affect marine ecosystems.

- Descriptor 8: Concentrations of contaminants are at levels not giving rise to pollution effects.

- Descriptor 9: Contaminants in fish and other seafood for human consumption do not exceed levels established by Community legislation or other relevant standards.

- Descriptor 10: Properties and quantities of marine litter do not cause harm to the coastal and marine environment.

- Descriptor 11: Introduction of energy, including underwater noise, is at levels that do not adversely affect the marine environment.

The tenth descriptor is directly related to marine litter which evaluated the harm into three categories. Firstly, the ecological impact of the litter (mortality or sub-lethal effects to plants and animals through entanglement, physical damage and ingestion including uptake of microplastics, accumulation of chemicals from plastics, facilitating the invasion of alien species, or altering the benthonic community structure); secondly, economic impacts (e.g. cost to tourism, damage to vessels, fishing gear and facilities, losses to fishery operations, cleaning costs); and thirdly, social impacts (reduction in aesthetic

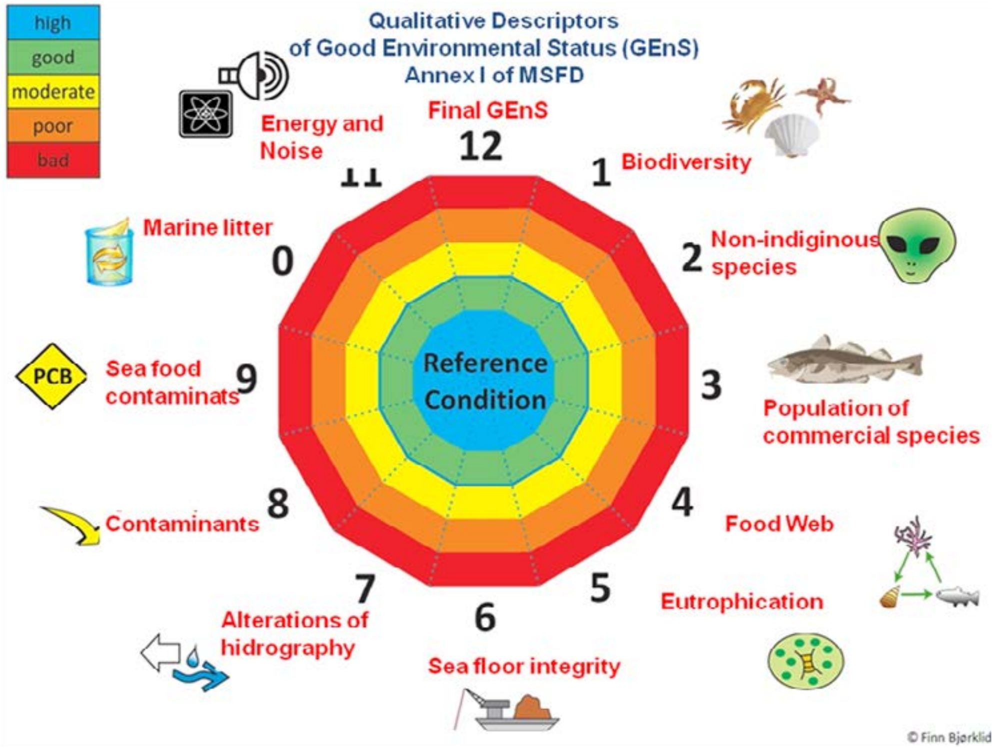


Figure 1.11. The eleven qualitative descriptors of Good Environmental Status (GEnS) following the MSFD. *(Extracted from: FP7 KnowSeas project, www.msfd.eu)*

value and public safety) (Galgani et al., 2010). A series of compartments are also proposed in order to determine the acceptable levels of harm in these categories, starting with the marine environment (seabed, sea surface, water column, coastline), ecological effects of marine litter, problems associated with degradation of litter and social and economic effects affected by marine debris (Galgani et al., 2010).

Due to the wide range of the effects of marine litter might be several links to other descriptors within the MSFD. The second descriptor, associated with non-indigenous species, is intrinsically linked to reports submitted on the transport of these species by marine debris (Barnes et al., 2009; Gregory, 2009; Ogunola and Palanisami, 2016), in addition, the accumulation and release of the potential toxic compounds (Mato et al., 2001; Oehlmann et al., 2009; Teuten et al., 2009, 2007) and the impact by ingestion of plastic particles (Gregory, 2009;

Laist, 1997; Lusher et al., 2013; Schuyler et al., 2014) is possible that are linked or overlap with fourth and eight descriptors (Galgani et al., 2010).

In addition to this marine strategy, the Commission of the European Union has established as a priority a new strategy for plastics within the basis of the circular economy that sets objectives that will facilitate the reduction of the plastic problem by 2030 (COM, 2018).

1.4.4. National Instruments in the Mediterranean Sea

Despite the previous international and regional instruments, few nations have transposed some of these instruments to their own regulations or legislations (UNEP and GRID-Arendal, 2016). Due to the enormous complexity of the legal systems of different countries and the continuous adaptations of the legal tools, only some of the most relevant measures, in terms of reducing plastic waste, will be introduced here.

Some member states of the European Union with coastal waters in the Mediterranean Sea, have taken measures to reduce litter in the retail levels. Italy (2014), France (2016) and Spain (2017) began with the ban on commercialization of single-use plastic bags (L.116/2014, Décret n°2016-379, and Ley 5/2017 28 de Marzo, respectively) from non-biodegradable sources and by 2020 all single use plastic tableware will be banned (Décret nº2016-1170). In the case of Spain, the current law 5/2017 of waste and contaminated soils, introduces some restrictions for the bags for single use non-biodegradable, and shortly, the draft Royal Decree will be approved that will ban the light plastic bags not compostable under the transcription of the European Directive (UE) 2015/720.

Morocco, that has been the second plastic bag consumer after United States, has banned the production, import, sale and distribution of plastic bag on July 1, 2016 (Joseph, 2016). However, there is a continuous revision of national legislations which could enacted similar instruments in the Mediterranean region in the next years. Other potential measures at the level of manufacturing are only considered as a second further step for the countries of the Mediterranean basin and not been implemented yet.

1.5. Aims and Outline of the thesis

This work is based on the assumption that plastic pollution is a problem with deep social-ecological implications. The main objective of this doctoral thesis was to "***assess the current state of floating plastic debris in the Mediterranean Sea and to explore perception and awareness from people***". To achieve this objective, the following major sub-objectives were identified:

- Determine the spatial distribution of floating plastic debris and its associated factors.
- Estimate the seasonal variability of plastics on the surface of the sea using a local scale pilot study.
- Characterize plastic litter on the surface of the Mediterranean Sea.
- Estimate the spatial-temporal factors that drive the distribution of plastic debris on the surface of the Western and Central Mediterranean Sea.
- Build an emerging framework of the issues generated by plastics, examining the insights of key stakeholders.
- Analyze beach users' perceptions as a component of the plastic social issue.

This thesis was born as a part of social science project with a marked historical character, the travels of Archduke Ludwig Salvator of Austria through the Mediterranean Sea. It has been decided to introduce in each chapter a brief opening paragraph that highlights the relationship between current research and the work carried out by the Archduke. The thesis is sub-divided into two main parts that reflects its ecological and social dimension according to the following structure:

Part I: The Ecological dimension

Chapter 2: General methods of the ecological dimension

Here we explain in depth the methodology adopted throughout the work carried out. It has been structured independently of the chapters with the aim of avoiding the continuous repetition of the methods used, especially in this first part of the thesis.

Chapter 3: Floating plastic debris in the Central and Western Mediterranean Sea

Due to the characteristics of semi enclosed sea with a low rate of renewal and the strong anthropic pressure supported, the Mediterranean Sea predisposes the favorable conditions for a high concentration of plastic litter. This chapter provides the current state of plastic concentrations in the Mediterranean at regional macro-scale level through an extensive surface sampling. The new results should help to continue improving the necessary distribution models and to raise awareness in those areas with high concentration values to promote monitoring programs.

Chapter 4. The 'invisible' plastics around the Balearic Islands (Spain): floating plastic debris in the coastal waters of the Archipelago

This chapter provides a regional micro-scale distribution and concentration of floating plastics debris in the coastal waters of the Balearic Islands. Moreover, most of the plastics, that finally end up in the sea, are discarded from land-based sources (e.g. Jambeck et al., 2015), hypothesizing with a greater coastal concentration. Differences between the Balearic and the Algerian sub-basins of the Islands were also debated in function of the prevalent sea surface circulation.

Chapter 5. Seasonal variability of the surface distribution of plastics debris in the Marine Protected Area of the Menorca Channel (Spain)

Results from this chapter provide the initial current state and the seasonal variability of floating plastics in this recently approved MPA. Twelve sampling stations were analyzed quarterly (i.e. autumn, winter, spring and summer). Oceanographic and demographic variables (e.g. currents, wind, tourism) were used in a correlation approach to investigate the relevant factors inducing this seasonal distribution.

Part II- The Social dimension

Chapter 6. General methods of the social dimension

This chapter provides the methodology for last two chapters in the second part of this thesis. The methods in Chapter 7 focus on empirical qualitative analyzes to obtain mental maps from focus groups sessions. In Chapter 8, a quantitative methodology was used based on a questionnaire in order to explore beach users' perceptions.

Chapter 7. The social dimension of the problem of plastic debris: exploring the perceptions of Mallorca's stakeholders that influence in decision-making processes

The perceptions of three focus groups (experts, public administration and companies) were analyzed with the aim of exploring the mental maps and the interrelationships generated in them to build a framework of the issues generated by the environmental problem of plastic debris. From this exploration, the main themes that govern the perception of these stakeholders were identified that should be used to enhancing measures facing plastic pollution.

Chapter 8. The problem of plastic debris: exploring beach users' perceptions, attitudes and motivations

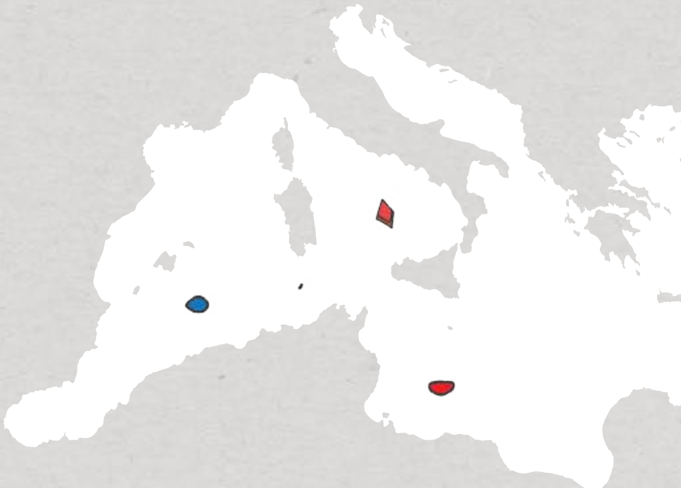
A large part of the waste abandoned on the beach is associated with its users (Martinez-Ribes et al., 2007). With the aim to analyze perceptions users were surveyed in several beaches of Mallorca (Spain). We also evaluated their precognitive views and deepened in their attitudes and motivations.

Part III- Discussion and Conclusion

Chapter 9: General Discussion and Conclusions

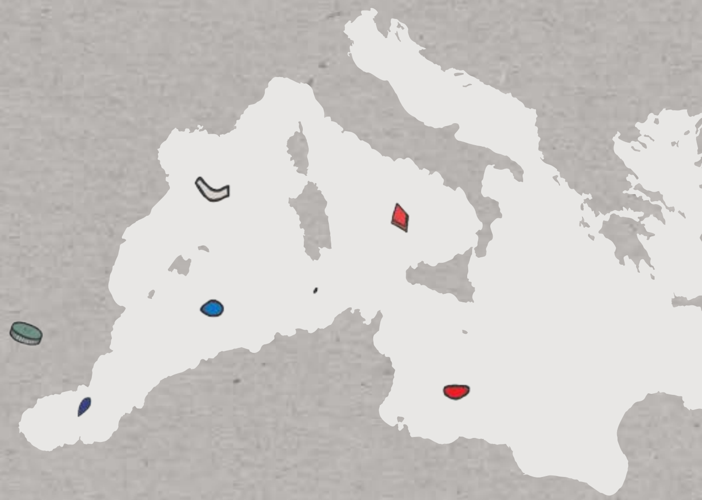
This chapter provides the general discussion to the work carried out in this doctoral dissertation and the main conclusions extracted in it. Moreover, we include the future perspectives for the research realized here.

References to literature used in this work are cited in Chapter 10 and supplementary materials are provided in the annexes, Chapter 11.



Part I

The Ecological dimension



Chapter 2

General methods of the ecological dimension

2.1. Introduction

The purposes of this chapter is to give an overview of the methodologies used throughout the ecological dimension of this work. This first part will deal with the design and the methods to analyze the floating plastic debris distributions and concentrations in several scales of the Mediterranean Sea in order to assess the environmental problem. The chapter is divided into three main parts: (a) sample collection and preservation, (b) laboratory work and (c) data analysis.

2.2. Sample collection and preservation

2.2.1. Sampling design

In 2009, the NIXE III project (FIAyC) was initiated in Mallorca (Balearic Islands, Spain) to replicate part of the expeditions that the Archduke Ludwig Salvator of Austria did at the end of the 19^{th} and beginning of the 20^{th} Century. Different sea voyages (expeditions) in the Mediterranean Sea were carried out. These expeditions allow us the possibility to perform an opportunistic random sampling for floating plastics in the Northwestern and Central Mediterranean Sea. The main aim of this work was to provide new information about distribution, abundance and size composition of floating micro- (< 0.5 mm), meso- (5 – 25 mm) and macro- (25 – 1,000 mm) plastics in this region in accordance with the marine litter descriptor established under the European Union Marine Strategy Framework Directive (MSFD, 2008/56/EC). The final study was designed to analyze the distribution of these plastic debris at three different spatial and temporal scales in the Mediterranean (Figure 2.1):

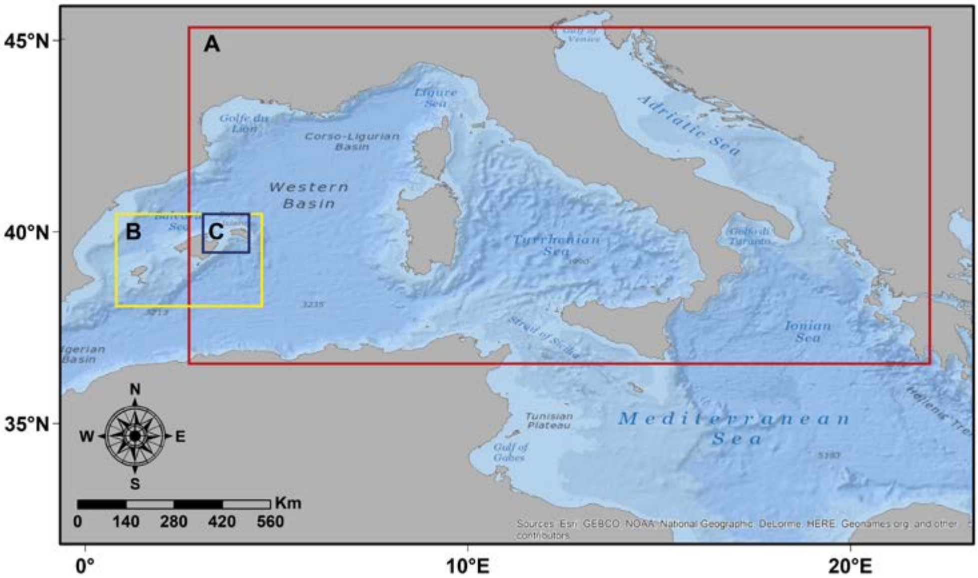


Figure 2.1. Study area: *(A) Regional macro scale, (B) Regional micro scale and (C) local scale. Source of background layer: Esri.*

A) *Regional macro spatial scale*: the study focused on the analysis of floating plastic debris in the Northwestern and Central Mediterranean Sea. Sampling area extended from 3° 12' 6.00" E to 21° 53' 22.20" E and 43° 45' 3.90" N to 37° 54' 52.26" N. To coverage this area, samples were collected from surveys conducted during two research expeditions. The first study (May 25 – July 2, 2011) covered the area from the Balearic Islands (Northwestern Mediterranean Sea) to the Adriatic Sea, carried out on the R/V *Wizard*. The second study (April 30 – June 14, 2013) covered the area from the Balearic Islands to the Ionian Sea and was conducted on the R/V *Rossina di Mare*.

B) *Regional micro spatial scale*: the Balearic archipelago was the central focus of attention in this spatial scale. On board the R/V *Pola*, the coastal regions of the main five islands that formed the Balearic Islands (Mallorca, Menorca, Ibiza, Formentera and Cabrera) were sampled between a distance to land from 0.14 to 46.83 km. The expedition was carried out between June 4 and July 17, 2014.

C) *Local seasonal scale*: this study covered the area comprised the Menorca Channel (between the islands of Mallorca and Menorca). Four research cruises were performed during the year. The first cruise (autumn season) took place from October 9 to 10, 2014; the second one was carried out in Winter from January 7 to 8, 2015; the third, during the Spring, from April 24 to 25, 2015; and the last one in Summer, on July 12, 2015. In total, twelve sampling stations were established for seasonal study with the support of the R/V *Wizard* and R/V *Pola*.

2.2.2. Survey methods

Sampling: Manta trawl net

Samples were collected using a Manta trawl net (0.6 m × 0.25 m, rectangular frame opening) and characterized by the two rigid fins attached to its outside to allow some buoyancy when it is towing. The tool was equipped with a net of 333 µm mesh size and a collecting bucket (cod-end) at the end of it (Figure 2.2). According to previous research recommendations (e.g. Collignon et al., 2012; Moore et al., 2001), the net was towed from the side of the boat at some distance to prevent the disturbance of floating debris. The net was towed at a speed of 2.0 – 3.4 knots for periods of 15 – 30 minutes in each sampling station. After this period, the net was raised on board with seawater to accumulate the entire sample in the cod and transferred to 225 µm sieve to ensure microplastic retention.

Water filtered: flowmeter

A flowmeter (General Oceanics, Inc.) was installed at the center of the manta net mouth to record the volume of seawater filtered (Figure 2.3). Initial and final rotor counts were annotated in each deployment to calculate the

Figure 2.2. Example of the tools used during sampling. *(A) Manta trawl net, (B) Net and cod-end, (C) transfer to the sieve, and (D) sample extracted in the sieve. (Image attributions: Chapter 10 - References).*

Figure 2.3. Example of flowmeter used in campaigns. *(Image attribution: Chapter 10 – References).*

volume filtered. The approach filtering distance (1) was obtained in relation to the difference of the counter and the rotor constant (standard speed rotor constant = 26,873), which is applied in (2) to obtain the filtered cubic meters based on the area of the mouth of the submerged net.

$$Distance\ (m) = \frac{Difference\ in\ Counts \cdot Rotor\ constant}{999999} \quad (1)$$

$$Volume\ (m^3) = Distance\ (m) \cdot 0.60\ (m) \cdot 0.25(m) \quad (2)$$

Sample preservation

The samples obtained were observed to ensure that no protected species had been captured. Then, each sample was transferred to 250 ml lab jars, washed in 5% formalin to minimize possible predation effects of the collected particles and fixed in 50% ethanol (EtOH). Samples were stored until their analysis in the laboratory.

2.3. Laboratory work

2.3.1. Sample processing

Samples were extracted from the preservation medium using a Tayler sieve with mesh size of 225 µm. To assure obtaining the entire sample, we decided to use this smaller mesh size compared with the used in the Manta trawl net. Subsequently, it was transferred into a 5 L container of filtered water to carry out the density separation. Both the supernatant and sink (water column and bottom) fractions were separately extracted.

2.3.2. Sample classification

Each fraction was inspected visually and manually separated under a dissecting stereo-microscope (Olympus). In case of doubt about the nature of a particle (particularly, particle sizes < 5 mm) it was identified with an optical microscope (Nikon). Due to some plastic particles adhere to other components (e.g. bee setae, tar balls), the separation time for each sample ranged from 4 hours to 2.5 weeks. Six groups were selected to categorize samples: plastics, tar ball-pellets (charcoal fragments and hydrocarbons solid or semi-solid fragments), vegetable organisms (natural fragments from Plantae and Chromista kingdoms (Ruggiero et al., 2015)), animal organism, paper or paperboard and unclassified materials. In addition, plastic category were counted and reclassified using Tyler sieves into three size categories: microplastics (< 5 mm), mesoplastics (5 mm – 25 mm) and macroplastics (25 mm – 1,000 mm) (Collignon et al., 2012; Lippiatt et al., 2013; Ruiz-Orejón et al., 2016), and categorized by the kind of plastic (i.e. hard fragment, foams, fibers, etc.). Fibers were counted but were not considered in the concentration computation, to avoid error for environment contamination (i.e. volatile fibers not present at the time of sampling).

Some of plastic particles were found with organism adhered or impregnated with hydrocarbons in semi-solid state, therefore we proceeded to manually removing them. According to the study presented by Dehaut et al., (2016) about plastic extraction on seafood, it has been found that several of digestion processes may introduce an underestimation as a result of the degradation produced in the particles, it was decided to use the manual removal of these adhered compounds due to the possibility that the use of methodologies based on chemical digestion could affect the particles.

The five separated groups plus the three subgroups of plastic material were transferred to tared glass vials. These vials were introduced into the laboratory oven (Heraeus) at a temperature of 65°C for a minimum of 24 hours. After cooling down in the desiccator, they weighed on a precision balance (Sartorius) to obtain the dry weight (DW) of each group.

2.3.3. Plastic size (surface area and length size)

Size was analyzed by digitizing all particles from each sample. Plastic particles were placed on a matt black surface, on their greater stability side, with a calibrate and known reference (Figure 2.4; see also Supplementary

Materials Figure S2.1.: Annex A). Calibrated photographs were obtained by a camera equipped with an 8-megapixel sensor resolution and processed with free software ImageJ (National Institute of Health, NIH) v1.49p (regional macro scale) and v1.50f (regional micro and local scale). The entire range of particle shapes was determined including variations in the shape factor from 1 to 0 (SF = 4π area/perimeter) according to the recommendations of Filella (2015). The results of the digitization were reviewed to correct possible failures in the detection of the particles, particularly with the dark particles that resembled to the background. Plastic sizes in this work were normalized

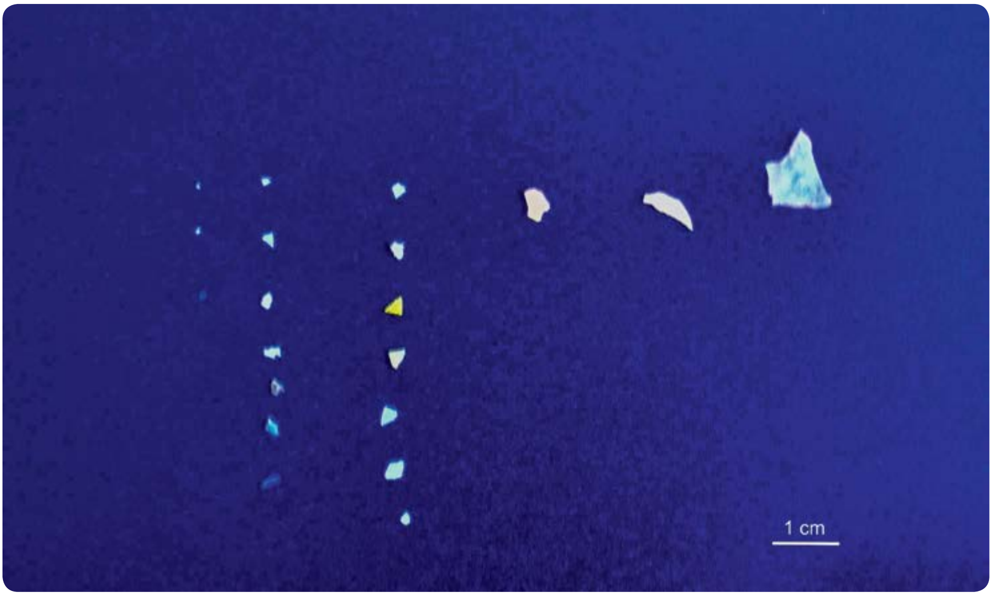


Figure 2.4. Example of calibrated photography to analyze particle sizes (area and length).

using square millimeter intervals to uniform the size classes in the surface size (Chapter 3). To ensure the comparability between all the campaigns carried out in this thesis, we followed the same methodology explained in the paragraph below with these size limits (1 – 50; 50 – 100; 100 – 150; 150 – 200; 200 – 250; 250 – 300; 300 – 400; 400 – 500; 500 – 1,000; 1,000 – 1,500; 1,500 – 2,000; 2,000 – 5,000 and 5,000 – 10,000 mm^2).

The length size of plastic particles was also measured (Chapter 4 & 5) using the same calibrated photographs that in the analysis of surface area, according to their maximum linear length. The particles were separated into ten size classes from 0.33 to 2,000 mm (size intervals = 0.33 – 0.4, 0.4 – 0.5, 0.5 – 0.7, 0.7 – 1.3, 1.3 – 2.5, 2.5 – 4.0, 4.0 – 7.9, 7.9 – 20.0 – 50.0 and 50.0 – 2,000.0 mm). Due to some flexible particles exceeded the size of the net mouth, size classes larger than the width of the net mouth were considered in this thesis. To be comparable with other reported data, size distribution was also normalized. Following Cózar et al. (2017) methodology, frequency of plastic particles were divided by its size class obtaining the normalized abundance and in turn, it was divided by the sum of the normalized abundances to be independent of the dimensions and number of particles analyzed (3) which results were the dimensionless relative normalized distribution (Nd_i).

$$Nd_i = \frac{(particles_i / size\ class_i)}{\sum_{i=1}^{n} (particles_i / size\ class_i)} \quad (3)$$

2.4. Data processing analysis

2.4.1. Plastic data correction

The vertical distribution of plastics in the sea surface is altered by mixing effect of the wind. To prevent this effect, and to allow the trawl to work correctly, all samples collected during the field campaigns were obtained in low wind conditions (< 7 knots), where 12% of samples taken exceeded 5 knots. Plastic particle concentrations (item·km^{-2}) were corrected following the study of Kukulka et al., (2012) for tows carried out with an average friction velocity in water (u_{*w}) of > 0.6 cm·s^{-1}

Wind data (U_{10}) were extracted from meridional (V) and zonal (U) vectors of the Physical Oceanography Distributed Active Archive Center (Podaac, NASA) (http://podaac.jpl.nasa.gov) database for the first campaign (Chapter 3) and from Global Ocean Wind L4 Near Real Time 6 hourly Observations produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS) (http://marine.copernicus.eu) database for the rest of campaigns (Chapter 3-4-5). This change occurred due to the lack of data for the first campaign in the second source at the time of analysis and vice versa. Resolution used were the same as the both original databases (0.25° × 0.25°) and time frequency of 6 hours. However, two coefficients were needed to determine the frictional velocities produced by the wind. Firstly, drag coefficient (C_D) considered as the resistance of seawater against the air fluid medium (4)

$$\boldsymbol{C_D} \approx 10^{-3}(a + bU_{10}) \quad (4)$$

in a linear form in which a = 0.75 and b = 0.067 (Massel, 2013) and secondly, wind stress (τ) that is the tangential force produced by the wind in the ocean-atmosphere interaction (5).

$$\tau = \rho_{air}\, C_D {U_{10}}^2 \quad (5)$$

Air density (ρ_{air}) were assumed constant and with value of 1.29 kg·m^{-3}. Frictional or shear water velocity (u_{*w}) (6) assuming Mediterranean surface water density (ρ_w) constant and equal to 1,027 kg·m^{-3}, frictional air velocity (u_{*a}) (7), through its relationship with (6), and significant wave height (H_s) (8). Where g = 9.81 m·s^{-2} is the gravity acceleration and assuming a fully developed sea, the wave age is σ = 35 (Komen et al., 1996; Kukulka et al., 2012).

$$u_{*w} = (\tau/\rho_w)^{1/2} \quad (6)$$

$$u_{*a} = \sqrt{\frac{\rho_w\, {u_{*w}}^2}{\rho_{air}}} \quad (7)$$

$$\boldsymbol{H_s} = 0.96 g^{-1}\, \sigma^{3/2}\, {u_{*a}}^2 \quad (8)$$

Previous parameters (5, 6, 7) and the von Karman constant (κ=0.4), serve to model the mixing effect produced on the surface of the sea by the turbulent exchange coefficient near surface (A_0) (9), which modify the vertical distribution of the floating particles as effect of breaking waves and Langmuir circulations. (Kukulka et al., 2012; Thorpe et al., 2003).

Finally, equation (9) is applied to the Kukulka model (10) for the plastic particle concentration obtained in the surface layer (N_{tow}) during sampling. Because rise velocity of particles is highly variable according to their properties, the buoyant rise velocity was assumed as $w_b = 0.005$ m·s^{-1} (Kukulka et al., 2012). Where (d) is the immersion depth of the manta trawl net equal to 0.25 m and (N) is the deep integrated plastic concentration.

$$\boldsymbol{A_0} = 1.5 u_{*w} \kappa H_s \quad (9)$$

$$\boldsymbol{N} = \frac{N_{tow}}{1 - \exp\left(-d w_b {A_0}^{-1}\right)} \quad (10)$$

2.4.2. Variables

To analyze the factors that could affect the distribution of plastics in the Mediterranean Sea, the following oceanographical and social variables were used:

Oceanographic variables

- *Wind*: wind U_{10} data used for plastic correction in section 2.4.1. were reused for this analysis. This data, produced and distributed by the Physical Oceanography Distributed Active Archive Center (Podaac, NASA) database for the first campaign (Chapter 3) and the Copernicus Marine and Environment Monitoring Service (CMEMS) (Chapters 3-4-5), have a horizontal and vertical resolutions of 0.25° × 0.25° and time resolution of 6 hours, as it is mentioned above. The data are estimated from three scatterometers (ASCAT, OSCAT, ECMWF).

The angle and direction of wind were additionally obtained to the wind speed in each sampling point. To simplify the analysis, the wind direction was regrouped according its angle in: North (337.5°-22.5°, N), Northeast (22.5°-67.5°, NE), East (67.5°-112.5°, E), Southeast (112.5°-157.5°, SE), South (157.5°-202.5°, S), Southwest (202.5°-247.5°, SW), West (247.5°-292.5°, W) and Northwest (292.5°-337.5°, NW).

- *Surface current*: daily mean meridional and zonal vectors were obtained from Mediterranean Sea Physics Reanalysis database, produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS). The spatial resolution of this database is 1/16° (0.063° × 0.063°) and daily time resolution. The hydrodynamics of this database are provided by Nucleus for European Modelling of the Ocean (NEMO) and the solutions are corrected based on a 3DVAR scheme (temperature, salinity and sea level anomaly) (Adani et al., 2011). To analyze the prevailing mesoscale surface currents in the Balearic region (Chapter 4), the average vector components of June and July 2014 was obtained through its analysis in the R software from the daily mean data and transferred to ArcGIS software. In the case of Menorca Channel (Chapter 5) the data were averaged from a week period before the last date of each seasonal sampling (8 days).

- *Sea Surface Temperature (SST)*: data were extracted from the Mediterranean Sea Physics Reanalysis, produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS). The spatial resolution of this database was 1/16° 1/16° and daily time resolution. The data are obtained from infrared methods through satellite radiometers (Buongiorno Nardelli et al., 2013). Temperature extracted were linearly interpolated in time and space for each trawl conducted in the Menorca Channel (Chapter 4 & 5).

- *Salinity (psu)*: from the Mediterranean Sea Physics Reanalysis database, produced and distributed by the Copernicus Marine and Environment Monitoring Service (CMEMS). The spatial and time resolutions were of 1/16 ° and daily, respectively. The same methodology was used as the SST to obtain the mean of the study period using software R in the study conducted in the Menorca Channel (Chapter 4 & 5).

Demographic variables

- *Population*: population was used for the regional study (Chapter 4). Data were obtained from the *Institut d'Estadística de les Illes Balears* (IBESTAT, http://www.ibestat.cat/ibestat/estadistiques/poblacio/padro) services. The coast in the Balearic Islands is easily accessible to all its population due to its limited extensions; however, in order to analyze the demographic characteristics, monthly average data of resident population were obtained from the coastal municipalities adjacent to each sampling point.

- *Tourism*: we used two measures to analyze the variability of tourism. Firstly, we obtained the flux of tourists (non-resident) entering in the Balearic Islands and secondly, the percentage of hotel and apartment occupation in the municipal areas. Data were obtained from the IBESTAT services (http://www.ibestat.es/ibestat/estadistiques/economia/turisme/ocupacio-oferta-turistica-hotels/614884d6-737a-401d-a8c3-a35519b8fec9). We have used the delimitations of coastal municipal areas adjacent to the sampling positions carried out, as in the case of the population data.

Other variables

- *Coastal cleaning service*: mirroring demographic variables, this data was only used for the Balearic island study (Chapter 4). The autonomous community of the Balearic Islands has a coastal cleaning service coordinated by the *Agencià Balear de l'Aigua i la Qualitat Ambiental* (ABAQUA, http://abaqua.es/es/escalidad-ambiental/limpieza-del-litoral). This service collects the macro residues in a strip of 20 m to 300 m off the coast, acting between the months of June to September of each year, with a categorization of waste in: wood, organic matter, plastic, oil, seaweeds and others. We consider only the 'plastic' category of coastal areas corresponding to the sampling points of this study; however, the service was inactive for more than half of the sampling period of 2014, so we obtained the average data for the summer season (July - September 2014).

2.4.3. Statistical analysis

Normality and homogeneity of variance was checked and the level of statistical significance was set at *p-value* < 0.05. Nonparametric analysis was used to examine the data after assessing non-normal distribution through the Kolmogorov- Smirnov test. Spearman's correlation coefficient was used to test significant relationships between plastic concentration (weight and particle) and environmental variables, as well as with the size of plastic classes. To compare differences in plastic concentrations (weight and particle) between the Mediterranean regional seas and spatial scales, a Mann-Whitney-Wilcoxon test (also Mann Whitney U test) for pair-wise comparisons was used. Instead, seasonal differences were analyzed through a Kruskal-Wallis test.

Differences in plastic composition of meso and microscale level in this dissertation were also analyzed with the Kruskal-Wallis test. In addition, seasonal differences in the plastic composition were studied through a Principal Component Analysis (PCA) based on a variance-covariance matrix of the normalized frequencies of hard, film and foam fragments along with industrial pellets, fishing lines and plastic rope.

Data analysis was performed using IBM SPSS Statistics 22 and R v: 3.1.3 software, except the PCA that was performed using PAST v: 3.15 software.

Chapter 3

Floating plastic debris in the central and western Mediterranean Sea[1]

[1]Based on: Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2016. *Floating plastic debris in the central and western Mediterranean Sea.* Mar. Environ. Res. 120, 136–144. doi:10.1016/j.marenvres.2016.08.001

Abstract

Taking advantage of two sea voyages throughout the Mediterranean (2011 and 2013) that repeated the historical travels of Archduke Ludwig Salvator of Austria (1847-1915) a total of seventy-one samples for floating plastic debris were obtained with a Manta trawl. Floating plastic were observed in all sites sampled with an average weight concentration of 579.3 g(DW)·km^{-2} (maximum value of 9,298.2 g(DW)·km^{-2}) and an average particle concentration of 147,500 items·km^{-2} (maximum value of 1,164,403 items·km^{-2}). Obtained plastic size distribution showed microplastics ($<$ 5 mm) at all sizes. The most abundant particles where around 1 mm^2 in surface (mesh used 333 µm). A general estimate totaled a value of 1,455 tons (DW) of floating plastic for the entire Mediterranean region with various potential spatial accumulation areas.

3.1. Introduction

3.1.1. Background

During the 19th century, there was a literary explosion in the development of travel books (Alzaga Ruiz, 2006). These books were one of the products of the Enlightenment movement of previous years together with the impulse of the industrial revolution, in which the European nobility established the trips to other regions as a base for the development of their education. The Archduke Ludwig Salvator was one of the greatest exponents of the second part of the century, focusing his work on the coasts of an already populated Mediterranean Sea.

Nowadays, approximately one third of the 500 Million population of the Mediterranean is concentrated along its coastal regions [100 million people within 10 km coast strip (Cózar et al., 2015) and 200 million within 50 km (Jambeck et al., 2015)], in the largest of the semi-enclosed European seas. These features provide high potential for plastic retention (Reisser et al., 2013; Ryan, 2013) and makes the Mediterranean Sea as a particularly sensitive ecosystem to the accumulation of plastic debris (e.g. Cózar et al., 2015; Galgani et al., 2010) comparable to average concentrations of the five subtropical gyres (Cózar et al., 2015).

The accumulation of plastics in the marine surface is mainly produced by the drag of the particles, according to their density, in the action of winds and surface currents (e.g. Derraik, 2002; Filella, 2015; Ryan et al., 2009). In the oceans, there are stable retention areas due to the convergence zones formed by the action of the Ekman drift and in the less energetic geostrophic currents (Law et al., 2014; Titmus and Hyrenbach, 2011). Some surface currents observed in the Mediterranean could be considered predominant (Figure 3.1). The main surface waters, also known as Atlantic Waters (AW), enter the Mediterranean through the Strait of Gibraltar developing anticyclonic gyres (Figure 3.2). The formation of gyres, due to the instabilities, are continuous in the route along Algeria and Tunisia coasts to Strait of Sicily; where there is a subdivision of the water masses, in which a part recirculates in the western sub-basin and the other major part continues towards the eastern sub-basin. The geographic outline of the Mediterranean has a strong influence on the AW that together with the high variability (Ayoub et al., 1998; Millot and Taupier-Letage, 2005), hinder the formation of stable retention zones for plastic particles (Mansui et al., 2015).

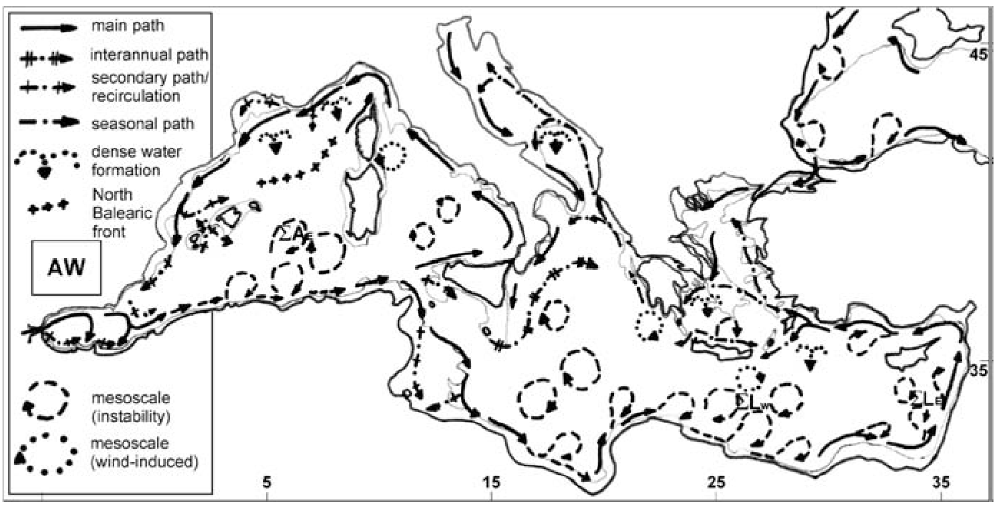


Figure 3.1. ***Surface water circulation in the Mediterranean Sea.*** *Predominant surface currents with mesoscale circulations. (Extracted from: (Millot and Taupier-Letage, 2005)).*

Diverse studies related with plastic pollution have been carried out in some areas of the Mediterranean Sea since the early 80s, where several methods have been used to determine the distribution of floating particles on it (Table 3.1 and Figure 3.3). Visual surveys have been carried out throughout this Sea mainly due to the advantage of sampling large areas reporting values ranging from 0 to 1,400 items·km^{-2} (Aliani et al., 2003; McCoy, 1988; Morris, 1980; Suaria and Aliani, 2014; Topcu et al., 2010), however, this method of sampling is usually focused on the estimation of macro and mega-sized particles. On the other hand, two main kind of nets have been used in the surface trawling with different mesh size (from 200 to 500 µm). Firstly, results from neuston net with simple rectangular opening have been reported in throughout Mediterranean and in specific areas of Crete and Corsica (Collignon et al., 2014; Cózar et al., 2015; Kornilios et al., 1998), and secondly, the manta trawl net with results mainly in the western Mediterranean from 116,000 to 130,000 items·km^{-2} and from 57 to 2,020 g·km^{-2} (Collignon et al., 2012; Faure et al., 2015) or 0.15 items·km^{-3} (de Lucia et al., 2014).

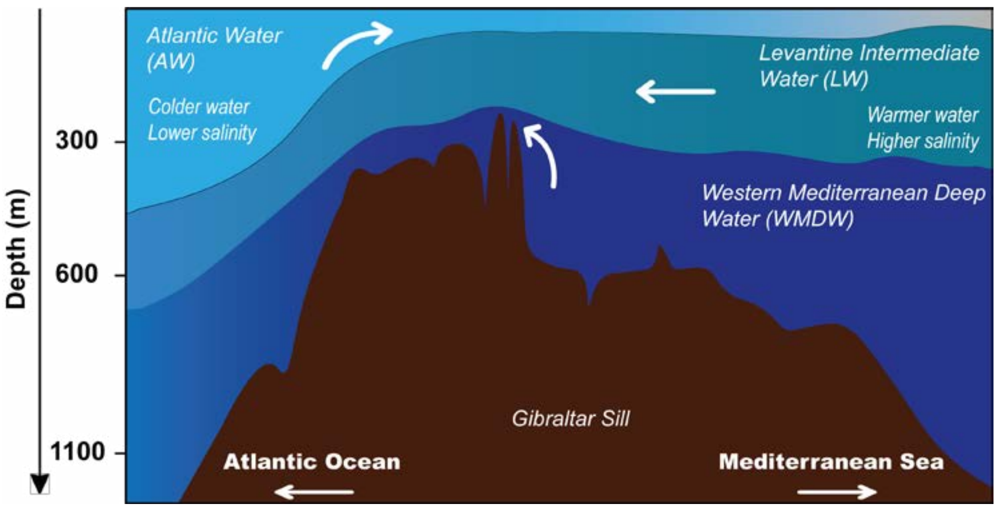


Figure 3.2. Vertical water circulation in the Strait of Gibraltar.

Table 3.1. Main results from previous studies of plastics on the surface of Mediterranean Sea. *Some values have been transformed to display them in the same units. Italics represent the particle concentration of plastics in "items·km⁻³" units. Non-exhaustive.*

Area	Weight conc. (g·km^{-2})	Particle conc. (Items·km^{-2})	#	Method	Mesh size (µm)	Ref.
NW Mediterranean	57	130,000	41	Manta trawl	333	Faure et al., 2015
Mediterranean	423	243,853	39	Neuston net	200	Cózar et al., 2015
W Sardinian Coast	-	0.15 items·km^{-3}	30	Manta trawl	500	de Lucia et al., 2014
Western and Central	-	24.9		Visual	-	Suaria and Aliani, 2014
Bay of Calvi (Corsica)	-	62,000 (mean annual variation)	38	Neuston net	200	Collignon et al., 2014
NW Mediterranean	2,020	116,000	40	Manta trawl	333	Collignon et al., 2012
Ligurian-Sardinian Sea	-	0.31	23			Fossi et al., 2012
Aegean Sea (E Med.)	-	1.31 - 2.64 (near-shore) 0 - 0.14 (offshore)		Visual	-	Topcu et al., 2010
Ligurian Sea (N Med.)	-	15 - 25 (1997 yr) 1.5 - 3 (2000 yr)	-	Visual	-	Aliani et al., 2003
Cretan Sea (E Med.)	119	-	25	Neuston net	500	Kornilios et al., 1998
SW Malta	-	1,200 -1,400	-	Visual	-	Morris, 1980

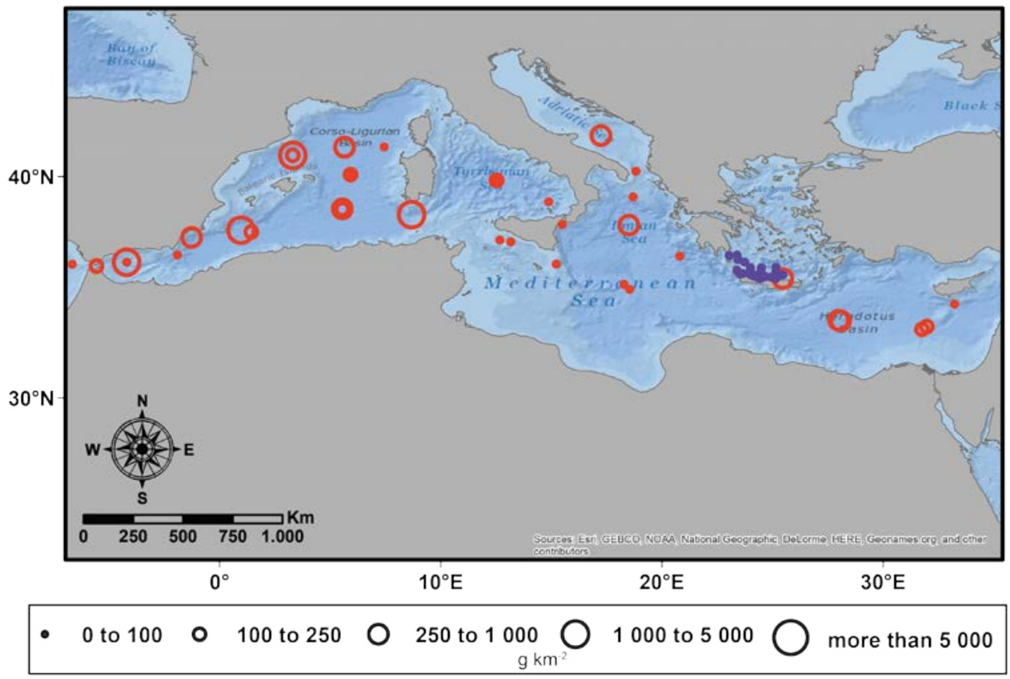


Figure 3.3. Concentration of plastic in surface units (g·km-2) of previous studies with open position data reported until the year 2015 in the Mediterranean Sea. *Results in orange from Cózar et al., (2015) and purple from Kornilios et al., (1998). Source of background layer: Esri.*

3.1.2. Study aims

The main aim of this chapter is to present a research about the current situation of floating plastic debris in the Central and Western Mediterranean Sea at macroscale regional level. This study was carried out through two oceanographic campaigns that followed the routes of the Archduke Ludwig Salvator of Austria. The specific objective of this study were the analysis of distribution, abundance and size composition of micro- (< 5mm), meso- (5 – 25 mm) and macro- (25 – 1000 mm) plastics (Lippiatt et al., 2013) in accordance with the descriptor established under the European Marine Strategy Framework Directive (MFSD, 2008/56/EC).

3.2. Results

3.2.1. Plastic distribution

Plastics were detected in all samples obtained in the Mediterranean Sea. The entire set of 71 trawls yielded a total of 17,495 particles, providing one of the first large-scale results for the Mediterranean region (see Supplementary Material Figure S3.1 & Table S3.1.: Annex B; see also sections 2.2 & 2.3 of methods – Chapter 2). Floating plastic weight concentration in samples varied from 7.43 g(DW)·km^{-2} to 9,298.24 g(DW)·km^{-2} (average value of 579.35 ± 155.92 *s.e.* g(DW)·km^{-2}; median value of 140.99 g(DW)·km^{-2}). Although we found a high variability in plastic concentrations, in sixty percent of the samples, the weight obtained was higher than 100.00 g(DW)·km^{-2}. Particle concentrations ranged from 8,999 to 1,164,403 items·km^{-2} (average value of 147,500 ± 25,051 *s.e.* items·km^{-2}; median value of 59,415.05 items·km^{-2}) (Figure 3.4). Positive correlation was found among weight and particle concentrations ($r_s = 0.479$; $p < 0.01$). In general terms, results from Mann-Whitney-Wilcoxon test (Table 3.2) on plastic particle concentration reflected homogeneous distribution across all sub-regions analyzed however regarding to plastic weight concentration, significant heterogenicity was found among Tyrrhenian Sea – Ionian Sea and Ionian Sea – Adriatic Sea sub-regions. No significant differences were found between two campaigns in comparable sub-regions of Sea of Sardinia and Tyrrhenian Sea (see section 2.4 of methods – Chapter 2).

Maximum values of particles concentration were identified in the Ionian Sea: concentration by weight in the mouth of the Gulf of Taranto (9,298.2 g(DW)·km^{-2}) and concentration by particles between the Greek islands of Antipaxi and Lefkada (1,164,403 items·km^{-2}). On the other hand, minimum values related with concentration by weight and concentration by particles were respectively found in northeast of Zakynthos island (7.44 g(DW)·km^{-2}) and in the Sea of Sardinia (8,999 items·km^{-2}). See detail of zones in Figure 3.5 and Figure 3.6.

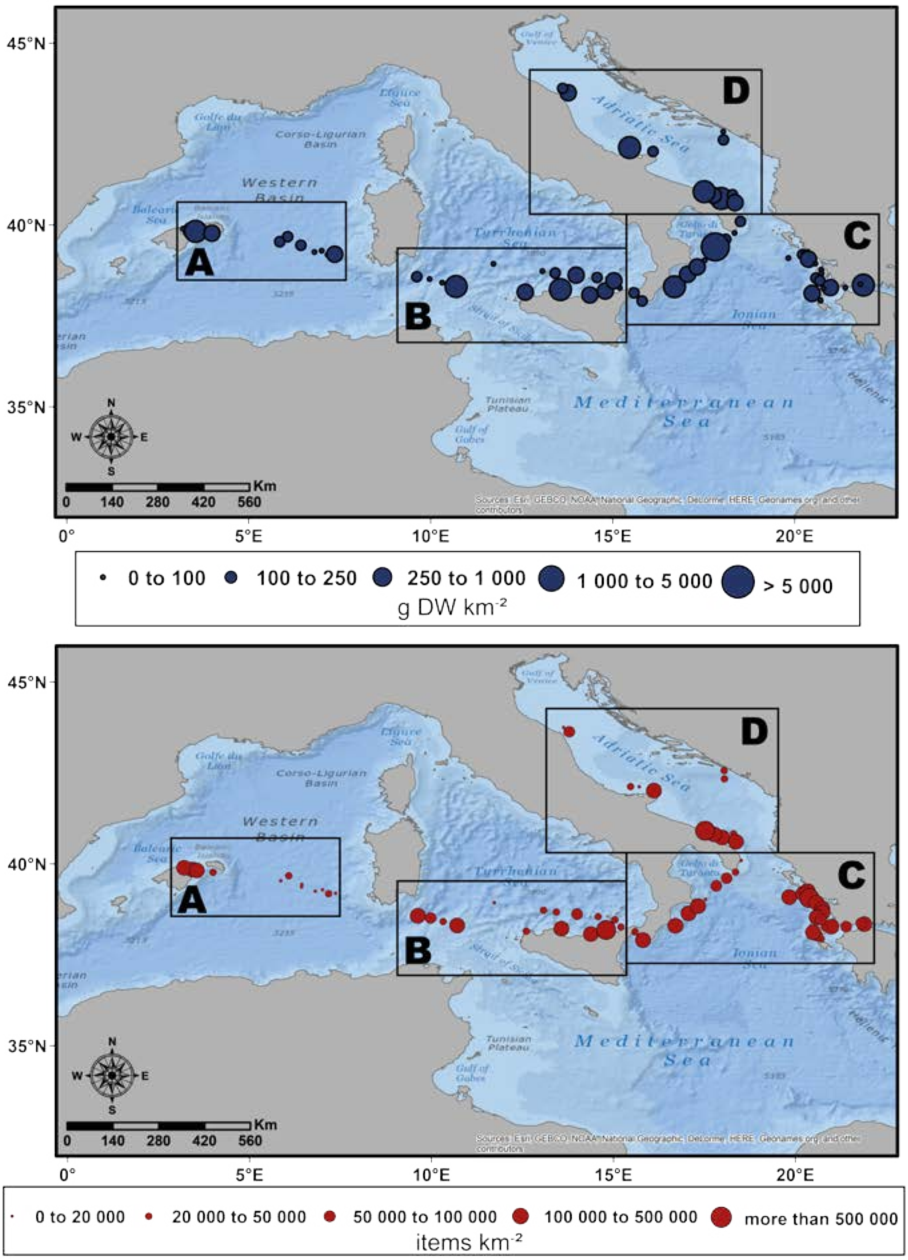
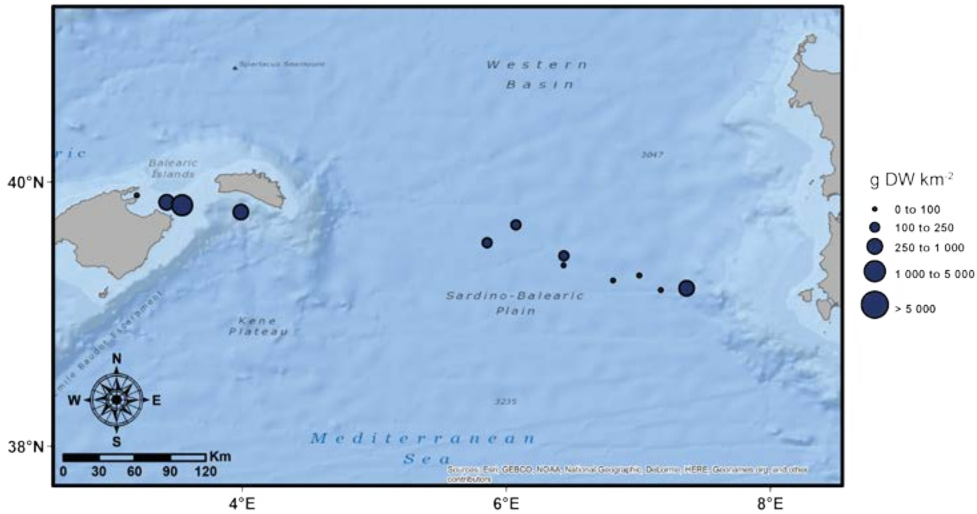
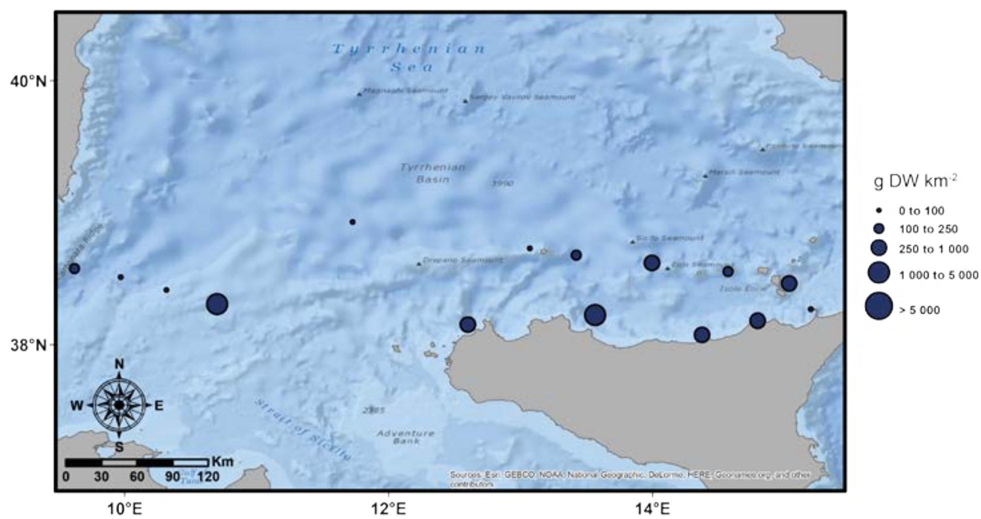


Figure 3.4. Concentration of plastic in surface waters of Mediterranean Sea. *Upper image represents plastic weight concentration (g(DW)·km-2; blue dots) and lower image, plastic particle concentration (items·km-2; red dots). Particle concentrations represented include wind effect correction. Words represent the samples belonging to each Mediterranean sub-region. Zone A: Sea of Sardinia; Zone B: Tyrrhenian Sea; Zone C: Ionian Sea and Zone D: Adriatic Sea. Source of background layer: Esri.*

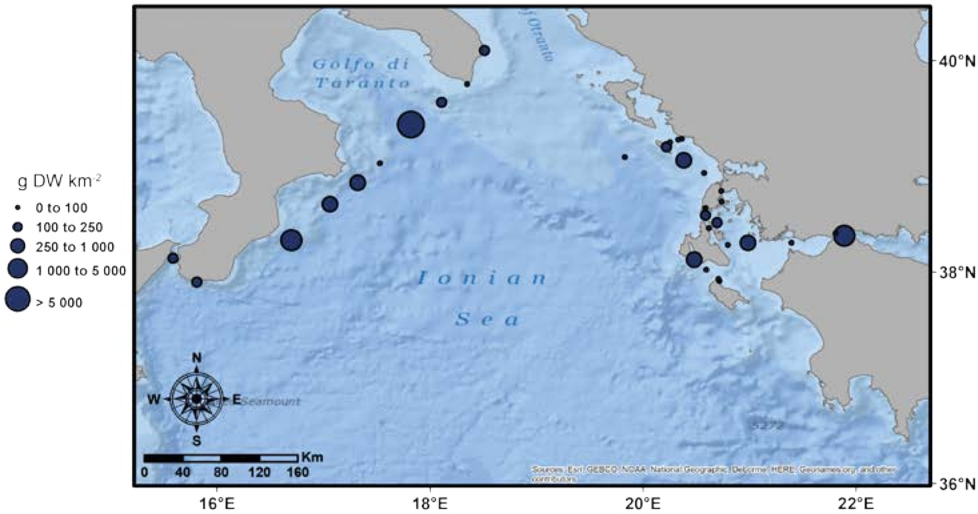


Zone A

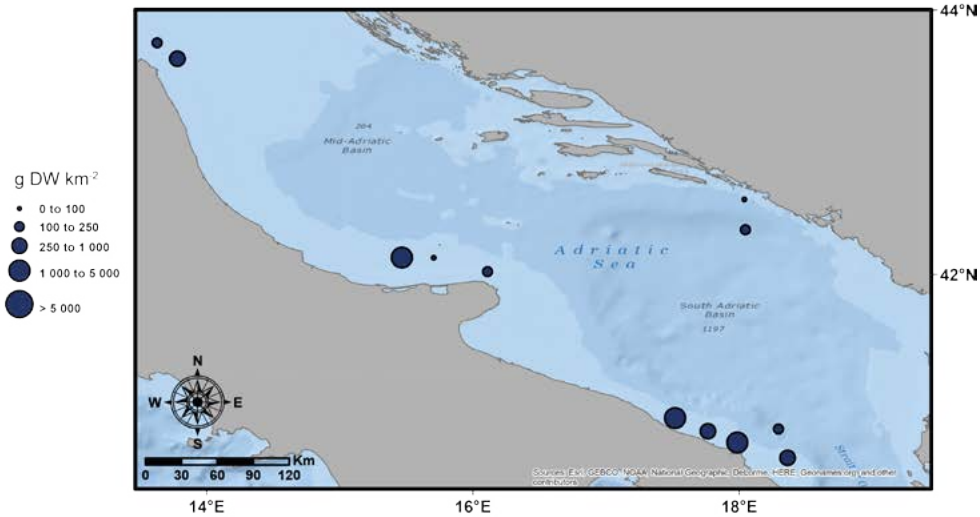


Zone B

Figure 3.5. Detailed zones of plastic weight concentration (g(DW)·km-2).
Zone A: Sea of Sardinia; Zone B: Thyrrenian Sea; Zone C: Adriatic Sea; and zone D: Ionian Sea.

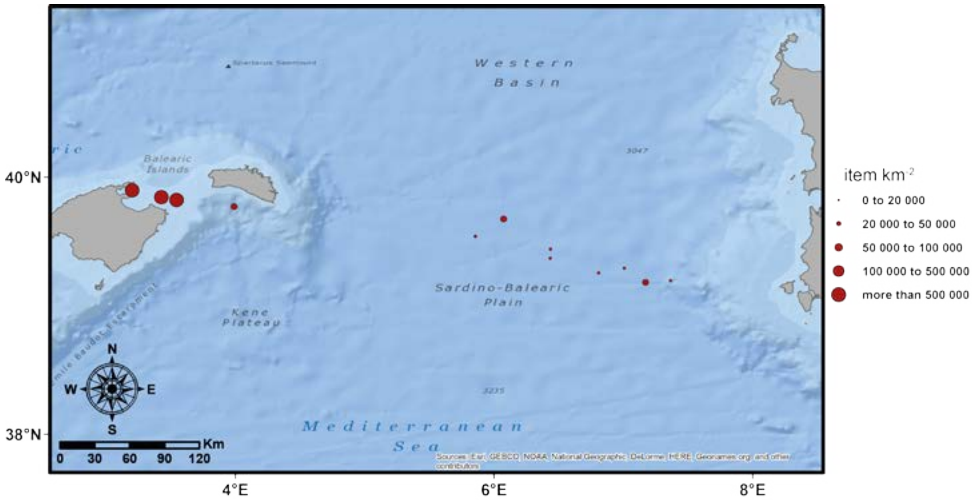


Zone C

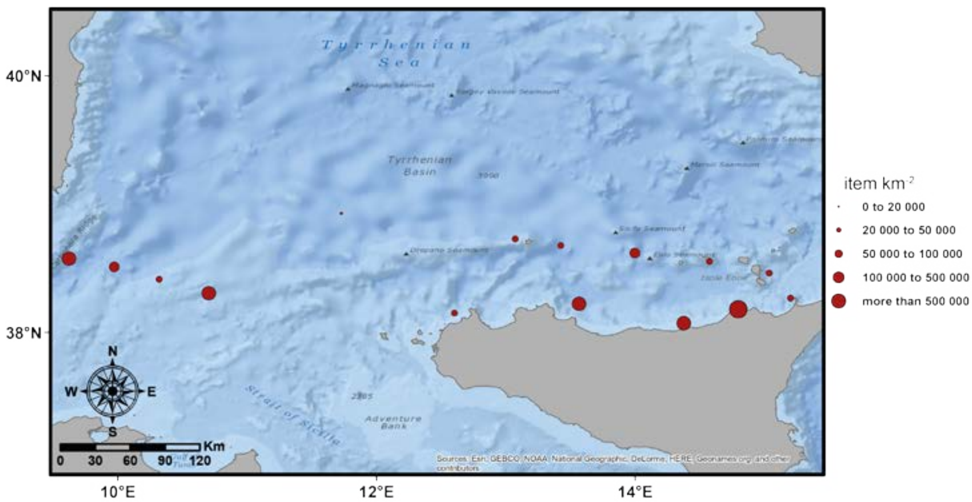


Zone D

Figure 3.5. (Continued)

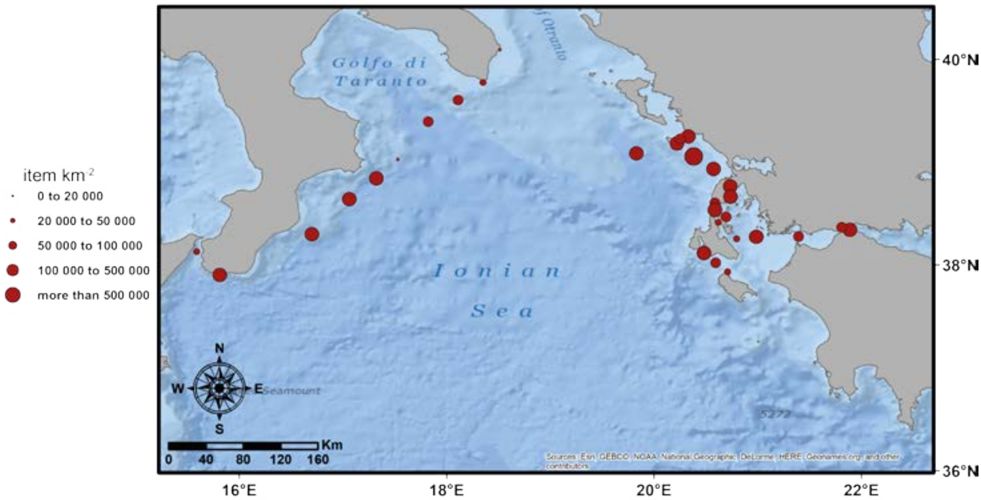


Zone A

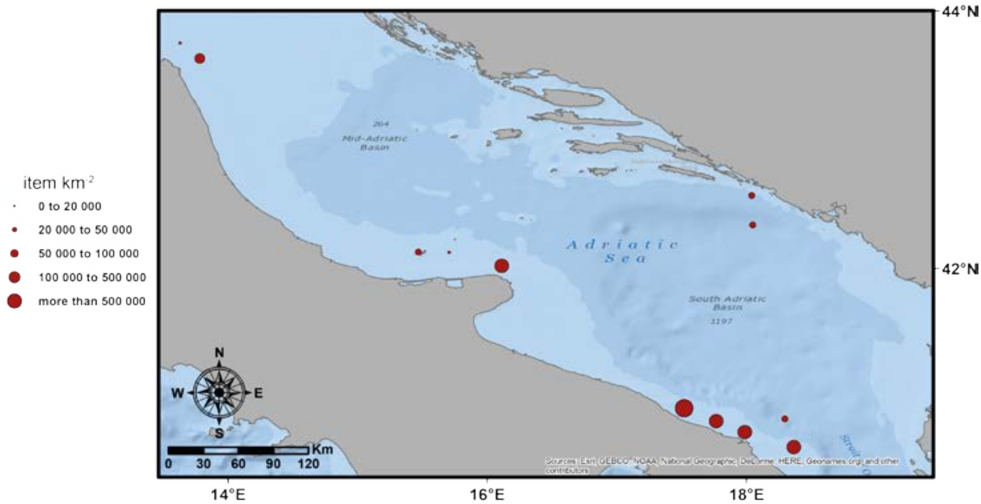


Zone B

Figure 3.6. Detailed zones of plastic particle concentration (item·km-2). *Zone A: Sea of Sardinia; Zone B: Thyrrenian Sea; Zone C: Adriatic Sea; and zone D: Ionian Sea. Source of background layer: Esri.*



Zone C



Zone D

Figure 3.6. (Continued)

Table 3.2. Results from pairwise Mann-Whitney-Wilcoxon test comparisons between concentration by weight (above the diagonal) and concentration by pieces (below the diagonal) in all Mediterranean sub-regions. Significant p-values are in bold (p-value < 0.05).

	Sea of Sardinia	Tyrrhenian Sea	Ionian Sea	Adriatic Sea
Sea of Sardinia		0.8501	0.0923	0.3013
Tyrrhenian Sea	0.5693		**0.0479**	0.6848
Ionian Sea	**0.0342**	0.1205		**0.0479**
Adriatic Sea	0.1099	0.8394	0.4548	

Although several effects at meso and local scale driving distribution of floating plastic makes difficult to establish strong relationships. Figure 3.6 shows the distribution of plastic concentration (by weight-upper figure and particle-lower figure) in all samples in relation to their distance to land. In both cases numbers were higher in the proximity of the coastal area. In order to obtain a general estimate of floating plastics in the Mediterranean, we divided all samples into two groups; samples near to coast (less than 25 km of distance) and samples outside this area (Fig. 3.7; Supplementary material Figure S3.2.: Annex B), showing a significant difference when comparing both groups in the case of plastic particle concentration (*p-value* = 0.001).

In the other hand, although samples have a non-linear display, we found a weak significant negative correlation between plastic particle concentration regarding to nearest point to coast (r_s = - 0.253; *p-value* = 0.033) however, it was not fulfilled for the plastic weight concentration (r_s = 0.159; *p-value* = 0.184). Assuming that the range of concentrations for the entire Mediterranean is similar to study area and the total extension is 2,510,000 km^2, we extrapolated values and reached a rough estimate of 1,455 metric tons (DW) and 3.7 x 10^{11} particles of floating plastics in the sea.

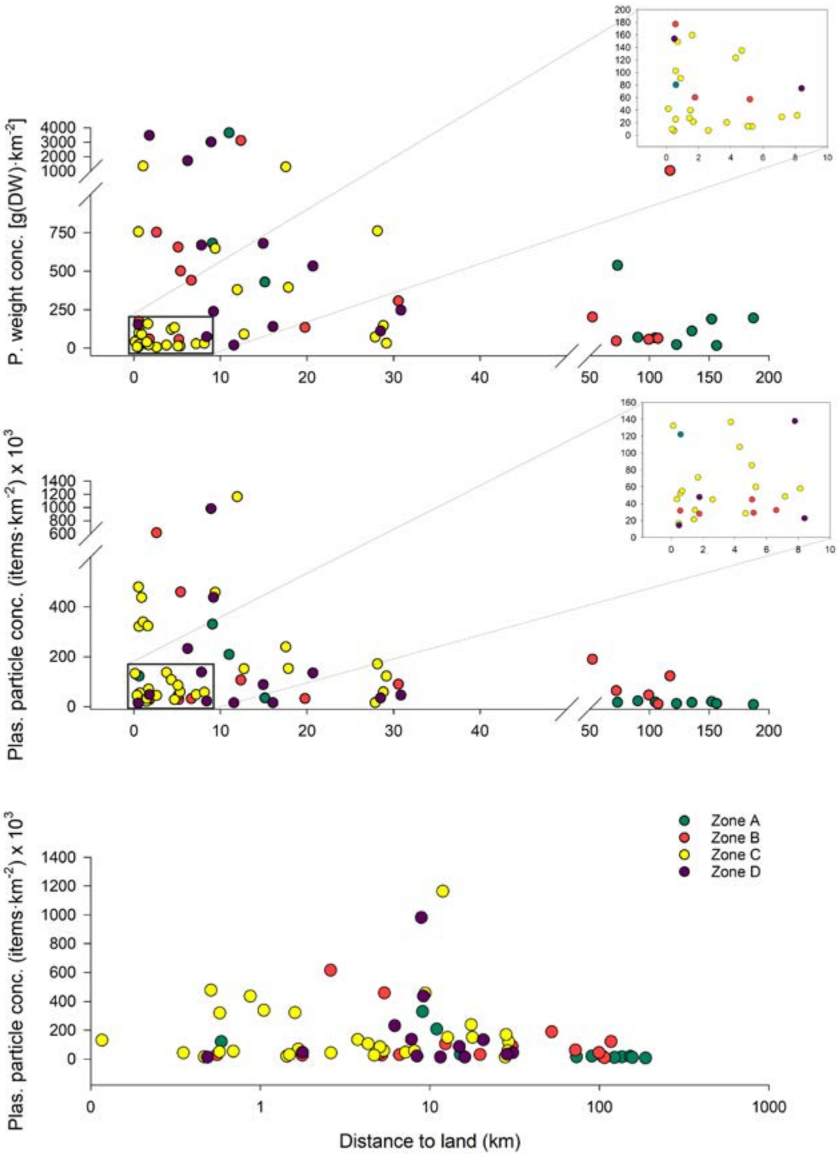


__Figure 3.7. Plastic concentration in relation to distance to land.__ Upper graph: plastic by weight concentration [g(DW)·km-2]; middle graph: plastic by particles concentration (items·km-2); and lower graph: particle concentration (items·km-2), horizontal axis is in logarithmic scale. Colors represent the samples belonging to each sub-region. Green dots: Sea of Sardinia; Red dots: Tyrrhenian Sea; Orange dots: Ionian Sea and Purple dots: Adriatic Sea.

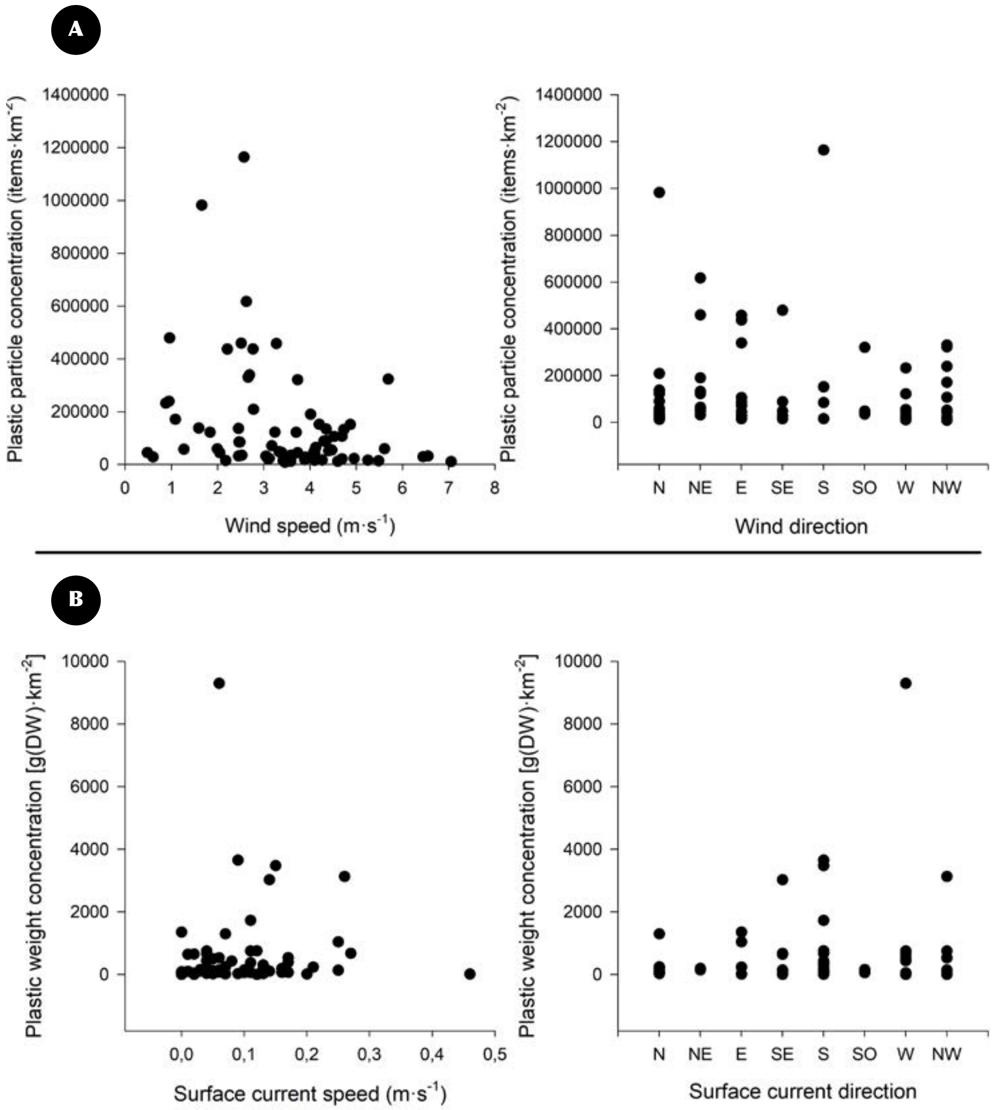


Figure 3.8. Plastic concentrations in function of wind speed and surface current speed. *(A) Plastic particle concentration (items·km-2) in function of wind speed (left) or direction (right). (B) Plastic weight concentration [g(DW)·km-2) in function of surface current speed (left) or direction (right). No differences between sampled regions were observed so no different colors are used for the graph.*

Although during the sampling periods we did not observed storm conditions and high wind speed, plastic particle concentration presented a slight significant negative correlation (r_s = - 0.337; *p-value* = 0.004) with higher concentrations between 1.5 and 4 $m \cdot s^{-1}$ (Fig. 3.8-A), similar distribution in surface current to that produced by wind is showed with higher values among 0.1 and 0.2 $m \cdot s^{-1}$ (see Supplementary Material Figure S3.3.: Annex B). In the case of weight concentration, a weak direct correlation in relation with surface current speed ($m \cdot s^{-1}$) was presented ($r_s = 0.278$; *p-value* = 0.018) (Fig. 3.8-B). More abundant particles areas were found as result of South and North wind direction however, higher values of weight concentration were observed with East and North surface current directions (see section 2.4 of methods – Chapter 2).

3.2.2. Sample Composition

According to the origin of the components found in the samples, we divided them into three main categories: a) components with natural origin (animal and vegetable materials), b) components with anthropogenic origin (plastics, tar pellets and paper) and c) other unclassifiable objects. The natural group represented 57.14% of all dry weight while anthropic debris yielded 40.58% and only 2.28% the unclassifiable materials. However, when considering the six groups, plastics was the group that weighted more than the others (39.31%) followed by the vegetal group (mainly algal fragments and pieces of wood) with 31.71% and the animal group (mainly fish and larvae) accounting for 25.43%. The remaining three groups accounted for 2.28% (Rest), 1.24% (Tar-bar pellets) and 0.03% (Paper fragments) respectively (Figure 3.9, left graph).

Concerning the natural origin components, the maximum weight value obtained for the vegetal group was found between the islands of Antipaxoi and Lefkada (15,845.20 $g(DW) \cdot km^{-2}$) and the maximum weight value for the animal group (3,643.37 $g(DW) \cdot km^{-2}$) in the western basin of Mediterranean Sea. A positive correlation between animal and vegetal organisms was found ($r_s = 0.644$; *p-value* < 0.01) (see Supplementary Material Table S3.2.: Annex B). When those groups were put together with the other four, tar pellets had a positive correlation between animal and vegetal organisms ($r_s = 0.484$ and $r_s = 0.507$; *p-value* < 0.01, respectively) and vegetal organisms, animal organism and tar pellets were positively correlated with the group rest ($r_s = 0.428$, $r_s = 0.452$, $r_s = 0.501$; *p-value* < 0.01).

Although the weight of plastic fraction accounted for 39.31% of total sample composition, considering only man-made debris (plastics, tar-bar pellets and paper), plastics were responsible for 96.87% of all floating debris in the Mediterranean Sea. We observed a majority composition of hard plastic fragments (87.29%) followed by foamed plastics (5.48%) and films fragments (3.93%). To a lesser extent, fishing lines (1.69%), cigar tips (0.01%), bottle caps (0.01%) and plastic ropes (0.01%). Fibers accounted for the remaining 1.58% but they were not considered for the concentration computation.

3.2.3. Plastic size

A total of 16,719 micro-plastics, 691 meso-plastics and 85 macro-plastics were found in both campaigns (Figure 3.9, right graph in function of particle concentration). Plastic particle size distribution obtained in our analysis can be seen in Figure 3.10. A total of 13,528 particles were measured between sizes of 0.1 to 92,780.1 mm^2 (see section 2.3 of methods – Chapter 2). The results do not show a left-truncated unimodal distribution but rather a kind of domes distribution. From all of these sizes and taking into account the mesh size used, particle sizes around 1 mm^2 were the most frequent ones. Figure 3.10 (large graph) shows particle surface classes grouped by units of 1mm^2.

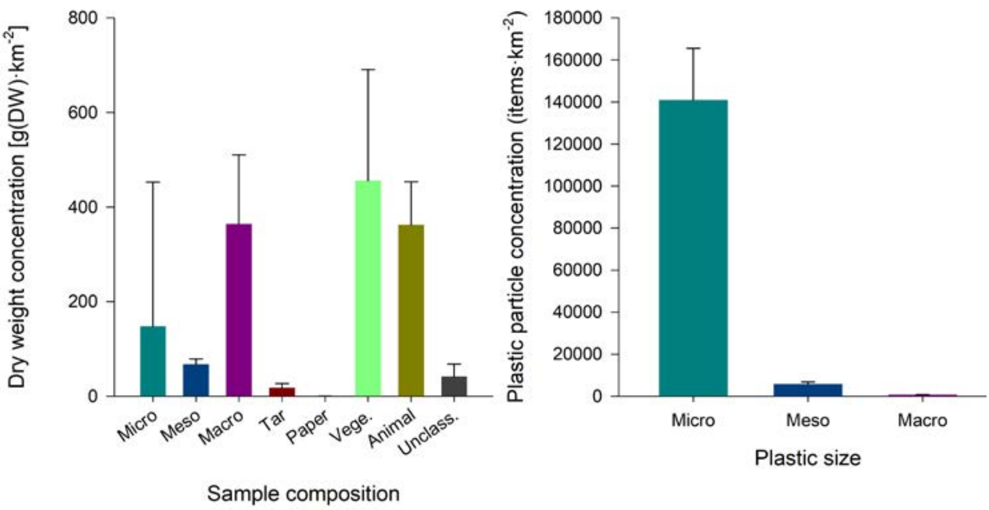


Figure 3.9. *Sample composition by dry weight concentration (left panel) and proportion of plastic size classes expressed as number of items·km-2 (right panel). Error bars represent standard error of the mean.*

The most abundant one is the first class (1 mm^2) that grouped all particles found from 0.1 to 1 mm^2.

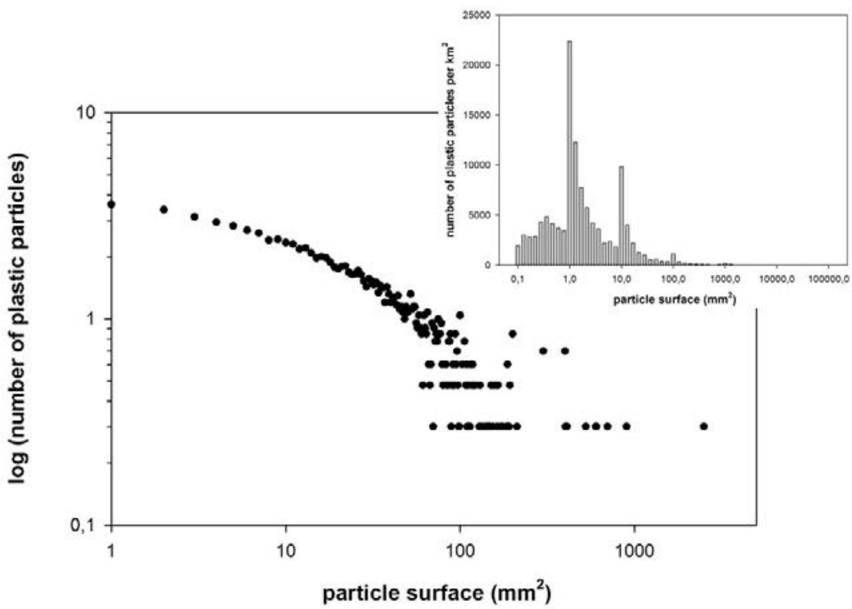


Figure 3.10. Plastic size distribution of the floating plastic particles in the Mediterranean Sea. *Size distribution normalized at the bottom chart. Upper right chart shows non-normalized sizes of plastic particle concentration.*

3.3. Discussion

Plastic pollution occurs in all ocean waters, but the presence of convergences acting as retention areas of debris and which are controlled by Ekman transport however, eddies and fronts have greater relevance at lower scales (Maximenko et al., 2012; van Sebille et al., 2012). In the Mediterranean case the high variability of the surface currents and the instabilities produced during the year, limit stable retention areas (Béranger et al., 2005; Cózar et al., 2015; Mansui et al., 2015; Millot, 1999). However, our results show a higher concentration of particles that might be produced by the lack of vertical mixing of particles due to the low wind speed. Wind direction indicated a greater accumulation towards continental shores exposed to this wind direction, similar to that reported by Collignon et al., 2014 in the Bay of Calvi. On the other hand, sampling points with high concentration by weight of plastics may point to a certain accumulation on fronts and outside borders of eddies (see Supplementary Material Figure S3.3.: Annex B), as indicated by Maximenko et al., 2012.

Other factors as boundary effects, discharge of large rivers, coastal population, tourism, added to the previous (Cózar et al., 2015; Jambeck et al., 2015; Lebreton et al., 2012; Mansui et al., 2015), could influenced in a higher plastic particle concentration in areas near the coast. Notwithstanding variability of these factors, a weak correlation was found in relation of particle concentration and distance to land, confirms an inverse relationship. However, concentrations by weight showed a certain homogeneous distribution burdened by macro-particles which usually are associated with an increase in weight.

Our results show four seasonal potential accumulation areas produced in meso or local scale in relation to both concentrations. Firstly, Otranto Strait area converge the coastal surface circulation from the northwest of Italian peninsula with surface recirculation produced in the Strait where also confluence with population centers (i.e. Bari, Italy), which is consistent with accumulation retention areas modeled by Liubartseva et al., 2016. Secondly, Northern coast of Sicily, where surface coastal current flows from Messina Strait (in the east) to west from variation of the stable current of the Tyrrhenian Sea (Thyrrenian summer circulation, Iacono et al., 2013) and goes through important populations like Palermo, also it is shown a decrease in concentration with distance to land (Figure 3.3). Thirdly, Ionian islands where accumulation is driven by the variability of factors however, we found a higher values of particles concentration in northern Ionian islands, that could be more influence by prevalent winds and surface currents, and higher weight concentration at the exit of the Gulf of Corinth, where anthropic factors may be more important. Finally, Menorca Channel (Balearic Islands, Spain) with low depth (around 100 m) and limited current circulation due to two defined density fronts (García et al., 1994) might influence a seasonal accumulation in this area. The potential accumulation zones derived from model distribution (van Sebille et al., 2015) are consistent with our results.

Average floating plastic weight concentration estimated in this study (597.3 g(DW)$\cdot$km^{-2}) is comparable with other values given in past studies for the Mediterranean (Table 3.1). A gradual increase in concentration by weight is observed from the first reports of plastic surface in the Mediterranean however, they are within the same order of magnitude. In relation to concentration by particles, there is great variability in the results according to the sampling method chosen, although when selecting similar methods (manta trawl and neuston net) comparable results are obtained, our value shows an average of 147,500 items·km^{-2}. Main differences with most recent study at regional scale (Cózar et al., 2015), emerge from observing the areas of the Tyrrhenian Sea and Ionian Sea, where there is a discrepancy of concentrations that might be influenced by the variability of hydrodynamic characteristics along with offshore and coastal waters sampling. However, as the results reported by Cózar et al., 2015, our estimate of plastic load was one order of magnitude lower than derived from models (Eriksen et al., 2014; Lebreton et al., 2012; van Sebille et al., 2015) except for Maximenko model (Maximenko et al., 2012).

In addition, micro and meso-plastics analyzed in this study follow similar spatial distribution to the captured organic fraction, mostly having both similar size ranges. The effects associated with the ingestion of these two groups of particles by organisms not only affect trophic webs (de Stephanis et al., 2013; Lusher et al., 2013; Wright et al., 2013), its ingestion, also has consequences at different stages of their life cycles (e.g. variation in the area of their habitat, oviposition or invasive process) (Barnes, 2002; Goldstein et al., 2014, 2012), that also adds effects produced by tar balls-pellets (Kornilios et al., 1998; Martin et al., 2014; Minchin, 1996) concurring in some samples of our study (see Supplementary Material Table S3.1.: Annex B). Moreover, chemical additives added during plastic manufacture (Oehlmann et al., 2009; Tanaka et al., 2013) and the ability of plastics and tar balls-pellets for retention and/or attraction of pollutant compounds (Ashton et al., 2010; Holmes et al., 2012; Martin et al., 2014; Mato et al., 2001) altogether sources of pollutants when these particles are ingested. In contrast, the relationship with vegetable fraction would corresponds to a result of erosive effects on marine flora after storms or land runoff (e.g. floods).

Size composition in our samples was initially affected by the sampling device used in our research. On one side, the device used (manta trawl) tend to exclude large size particles (Barnes *et al.*, 2009; Ryan *et al.*, 2009; Suaria and Aliani, 2014), and on the other hand, the mesh size used excluded particles smaller than 333 µm, being those clearly underestimated. Particles of 1 mm^2 were the most frequent with similar normalized shape distribution reported by Cózar et al., 2015. Size diversification means greater availability for fragment ingestion of different scale organisms affecting several trophic levels (Farrell and Nelson, 2013). It is clear that to find the smallest classes as the most abundant ones put pressure into the research of what is happening at classes below ranges obtained in this paper. That could also be applicable to fibers than can escape our sampling methodology.

3.4. Conclusions

In our samples, plastic particles constituted 96.87% of all floating marine litter in the Mediterranean Sea. Previous estimations reported between 70-90% constituted this litter (Galgani et al., 2010; Morris, 1980; UNEP, 2009), despite the different methodology used, it might infer that plastic increases its predominance as the size is smaller. Large population centers near coast (i.e. Palermo and Bari, Italy; Patras, Greece) in coastal regions with more than 95% of their population living within first 50 km from the coastline (Collet and Engelbert, 2013), related with land-based origin of litter (Browne et al., 2011; Galgani et al., 2000)(Browne et al., 2011; Galgani et al., 2000), and the low rate of water renewal (Millot and Taupier-Letage, 2005) may explain the high concentration of floating plastic. While global plastic production continues to increase, reaching 299 M tons in 2013 (PlasticsEurope, 2015), inappropriate waste management systems and improper people behavior allow us to forecast that plastic concentration will keep growing (Suaria and Aliani, 2014; UNEP, 2009). The concurrence of our data with other studies (Collignon et al., 2012; Cózar et al., 2015) corroborate the hypothesis of the existence of sinks, due to the existence of a gap between annual input of plastics entering to the sea and those found on the surface, related with degradation, ingestion, biofouling or beaching (Andrady, 2011; Barnes et al., 2009; Cózar et al., 2015, 2014; Eriksen et al., 2014; Woodall et al., 2014; Zettler et al., 2013). We hope that the results of this study provide valuable information, which could complement the floating plastic pollution research (Figure 3.11).

Future spatial-temporal studies are required to study the whole Mediterranean environment (surface, water column and seafloor) to understand the processes and their variability related to the origin and sinks of particles, focusing on the analysis of micro and nano-plastics, and dealing with social perception and problem awareness to help in efforts to reduce plastic pressures into the marine environment. One hundred year after the Archduke Ludwig Salvator de Austria explored the Mediterranean in a time when conservation meant nothing, present reality indicates that the concentration of floating plastic particles in the Mediterranean Sea is high and it is probably increasing. Changes in the states of the Mediterranean Sea as a consequence of this pressure should move the problem into the political agenda to accelerate new policies that contribute to stop the pressure and its further environmental degradation.

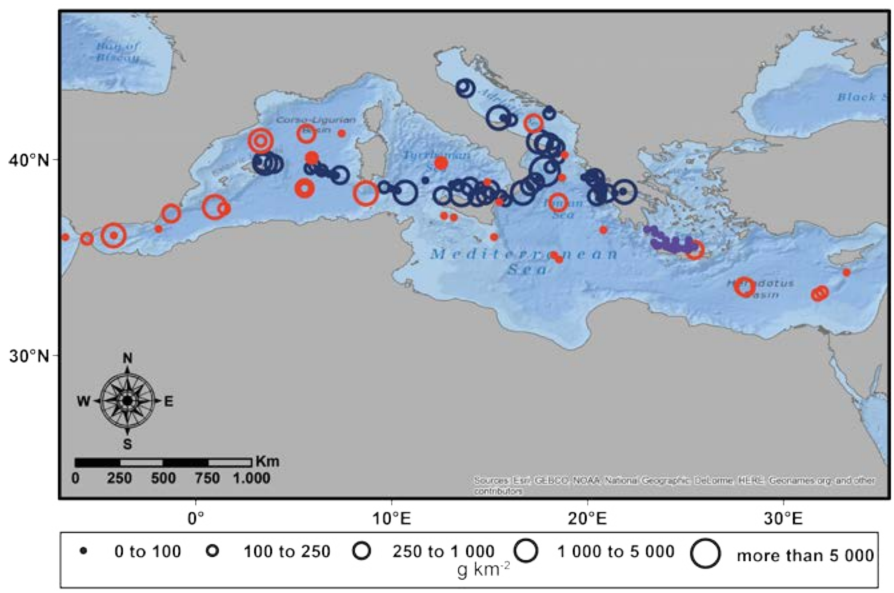


Figure 3.11. Concentration of plastic in surface units (g·km-2) of previous studies with open position data reported until the year 2015 in the Mediterranean Sea and the results of this study. *Results in orange from Cózar et al., (2015) and purple from Kornilios et al., (1998). The results of this study are in blue. Source of background layer: Esri.*

Chapter 4

The 'invisible' plastics around the Balearic Islands (Spain): high concentrations of floating plastics debris in the coastal waters of the archipelago

Abstract

Coastal ecosystems are under significant human pressure, partly due to the proximity of pollution sources. The seriousness for coastal systems caused by plastic pollution is widely known; however, the state of many coastal areas is still unknown. In this study, the Balearic Islands coastal waters were sampled to examine the distribution of floating plastic debris. Plastic concentrations showed high variability along the coast, the higher particle concentration (max: 4,576,115 items·km^{-2}) and weight (max: 8,102.94 g(DW)·km^{-2}) values were located at the north of the Balearic Promontory; which are among the highest reported in the Western Mediterranean. The Balearic Islands have a strong seasonal population density, although the differences with the distribution of floating plastic made it possible to hypothesize about the influence in the particle transport of the high-residence time of the North Current and the formation of the Balearic Front along with the mesoscale currents from the Algerian sub-basin.

4.1. Introduction

4.1.1. Background

In 1867, the Archduke Ludwig Salvator visited the Balearic Islands for his first time, after which he fell in love with the beauty of its landscapes, its surroundings and its people. Later, he decided to establish his habitual residence in the island of Mallorca. He dedicated his more extensive work to the Balearic Islands, *“Die Balearen, geschildert in Wort und Bild”* (1869-1891), consisting of nine volumes in its original edition (Alzaga Ruiz, 2006). Volumes were regrouped into four sections: *“Die Alten Pityusen”* (Ibiza and Formentera islands), Mallorca and Cabrera islands, the city of Palma and “Die Insel Menorca” (Menorca island). During his life in the archipelago, he managed to attract great thinkers from all areas that expanded the knowledge about the islands and with that, possibly, enhanced the internationalization that the islands have developed throughout the 20th and 21th centuries.

The Balearic archipelago is located in the western part of the Mediterranean Sea between 38°30’ – 40°10’ N and 1°02’ – 4°28’ E (Figure 4.1). It is part of the extension of the Betic Mountain Range, within the denominated Balearic Promontory (Duran, 2006). The islands are formed by two groups called: Gimnesias (Mallorca, Menorca and Cabrera) and Pitiusas (Ibiza and Formentera). In relation to its ocean surface circulation, the Balearic Islands present two main different hydrodynamic regimes both sides of the Balearic Promontory. On the northern basin (Balearic sub-basin), the presence of the Northern Current running along the coast of the Iberian Peninsula towards SW with slightly colder and saline waters and on the southern basin (Algerian sub-basin), more influenced by the Alger Current, with temperate and less saline waters, together with the high variability of the editions that are formed in its route towards the center of the Mediterranean Sea (La Violette et al., 1990; Monserrat et al., 2008; Pinot et al., 2002). Still, there is some exchange on the surface between the two promontory slopes through the channels of Ibiza and Mallorca (Pinot et al., 2002).

Despite its limited surface, the Balearic region ends up 2016 with a population of 1,144,396 inhabitants (1,103,442 in 2014; source: IBESTAT). However, due to the large tourist attraction of these islands (3rd autonomous community in Spain as tourist destination in 2014 and 2nd in 2015 and 2016; source: Ministerio de Energía, Turismo y Agenda digital, 2017), the seasonal peak of population went up to almost 2 million people in 2016 that made for many residents a saturation feeling (1,863,051 people in August 2014; source: IBESTAT).

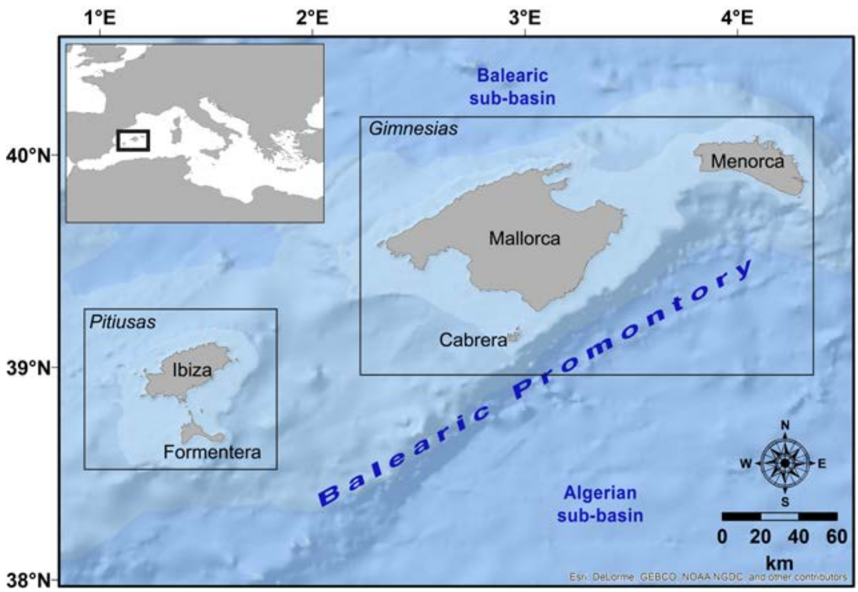


Figure 4.1. Study site located in the Balearic Islands (Spain). *The black and blue typographies represent political and physical characteristics, respectively. Source background layer: Esri*

Coastal areas provide diverse ecosystem services able to improve the socio-economic activities and human well-being of societies living along (Brenner et al., 2010; Krelling et al., 2017; Lozoya et al., 2011). Nevertheless, coastal ecosystems are subjected to human pressures such as plastic pollution, whose presence poses a recognized environmental threat (Galgani et al., 2015; Ivar do Sul and Costa, 2014; Thompson et al., 2009; UNEP/MAP, 2015; UNEP, 2009, 2005).

Plastic particles that reach marine ecosystems are subjected to different physical dispersion factors from the release points of origin, being wind and ocean currents the most important ones (Aliani et al., 2003; Critchell et al., 2015; Critchell and Lambrechts, 2016). Despite the well-known subtropical ocean gyres acting as accumulation areas for floating plastic debris, the spatial distribution of these particles in the Mediterranean Sea are affected mainly by the variability of the surface circulation which hampers the formation of stable retention zones (Cózar et al., 2015; Mansui et al., 2015). In addition, recent studies have shown elevated concentrations of floating plastics in the first kilometers from the coast suggesting the contribution of other factors such as prevailing boundary surface currents in the Mediterranean as well as coastal populations as land-based sources (Gündoğdu and Çevik, 2017; Pedrotti et al., 2016; Ruiz-Orejón et al., 2016; van der Hal et al., 2017). Since microplastics represent the majority fraction of floating plastics, the distribution of these particles has been among the most analyzed; notwithstanding, the distribution processes affecting plastic waste may differ according to the size of the particles (Ourmieres et al., 2018).

The marine plastic pollution problem is not external to the Balearic Islands, where larger amounts of this debris have been reported in its seafloor (Pham et al., 2014; Ramirez-Llodra et al., 2013), beaches and coastal shallows (Alomar et al., 2016; Martinez-Ribes et al., 2007). On their sea surface some studies have been carried out , Suaria and Aliani (2014) reported from macro-litter visual surveys values from ~ 40 items·km^{-2} in the east of Menorca, while some recent study reveals values of around 300 g·km^{-2} of plastics in this same area (Suaria et al., 2016). At coastal level, Faure et al. (2015) reported values of microplastics higher than 320,000 items·km^{-2} (max: 420,000 items·km^{-2}) in the North-Northwestern of Ibiza and around of the bay of Palma (Mallorca); however, the maximum values were founded in the Menorca Channel (Ruiz-Orejón et al., 2016). The Balearic Islands became also, an area of relatively high concentration of plastics when running different numerical models (Eriksen et al., 2014; Lebreton et al., 2012; Mansui et al., 2015; van Sebille et al., 2015). Despite all these data and models, continuous monitoring is critical for building a strong evidence of the variability in the distribution process of plastic waste as a reference state of the coastal waters of the Balearic Islands.

4.1.2. Main objective

Continuous monitoring is critical for building a substantial evidence of the variability in the distribution process of plastic litter as a reference state of the coastal waters; however, this information is still limited in the Mediterranean and also the Balearic Islands. In the present chapter, floating plastic debris were sampled in the coastal waters of the Balearic Archipelago during the summer of 2014 to contribute to the European Marine Strategy Framework Directive (2008/56/EC) objectives. The main aim of this study was twofold, on one side to describe present status of the Balearic Islands regarding the floating plastic pollution problem in comparison to the Mediterranean region, as well as, the analysis of the size distribution and the area-length relation of these plastic particles. On the other side, the analysis of anthropic and/or natural factors that could explain its present distribution and variability.

4.2. Results

4.2.1. Floating debris composition

Samples were dominated by vegetal fragments (47.38%) and plastics (36.39%), followed remotely by animal organisms (14.03%), tar ball-pellets (2.06%) and unclassified objects (0.14%); in this sampling, we did not find any remains of paper or cardboard (see section 2.3 of methods – Chapter 2). The highest concentrations were found in front of the northwestern coasts of Ibiza and Mallorca, obtaining maximum values for vegetal fragments (11,261.34 g(DW)·km^{-2}), animal organisms (1,919.25 g(DW)·km^{-2}), tar ball-pellets (1,181.17 g(DW)·km^{-2}) and unclassified materials (39.09 g(DW)·km^{-2}) fractions. The groups were strongly correlated with each other except for the unclassifiable fraction (Table 4.1).

Table 4.1. ***Correlation values between groups.*** *Statistical test used for the correlation was the Spearman correlation test (r_s). (p) represent the p-value. Significant values are represented by bolds (p-value < 0.05). Paper group was omitted due to non-existence in the samples.*

		Plast. total	Micro Plast.	Meso Plast.	Macro Plast.	Tar-b. pellets	Veg.	Anim.	Unclass.
Plast. Total	r_s	1	**0.812**	**0.827**	**0.683**	**0.676**	**0.565**	**0.576**	**0.565**
	p	-	**<0.001**	**<0.001**	**0.001**	**0.001**	**0.009**	**0.008**	**0.009**
Micro Plast.	r_s		1	**0.864**	0.413	**0.854**	**0,720**	**0.483**	0.309
	p		-	**<0.001**	0.07	**< 0.001**	**<0.001**	**0.031**	0.185
Meso Plast.	r_s			1	0.377	**0.753**	**0.668**	**0.550**	0.356
	p			-	0.101	**<0.001**	**0.001**	**0.012**	0.123
Macro Plast	r_s				1	0.387	0.350	0.273	**0.493**
	p				-	0.092	0.130	0.245	**0.027**
Tar-b pellets	r_s					1	**0.578**	**0.457**	0.237
	p					-	**0.008**	**0.043**	0.313
Veg.	r_s						1	0.313	0.407
	p						-	0.179	0.075
Anim.	r_s							1	0.317
	p							-	0.174
Un-class.	r_s								1
	p								-

When we compared floating debris composition between samples taken in the central and western Mediterranean (Chapter 3) and the ones taken in the Balearic Islands, we did not find significant differences except for the vegetal fragments and animal organisms groups (*p-values* = 0.001 and 0.011, respectively), see Figure 4.2.

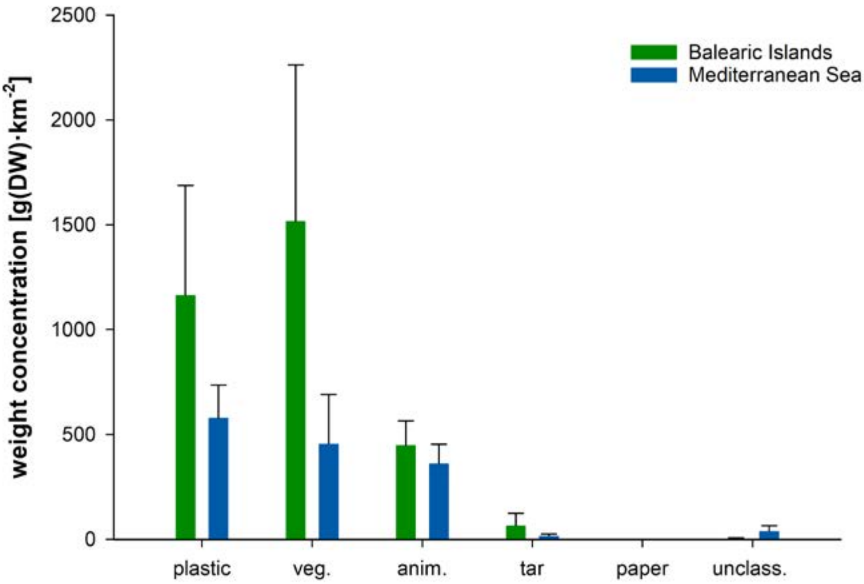


Figure 4.2. Differences between Balearic (green) and western-central Mediterranean (blue) sample composition in terms of weight concentration. *Mediterranean data reported by Ruiz-Orejón et al., 2016. Error bars represent the standard error of the mean.*

4.2.2. Floating plastic distribution

Plastic debris were found in all surface net tows in the NIXE III data set (Figure 4.3; see Supplementary Material Table S.4.1. and Figure S4.1.: Annex C). Synthetic fibers were removed due to the risk of contamination in the handling of samples during the campaign or in the laboratory processes and were not considered for concentration calculations (see section 2.3 of methods – Chapter 2). Plastic concentrations from the 20 samples taken around the coastal waters of the Balearic Islands ranged from 7,199 items·km^{-2} at the north coast of the natural park *S'Albufera des Grau* [NE of Menorca- sampling point (SP) 2] to 4,576,115 items·km^{-2} of the NW coast of Ibiza (SP 11) (average value: 900,324 items·km^{-2}; median value: 447,393 items·km^{-2}; additional values in Table 4.2). Plastic particle concentration was high; in 45% of the samples we obtained more than 500,000 items·km^{-2} and a concentration higher than 250,000 items·km^{-2} in 70% of them where microplastics were the main compound (Table 4.2 and Figure 4.3).

*Table 4.2. **Additional values of floating plastic concentrations in the Balearic Islands.** Values correspond to the mean and median of the samples obtained in the Balearic campaign (n = 20) of the NIXE III project. Concentrations are expressed in surface and volume units. S.D. = standard deviation. Plastic particle concentration in (items·km^{-2}) units, were adjusted following Kukulka et al. (2012).*

	Particle Concentration		**Weight Concentration**	
	Items·km^{-2}	*Items·m^{-3}*	*g(DW)·km^{-2}*	*g(DW)·m^{-3}*
Average ± (S.D.)	900,324 ± (1,171,738)	3.28 ± (4.05)	1,165.72 ± (2,335.84)	0.01 ± (0.01)
Median	447,393	1.65	231.65	0.001
Microplas. avg.	875,466	3.19	298.13	0.14×10^{-2}
Mesoplas. avg.	23,299	0.08	161.49	0.07×10^{-2}
Macroplas. avg.	2,897	0.01	706.10	0.33×10^{-2}

Plastic weight concentration ranged from 1.41 g(DW)·km^{-2} to 8,102.94 g(DW)·km^{-2} (average value: 1,165.72 g(DW)·km^{-2}; median value: 231.65 g(DW)·km^{-2}; additional values in Table 4.2), where the highest concentration of plastics in relation to their weight were located in the north-western of Mallorca and Ibiza islands (8,102.94 and 7,420.77 g(DW)·km^{-2}; SP 19 and 11 respectively).

The distribution of floating plastic particles concerning the distance to coast showed a higher concentration around the first kilometer off the coast. Due to the eminently coastal character of our samples (Figure 4.4), we combined our data with datasets of previous studies that were available in the literature (Pedrotti et al., 2016; Ruiz-Orejón et al., 2016), to explore differences in the distribution of particles near the coast. We used uncorrected vertical wind mixing data to compare it properly. Other studies rather than previous two were excluded due to the difference between the methodology used in the sampling or the uncertainty of the specific spatial position of the samples. The highest concentrations of plastic particles were found very close

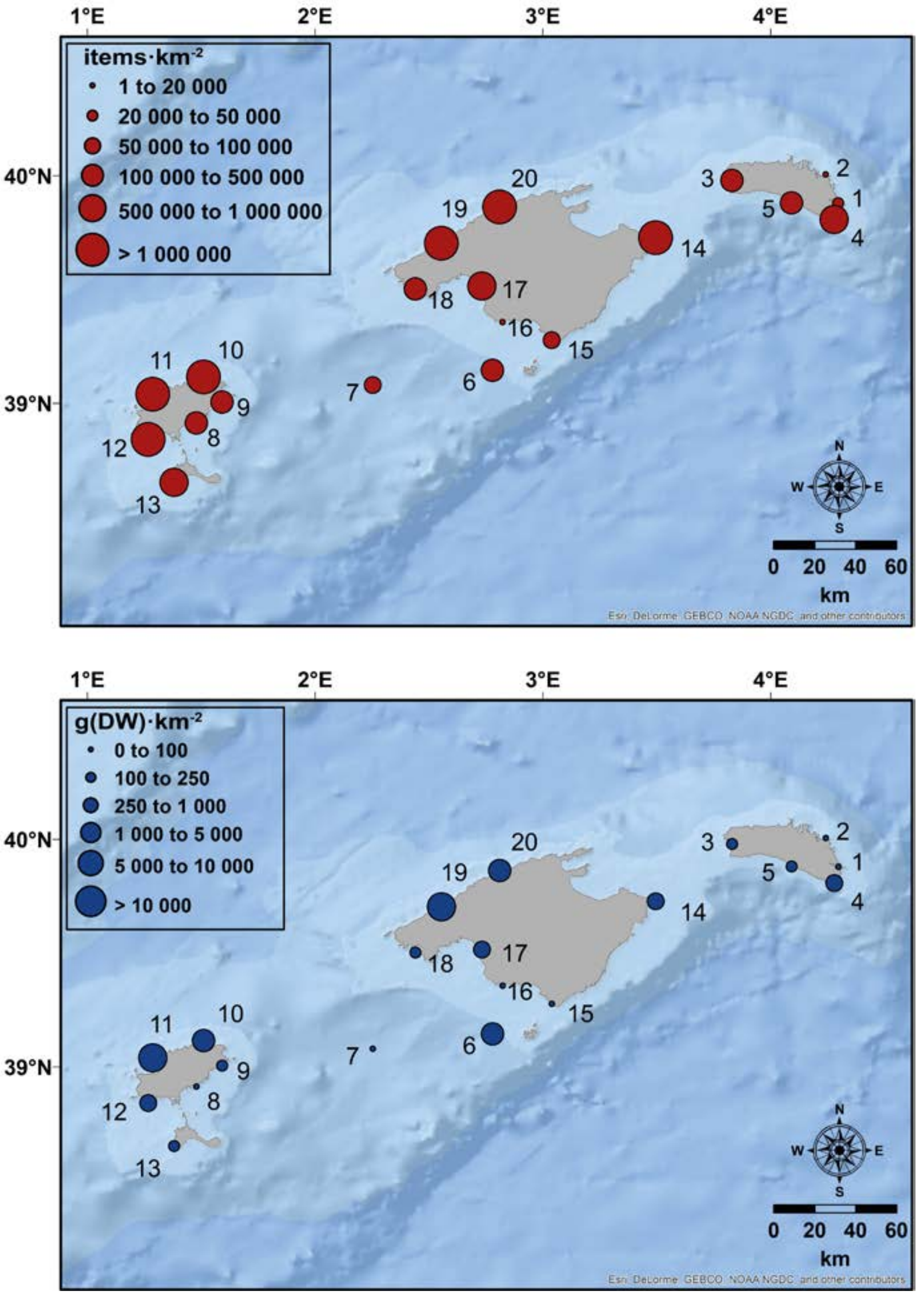


Figure 4.3. Spatial distribution of the surface plastic debris in the coastal waters of Balearic Islands. *Upper graph represent the plastic particle concentration (items·km^{-2}) and below graph, the plastic weight concentration (g(DW)·km^{-2}). Source background layer: Esri.*

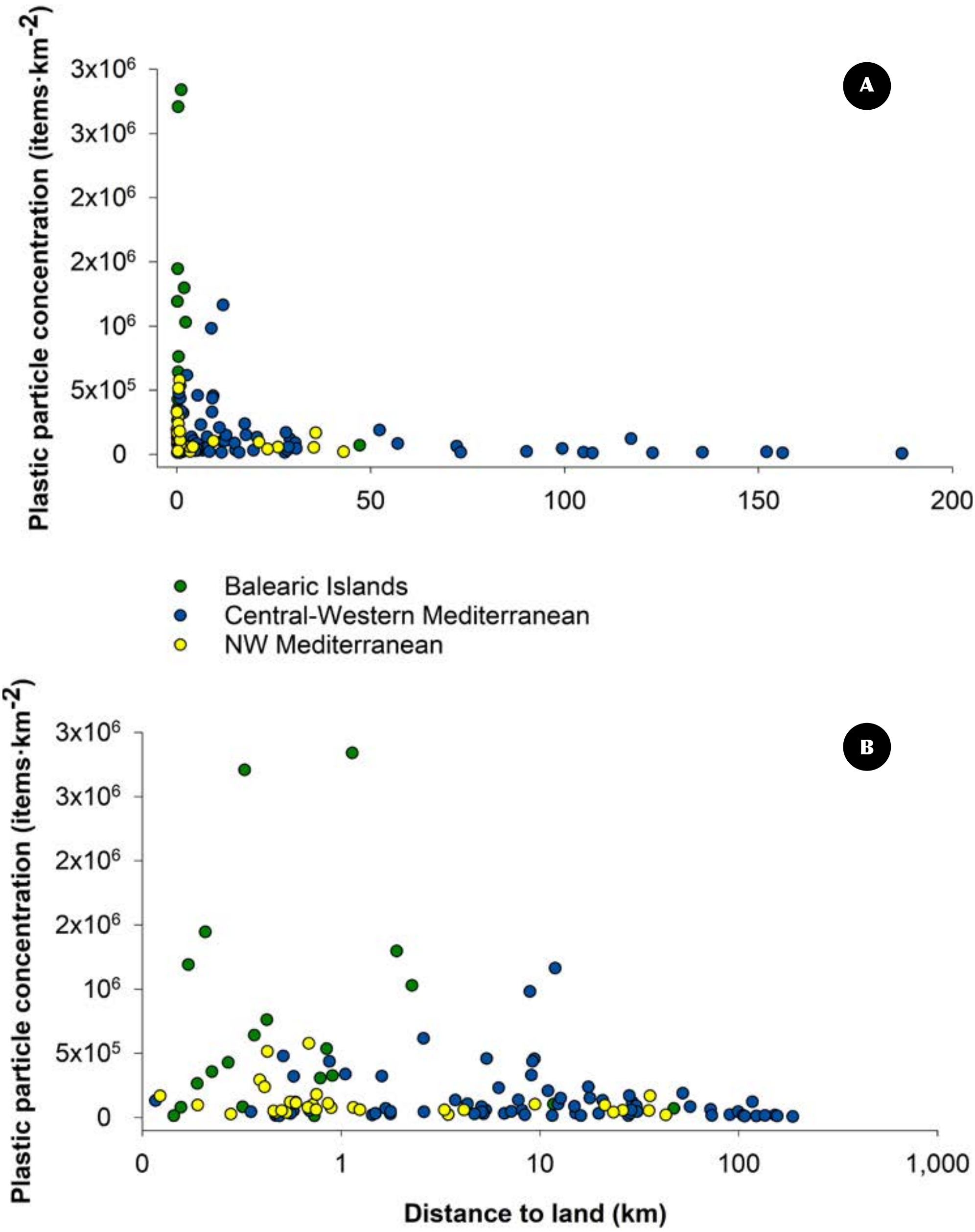


Figure 4.4. Concentration of floating plastics in relation to the distance to land in the Mediterranean Sea. *Particle concentration without primary horizontal axis in logarithmic scale (A) and with primary horizontal axis in logarithmic scale (B). Include data measured in the Balearic Islands (green dots) and data reported by Pedrotti et al. 2016 (yellow dots) and Ruiz-Orejón et al. 2016 (blue dots). Samples were taken with 333 μm mesh size. The values represented were not corrected by vertical wind mixing.*

to the coast (Figure 4.4-A) and especially in the first 10 km (Figure 4.4-B). Overall, plastic particles were significantly (*p-value* = 0.003) more abundant in this strip of the Balearic Islands (793 ± 145,584 s.e. items·km^{-2}; n = 18) than in the rest of the same strip length in the central and western Mediterranean (367 ± 1,065,661 s.e. items·km^{-2}; n = 76), due mainly to the significant higher concentration produced in the north-northwestern coasts of the islands of Mallorca and Ibiza (Figure 4.4-B).

During the sampling period, the surface oceanographic conditions showed the cyclonic turn produced by the North Current (NC) forming the Balearic Current (BC) in a northeastern direction bordering the north-northwest coasts of the islands of Mallorca and Menorca (Figure 4.5). The Balearic current was also reinforced by the waters from the Algerian sub-basin, crossing the Mallorca Channel. In contrast, the situation of the surface circulation in the Pitiusan islands (Ibiza – Formentera) was conditioned by the anticyclonic (AC) progress of the waters that crossed the Ibiza Channel and returned to the Algerian sub-basin through the Mallorca Channel. On this path, the situation of Ibiza and Formentera remained in the interior of the surface gyre. The surface mean kinetic energy (MKE) provide a better insights of the prevalent surface circulations (Mansui et al., 2015), we also analyzed it to confirm the surface sea state (Figure 4.4 lower graph; see section 2.4. of methods – Chapter 2). Besides these oceanographic conditions, we did not find any significant correlation (*p-value* > 0.05) between plastic concentrations and the assessed environmental variables (i.e. salinity, temperature, sea surface velocity and friction velocity in water; see Supplementary Materials Figure S4.2.: Annex C).

In terms of general demographic conditions (see section 2.4. of methods – Chapter 2), the resident population at the coastal municipalities of the Balearic Islands was inversely correlated with the plastic concentrations (r_s = - 0.57, *p-value* = 0.013 for particle concentration; r_s = - 0.49, *p-value* = 0.037 for weight concentration; non-coastal samples were eliminated (see Supplementary Materials Figure S4.3 and Table S4.3.: Annex C). Tourism supposes a high increase in the population density of the municipalities of the Islands (see Supplementary Materials Figure S.4.4 and Table S4.4.: Annex C); however, after the analysis of the tourist flow and the percentage of hotel and apartment occupancy did not report significant correlations. The reasons of these unexpected pattern could be in the important cleaning service of coastal waters performed by municipalities.

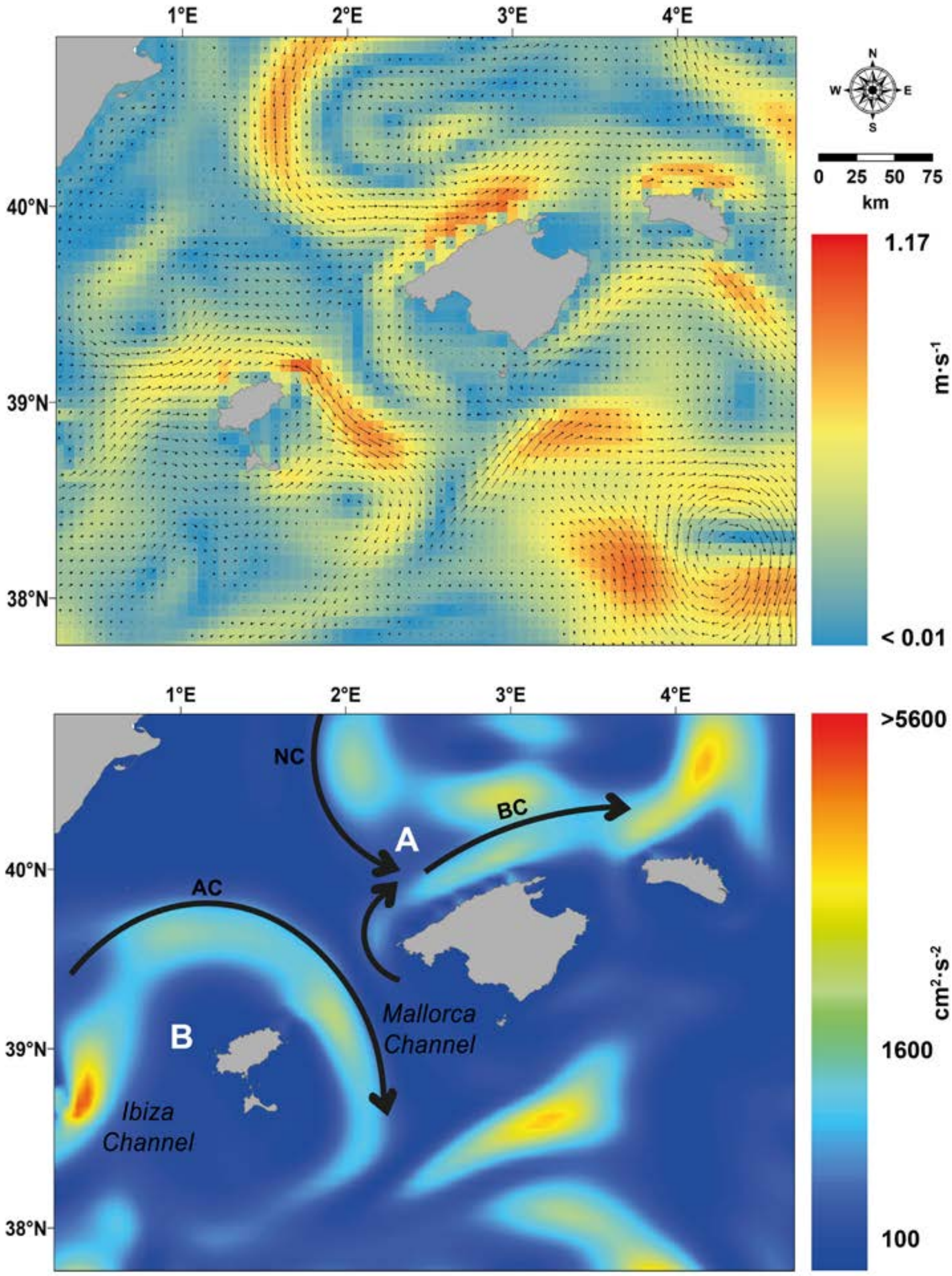


Figure 4.5. Surface currents in the Balearic Islands. *Maps from June 4^{th} to July 17^{th}, 2014. (Upper graph) represent the surface current velocity ($m \cdot s^{-1}$) with 1/16° spatial resolution and vectors (magnitude and direction). (Lower graph) Mean Kinetic Energy (MKE) in $cm^2 \cdot s^{-2}$, where the results were smoothed to increase the initial spatial resolution (1/16°). Daily data were extracted from CMEMS (http://marine.copernicus.eu) database averaged for the sampling dates. (see section 2.4 of methods – Chapter 2)*

The coastal cleaning service performs an extensive work in the removal of waste from the surface of the coastal waters of the Balearic Islands; in this sense, we evaluated the relationship between the plastic waste removed by this service and the results of this study (see Supplementary Materials Table S.4.5.: Annex C). Unfortunately, the service was inactive for more than half of the sampling period of our study, so for its evaluation, we obtained data for the summer season (July – September 2014), although the results were not significant either ($r_s = 0.15$, *p-value* = 0.57 for particle concentration; $r_s = 0.11$, *p-value* = 0.67 for weight concentration; non-coastal samples were eliminated).

4.2.3. Floating plastic composition

A total of 14,576 plastic particles obtained in the samples (see section 2.3 of methods – Chapter 2). 91.41% were hard fragments as the primary compound of floating plastic debris, and films fragments (5.69%) represented the second one, while 0.10% were just industrial pellets in the Balearic Islands (Figure 4.6-left graph). The results remained similar when analyzing the islands one by one (Figure 4.6-right graphs). Industrial pellets (0.17%) and fishing lines (2.15%) were proportionally higher in Menorca respect to Mallorca, Ibiza and Formentera, while the film fragments (6.97%) were more abundant in proportion in Ibiza and Formentera. Nevertheless, the only slight significant difference obtained was the smaller quantity of foam fragments on Menorca compared to the rest ($H(2) = 5.997$, *p-value* = 0.5).

4.2.4. Plastic size distribution

Size distribution revealed a strong predominance of microplastic particles (97.09%) compared to meso and macro sizes (2.58% and 0.32% respectively; see also Table 4.2). Despite the unequal size composition, the concentration of microplastics was positive correlated with the rest of studied sizes ($r_s = 0.87$, *p-value* < 0.001 with meso; $r_s = 0.59$, *p-value* = 0.007 with macro). From the total of particles obtained in the samples ($n = 14{,}576$), the surface area of 9,837 plastics was measured (see section 2.4. of methods – Chapter 2). The distribution of the items was similar to that obtained in the Mediterranean Sea (Figure 4.7); however, the relative abundances of particles were higher in the Balearic waters for practically all the surface sizes analyzed.

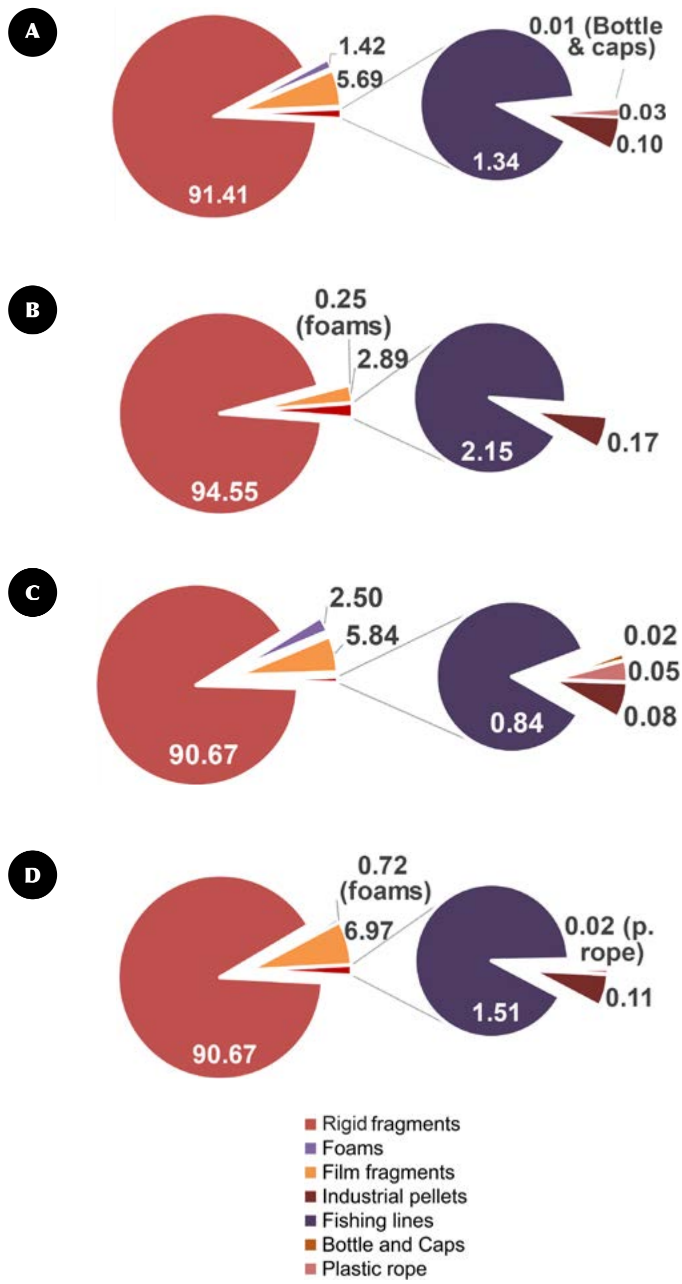


Figure 4.6. Floating plastic composition of all particles (n = 14,576) in the Balearics Islands. *(A) represents the plastic composition of total proportions in the Balearic Islands. Right graphs represent the plastic composition of each island where (B) was the plastic particle composition of Menorca, (C) Ibiza & Formentera and, (D) Mallorca. Values are expressed in percentages.*

Due to the high variety of methods to measure the particle size distribution, we analyzed the relationship between the surface area and the length of particles that also verified a strong positive correlation ($r_s = 0{,}95$, *p-value* < 0.001), see Figure 4.8. We obtained a distribution of the longitudinal size of the particles with a greater relative abundance of the particles between 0.5 and 1.3 mm (Figure 4.9; see also Chapter 2). While the larger size of the plastic tends to decrease its concentration on the sea surface, the amount of microplastics showed a tendency to stabilize.

Plastic weight concentration, by its size, did not reflect significant differences between the central and western Mediterranean and the Balearic Islands (*p-value* > 0.05). However, as in the coastal strip, particle concentration was higher than the concentration in the Mediterranean (Mann-Whitney U, *p-value* < 0.001, N = 91), mainly due to the contribution of microplastics (Figure 4.10).

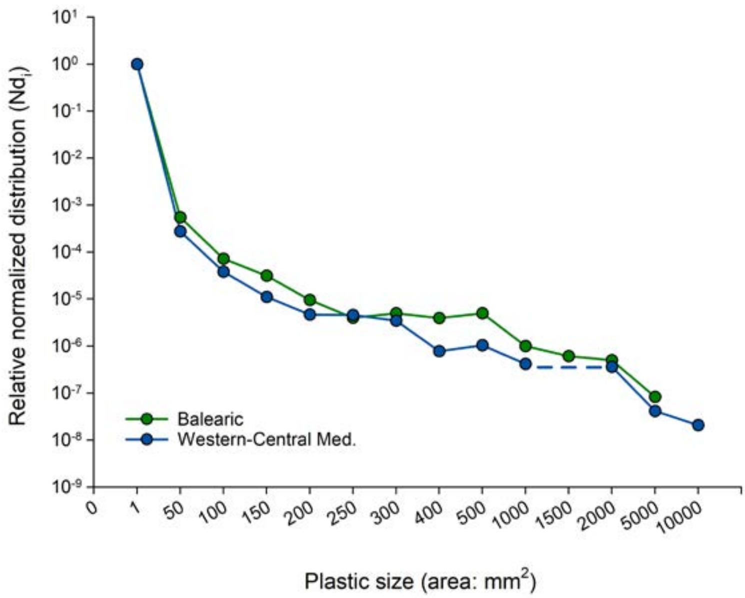


Figure 4.7. Surface size distribution of floating plastic particles collected in the Balearic survey. *Normalized concentration values (green and blue dots). Particles were grouped according size intervals in the horizontal axis. Dots represent the data measured in the Balearic Islands (n = 9,837; green dots) and data reported by Ruiz-Orejón et al. 2016 (blue dots). Primary vertical axis is in logarithmic scale. Dash line represent a gap in size distribution.*

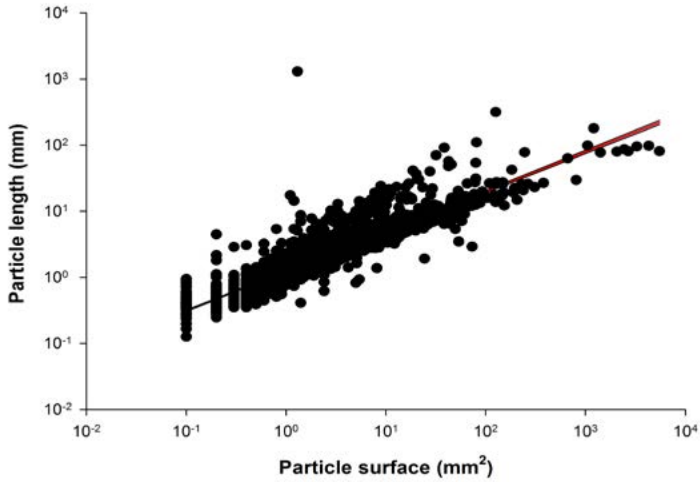


Figure 4.8. Relation between particle surface and length of floating plastic debris in the Balearic survey. *Maximum length of particles was manually measured through Image-J software (n = 3,145) and compared to their surface, obtained for the previous analysis (Figure 4.4). Axis are in logarithmic scale. Spearman correlation previous logarithmic transformation: rs = 0.95, p-value < 0.001*

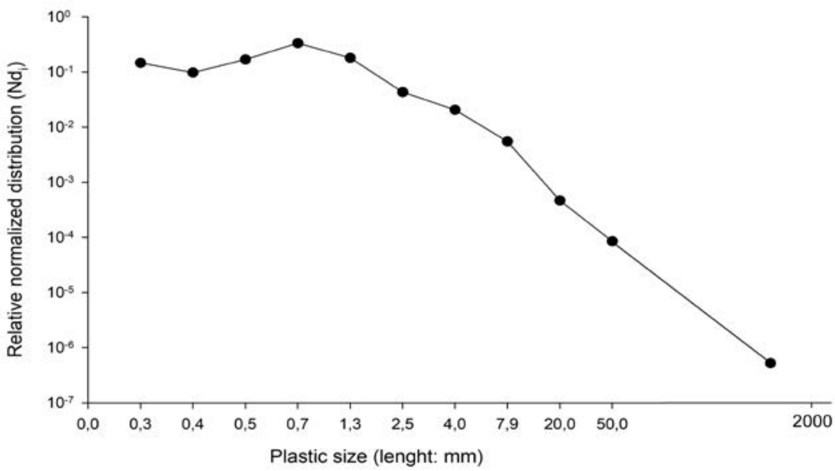


Figure 4.9. Size distribution according size length of particles. *Normalized abundance values were obtained dividing the number of particles counted (n = 3,145) in each size class (horizontal axis). Vertical axis is in logarithmic scale.*

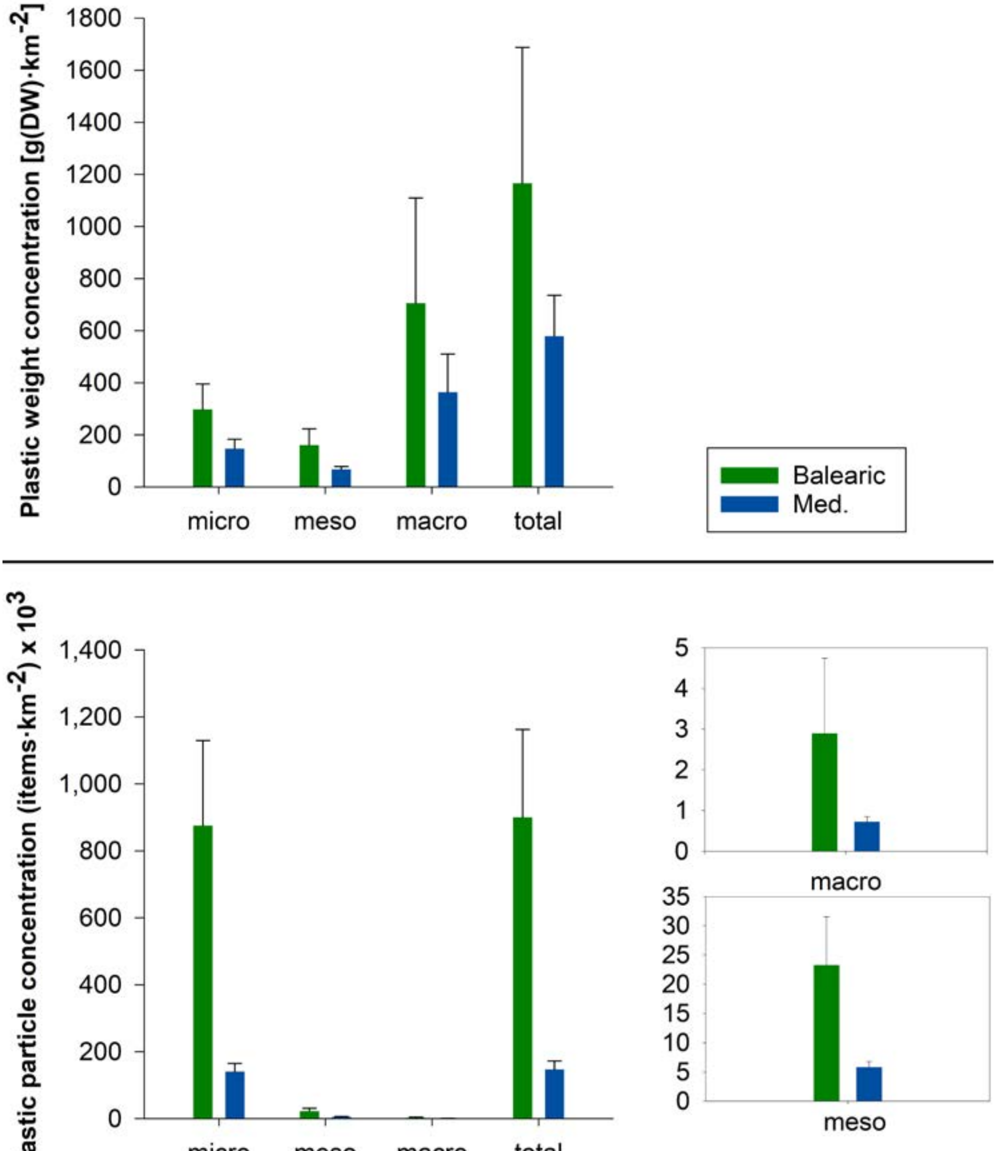


Figure 4.10. Differences between Balearic (green) and western-central Mediterranean samples (blue) in terms of weight and particle concentration of plastics. *Micro, meso and macro sizes represent the following ranges: < 5 mm, 5 – 25 mm and 25 – 1000 mm, respectively. Mediterranean data reported by Ruiz-Orejón et al., 2016. Error bars represent the standard error of the mean.*

4.3. Discussion

The results found in the coastal area of the Balearic archipelago shows a relative high concentration of floating plastic particles, which is in agreement with the short-term accumulation predicted by numerical models (Mansui et al., 2015) and with data reported from surveys in some areas of the islands (Faure et al., 2015; Ruiz-Orejón et al., 2016; Suaria et al., 2016). Although the western basin of the Mediterranean has been one of the most analyzed areas for floating plastic pollution, the values obtained in this work represent some of the highest concentration values in average reported in the western basin, being only surpassed by Collignon et al. (2012) (2,020 $g \cdot km^{-2}$). The first kilometer off coast showed the highest proportion of floating plastics, as it has been reported in previous studies in the Mediterranean sea (Pedrotti et al., 2016; Ruiz-Orejón et al., 2016). Values in the coastal strip of the Balearic Islands duplicate those of the same breadth obtained in other areas of the Mediterranean Sea. Nevertheless, we need to take into account that all these measures are highly dependent of the sampling technique and strategies, numbers from other areas could be higher of simply could have been prepared to get particles of small size range.

The main path of entering plastic waste into the sea and to increase its concentration are from land-based sources (Ryan et al., 2009). The Balearic Islands are one of the leading European tourist destinations (Garín-Muñoz and Montero-Martín, 2007; UNWTO, 2015). During its summer season, the seasonal population almost double its resident population (IBESTAT, 2014). Nevertheless, the distribution of this population was not homogeneous in the islands, with a lower density on the coasts of the Balearic sub-basin (particularly in Mallorca). We are aware that correlation is not a sufficient condition to drive causality between a pair of variables; but we regard it as necessary condition to hypothesize about the causal mechanisms. The non-significant correlation between tourism numbers and the floating plastic concentrations, in addition to the inverse correlated results from population data, suggested that other factors could have more importance in the distribution of plastics in this area (e.g. winds, surface currents); as well as reported in their beaches (Martinez-Ribes et al., 2007). In our study, the highest density points of plastics were found on the north-west coasts of the islands of Ibiza and Mallorca where the islands are geomorphologically more abrupt and present pocket beaches, hindering their access and therefore, are less frequented than other beaches in these Islands. Therefore, the oceanographic conditions seemed to actively modify the floating plastic concentration around the islands. The surface oceanographic regime observed around the islands followed the characteristics formed in spring and summer seasons when the northern conditions have weakened and the surface waters form the Algerian sub-basin cross the channels of Ibiza and Mallorca (Barberá et al., 2014; López-Jurado et al., 2008).

These conditions suggested two scenarios acting synergistically that favored the temporal accumulation of plastics in the north-northwestern coast of Mallorca and Ibiza. The first scenario was strongly influenced by the North Current (NC), which circulation runs along the coasts of southern Europe through densely-populated areas and mouths of large rivers (El-Geziry and Bryden, 2010; Millot and Taupier-Letage, 2005). When these waters reached the Balearic sub-basin, conformed the Balearic Front (BF) with the reinforcement of the surface waters from the Algerian sub-basin during this period (Barberá et al., 2014; López-Jurado et al., 2008; Pinot et al., 2002), where the accumulation of the particles transported or retained off the Mallorcan coast was favored. Emerging modeling studies reflect the retention of plastics in the Balearic sub-basin (Coppini et al., 2018; Liubartseva et al., 2018; Mansui et al., 2015; Zambianchi et al., 2017), which is supported by our results. The second scenario suggested that the mesoscale anticyclonic gyre produced around the *Pitiusan* islands seemed to act as a retention structure for floating plastic transported as well as those coming from the islands towards the inside of the gyre.

Plastic redistribution of marine debris from a source or release point is a known process that may be affected by the fluid dynamics and it also reflected in deep and shallow sediments (e.g. Alomar et al., 2016; Oliveira et al., 2015). Fronts and eddies have a higher relevance in the distribution of plastics at lower scales in the surface waters (Maximenko et al., 2012; Ourmieres et al., 2018; van Sebille et al., 2012), that they may also act as barriers to land-coastal debris together with coastal morphology and form retention zones nearshores (Fossi et al., 2017; Pedrotti et al., 2016). However, due to the high spatial and temporal variability of the Mediterranean surface circulation, the retention areas are not stables (Cózar et al., 2015; Mansui et al., 2015; Zambianchi et al., 2017). We could not compute the effect of vertical plastic distribution, contribution and its changes beyond obtaining samples on condition of calm and subsequent correction of the data, as similar studies (e.g. Reisser et al., 2015).

Floating plastic concentration was mainly composed by hard fragments (91.41%), with similar proportions to that recently reported in the Mediterranean – 73% (2011-2012; Faure et al., 2015), 87.7% (2013; Cózar et al., 2015), 87.29% (2011 & 2013; Ruiz-Orejón et al., 2016) and 93.2% (2013; Suaria et al., 2016). Although we could expected some heterogeneity with compounds of higher density due to proximity of land-based sources (Pedrotti et al., 2016; Suaria et al., 2016), our sampled fragments could be composed by low-density polymers such as polyethylene (PE) and polypropylene (PP).

Macroplastic fragments tend to break down into smaller pieces mainly due to photo-oxidation and other chemical or physical processes (Andrady, 2015, 2011; Barnes et al., 2009), given pass to micro and nanoplastics. The presence of these microparticles suggest fragmentation processes that indicate their persistence in the environment (e.g. Cózar et al., 2017), and therefore susceptible to transport by surface currents. In addition, higher relative abundances of particles larger than 50 mm^2 were observed in the Balearic Islands in relation to the previous Mediterranean surveys (Ruiz-Orejón et al., 2016). The plastic particle surface characteristics may profoundly influence its interactions in the environment (Filella, 2015; Fotopoulou and Karapanagioti, 2012); however, due to the high diversity of plastics and the missing information of particle surface and their characteristics, further research is needed. Although, the area and length of measured plastic particles showed an expected strong relation ($r^2 = 0.85$).

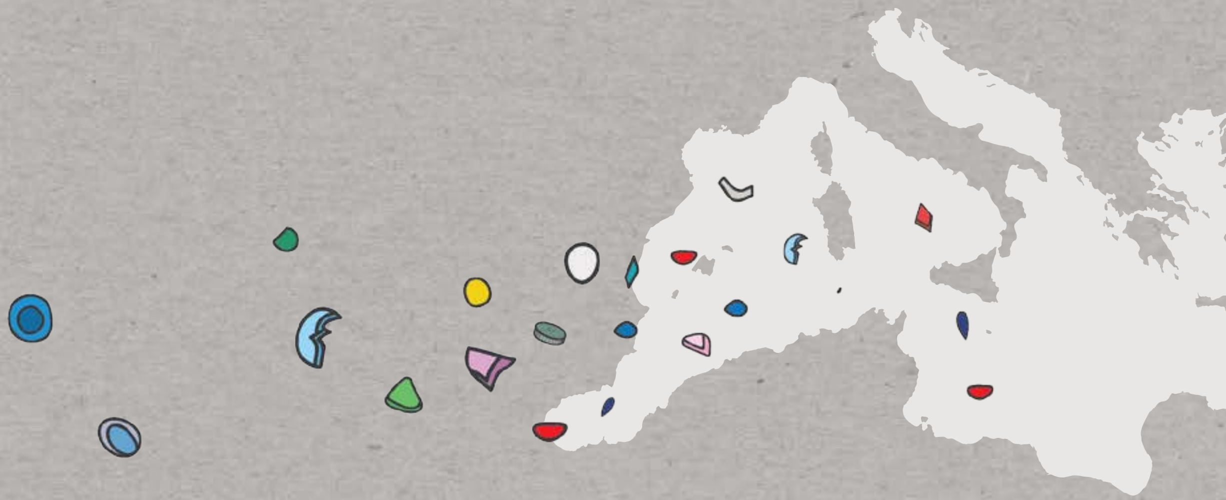
Despite certain unanimity in research on the removal of smaller particles from the surface (Cózar et al., 2015, 2014; Lusher et al., 2014; Morét-Ferguson et al., 2010; Pedrotti et al., 2016), our results showed a slight decrease but with a tendency to stabilize from the large number of particles analyzed in length ($n = 3{,}145$) suggesting a distribution similar to that recently reported in Mediterranean waters (Suaria et al., 2016). From the Isobe et al., (2014) model, a higher amount of mesoplastics in the coastal waters could be predicted by Strokes drift. Nevertheless, the presence of the coastal cleaning service (mainly focused on the macroplastics and mesoplastics recovery) may be also altering the real ratio between the smaller and larger pieces.

4.4. Conclusion

The results of this study revealed that the high concentration of floating plastic debris in the surface coastal waters of the Balearic Islands were of the same magnitude order than values found across the Mediterranean Sea except for higher average concentration in some regions of the eastern basin (van der Hal et al., 2017). The exceptionally high plastic concentration values in the north-northwestern coast of Ibiza and Mallorca suggested that despite the high population density (especially during tourist seasons), the plastic particles were mostly conditioned by the hydrodynamic surface conditions at the Balearic Islands.

Further temporal research is needed to know the coastal origin, distribution, retention and sink processes in surface waters of the Islands, as well as consider other factors that allow the entrance of litter from land-based sources and discharges in-situ, in order to promote efficient management of the plastic pollution problem and achieve the objectives of the European Marine Strategy Framework Directive (2008/56/EC). However, in the meanwhile, unintended social losses of people in the islands are coming by self-interested actions (not taking appropriate care of plastic wastes) that does not take into account the negative consequences on the provision on ecosystem services by the Sea around the islands, an unintended invisible plastic layer (materials that we do not see but they are accumulating) is increasing. The high concentration of floating plastic debris in the coastal waters of the Archipelago is the result of a combination of the, in this case, "negative" consequences of the invisible hand (Smith, 1776) and the Hardin's Tragedy of the Commons (Hardin, 1968).

The Balearic Islands have attracted people through history due to its strategy positions and commercial possibilities. Its natural beauty was also considered by the high upper classes of the XIX Century as a possibility to get out of urban environments during the industrial revolution. Archduke Ludwig Salvator be considered as a key person to show the Social and Natural Capital of the Islands. From the very beginning, he also pointed out people's pressures on its natural environments (forest overexploitation). Today another high anthropogenic pressure derived from human frequentation, revealed a different type of threat especially on marine ecosystems due floating plastic debris.



Chapter 5

Seasonal variability of the surface distribution of plastics debris in the Marine Protected Area of the Menorca Channel (Spain)

Abstract

Marine protected areas (MPAs) are a key tool for preserving its Natural Capital as well as good and ecosystem services that goes beyond their boundaries. Contingency plans to deal with marine litter, being plastics most of its composition, are usually not considered in its management parts. This study analyzed seasonally the concentrations of floating plastics debris in the recently approved Menorca Cannel's MPA (end of 2015) to establish the first insights of its current state. Particle abundances ranged from 138,293 item·km^{-2} in autumn to 347,793 items·km^{-2} during the spring, while weight densities varied from 458.15 g(DW)·km^{-2} in winter to 2,016.67 g(DW)·km^{-2} in summer. The low depth of the Menorca Channel promotes a limited sea currents circulation generating a low-energy zone, in which, we hypothesized about the seasonal accumulation directed by the currents on both sides of the channel and the strongly seasonal anthropic pressure in it.

5.1. Introduction

5.1.1. Background

From 1867 to 1888, the Archduke Ludwig Salvator of Austria travelled to the island of Menorca (Balearic Islands) and made the volumes dedicated to this land (*"Die Insel Menorca"*) included in his large encyclopedia *"Die Balearen"* (Alzaga Ruiz, 2006). To write these volumes, he did numerous travels back and forth between the two islands Mallorca where he lived, and Menorca through its Cannel. Although he accurately detailed the coastal zones on both sides of the Channel, highlighting the social and natural potentials through words and engravings, he did not detail in great depth the Channel itself.

Nowadays, the Menorca Channel is included in the Natura 2000 Network due to the wide range of species and habitats of high conservational value. The European project Life+ INDEMARES established the bases for the designation of three Special Protection Areas (SPA) and a Site of Community Importance (SCI) within the Natura 2000 Network. Through the Order *AAA/1260/2014* of July 9, 2014, the Spanish state declared the three SPA zones: the *Marine Area of Northern Mallorca* (ES0000520), the *Marine Area of Northern and Western of Menorca* (ES0000521) and the *Marine Area of Southeast of Menorca* (ES0000522). The Order *AAA/1299/2014* of

July 9, 2014, approved the proposal to include the SCI *Menorca Channel* (ESZZ16002) within the Natura 2000 Network and finally declared by the European Union at the end of 2015 (*Commission Implementing Decision (UE) 2015/2374;* see Figure 5.1). In addition, this zone is shared with other previously approved marine protection areas in the same study area: the SCIs of *Bays of Pollença and Alcúdia* (ES531000), *Cap Negre* (ES5310068) and the *Artá Mountains* (ES0000227), together with the *Marine reserve of east of Mallorca-Cala Ratjada* (Orden Ministerial APA/961/2007).

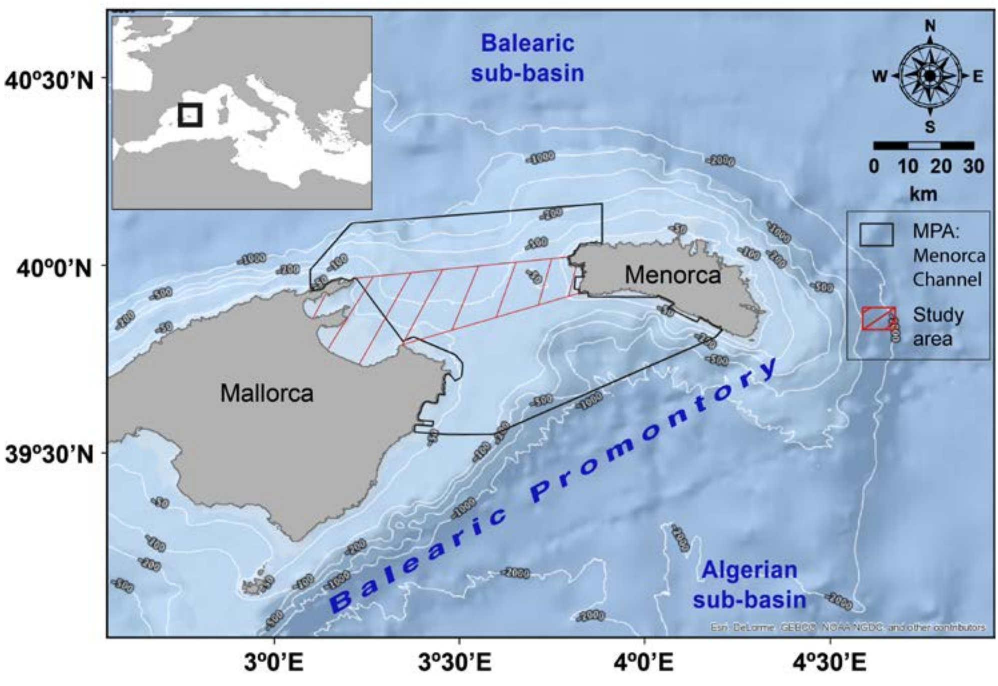


Figure 5.1. Study area in the Menorca Channel, the marine protected area of Menorca Channel and the bathymetric contours. *Bathymetric contours obtained from (Bathymetry Consortium EMODnet, 2016). Source of background layer: Esri.*

The Menorca Channel is located between the islands of Mallorca and Menorca in the northeastern part of the Balearic Promontory of the Archipelago, it comprises 98,700 Ha of continental shelf (Barberá et al., 2012). The depth (Figure 5.1), in the central area of the Channel itself, ranges from 50 m to 175 m falling abruptly on the southeast slope and softly in the northwest (Barberá et al., 2014). The limited channel depth acts as a barrier to deep currents, establishing the most limited surface exchange regime between the Balearic sub-basin and the Algerian sub-basin (Balbín et al., 2014; Barberá et al., 2014; López-Jurado et al., 2008; Pinot et al., 2002)in the framework of the \”IDEA Project\” (acronym for \”Influence of oceanographic structure and dynamics on demersal populations in waters of the Balearic Islands\”. Water exchange in the Channel is mainly influenced by the Balearic density Front, in the north of the Channel, and by the mesoscale structures, which are usually formed in the south (Balbín et al., 2014; López-Jurado et al., 2008; Pinot et al., 2002, 1995). The Channel is also affected by northerly winds that are predominant over the Balearic Islands which increase their frequency and intensity during the winter season (Pinot et al., 2002).

The Channel suffers different anthropogenic pressures that facilitates the entry of plastic debris into its marine ecosystems (e.g. Jambeck et al., 2015; Ryan et al., 2009)but the quantity of plastic entering the ocean from waste generated on land is unknown. By linking worldwide data on solid waste, population density, and economic status, we estimated the mass of land-based plastic waste entering the ocean. We calculate that 275 million metric tons (MT. Despite less intensity than other sites of the Balearic Islands, the Channel presents a strong seasonal tourist activity in its coast, especially in the northeast of Mallorca (bays of *Pollença* and *Alcúdia*) and western Menorca (area of *Ciutadella*), and it is also affected by the intense maritime traffic produced in the Balearic sub-basin, a continuous connection between the ports of *Alcúdia* and *Ciutadella* and the increase in nautical tourism during summer seasons. Nor should the temporary retention capacity of the Balearic sub-basin be underestimated (Coppini et al., 2018; Liubartseva et al., 2018; Mansui et al., 2015; Zambianchi et al., 2017), acting as a potential source of plastic litter for the protected area.

At the sea surface level, some exceptional Channel data have been reported as part of wider campaigns with values in the range of 80.68 – 3,656.17 g(DW)·km^{-2} and 122,284 – 330,397 items·km^{-2} (Ruiz-Orejón et al., 2016) and others at the outer ends outside the Channel itself: between 80,000 – 320,000 items·km^{-2} at the north (Faure et al., 2015) and around 300 g·km^{-2} at the east of the Menorca Channel (Suaria et al., 2016).

The accountably for the presence of floating plastic debris in the Mediterranean MPAs is still limited. The Pelagos Sanctuary (NW Mediterranean) has been the most widely studied MPA in this sea, a research study reported plastic concentration from 0 items·km^{-2} (winter) to 68.8·10^{4} items·km^{-2} (spring) in a seasonal study in the Bay of *Calvi* (Corsica) (Collignon et al., 2014), while 0.17 items·m^{-3} were obtained in the Gulf of *Asinara* (Sardinia) (Panti et al., 2015). Pedrotti et al. (2016) evaluated the differences between coastal and open sea concentrations in the North of the Pelagos Sanctuary reporting values from 5.78·10^{5} to 2.4·10^{4} items·km^{-2}, respectively. Other studies have evaluated the plastic concentration at the fin whale feeding areas in this MPA yielding microplastic values of 0.31 items·m^{-3} (Fossi et al., 2016) and recently, 94.6·10^{3} items·km^{-2} (micro and mesoplastics) (Fossi et al., 2017).

5.1.2. Study aims

In this chapter, we present the results of a seasonal study on the concentration of floating plastics in the recent approved MPA of Menorca Channel. The aim of this seasonal surveys was to provide initial status of floating plastic debris in this area and the analysis of the potential oceanographic and demographic drivers that regulate the surface accumulation. Looking forward for the Good Environmental Status of European Seas (Galgani et al., 2013), this work serves as baseline to be incorporated into the management practices of the Menorca Channel's MPA.

5.2. Results

5.2.1. Floating sample composition

During October 2014 – July 2015, a total of 48 surface net-tows were obtained in a quarterly basis [12 samples taken in each campaign at four seasons during the year, one at each designated sampling station (see section 2.2 of methods – Chapter 2 and Supplementary Materials Figure S5.1 and Table S5.1, Annex D)].

Sample composition showed a high variability throughout the different seasons (Figure 5.2). In weight terms, samples were mainly composed by floating plastic debris (from 9.13% in winter to 72.97% in summer), vegetal fragments (21.35% in summer – 74.64% in winter) and animal organisms (5.14% in summer – 20.18% in autumn). The rest of compounds such as tar ball pellets and unclassified objects, represented a residual contribution to the total composition, while the paper residues were not found in the samples throughout the surveys (see Table 5.1, see section 2.3 of methods – Chapter 2).

The maximum values for the presence of floating debris were generally obtained within the bays *of Pollença* and *Alcudia*. For the vegetal group, its maximum values were presented in the northwestern part of the channel during winter (33,533.87 g(DW)·km^{-2}. Sampling point 3, see Supplementary Materials Figure S5.1, Annex D), but constant high values were also obtained inside the bay of *Alcúdia*. In the same way, the maximum values for animal organisms (2,480.84 g(DW)·km^{-2}) were obtained during winter in the outer northern zone of the bay of *Alcúdia*.

While most of the analyzed groups showed maximum concentrations in weight during the winter and spring seasons, plastics showed an opposite distribution (i.e. autumn and summer). However, we did not find a correlation between the different groups analyzed (Table 5.2), except among different plastic groups. Occasionally, there were some relationship between some size plastic group and tar-ball pellets.

*Table 5.1. **Composition of the samples in the Menorca Channel in relation to the weight.** Values are expressed in percentages.*

	Plastics (%)	Vegetal (%)	Animal (%)	Tarball-p (%)	Paper (%)	Uclass (%)
autumn	56.56	22.87	20.18	0.20	0	0.19
winter	9.13	74.64	15.20	0.56	0	0.47
spring	32.26	48.62	17.03	0.35	0	1.74
summer	72.97	21.35	5.14	0.24	0	0.30

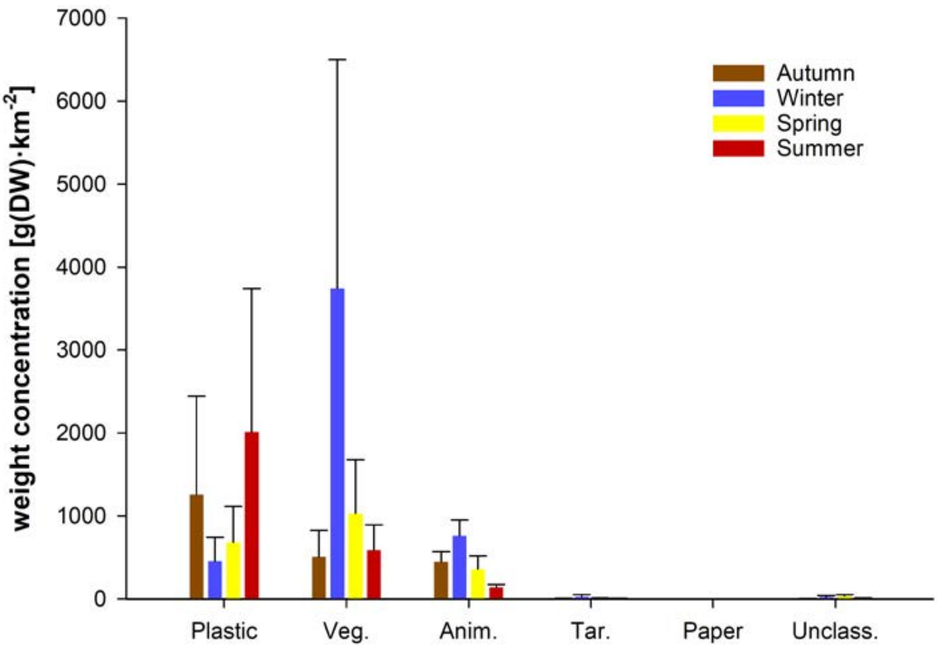


***Figure 5.2. Seasonal sample composition differences in terms of weight concentration in the Menorca Channel.** Results are expressed in (g(DW)·km^{-2}). Error bars represent the standard error of the mean.*

Table 5.2. Correlation values between sample composition groups. *Statistical test used for the correlation was the Spearman correlation test (r_s). (p) represent the p-value. Significant values are represented by bolds. Paper group was omitted due to non-existence in the samples.*

Winter \ Autumn		Plast. total	Micro Plast.	Meso Plast.	Macro Plast.	Tar-b. pellets	Veg.	Anim.	Unclass.
Plast. Total	r_s	1	**0.720**	**0.901**	0.473	0.203	0.273	0.161	**0.602**
	p	-	**0.008**	**<0.001**	0.120	0.527	0.391	0.618	**0.038**
Microplas.	r_s	**0.846**	1	0528	0.532	0.500	0,063	-0.063	**0.653**
	p	**0.001**	-	0.078	0.075	0.098	0.846	0.846	**0.021**
Mesoplas.	r_s	0.416	0.317	1	0.357	0.117	0.324	0.282	**0.657**
	p	0.178	0.316	-	0.254	0.718	0.304	0.375	**0.020**
Macroplas.	r_s	**0.666**	0.399	-0.053	1	**0.613**	0.237	0.371	0.429
	p	**0.018**	0.198	0.870	-	**0.034**	0.459	0.235	0.164
Tar.	r_s	0.517	**0.601**	0.310	0.345	1	0.377	0.297	0.263
	p	0.085	**0.039**	0.327	0.272	-	0.227	0.348	0.409
Veg.	r_s	-0.119	-0.147	-0.377	0.262	0.350	1	0.392	0.421
	p	0.713	0.649	0.227	0.411	0.265	-	0.208	0.173
Anim.	r_s	0.014	0.056	-0.238	0.291	-0.112	0.378	1	0.326
	p	0.966	0.863	0.455	0.358	0.729	0.226	-	0.301
Unclass.	r_s	0.470	0.484	0.134	0.049	0.231	0.075	-0.018	1
	p	0.123	0.111	0.678	0.881	0.469	0.817	0.956	-

Table 5.2. (Continued)

Summer \ Spring		Plast. total	Micro Plast.	Meso Plast.	Macro Plast.	Tar-b. pellets	Veg.	Anim.	Unclass.
Plast. Total	r_s	1	**0.902**	**0.819**	0.414	**0.677**	0.364	-0.329	0.056
	p	-	**<0.001**	**0.001**	0.181	**0.015**	0.245	0.297	0.862
Microplas.	r_s	0.538	1	**0.698**	0.263	**0.695**	0,413	-0.042	-0.070
	p	0.071	-	**0.012**	0.408	**0.012**	0.183	0.897	0.828
Mesoplas.	r_s	**0.704**	**0.648**	1	-0.063	0.508	0.388	-0.441	0.168
	p	**0.011**	**0.023**	-	0.846	0.092	0.213	0.151	0.601
Macroplas.	r_s	**0.735**	0.090	0.148	1	0.381	-0.091	-0.177	0.043
	p	**0.006**	0.782	0.647	-	0.222	0.778	0.581	0.894
Tar-b.	r_s	**0.762**	0.336	**0.592**	0.496	1	-0.086	-0.546	0.158
	p	**0.004**	0.286	**0.043**	0.101	-	0.791	0.067	0.624
Veg.	r_s	-0.378	-0.476	-0.455	-0.075	-0.559	1	0.287	-0.359
	p	0.226	0.118	0.137	0.818	0.059	-	0.366	0.252
Anim.	r_s	0.014	0.210	0.018	-0.093	-0.329	0.517	1	-0.211
	p	0.966	0.513	0.957	0.773	0.297	0.085	-	0.510
Unclass.	r_s	-0.035	-0.254	-0.134	0.049	-0.120	**0.704**	0.366	1
	p	0.913	0.427	0.678	0.880	0.711	**0.011**	0.242	-

5.2.2. Seasonal dynamics

Floating plastic distribution

Plastic particles were found in all samples of the NIXE III project data across the Menorca Channel (see Supplementary Materials Table S5.1, Annex D). When the four seasonal campaigns were put together, annual mean plastic particle concentration reached 224,294 items·km^{-2} (median = 117,331 items·km^{-2}), while the average weight concentration was 1,105.19 g(DW)·km^{-2} (median = 129.04 g(DW)·km^{-2}). The areas with the highest accumulation of floating plastic debris in the Channel were observed in the bays of *Alcúdia* and *Pollença* (Figure 5.3). The particle concentration showed some homogeneity in its distribution where the maximum and minimum values were found during spring season (1,509,536 items·km^{-2} Sampling point (SP) 1 and 23,625 items·km^{-2} SP 7, respectively). In contrast, the weight concentration seemed to present some heterogeneity in its distribution with the maximum value during summer (20,957.07 g(DW)·km^{-2}; SP 9) and the minimum in spring (1.03 g(DW)·km^{-2}; SP 12).

There was a seasonal pattern of the mean plastic particle concentration in the Channel (Figure 5.4) characterized by a peak during spring (347,793 items·km^{-2}) and a low particle concentration during autumn (138,293 items·km^{-2}). Following the spring peak, there was a decrease in particle concentration in summer (250,704 items·km^{-2}), while the average particle concentration in winter was 160,398 items·km^{-2} (additional values in Table 5.3). There was no significant difference in plastic particle concentration during the seasons (Kruskal-Wallis test H (3) 6.23; *p-value* > 0.5). Plastic weight concentration was characterized by a seasonal peak during autumn (1,260.64 g(DW)·km^{-2}) followed by a pronounced decrease in winter (458.15 g(DW)·km^{-2}) and continued by a slight rise during spring (685.33 g(DW)·km^{-2}), culminating with a second peak in summer of 2,016.66 g(DW)·km^{-2} (see Figure 5.3 and additional values in Table 5.3); however, there were also no significant differences throughout the seasons (Kruskal-Wallis test H (3) 5.72; *p-value* > 0.5).

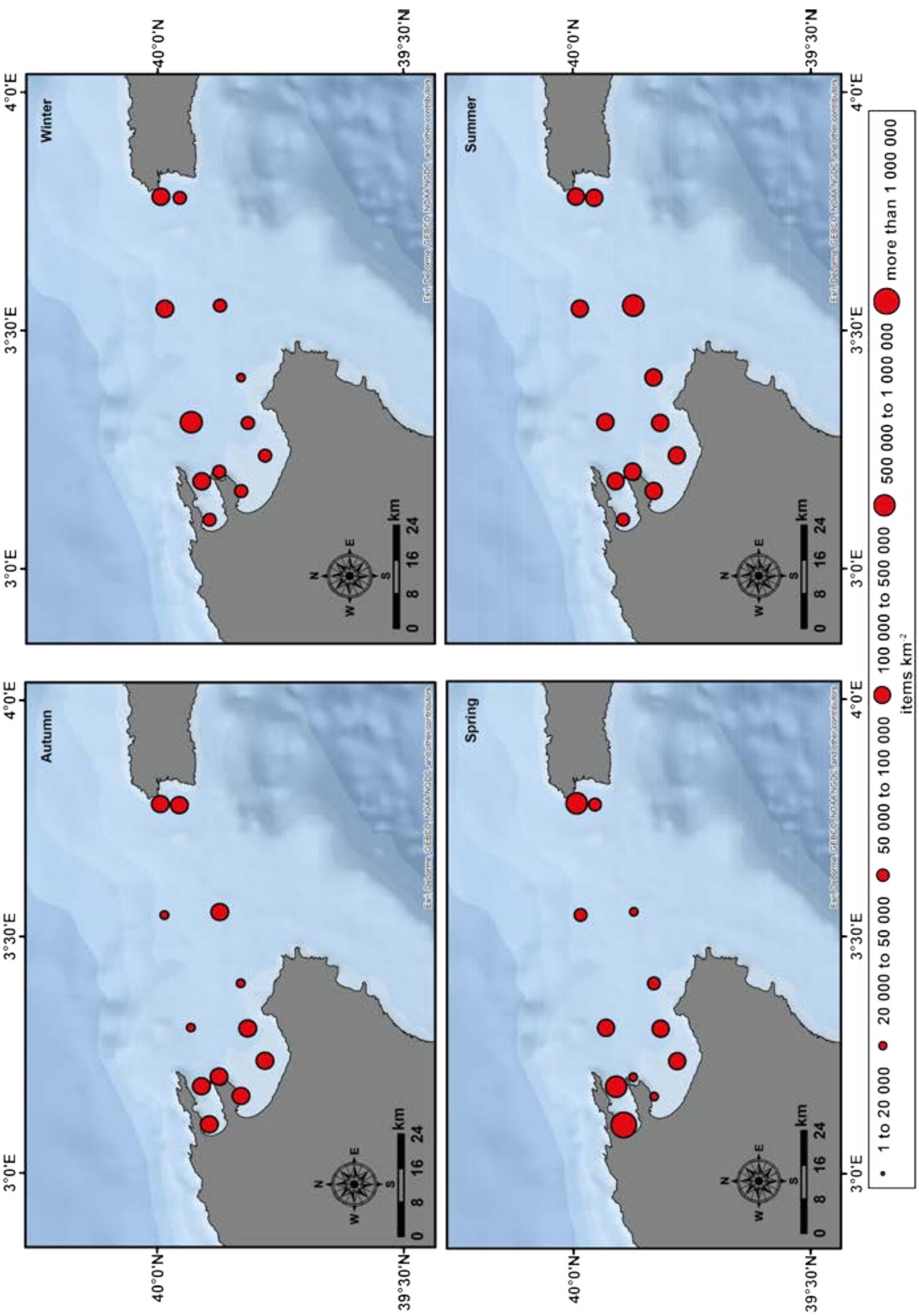


Figure 5.3. Seasonal spatial distribution of floating plastic concentrations in the coastal waters of Menorca Channel. *Seasonal plastic particle concentration (items·km*$^{-2}$*) in this page. Seasonal plastic weight concentration (g(DW)·km*$^{-2}$*) in the next page. Source of background layers: Esri.*

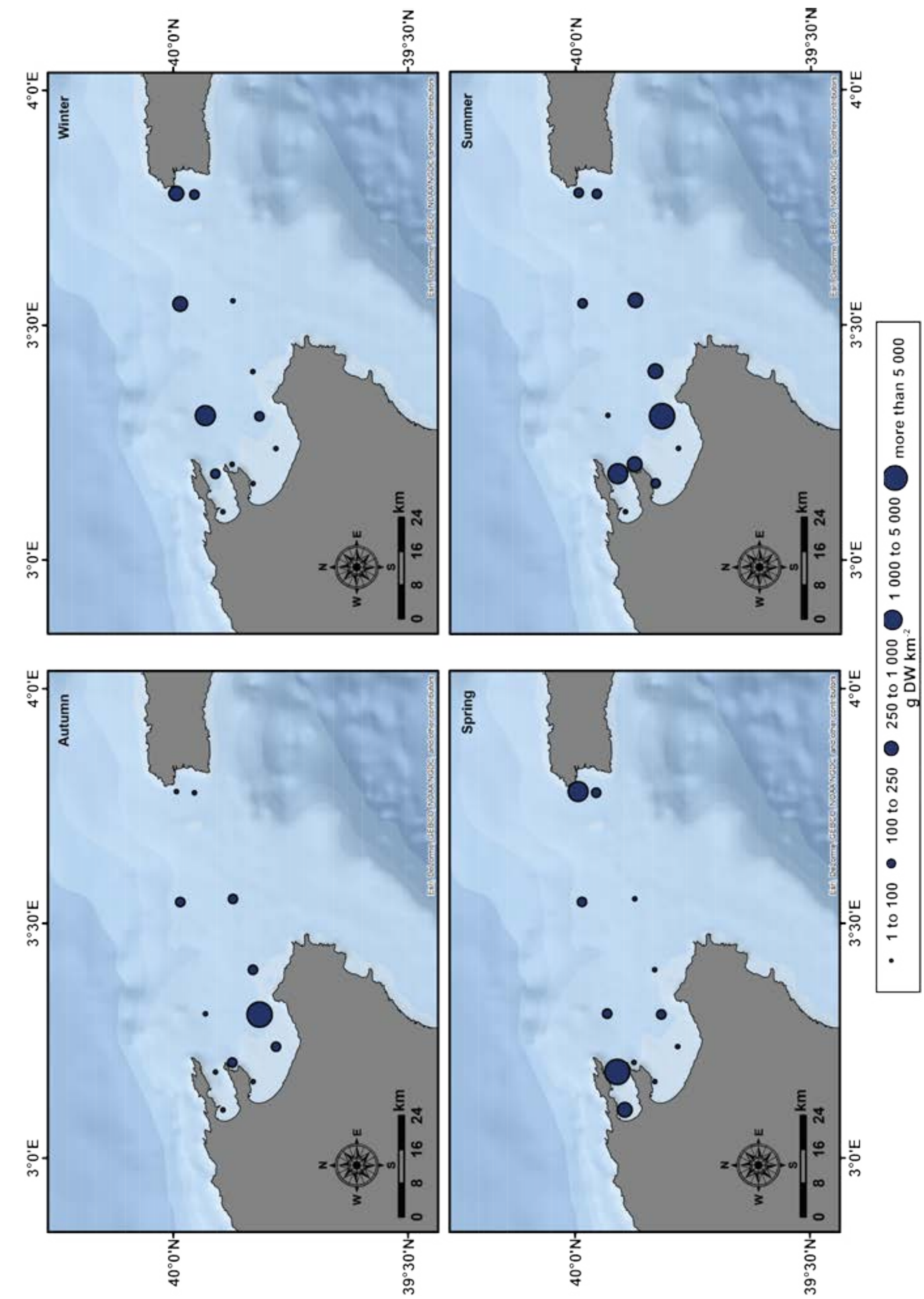


Figure 5.3. (continued)

The observed concentrations of plastic particles were lower than those obtained in the Balearic Islands to contextualize this study; however, these results were significative higher than reported in the Mediterranean during spring and summer seasons (*p-value* = 0.045 and 0.03; respectively) according the Mann-Whitney U tests. No significant differences were found in the distributions by weight when we compared the surveys of the Menorca Channel with those of the Balearic Islands and the Mediterranean (Figure 5.4).

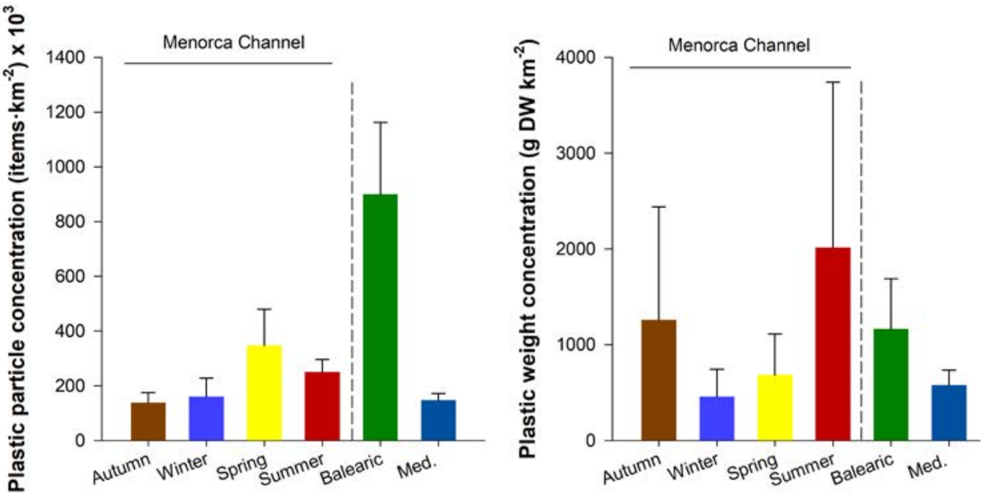


Figure 5.4. Differences between Menorca Channel, Balearic Islands (green) and western-central Mediterranean (dark blue) surveys in terms of particle and weight concentration of plastics. *Mediterranean data reported by Ruiz-Orejón et al., 2016. Error bars represent the standard error.*

Differences in the intra-seasonal distribution, concentrations were analyzed between the north (SP 1-5) and south (SP 6-12) of the Channel (Figure 5.3). Significant differences in particle concentration during the winter, spring and summer seasons (*p-value* = 0.005, 0.03 and 0.003; respectively) were found through a Mann-Whitney U tests. In terms of weight concentration, significant differences were revealed in the spring (*p-value* = 0.03), and barely in the autumn (*p-value* = 0.048) seasons. Conversely, no differences were found between the concentrations in the bays (SP 1-2 and 9-12) and those found in the canal itself (SP 3-8) during the seasons, except for the concentration of particles in autumn (*p-value* = 0.004).

Table 5.3. Additional values of concentrations in the Menorca Channel (Balearic Islands). *Values correspond to the mean and median of the samples obtained in the seasonal Menorca Channel campaigns (n = 12 each campaign) of the NIXE III project. Concentrations are expressed in surface and volume units.*

		Particle concentration		Weight concentration	
		Items·km⁻²	*Items·m⁻³*	*g(DW)·km⁻²*	*g(DW)·m⁻³*
Autumn	*Average ± S.D.*	138,293 ± 125,854	0.33 ± 0.27	1,260.64 ± 4,089.82	3.96×10^{-3} ± 1.27×10^{-3}
	Median	95,648	0.26	97.98	0.37×10^{-3}
Winter	*Average ± S.D.*	160,398 ± 235,603	0.39 ± 0.39	458.15 ± 988.48	1.36×10^{-3} ± 2.7×10^{-3}
	Median	69,262	0.25	93.23	0.37×10^{-3}
Spring	*Average ± S.D.*	347,783 ± 457,128	0.80 ± 0.77	685.33 ± 1,482.34	3.77×10^{-3} ± 9.78×10^{-3}
	Median	98,702	0.45	120.39	0.51×10^{-3}
Summer	*Average ± S.D.*	250,704 ± 166,161	1.10 ± 0.67	2,016.67 ± 5,971.53	8.48×10^{-3} ± 24.72×10^{-3}
	Median	212,383	0.88	209.89	0.98×10^{-3}
Autumn	*Microp. avg.*	133,517	0.32	54.54	0.19×10^{-3}
	Mesop.avg.	4,381	0.01	37.76	0.13×10^{-3}
	Macrop.avg.	395	0.15×10^{-2}	1,168.33	3.65×10^{-3}
Winter	*Microp. avg.*	152,158	0.37	275.30	0.50×10^{-3}
	Mesop.avg.	6,924	0.02	33.72	0.07×10^{-3}
	Macrop.avg.	1,315	0.29×10^{-2}	376.18	0.79×10^{-3}
Spring	*Microp. avg.*	336,131	0.77	149.72	0.74×10^{-3}
	Mesop.avg.	11,280	0.03	125.34	0.61×10^{-3}
	Macrop.avg.	373	0.07×10^{-2}	410.27	2.41×10^{-3}
Summer	*Microp. avg.*	240,651	1.06	142.18	0.57×10^{-3}
	Mesop.avg.	9,207	0,04	56.27	0.23×10^{-3}
	Macrop.avg.	846	0.37×10^{-2}	1,818.03	7.67×10^{-3}

The values obtained inside the Channel (SP 3-8) were used to estimate the total of particles and mass of floating plastic in the Menorca Channel (surface area of the MPA: 3,353.54 km^2) throughout the seasons (Table 5.4). Winter season showed the maximum values within the ranges obtained. Considering the bays of *Pollença* and *Alcúdia* as one of the likely sources-sinks for this MPA (approx.: 3,3662.54 km^2 in total), the maximum values of particulates and mass were estimated during the spring and summer seasons respectively (Table 5.4).

Table 5.4. Estimated seasonal total particles and mass in the Menorca Channel. *Values were obtained by computing 95% BCa bootstrapped confidence intervals of the mean concentration data of each season over the surface of the MPA (3,353.54 km^2) and including the bays of Pollença and Alcúdia (approx. 3,662.54 km^2). The values used to estimate the total Channel concentration were determined by the sampling points within the MPA (SP 3-8, left side of the table) and considering the bays as sources-sinks (all SP, right side of the table).*

	Particles	**Mass**	**Particles (including the bays)**	**Mass (including the bays)**
	Confidence intervals (items)	*Confidence intervals (kg)*	*Confidence intervals (items)*	*Confidence intervals (kg)*
Autumn	115,997,205 – 286,865,366	154,464.05 – 388,876.50	275,456,777 – 852,782,224	228,139.62 – 13,279,014.90
Winter	299,661,033 – 1,549,841,093	683,552.06 – 5,928,019.12	273,829,364 – 983,683,931	403,062.53 – 3,385,029.34
Spring	222,870,702 – 1,068,811,797	239,208.01 – 3,322,050.26	500,592,488 – 2,372,244,482	401,048.13 – 5,601,488.68
Summer	600,547,852 – 1,275,050,818	560,443.60 – 1,070,785.32	633,801,081 – 1,181,892,062	723,974.28 – 20,112,875.04

Oceanographic and demographic conditions

Hydrodynamic conditions showed great variability along the analyzed stations (Figure 5.5A-D). Mean surface velocity and kinetic energy circulation were used to provide a vision of the mean circulation each season analyzed (Mansui et al., 2015)(Figure 5.6A-B), where the ocean circulation in the Menorca Channel was associated with the limited interchange between the north and the south waters (e.g. Balbín et al., 2014; Barberá et al., 2014).

During autumn, the situation of the Balearic Front characterized mainly by a slightly higher salinity, marked the north channel conditions excepting by the intrusion of waters coming from the south in the middle-eastern of the channel. This situation allowed the formation of a low surface speed around the bays of *Alcúdia* and *Pollença* (Mallorca), which corresponded to the highest concentrations of particles of the season. In contrast, the winter season favored the incursion of north waters into the bays with an apparent reduction of the floating particles and their weight in these areas that in addition, which also coincided to a lower seasonal population pressure in the coasts (Figure 5.8). In both seasons, the anticyclone gyre produced by the mesoscale circulation at the south of the Channel, appeared to favor the circulation from south to the north.

Oceanographic conditions in the surface of the Channel were driven by the Balearic density front during the spring sampling analysis (Figure 5.5C). Besides, the lowest concentrations were presented in the channel itself, the central zone where the main current followed south direction. Meanwhile, *Pollença* bay suffered a great accumulation (particles and weight) along with the particle concentration in the interior zone of the bay of *Alcúdia* close to *Farrutx* Cape (East of the bay). Finally, summer circulation suggested a restoration in the currents to the initial autumn state. The highest concentrations of particles appear to be established in the lower energetic zones of the Channel with an increase in the bay of *Alcúdia* area respect to previous season, as well as, the apparent transport of particles produced by the mesoscale circulation from the south. However, we did not find significant correlations with the oceanographic variables studied (*p-value* > 0.05).

Tourism in the Balearic Islands shows a marked seasonal variability (Martinez-Ribes et al., 2007) and was highly correlated with plastic presence. In this sense, both the flow of tourists entering the islands of Mallorca and Menorca (see section 2.4 of methods – Chapter 2), as well as those who decided to stay in the areas surrounding the Menorca Channel, showed a similar distribution to the concentration of plastics by weight (Figure 5.7). *Farrutx* Cape, similar to floating particles, showed maximum concentrations by weight during autumn and summer seasons although the apparent anthropic pressure in lower than other areas in the Menorca Channel. Nevertheless, we did not find significant correlation between plastic concentration and tourist flow ($r_s = 1$, *p-value* $= 0.08$) or % occupation ($r_s = 0.8$, *p-value* $= 0.33$). (see Supplementary Materials Table S5.2 and Table S5.3.: Annex D).

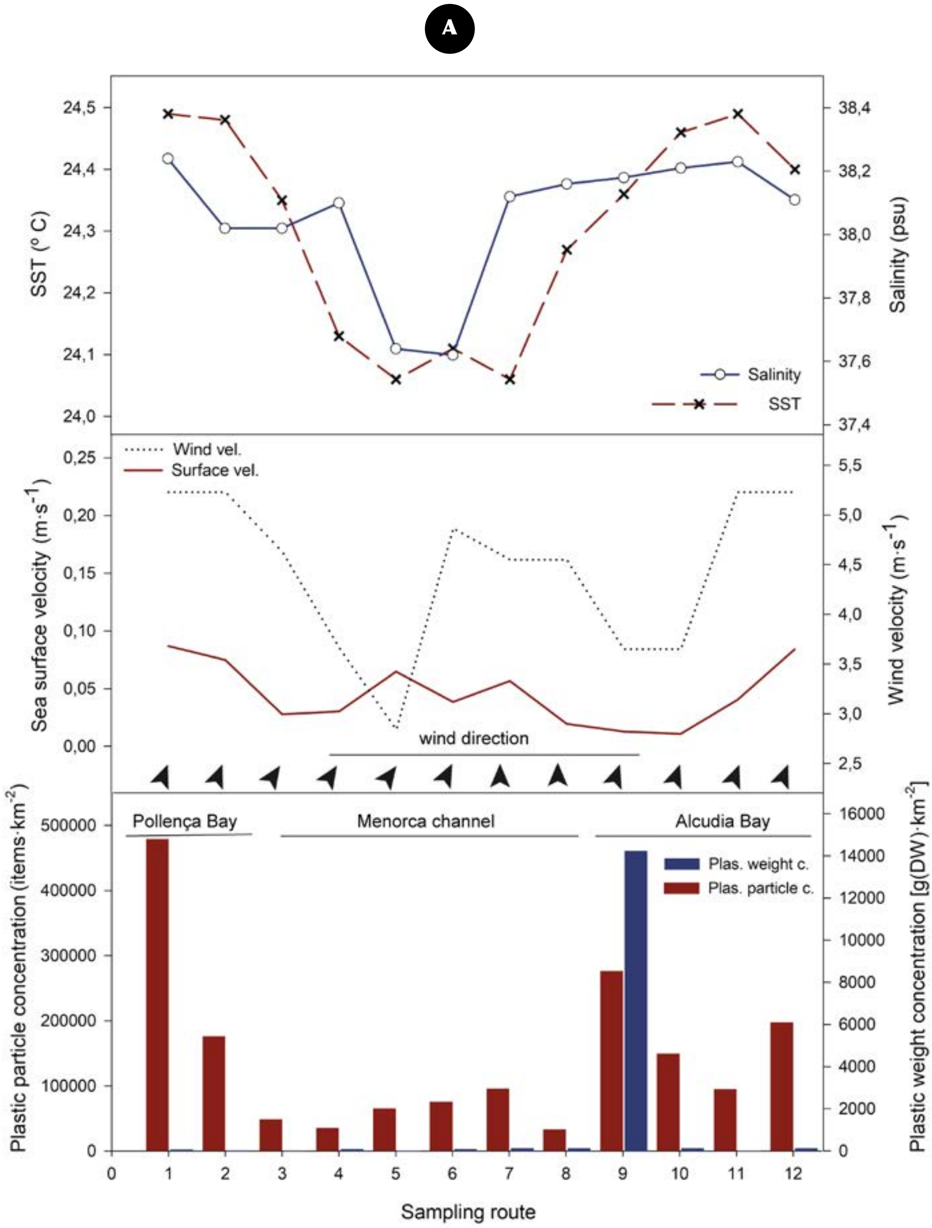


Figure 5.5. Oceanographic variables and plastic concentration in the Menorca Channel. *Plastic weight concentration [g(DW)·km^{-2}] and plastic particles concentration (items·km^{-2}; wind-mixing corrected values) are placed according the sampling route (Supplementary material Figure S5.1, Annex D). Data for the oceanographical variables: SST (°C), Salinity (psu), sea surface velocity (m·s^{-1}) and wind velocity (m·s^{-1}; U_{10}) were extracted from CMEMS (http://marine.copernicus.eu) database averaged for the sampling previous week (8 days). (A) correspond to autumn, (B) winter, (C) spring and (D) summer samplings.*

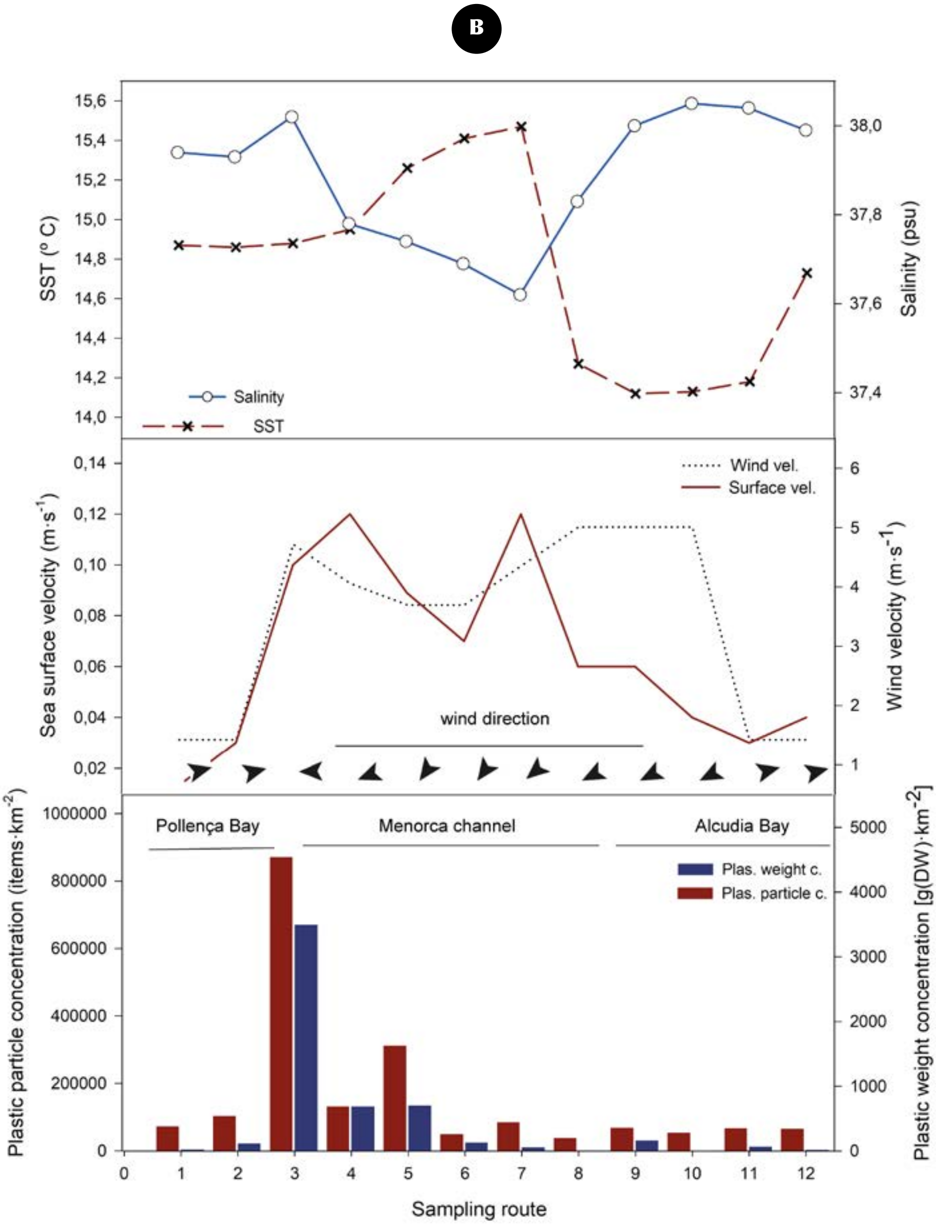


Figure 5.5. (continue)

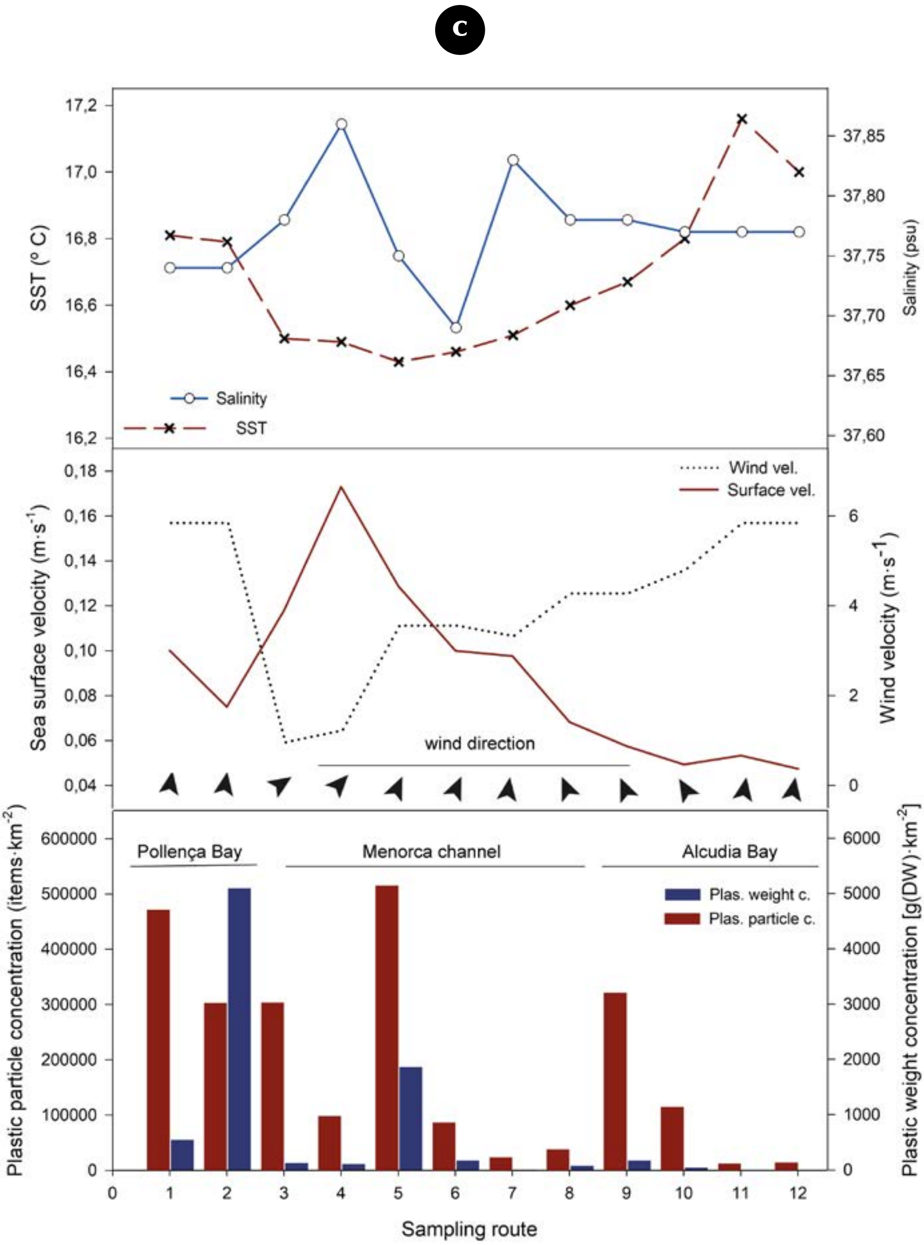
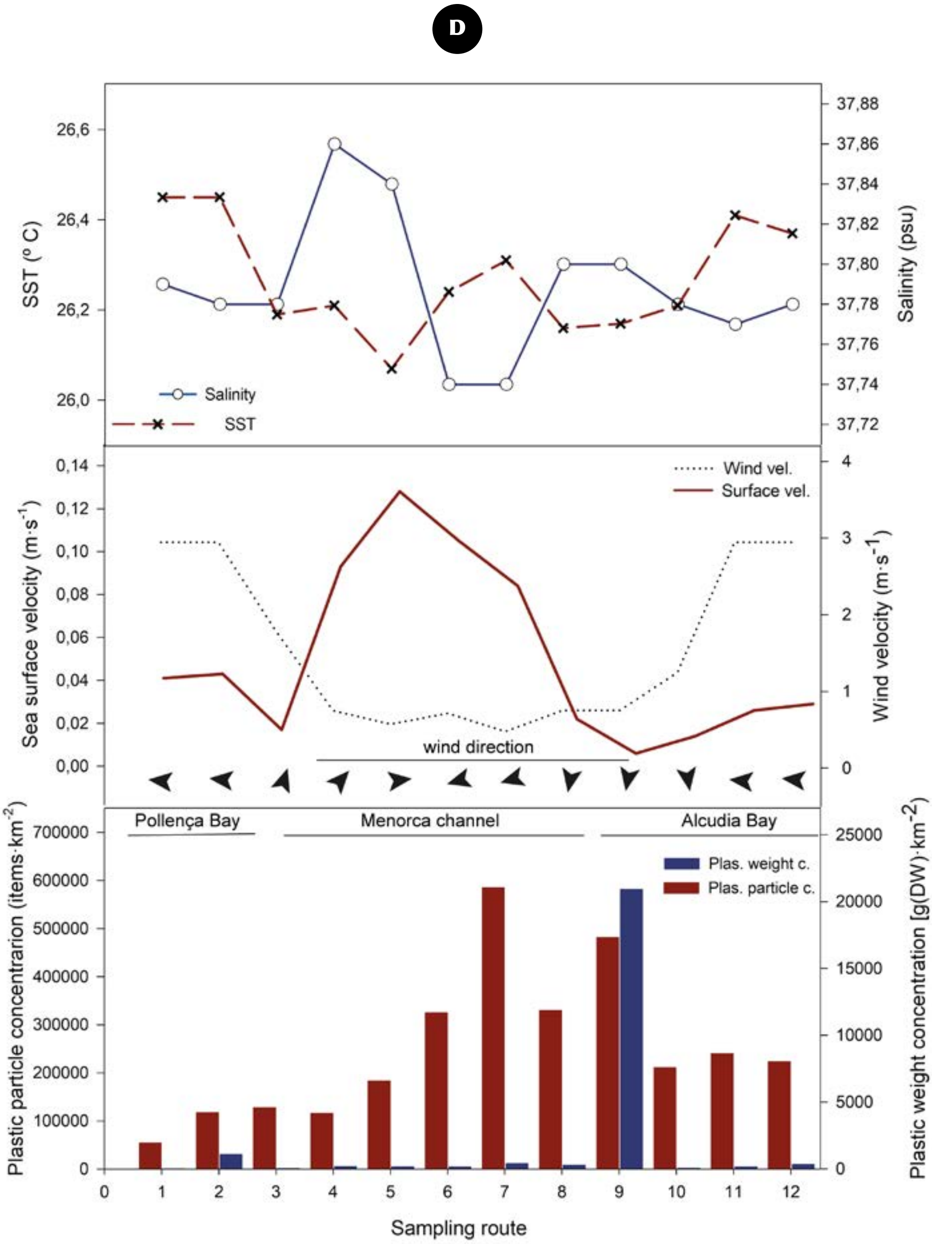


Figure 5.5. *(continue)*



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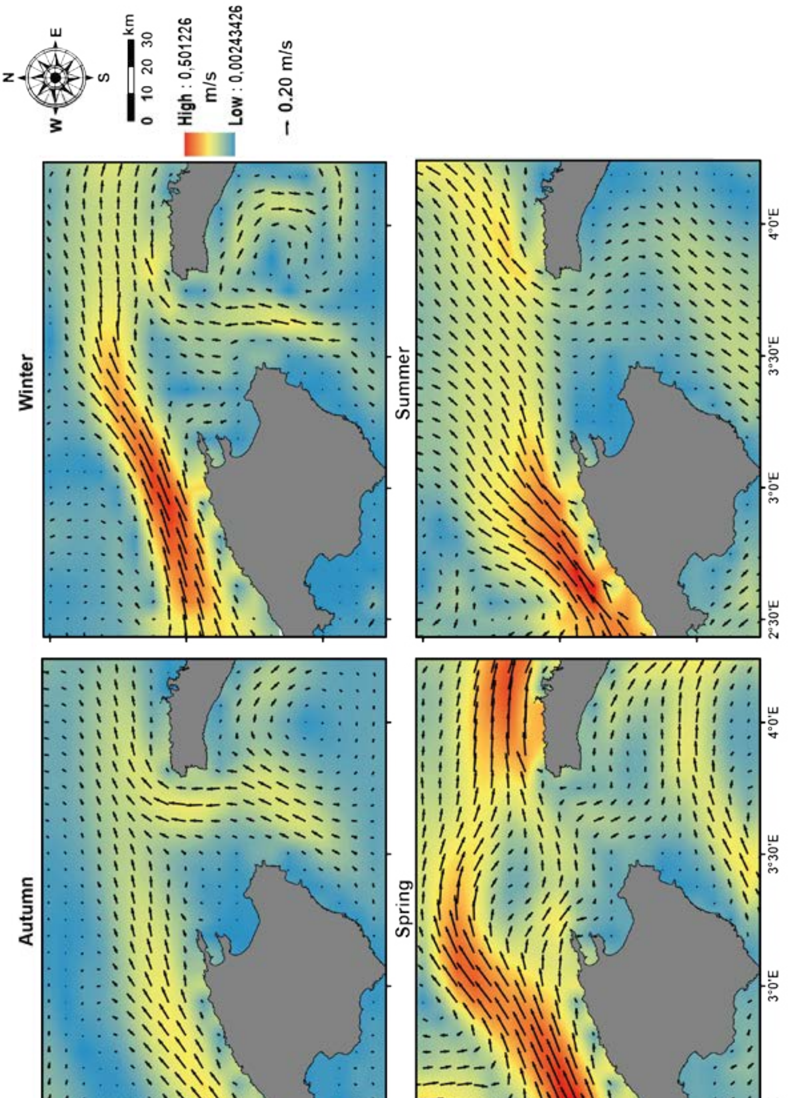


Figure 5.6. Main surface circulation in the Menorca Channel. *Maps from each season Autumn (2014), Winter (2015), Spring (2015) and Summer (2015). (This page) Mean surface velocity, units in are m·s^{-1} and the vectors indicated the magnitude and direction of surface currents. (Next page) Mean Kinetic Energy (MKE), units are in cm^2·s^{-2}. Daily data were extracted from CMEMS (http://marine.copernicus.eu) database averaged for the previous sampling week (8 days, see also section 2.4 of methods – Chapter 2). The results were smoothed to increase the initial spatial resolution (1/16°). BC corresponds to the Balearic current or Balearic front.*

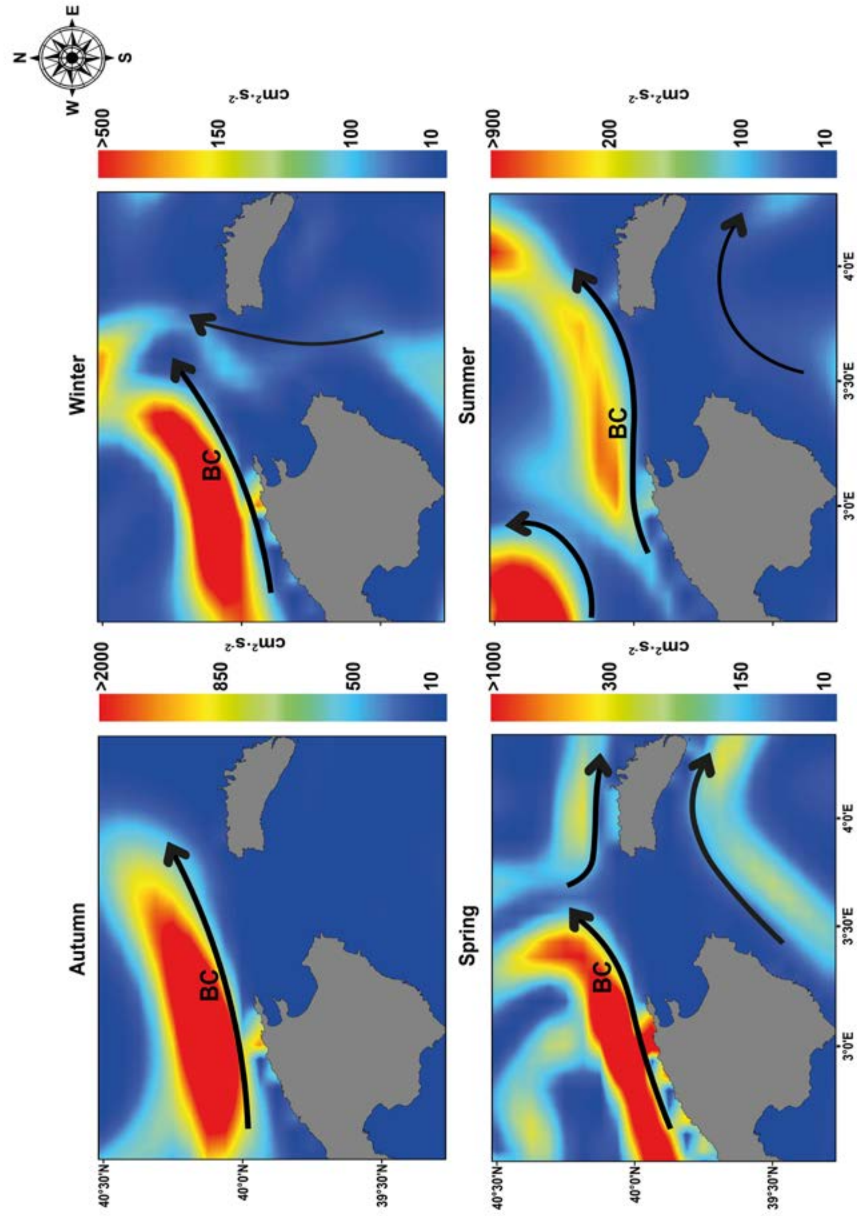


Figure 5.6. (*Continued*)

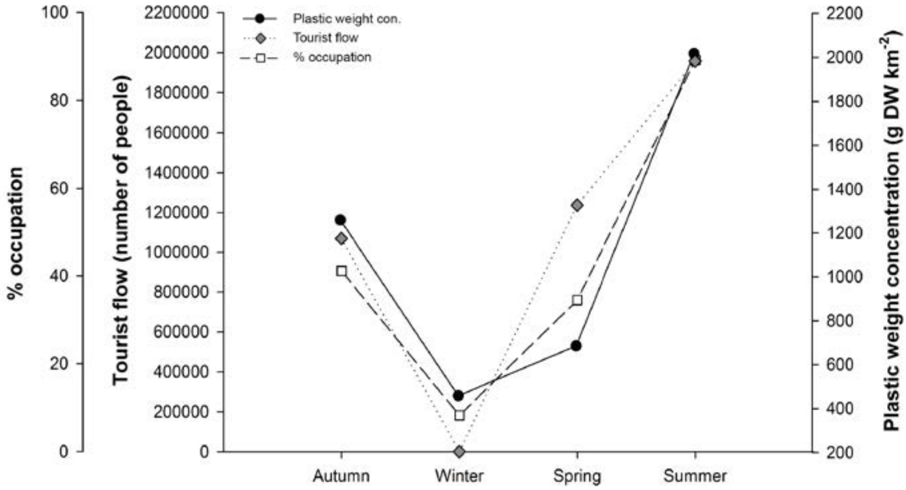


Figure 5.7. Seasonal changes in the average of weight plastic debris in relation to tourism. *Plastic weight concentration [g(DW)·km^{-2}] is represented in black circles. Tourism is represented in two forms during the months of sampling (source: IBESTAT, 2016); the first, represents the influx of tourists entering in the islands of Mallorca and Menorca (squares) and the second, is the percentage of hotel and apartment occupation (diamonds) in the municipal tourist areas surrounding the study area: Pollença, Alcúdia, Muro, Sta. Margalida, Artà and Ciutadella.*

Floating plastic composition

The total number of floating particles yielded 6,698 items of which 888 items were obtained in autumn, 1,104 items in winter, 1,958 items in spring and 2,748 in summer. Plastic fibers were removed and not considered in the study, due to the possible risk of contamination. Hard fragments predominated during all the seasons of the year totaling around 90% of all plastics (Figure 5.8); although, differences were detected between autumn-winter and summer seasons through Kruskal-Wallis test (H (3) = 10.04, *p-value* = 0.018). In contrast, foamed fragments and industrial pellets had their peak abundance in winter (6.61% and 0.72%, respectively) but only seasonal differences were found with foamed fragments (H (3) = 8.47, *p-value* = 0.037). There were two peaks of film fragments in the autumn and summer seasons with an abundance declined during winter and spring (H (3) = 11.51; *p-value* = 0.009). Fishing lures and lines showed a stable concentration along the seasons analyzed, while bottle and caps were not obtained during the throughout the sampling periods.

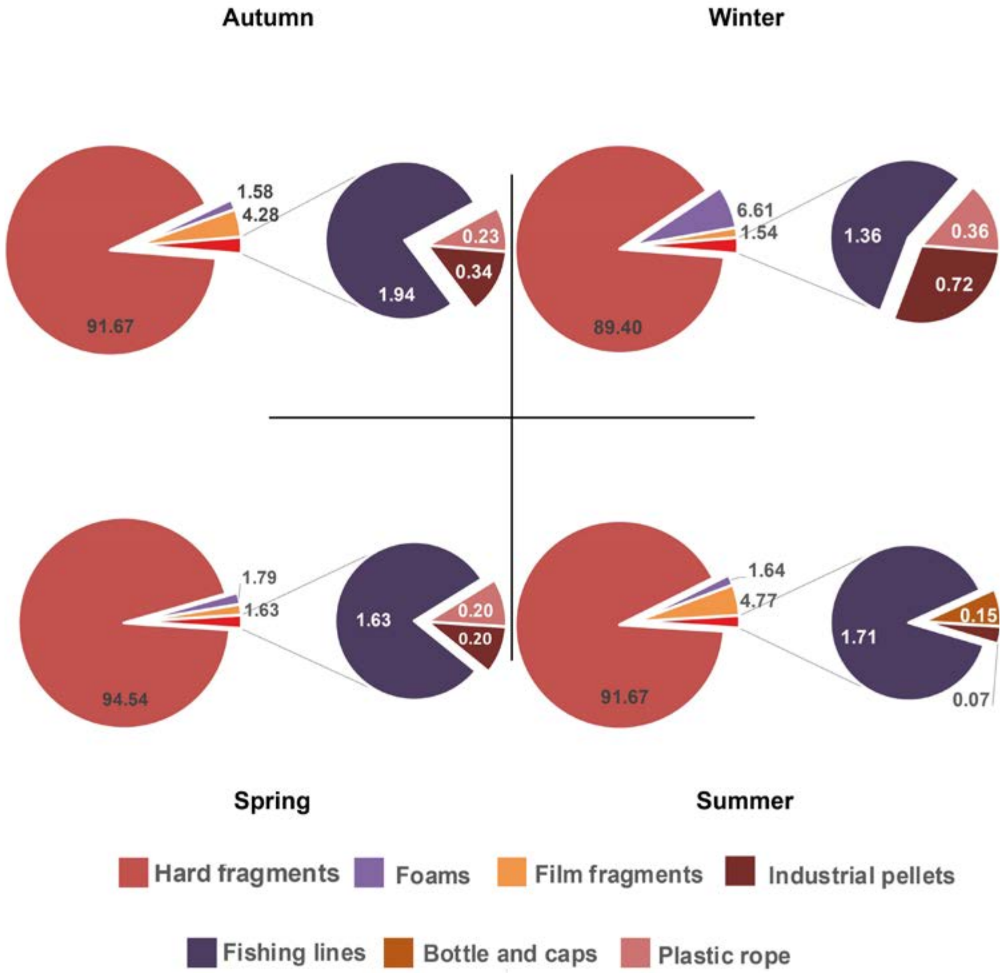


Figure 5.8. Seasonal plastic composition of all particles (n = 6,698).
Values are expressed in percentages.

PCA analysis produced two-dimension pattern, whit the two first component accountings for the 61.39% of the total variance (Figure 5.9). Despite the overlapping between seasons due to their high degree of similarity in plastic composition, the results reaffirm the seasonal differences. The larges separation occurred along PC1 axis, defined by the hard fragments (0.59), fishing lines (0.53) and film fragments (0.52). Instead, foam fragments (0.66) and industrial pellets (0.63) determined the separation throughout the PC2 axis.

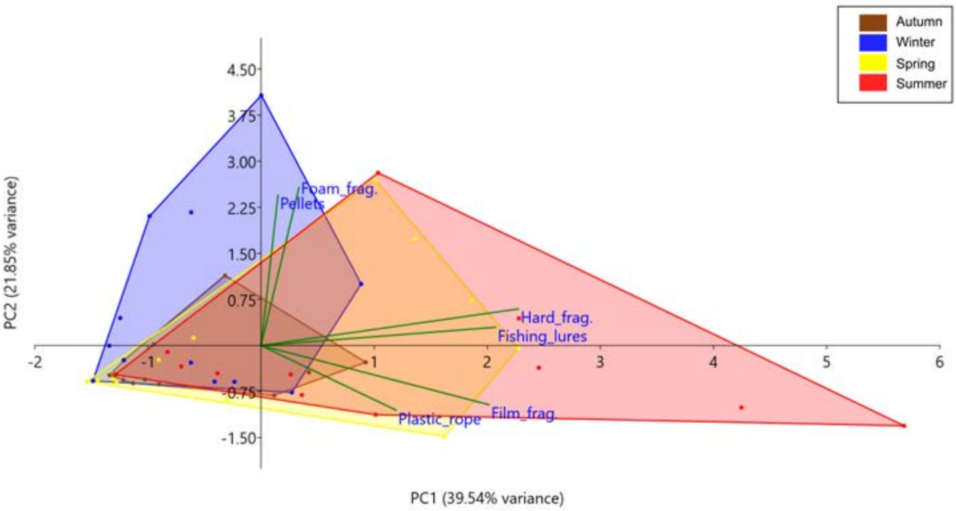


Figure 5.9. PCA ordination based on the seven plastic debris items categories. *The 48 samples divided into four seasons analyzed (12 samples each season) are plotted, showing the first two principal components (PC1 and PC2). Colors represent the season samples (brown = autumn, blue = winter, yellow = spring, red = summer).*

Floating plastic size distribution

In terms of size distribution, microplastics were the most abundant particles in each season (autumn: 95.99%; winter: 95.45%; spring: 96.72% and summer: 95.99%). In the Menorca Channel, we observed a significant correlation between some plastic sizes along the seasons (Table 5.5), but the strongest correlation was revealed among meso- and microplastics during spring ($r_s = 0.711$; *p-value* = 0.01). Particle concentration was strongly weighted by the number of microplastics, encountering their maximum in spring when the vertical correction of the particles was applied (Figure 5.10 A-B). In contrast, the maximum values of weight concentration were found both in autumn and summer by the greater contribution of the macroplastics (Figure 5.10 C).

The analysis of plastic sizes showed similar distributions between the different seasons (Figure 5.11 and Figure 5.12). However, the composition of surfaces was unstructured with numerous gaps in their distribution than in the Balearics and Mediterranean campaigns. Particles smaller than 100 mm^2 showed a relative predominance during the summer of 2015; while sizes larger than this were more abundant in the autumn-winter and in spring with the largest surface size. When compared with data taken from the Mediterranean, the relative distribution of smaller surface areas was similar, with a lower abundance of larger sizes in the Mediterranean data; while the Balearic Islands campaign, showed the highest number of particles smaller than 150 mm^2 from which, it begins to decrease below the values obtained in the seasons from autumn to spring in the Menorca Channel.

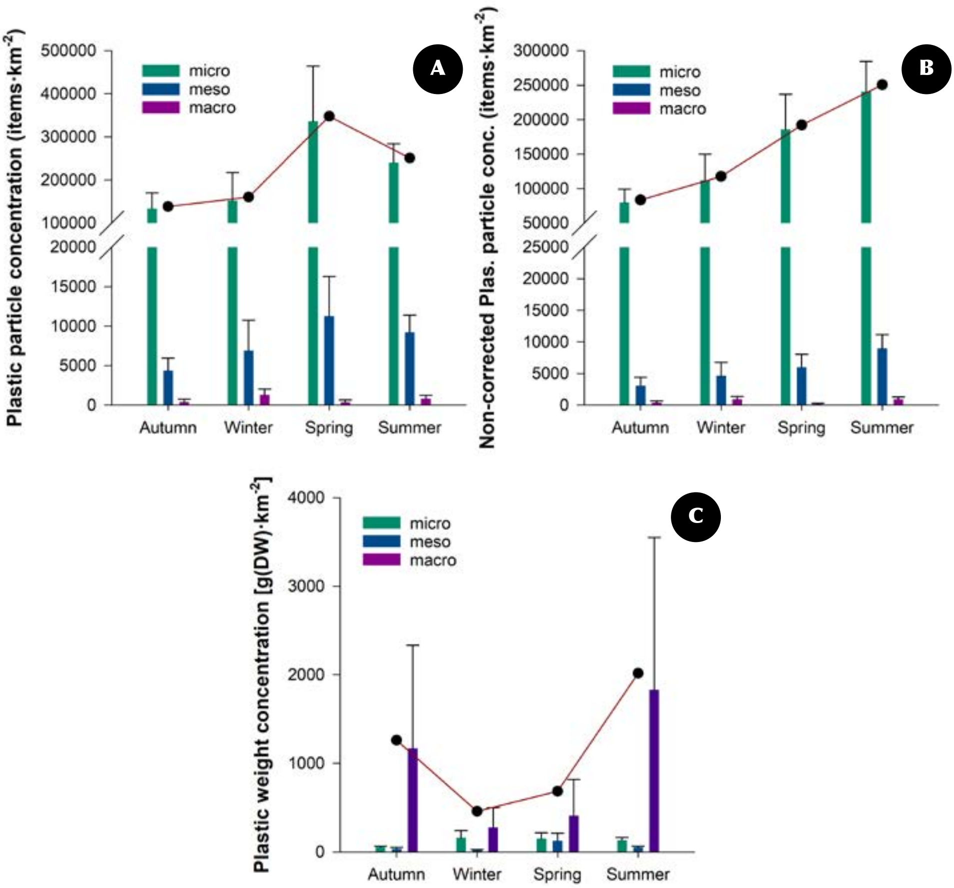


Figure 5.10. ***Seasonal concentration of plastics in the Menorca Channel.*** *(A) particle concentration (items·km^{-2}), (B) particle concentration (items·km^{-2}) without correction for wind vertical mixing and (C) weight concentration [g(DW)·km^{-2}]. Red line and black dots represent the total average concentration of each season. Micro, meso and macro sizes represent the following ranges: < 5 mm, 5 – 25 mm and 25 – 1,000 mm, respectively.*

Table 5.5. Results of Spearman correlation between the size of the plastic particles. *r_s is the value of Spearman correlation. Significant values (p-value < 0.05) are represented in bolds.*

			Microplastics	Mesoplastics	Macroplastics
Autumn	Microplastics	r_s			
		p-value			
	Mesoplastics	r_s	0.376		
		p-value	0.228		
	Macroplastics	r_s	0.522	**0.611**	
		p-value	0.228	**0.035**	
Winter	Microplastics	r_s			
		p-value			
	Mesoplastics	r_s	**0.579**		
		p-value	**0.048**		
	Macroplastics	r_s	0.513	**0.636**	
		p-value	0.088	**0.026**	
Spring	Microplastics	r_s			
		p-value			
	Mesoplastics	r_s	**0.711**		
		p-value	**0.010**		
	Macroplastics	r_s	0.324	0.033	
		p-value	0.304	0.918	
Summer	Microplastics	r_s			
		p-value			
	Mesoplastics	r_s	**0.586**		
		p-value	**0.045**		
	Macroplastics	r_s	0.434	0.409	
		p-value	0.158	0.187	

The overall size length revealed a prevalence of microplastic fraction over the seasons sampled (Figure 5.13). The maximum abundance was observed around particles of 0.7 mm but more pronounced during the fall. Particle size larger than 50 mm were observed in all seasons. However, there was a change in the trend of size distribution with an increase in macroplastic abundance during the autumn and a rapid decrease during the rest of the seasons.

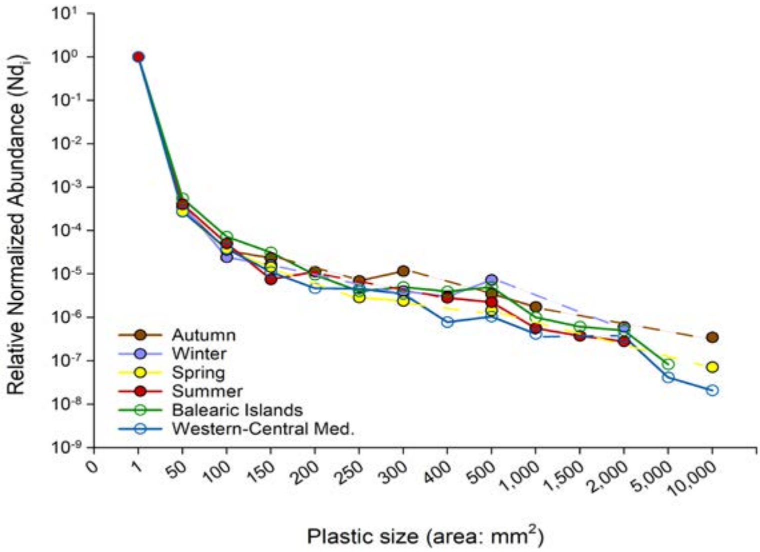


Figure 5.11. Surface size distribution of floating plastic particles collected in the Menorca Channel surveys. *Filled dots represent the data measured in the Menorca Channel (n = 4,698). Unfilled dots are the data reported from the Mediterranean survey by Ruiz-Orejón et al. 2016 (unfilled blue dots) and from the Balearic Islands survey (unfilled green dots - Chapter 4). Primary vertical axis is in logarithmic scale.*

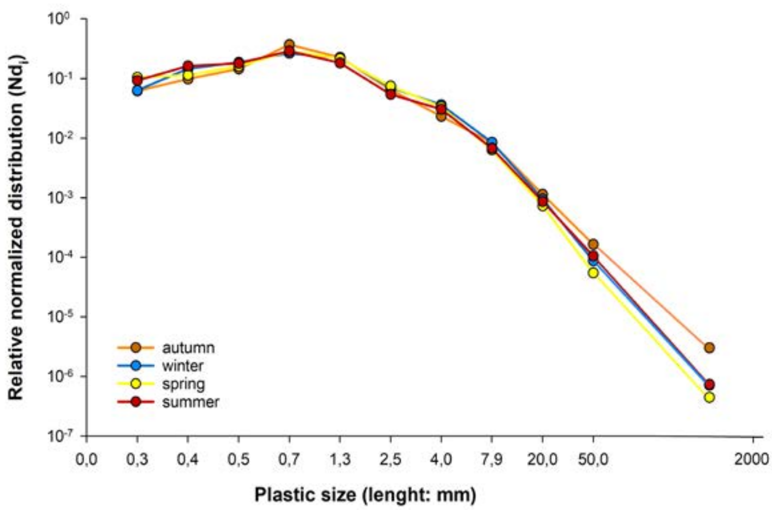


Figure 5.12. Seasonal size distribution according size length of particles. *Normalized abundance values were obtained dividing the number of particles counted (n = 3,632) in each size class (horizontal axis). Vertical axis is in logarithmic scale.*

5.3. Discussion

During last decades plastics have gone from being one more pollutant within the marine litter to being an emerging threat and the most frequent waste in the marine environment (e.g. Avio et al., 2016; Depledge et al., 2013; UNEP/MAP, 2015; UNEP, 2009). Besides this growing, there is a knowledge gap about spatial-temporal distributions and the effects of this man-made compound in many of the marine protected areas of the Mediterranean. The results of this study provide initial insights about variations of floating plastic pollution by reporting spatial and seasonal distributions in the current marine protected area of Menorca Channel.

The data obtained confirm the persistence of plastics and particularly microplastics in the Menorca Channel throughout the year. Floating plastic concentrations showed variability between the seasons sampled with an increase in particle density during spring and summer, similar to that reported in other areas of the Mediterranean (van der Hal et al., 2017). When compared to other MPAs in the Mediterranean, the average of particle concentration found in the Menorca Channel, during the autumn and winter season were comparable to the latest volume particle concentration data reported in the *Pelagos* Sanctuary MPA in the Mediterranean Sea (0.31 items·m^{-3}; Fossi et al., 2016); although, during spring and summer, values found in the Channel even rise by an order of magnitude. However, the presence of mesoplastics was lower throughout the sampled seasons than those observed in this other Mediterranean protected area (12,600 items·km^{-2}; Fossi et al., 2017).

The Mediterranean region is characterized by high spatial and temporal variability in its surface currents that could affect the distribution of floating plastic particles and could limit the formation of stable areas of plastic accumulation (e.g. Cózar et al., 2015; Mansui et al., 2015; Pedrotti et al., 2016; Zambianchi et al., 2017). The seasonal variability of currents observed in the Menorca Channel (Figure 5.7) seems to directly influence the plastic distribution in the channel, mainly due to the fronts and mesoscale regime occurring to the north and south of the channel; which have particular relevance at lower scales (Maximenko et al., 2012; van Sebille et al., 2012). In this sense, the concentration of the floating plastic in this area did not show significant seasonality in accumulation patterns; nevertheless, this low energetic zone favored the increase (in absolute values) of floating particles throughout each year season analyzed.

The concentrator and dispersant effects of surface circulation have been previously reported in prevalent frontal systems in the Mediterranean (e.g. Fossi et al., 2017; Pedrotti et al., 2016; Chapter 4). The exchange in the surface circulation between the Balearic density Front, which is reinforced with the inputs of the new Atlantic Waters (AW) through the Ibiza and Mallorca Channels (Balbín et al., 2014; García-Ladona et al., 1996; Pinot et al., 2002; Ruiz et al., 2009), and the mesoscale currents from the Algerian sub-basin, produced differences among the north and south of the Menorca Channel at intra-seasonal level. The interaction of both north-south circulations favored the difference in the seasonal plastic accumulation, which suggests a greater presence of particles in the north of the Channel when the Balearic Front is highly energetic as opposed to the accumulation of particles in the south when it is weaker. However, the periods with limited interaction where the Channel is formed as a low-energy area that favors the retention of particles in the bays of *Pollença* and *Alcúdia*.

In addition to the hydrodynamic effects, the Balearic Islands are subjected to a high seasonal anthropic pressure in their coasts. Tourist occupation in the Channel zone mirrored weight concentration accumulation, especially in the macroplastic fraction, suggesting the entry of these items from land-based sources to marine ecosystems. Similar trends, in terms of litter abundance, have been reported on the beaches of the Balearic Islands (Martinez-Ribes et al., 2007), but due to the transport and the degradation processes that can undergo the plastics until its arrive at the sea surface, weight concentration seems to be better described by the seasonality of the human pressure present in the Channel even though there may be other influential variables (e.g. maritime traffic or hydrodynamic conditions).

In this sense, between 89.40% (winter) and 94.54% (spring) of the analyzed plastics were composed of hard fragments predominating in all seasons. Similar proportions have been found in the Balearic Islands (Chapter 4) and in several surveys in the Mediterranean sea (Pedrotti et al., 2016; Ruiz-Orejón et al., 2016; Suaria et al., 2016). Surprisingly, during the autumn and summer season, we observed a considerable increase of the film fragments. The material of these fragments is more frequently "consumed" in coastal ecosystems during summer seasons, through products from industry (e.g. snack and cigarette packaging) along with the "home-made packaging" (e.g. sandwich wrap), which increase and the coastal distance suggests a land-based origin. The influence of other factors (e.g. maritime traffic, rainfall events) could not be addressed in this study, although these factors may also be influencing the variability of the concentrations obtained (e.g. Lebreton et al., 2012; Sharma and Chatterjee, 2017; UNEP/MAP-Plan Bleu, 2009).

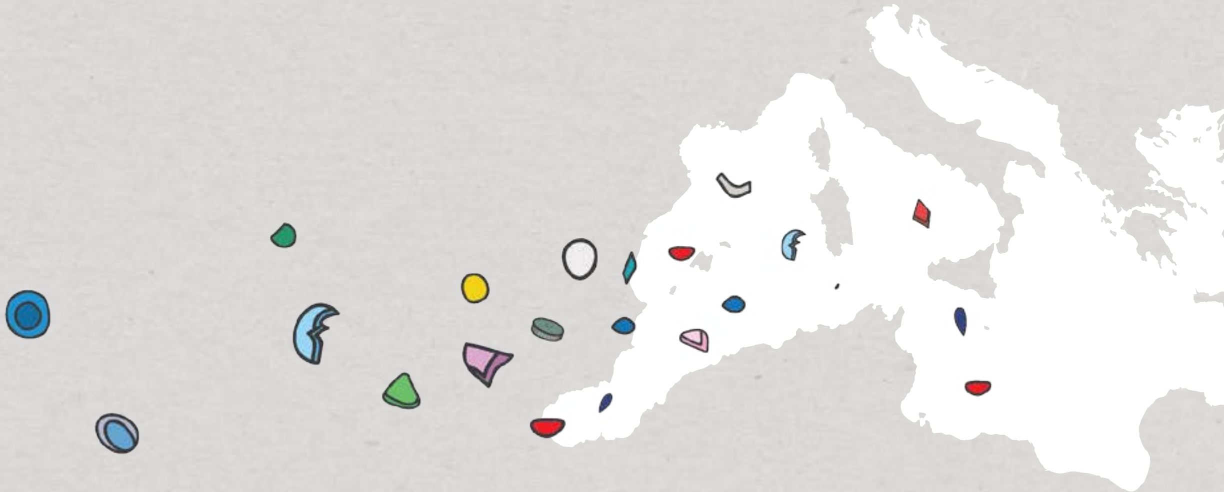
In general, size distributions followed a structure similar to the Balearic Islands and the Mediterranean campaigns (Ruiz-Orejón et al., 2016). Suaria et al. (2016) did not observed a removal of small fragments from the surface, our results tended to stabilize in the smaller sizes (particularly in spring and summer) suggesting a similar distribution despite differences in sampling. Contrary to expectations, the presence of larger plastics was lower in the summer seasons comparable to spring and winter seasons. This could suggest that the removal of surface wastes carried out by the coastal cleaning service operating in the Balearic Islands, which are mainly focused on the removal of these waste sizes during the summer season, could involve the rapid increase of large plastics after cessation of this activity even though anthropic pressure is still high. The cleanliness as a fundamental factor to achieve the influx of people to the beach (Ballance et al., 2000) and the importance of the Balearic Islands as a tourist destination (Garín-Muñoz and Montero-Martín, 2007; UNWTO, 2015), influence the presence of this service only during the summer season. Although, other variables that could be influencing the distribution of floating plastics (e.g. marine traffic or pluviometry) were not considered here.

Finally, the remaining sample composition reveals an inverse accumulation between the plastic and the animal and vegetal groups. Storm events (more frequents in winter) could cause damage to the marine flora (i.e. seagrass) (Cabaço et al., 2008; Larkum and West, 1990), that might suggest a higher concentration of vegetal debris on the sea surface during winter seasons over the spring and/or summer seasons.

5.4. Conclusion

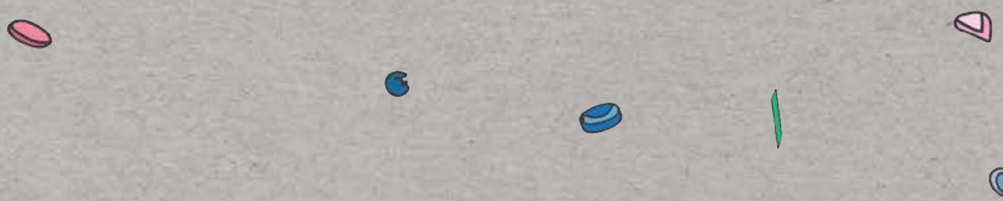
The present work provides the first spatial-temporal data of floating plastic debris in the Natura 2000 Marine Protected Area of the Menorca Channel. The Channel represents a marine protected area that counts on a great diversity of habitats and species, among which there are 58 protected species (Barberá et al., 2014). However, the proximity to the coastal areas of Mallorca and Menorca islands, with a strong population seasonality along with coastal recreational activity, commercial fishing and an intense maritime traffic, expose it to a high anthropic pressure that favors plastic litter entering the coastal waters and variability in its compounds. In addition, the circulation patterns in the canal appears to regulate the distribution and dispersion periods of floating plastics in the Menorca Channel. This result in higher concentrations than other MPAs in the Mediterranean that require some type of manage action. Better knowledge of long-term spatial and temporal patterns together with the sources, sinks and the input processes to the marine environment are urgently needed in the Mediterranean seas, and particularly in the marine protection areas in order to improve management of risks.

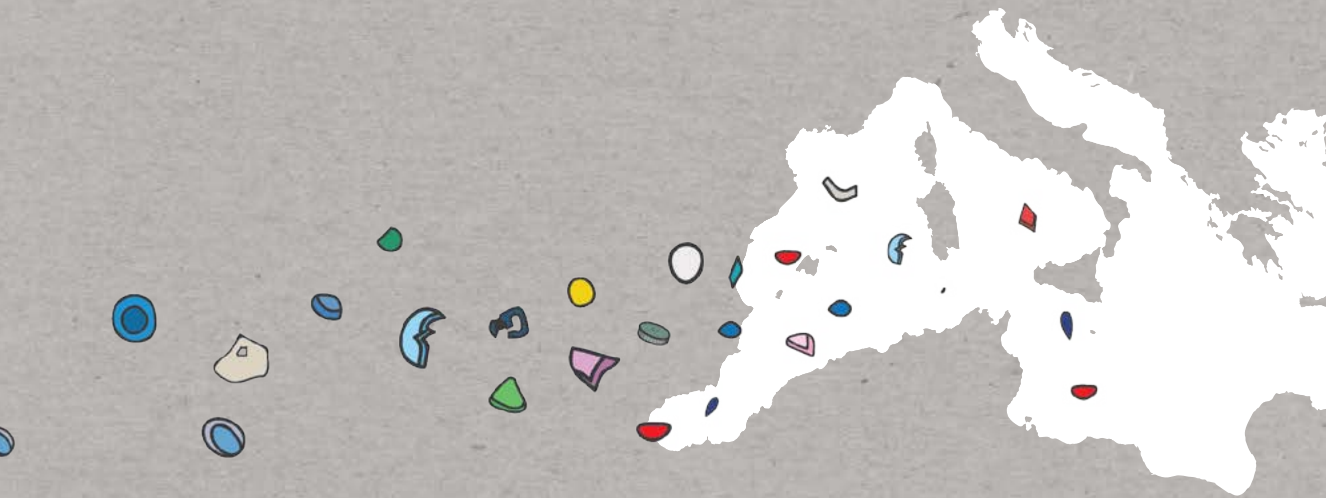
Back into the early XX Century, today UNESCO World Heritage "*Serra de Tramuntana*", started to be protected from forest overexploitation by Archduke Ludwig Salvator. Solving environmental problems today requires the spirit of the Archduke as protectionist should always be present for a correct natural functioning of the Balearic Islands and their marine protected areas.



Part II

The Social dimension





Chapter 6

General methods of the social dimension

6.1. Introduction

The second part of the methodology focuses on the description of the processes carried out to analyze the social perception and awareness of people in relation to plastic litter. This chapter will be divided into two main sub-sections reflecting in its first part, the methods used for the qualitative analysis of key stakeholders in Mallorca (Chapter 7), while the second part will be devoted to exploring the public perception of beach users (Chapter 8).

6.2. Qualitative mixed-methodology

The qualitative research analyzes thoughts and social behaviors in depth, with particular relevance on emerging issues (Pahl and Wyles, 2017). In this study, the inductive empirical approach was based in a mixed-methodological approximation to build theory (Eisenhardt, 1989; Weick, 1989).

6.2.1. Focus groups and participants

The qualitative approach was presented as the most useful technique for eliciting elaborate answers about the plastic pollution problem. This approach allowed us to construct the own participants' consensual insights (Bryman, 2015). In order to conduct the analysis, a focus group technique was

Table 6.1. Demographic details of participants.

ID	Area of work	Age	Sex
Focus Group 1 - Experts			
SN1	Geography researcher	36-45	Male
SN2	Marine ecology researcher	26-35	Male
SN3	Environmental consultant	46-55	Male
SN4	Marine ecology PhD student	26-35	Female
SN5	Oceanography and ecology researcher	46-55	Male
SN6	Environmental NGO volunteer	36-45	Female
SN7	Marine litter PhD student	26-35	Female
SN8	Field civil engineer	36-45	Female
Focus Group 2 - Public administrations			
PA1	Local administration	26-35	Male
PA2	County administration	46-55	Male
PA3	Local administration	46-55	Female
PA4	Regional administration	36-45	Female
PA5	Regional administration	36-45	Male
PA6	Local administration	36-45	Male
PA7	Local administration	36-45	Female
Focus Group 3 - Companies			
C1	Food industry	36-45	Female
C2	Hostelry	26-35	Male
C3	Aeronautic sector	46-55	Female
C4	Waste management sector	36-45	Female
C5	Waste management sector	36-45	Male
C6	Food industry	46-55	Female

used following the recommendations of Krueger and Casey (2014) and Morgan and Krueger (1998). This technique is widely used in social research because it allows to capture and verify changes of insights among the participants, as well as, the complexity in the formation of their own opinions (Anderson et al., 2016).

The research collected the perceptions of 21 volunteers (11 females, 10 males; see Table 6.1) during the summer of 2015. The participants were grouped into three different focus groups: 1) Scientists and NGOs (henceforth experts), 2) Public administrators and 3) company agents. All of them representing Mallorcan stakeholders with influence in different decision-making processes. Mixed groups were avoided to ensure a calm atmosphere and an active participation among members. They were randomly recruited from a database generated from the institutions and/or people related to the subject (e.g. environment department of a town hall). At each focus group, participants were briefed and lead by an experienced moderator and an assistant about the aim of the research.

6.2.2. Data gathering details

Each focus group lasted half a day (i.e. around 4 – 5 hours), where the sessions were divided into two parts and the participants expressed themselves freely, including open discussions (Krueger and Casey, 2014). The first part was focused on the generation of data related to the first research question: the main problems generated by plastics. An example of scenario was used to start the session. However, the experimental stimulus was determined by the participants' own observational experiences, which were shared and described with the group to favor the diversity of scenarios. Affinity Diagram or KJ method was developed by the participants themselves to organize and relate the data generated (Foster and Ganguly, 2007; Scupin, 1997). A mental map was developed for each group to make sense and facilitate the representations of the themes emerged from participants, based on entrepreneurship models (Verstraete, 1996).

In the second part, a free brainstorming was conducted to ensure the elicitation and contextualization of all factors related to the main issue (Lee et al., 2015) and which could have been limited by the volunteers' own observations. Participants were asked to explore all problems perceived that plastics could generate until the saturation limit was reached (i.e. the frequency of participants' input decreases around 1 – 2 per minute). These data will be used to corroborate the results obtained from the affinity diagram.

6.2.3. Procedure

The following steps were performed to carry out the two analysis according to the snow card technique (Figure 6.1): 1) clear and concise briefing of the procedure to the members; 2) give a supply of "memo stickers", pen, introduce the open-ended question, and the example scenario in the case of affinity diagram; 3) ask the participants to write it down three of four own stimulus related with the problem; only one stimuli per sticker; 4) each participant present their stimulus to the rest of volunteers and paste the sticker on a board; 5) let the participants move the stickers into affinity groups and encourage the debate among members; 6) when all the stickers are grouped and the participants reach a consensus, a title for each sticker group is requested to the members. Asked the participants if it is possible to create a higher category group joining several previous affinity groups; 7) Vote the most important sticker groups avoiding prior discussion between members. 8) Draw cause-effects relationships between affinity groups and ask volunteers for a final sentence to answer the initial open-ended question based on the exercise.

6.2.4. Data analysis

Content analysis method was used to analyze the content and develop the different themes and sub-themes emerging from the study (Hsieh and Shannon, 2005) in each session. The sessions were audio recorded, transcribed (see Supplementary Materials Text S7.1; Annex 7) and coded. Data were compared between the affinity groups emerged in the focus groups, fieldnotes and literature to obtain a general combined perception of the problem. First revision was independently carried out by two reviewers, adding codes and creating themes from the categories. They subsequently met to compare and discuss the codes, categories and themes to resolve inconsistencies and reach a consensus were all focus groups were included. Final revision was completed by the two reviewers using the consensus themes and results were combined for a final interpretation of the data. Situational and relational analysis was also conducted in order to establish the context of reference of the study (Yin, 1994).

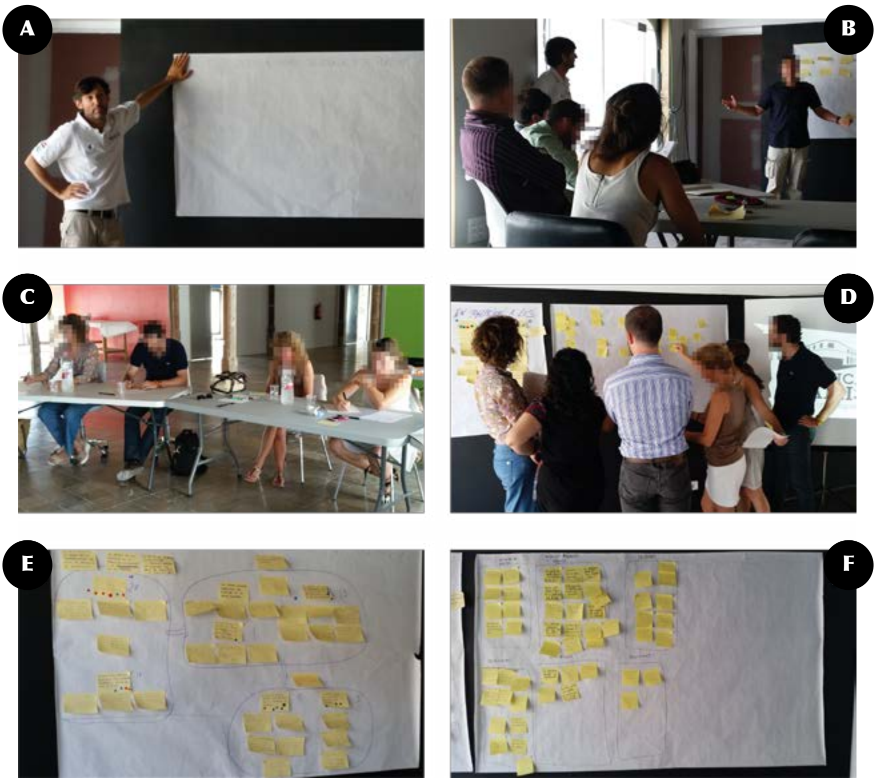


Figure 6.1. Focus groups sessions. *(A) Briefing session, (B) participant explaining his point of view, (C) participants writing down their perceptions in the first part of the focus group session, (D) discussion and classification of perceptions among participants, (E) result of the first part of the session and (F) result of the second part of the session (free brainstorming).*

6.3. Beach users' perception

6.3.1. Survey and procedure

To assess public perceptions regarding plastic pollution impacts a survey was carried out during July and August 2015 across ten beaches of Mallorca (Spain). The survey was based on a self-administered questionnaire to favor user's motivations. Three interviewers covered the total surface of the beaches during the period of the day with the higher influx of people on the beach (10:00 am – 6:00 pm), explaining the questionnaire objective and structure to respondents (Figure 6.2). In response to the high presence of international tourist, the questionnaires were distributed in both English and Spanish. A total of 15 questions were adjusted to a maximum of 15 minutes of response time. Respondents were at least 15 years old and were randomly selected ensuring the maximum diversity (i.e. gender, age, studies, activity). The surveys maintained the confidentiality of respondents.

6.3.2. Survey questions

Questions were prepared from previous assessments (e.g. Eastman et al., 2013; Jakovcevic et al., 2014; Santos et al., 2005), supplemented with themes reported in literature (e.g. Andrady, 2011; Andrady and Neal, 2009; Barnes et al., 2009; Thompson et al., 2009). Several questions were introduced based on the specific needs of the study. Survey were grouped into five main sections: (1) a section to define the initial cognitive knowledge of respondents based on the free word association (Donoghue, 2000) and semantic differential technique (Osgood, 1952; Osgood et al., 1957); (2) perception assessment, including impacts, causes, awareness, state and evolution of the plastic problem; (3) a section that assesses users' attitudes towards scenarios related to plastic litter; (4) motivation and information questions; and (5) classification variables to define the users' profile. Most of the questions avoided unidirectional responses (e.g. Yes/No questions) through a ten-point likert-scale approach and a "No Answer" option.

Figure 6.2. Example of interviewers explaining and preparing the questionnaire.

6.3.2.1. Cognitive questions

Two questions evaluated the initial approach of the respondents to the concept of "plastic". The first question was based on the free association word (e.g. Donoghue, 2000), as previously stated, which tries to obtain the first cognitive relationship with the word offered. In the second question, four pairs of polar adjectives were used to measure the degree of association of these adjectives with the selected concept, through the semantic differential technique (Osgood, 1952; Osgood et al., 1957).

6.3.2.2. Perception and awareness questions

Questions were defined to assess plastic debris causes and consequences in the different dimensions of the social-ecological systems, covering social, economic or plastic properties; as well as impacts on different types of ecosystems, human health and effects on leisure or economic sectors. In addition, questions were added regarding the association of plastics with coastal environments, as well as the general assessment of the state and evolution of Mallorca's beaches.

6.3.2.3. Attitudes and Motivations questions

Statements were selected to evaluate the attitudes about the plastic packaging and the presence of plastics in the environment, based on the degree of agreement of respondents on several affirmations.

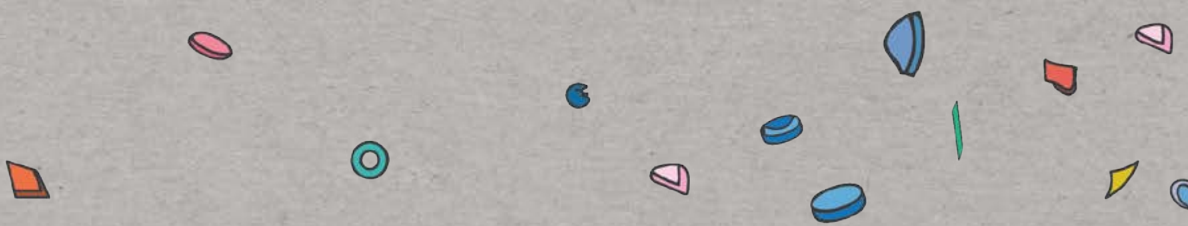
In order to evaluate the motivations of the respondents, they were previously asked about the evaluation of the information received from public administrations and companies on the management and processes of plastic production, respectively. Motivations were defined related to the concept of the three R's (reduce, reuse and recycle), in addition to terms on the application of normative focused on the regulation or limitation of certain aspects of plastic.

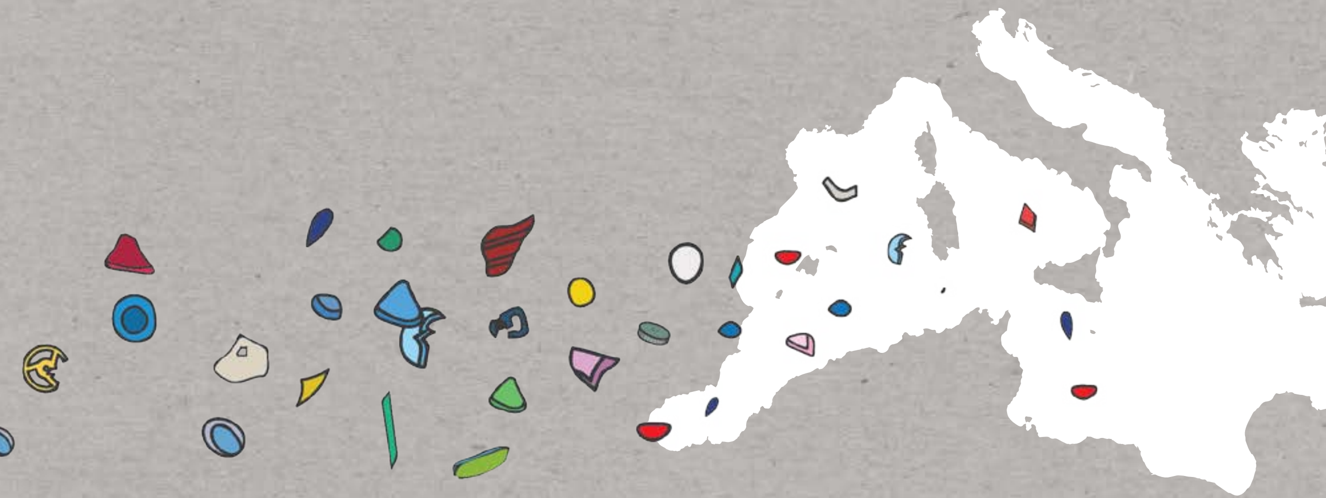
6.3.2.4. Respondent profile

We included social and demographic standard questions that ranged from gender, age, place of birth, level of education or occupation.

6.3.3. Data analysis

Users' answers were analyzed with SPSS v.23.0 and R v. 3.3.1. software. Descriptive analysis was the first step in the data exploring for each parameter. In order to prioritize the users' perception of impact and causal effects, the Total Mean Importance score (TMI) was calculated based on the category's coefficient (Lozoya et al., 2014). Chi-square tests of independence were used to compare groups in the motivations and attitudes sections, as well as in the perception of the Mallorcan coastline. Post hoc z-tests for proportions were also used in the comparisons to identify differences between users.





Chapter 7

The social dimension of the problem of plastic debris: exploring the perceptions of Mallorca's stakeholders that influence in decision-making processes

Abstract

The environmental problem of the plastic pollution has been widely studied in the last decades; however, the social analysis is still limited despite having a strong socio-economic origin. Local and regional stakeholders are crucial in the observation, decision and action within their scope of action, so their perception would facilitate understanding of the problems and develop effective measures to address them. Consequently, this study explored awareness of plastic issues in three key stakeholders focus groups: experts, public administrators and company agents from Mallorca (Spain). In-depth qualitative mixed-method analysis showed a consensus about the excess plastic used at present as one of the leading problems as well as in its social and economic origins. In contrast, during the analysis, observational differences emerged in each group suggesting the need for coordinated responses in decision-making processes that integrate the vision of social groups. This integrative research raises hypothesis and proposals to facilitate future communication and initiatives that address the plastic pollution.

7.1. Introduction

7.1.1. Background

Through the work of Archduke Ludwig Salvator of Austria, his deep interest in the analysis and observation of the Mediterranean environment is evident. The work was not only focused on environmental aspects (i.e. connotations of botany, geology, geomorphology, etc.), but it also had an extensive historical, cultural and social background based on an analysis that sought to integrate the social and ecological aspects of the study environment. At present, the integration of these aspects is once again of great importance in an attempt to achieve a better understanding of the issue when moved into its management processes.

Plastic pollution has emerged in the last decades as one of the main issues for the oceans with increasing concern, based on the scientific observations. The properties of plastics, such as lightweight, durability, safety or energy saving (Andrady, 2015; Andrady and Neal, 2009; Barnes et al., 2009; Hopewell et al., 2009; Thompson et al., 2009), have led to the rapid expansion since their commercialization; reaching 355 million metric tons (MT) of production in 2017 (PlasticsEurope, 2018). Although, the United Nations and recently, the World Economic Forum (UNEP, 2009, 2005; World Economic Forum et al., 2016; World Economic Forum and Ellen MacArthur Foundation,

2017) listed this pollutant as a challenge to resolve in the next years, around 4.8 – 12.7 million MT entering the ocean from land-based sources during 2010 with an upward estimate (Jambeck et al., 2015).

Plastics are ubiquitous in marine ecosystems (e.g. Obbard et al., 2014; Thompson et al., 2009b; Wright et al., 2013), where their low degradation allows them to persist for long periods of time (Browne, 2007). In the recent years, the risks of plastics are exponentially investigated (Ivar do Sul and Costa, 2014; Ryan, 2015), reporting impacts on wildlife such as ingestion, entanglement, toxicity or transport of potential alien species (e.g. Browne et al., 2013; Goldstein et al., 2012; Rochman et al., 2013; Wilcox et al., 2015; Wright et al., 2013). However, studies have also been reported on the potential impacts to human health (e.g. Galloway, 2015; Koch and Calafat, 2009; Meeker et al., 2009; Rochman et al., 2015; Seltenrich, 2015; Thompson et al., 2009a) or the coastal economies such as aquaculture, fishing, navigation or tourism (e.g. Ballance et al., 2000; McIlgorm et al., 2011; Mouat et al., 2010) or even a disadvantage in the economic revenue of specific areas (Leggett et al., 2014).

Numerous international treaties (e.g. GPA, UNCLOS or MARPOL), together with some national regulations have been developed to address the plastic debris issues. Although, still they have not shown to be effective (Gold et al., 2013). Considering the conditions and impacts generated by this material is essential to achieve an integrated approach that favors the development of effective policies and management processes. This study reports the analysis of perceived problems caused by plastics through the participation of three key stakeholders: Scientists-NGOs (experts), public administrators and company agents from Mallorca (Spain).

The perceived problems of plastics

Social research has focused on the evaluation of marine litter (e.g. Hartley et al., 2015; Veiga et al., 2016; Wyles et al., 2015), although these residues are mainly composed of plastic. A clear majority of these studies have focused on the analysis of public perception on the effects of marine debris. For example, Hartley et al. (2015) evaluated the association of marine litter pollution with risks to marine wildlife by children, while adults usually link it with adverse effects to human health (Anderson et al., 2016; Santos et al., 2005; Tudor and

Williams, 2003). On the contrary, there is a broad consensus on the impact on human well-being of the presence of residues on marine ecosystems (e.g. Santos et al., 2005; Wyles et al., 2016, 2014) and that in coastal environments cause the selection of the beach by the users (Tudor and Williams, 2006).

Current social research has identified awareness and education as the main factors that produce higher vulnerability in the context of marine debris. In this sense, although there is concern about marine debris problem, the awareness of impacts related to plastics, and particularly microplastics, is still low (Anderson et al., 2016; Chang, 2015; GESAMP, 2015; Hidalgo-Ruz and Thiel, 2013; Jacobs et al., 2015a). Some studies have tried to analyze the conditions that could modify these vulnerabilities towards pro-environmental behaviors. For example, Wyles et al. (2016) research analyzed the positive effects and educational values provided to volunteer students after beach cleanings sessions. In contrast, Hartley et al. (2015) emphasized in the marine litter education in children as a fundamental tool to enhance understanding and actions to reduce debris. However, other studies related to the charge in the single-use plastic bags, have shown that changes in attitudes and behavioral acts were produced through a balance between extrinsic and intrinsic factors to which people are subject (Jakovcevic et al., 2014; Poortinga et al., 2013; Thomas et al., 2016).

Littering threats and recycling behaviors have also been widely researched. Generally, a significant proportion of beach users tend not to admit that they leave waste on the beach (e.g. Eastman et al., 2013; Santos et al., 2005; Slavin et al., 2012) even though, they are estimated to be the primary source of litter during tourist seasons (e.g. Martinez-Ribes et al., 2007; Moore and Allen, 2000). Cingolani et al. (2016) examined the variation of the littering rates in fluvial beaches through persuasive messages communicated by volunteers to the user to find effective methods to reduce it; the litter was reduced in 35%. On the other hand, bad habits in recycling suppose another threat in the attempt to reduce waste, where the communication and information should be encouraged to reinforce the user's utility (Ojala, 2008).

At the level of analysis of the perception of various stakeholders, some studies have highlighted the high need for dialogue between the actors involved. The STAP framework highlights the need for interlocution between relevant stakeholders in the search for solutions to plastic pollution (STAP, 2011). Baztan et al. (2015) reflected the experience of five years of work carried out in the Canary Islands (Spain) on the work between different stakeholders, reflecting a series of future recommendations that urging the implementation of working groups to combat the effectively plastic pollution. As an example, the European MARLISCO project examines perceptions, attitudes and behaviors of stakeholders focused in the social awareness and the co-responsibility to achieve sustainable management of marine litter (Veiga et al., 2016). Alternatively, in the cases of the Honolulu strategy where conceptual maps were established as a long-term strategy to solve marine litter problems form experts' perspective, including aspects of social, legislative or managerial aspects i.a. (NOAA and UNEP, 2011). However, despite these previous social research about marine litter and in the last years in microplastics, the literature is still sparse (e.g. Hidalgo-Ruz and Thiel, 2013; Munari et al., 2016; Pahl and Wyles, 2017; UNEP, 2009).

7.1.2. The present study

The Mediterranean is a region with an intense pressure of anthropic origin due to the development produced along its coasts. This process has promoted an essential economic activity among which are the industry, the maritime transport and tourism, among others. However, it has also led to a change in coastal environments and increased pollution in the Mediterranean waters. Plastic waste is a clear example of the type of marine pollution that has been increasing in recent years. Numerous studies are describing the pervasiveness of this pollutant on the surface of the Mediterranean Sea (e. g. Cózar et al., 2015; Ruiz-Orejón et al., 2016; Suaria et al., 2016), where the waters and coasts of Mallorca (Balearic Islands - Spain) are not an exception (Faure et al., 2015; Martinez-Ribes et al., 2007; Chapter 4 and Chapter 5).

The need to deepen knowledge of human perceptions, awareness and behaviors that reveal the causes of marine debris is increasingly necessary to understand and regulate effective policies that reduce or mitigate marine pollution (Chen, 2015). Therefore, this study will evaluate how three critical stakeholder groups from Mallorca perceive the problems generated by the plastics through an in-depth qualitative mixed-method analysis.

The main questions of this research are the following:

a)What are the main perceived problems associated with plastics?

b)What are the main differences and similarities between stakeholder groups?

c)What is the main problem-statement in relation to plastics?

7.4. Results

7.4.1. Key stakeholders' perceptions of problems generated by plastics

This section discusses the topics arising from perceptions of the problems that plastics cause from the observational perspective of the selected stakeholder groups in this study. We will present the results obtained from the affinity diagram technique for each group as a basis for answering the first key research question. Also, a free brainstorming session was implemented during the sessions to increase the perspective of the plastic problem. The topics emerged were examined by focus group managers and synthesized in a mental map.

7.4.1.1. Main perceived problems from experts

Perception from observations (affinity diagram)

A total of seven sub-themes classified into three main themes emerged during the analysis of the experts' observations (Figure 7.1): Lack of awareness & education, Accumulation and Adverse effects.

Experts classified the excess of plastic used today as the most critical problem, whose origin comes from its overuse by industry and consumers due to the lack of awareness and education. The dumping of plastic into the environment was considered a consequence of excess; however, the descriptions pointed out that these processes could occur unintentionally or intentionally. Loss due to occasional accidents or lack of proper management determined the unintentional paths by which plastic waste reaches natural systems, while the intentional ones were referred to deliberate acts mainly focused on abandoning waste in the environment such as product packaging (e.g. tobacco package wrapping or snacks).

The second set of themes developed was based on the accumulation of plastics in the environment. On this issue, that plastic could be concentrated in certain seasons and that it could be affected by marine currents once it enters in marine ecosystems (i.e. particle transport). The pollution of marine ecosystems by this type of material was highlighted as a result of the accumulation in these environments.

Finally, the adverse effects produced by plastic material focused mainly on damage caused to marine fauna. Some of the descriptions related the direct impacts focusing on choking and strangulation. Subsequently, the negative effects on socioeconomic sectors were commented on descriptions related to human health and leisure (e.g. fishing, beach use experience).

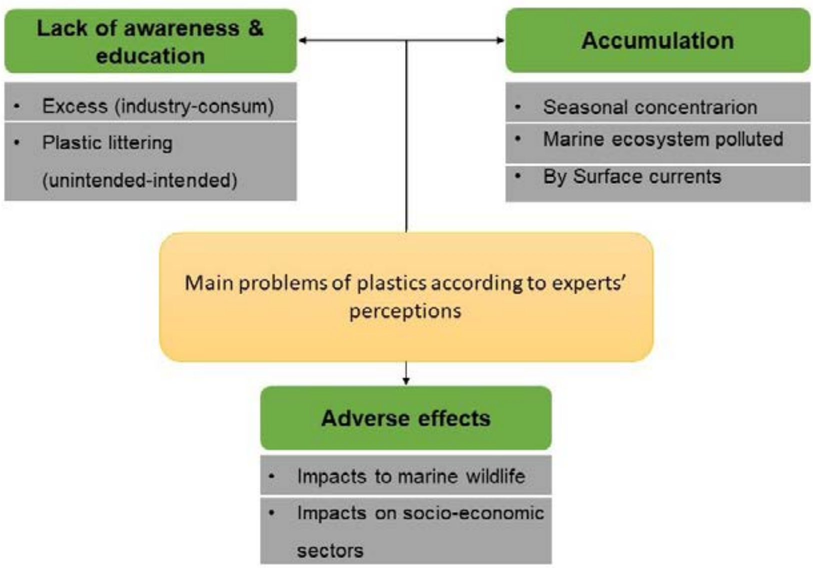


Figure 7.1. Affinity diagram of the main problems of plastics perceived by the focus group of experts. *The association in groups of observations was determined by the similarities between them by the participants. Both first- (green) and second-(grey) order titles were determined by the association of the observations that emerged and were agreed between the participants.*

Perception based on ideas (brainstorming session)

The brainstorming session was used as an enlargement through ideas or concepts of perceptions obtained from observations. A total of 28 ideas or concepts were established, classified into eight categories (Figure 7.2): Accumulation, Demographic trends, Plastic properties, Education & Awareness, Directives & Cooperation, Impacts, R+D+I+design and Productive model.

The group began building issues from it observed experience into ideas related to the plastic problem. In the first approach, the marine areas where plastic accumulates and increases its concentration (Accumulation), the absence of social and educational campaigns that raise awareness among the population (Awareness-education), and the indirect harmful effects or as a factor for the transport of invasive species (Adverse effects), were fundamentally incorporated. However, problems related to the political and management sectors (Directives & Cooperation) were added to those associated with the lack of alternatives and innovation (R+D+I+desing), aggravated by causes of social (Demographic trends) and economic (Productive model) origin in addition to the properties of plastic.

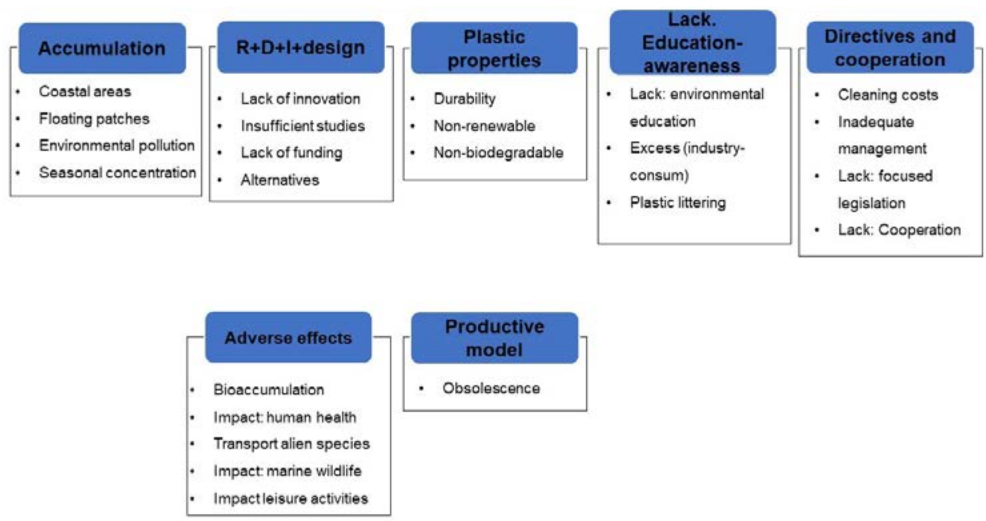


Figure 7.2. Results of the brainstorming session of the focus group of experts. *The association in groups of ideas was determined by the similarities between them by the participants. The titles of each group correspond to the final decision agreed between the participants of this focus group.*

7.4.1.2. Main perceived problems from public administrators

Perceptions from observations (affinity diagram)

The number of topics developed by public managers reveals a wide variety of primary themes (Figure 7.3): Excess, Plastic littering, Dispersion, Plastic on the coast, Plastic degradation-complex management. Only three subthemes emerged; two included in the excess and one in plastic degradation.

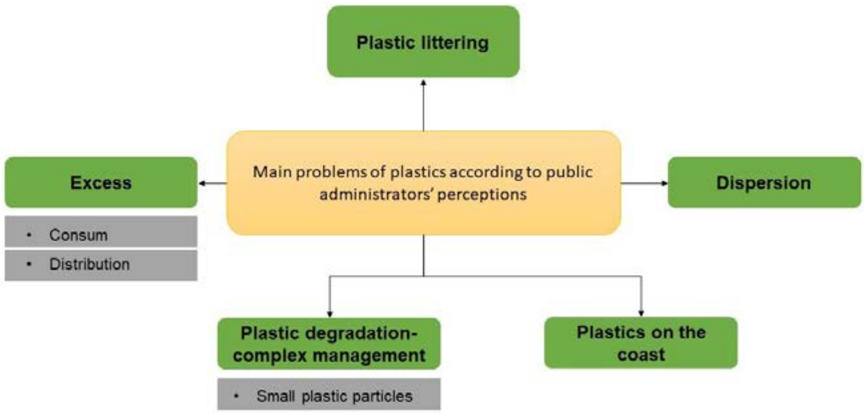


Figure 7.3. Affinity diagram of the main problems of plastics perceived by the focus group of public administrators. *The association in groups of observations was determined by the similarities between them by the participants. Both first-(green) and second-(grey) order titles were determined by the association of the observations that emerged and were agreed between the participants.*

Public administrators described the distribution, associated with production processes, and consumer as the main contributors to the excess of plastics. This duality in the responsibility was also perceived by participants when considering plastic littering in their discussions. However, participants began to depict the dispersion concept, referring to the fact that several natural agents (e.g. wind, torrents, marine currents) could transport plastic litter; even though, the group mentioned coastal environments as the main accumulation systems.

The evolution of the problem of plastic outlined by public administrators reflected the importance of expressing the difficulty of removing the smallest plastic particles from natural ecosystems for management processes. In this context, participants focused the complexity of management activities on removing microplastics from the beaches, which are limited to manual disposal techniques.

Perception based on ideas (brainstorming session)

Public administrators developed a total of twenty-one concepts out of a total of eight main ideas (Figure 7.4): Lack of government involvement, Advantages, Lack of information, Effects on the environment, Effects on human health, Inexpensive material, Capitalist system and Lack of awareness.

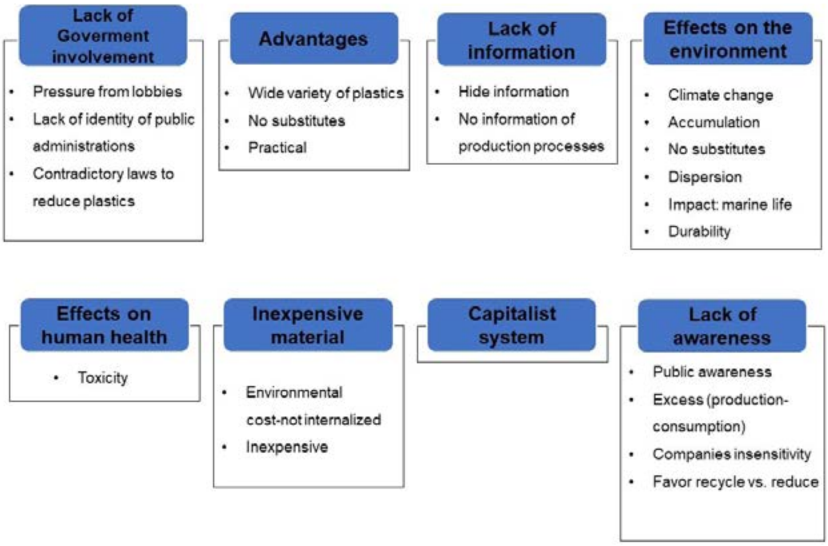


Figure 7.4. Results of the brainstorming session of the focus group of public administrators. *The association in groups of ideas was determined by the similarities between them by the participants. The titles of each group correspond to the final decision agreed between the participants of this focus group.*

The extension was constructed by including perceptions from observations grouped into higher categories according to the causes and consequences of the problem of plastic. The excessive use of plastic was contextualized within the lack of social awareness, including details of the aspects about distribution and consumption previously expressed; while the environment brought together the topics of dispersion and accumulation, incorporating concepts about the impacts to marine wildlife or climate change in the production and disposal of material.

The elicitation of new ideas focused mainly on problems caused in the areas of government (i.e. politics and management) arguing the loss of power by some public institutions, as well as the absence of information provided from the production sectors. Furthermore, participants expressed some degree of ambivalence between the advantages associated with plastic material (advantages and inexpensive material) and the consequences for human health, mainly regarding toxicity.

7.4.1.3. Company agents

Perceptions from observations (affinity diagram)

Three central themes emerged in the analysis of the group of company agents (Figure 7.5): Lack awareness-education-information, Excess and Complex management. Six sub-items completed their observations.

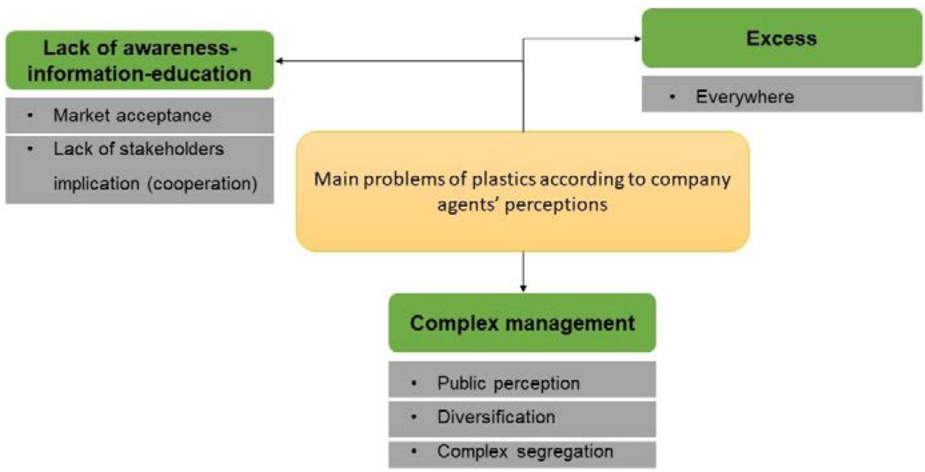


Figure 7.5. Affinity diagram of the main problems of plastics perceived by the focus group of company agents. *The association in groups of observations was determined by the similarities between them by the participants. Both first- (green) and second-(grey) order titles were determined by the association of the observations that emerged and were agreed between the participants.*

On the one hand, the participants associated the lack of awareness, with the lack of information and education. However, the visions of the company agents showed the lack of cooperation (i.e. all sector of society) as a considerable problem to change the current situation. They also added that the market (i.e. the general public) does not bother to accept changes towards plastic increment models, particularly about plastic packaging.

The following topic emerged from the content analysis, referred to the excess plastic used and therefore, could be found everywhere. In this case, the participants mainly referred to waste found in the environment.

Finally, the complexity of management processes as a fact framed by a large number of types of plastics (diversification) that currently exist, which make segregation systems difficult. In the latter case, it was also pointed out that separation at source (i.e. social) is not usually performed correctly, contributing to its complexity.

Perception based on ideas (brainstorming session)

Company agents expressed a total of twenty-five ideas grouped into five main categories (Figure 7.6): Advantages, Disadvantages, Plastic-population relationship, Legislation and Solutions.

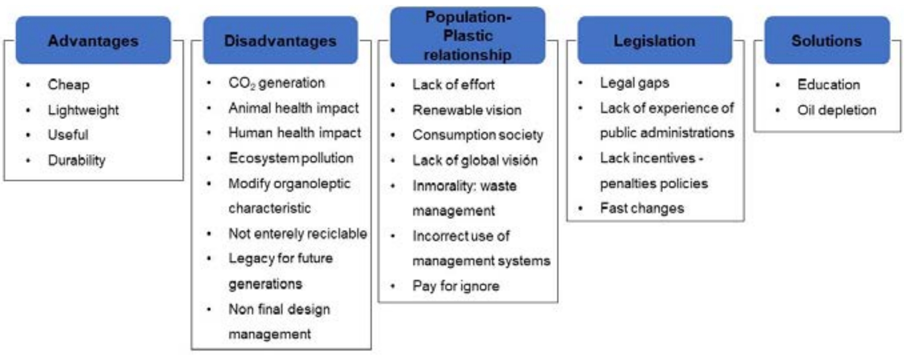


Figure 7.6. Results of the brainstorming session of the focus group of company agents. *The association in groups of ideas was determined by the similarities between them by the participants. The titles of each group correspond to the final decision agreed between the participants of this focus group.*

The initial concepts were based on a vision of the problems caused by society's interaction with plastic, incorporating elements of management, use and its acceptance as material. These relationships revealed deficiencies and misuse in waste management systems; although, from the social point of view, concepts related to lack of awareness and even aspects related to indifference-idleness were also listed. Nevertheless, the flaws in the current legislation were assessed with ideas ranging from legal gaps or the lack of experience of public institutions, to rapid and untargeted changes in legislation.

The progression of the analysis produced an ambivalence of ideas between the advantages and disadvantages of plastic. Concepts commonly associated with plastic such as durability, lightness or price were the ones that composed this category. Conversely, disadvantages brought together topics of social and environmental consequences, but also ideas related to effects on food products and waste management difficulties emerged.

As a group characteristic, the ideas encompassed as solutions were added, limiting it to an increase in education or the depletion of one of the raw materials.

7.4.1.4. Importance of the plastic problems

To know the importance of the problems of plastic elucidated in each group, the participants evaluated them according to their observations (Table 7.1). In this sense, the categorization establishes the relative priorities on which to act that could favor a reduction of the general problem.

Table 7.1. Results of the evaluation of problems related to plastic extracted from the affinity exercise.

Themes	%Votes
Focus Group 1	
Experts	
Excess	40.00
Littering	22.86
Accumulation	18.57
Impact on marine wildlife	12.86
Impact on socio-economic sectors	4.29
Polluted marine ecosystems	1.43

Focus Group 2

Public administrations

Excess	55.56
Complex management	19.05
Accumulation	17.46
Dispersion	1.59

Focus Group 3

Company agents

Excess	33.33
Complex management	22.22
Market acceptance	20.37
Lack of implication	20.37
Diversity (plastic types)	1.85
Dispersion	1.85

Experts evaluated the excess as the primary perceived problem related to plastics (40.00% of votes). Littering behaviors, plastic accumulation and impacts to marine wildlife were considered in the second order of importance (22.86%, 18.57% and 12.86%; respectively), while other impacts and polluted marine ecosystems were the least voted. This categorization is reflecting the prioritization and gradation of causal origins over the adverse effects produced.

Public administrators and company agents shared their concern about the main problems caused by plastics. They considered the excess of plastics as the main problem (55.56% and 33.33 % of votes respectively), while the second order was classified the complexity of management (19.05% and 22.22% respectively). In contrast, the following assessments varied between these two groups of participants. The administrators placed the accumulation (17.46%) as the next significant problem and the agents ranked the socio-economic problems (20.37%, see Table 7.1). However, both groups again agreed on dispersion topic as the less important problem (1.59% and 1.85% respectively); although agents also included the diversity of plastics (1.85%).

7.4.2. Main diferences and similitudes between stakeholdersk:

constructing a synthetic framework of reference.

The situational analysis of the themes extracted in the affinity diagram led to a series of differences and similarities between the groups during their construction. In this section, a description of the main differences and similarities identified will be developed to answer the second main research question. The themes and sub-themes elucidated were examined through a cross-group analysis to reduce the redundant ideas, eliminate non-related themes and compare groups effectively. A list of the themes and the selected verbatim were developed to facilitate the understanding of the themes (see Supplementary Materials Table S7.1, Annex F).

There was a general gradation in importance from problems with social origins to issues related to the consequences of plastics in all groups; however, the most important difference between the three groups analyzed was produced in the general observational conception. The experts covered causes and consequences of the problem of plastics, focusing on repercussions up to adverse effects on both ecosystems and socio-economic sectors and accumulation processes. Although public administrators expressed a threat in the accumulation of plastics, they and company agents fundamentally discussed characteristics linked to management problems.

Although plastic pollution has a strong social origin, the causes of excess were only expressed by experts and agents in the form of lack of awareness; but they differed in some aspects of the conceptualization of the theme. For experts, lack of awareness determined the behaviors that lead to produce-consume excessive plastic and liked to its subsequently littering. On the contrary, the agents considered that the unawareness produces the plastic acceptance and aspects related to the lack of cooperation, but there were no implicit connections with the excess and littering. The connections with social aspects grew in depth from the development of ideas in all groups.

In the same way, complexity in management processes was one of the most important commonalities between managers and business agents. Nevertheless, each group defined it for its management areas (i.e. from public or private sectors). In the case of administrators, mainly in the field of public space management (i.e. beaches, cities). On the other hand, company agents in the field of waste management systems and the difficulty of adequately managing all different types of plastics.

Common points of reference were found in the perception of plastic accumulation in marine and coastal ecosystems among experts and managers. These connections were based on determining coastal environments (including coastal waters) as areas of particular plastic debris accumulation. In the case of the experts, they explored the idea of oceanographic factors (e.g. surface currents) as contributors to the movement of plastic particles towards certain areas. However, this point was not raised from the observations of the company agents.

The main common similarity among all participants was in defining the excess of plastic as the main problem related to this material, which most similar common approximation occurred between experts and managers in defining the origin of excess in social and production (i.e. industry) origin. From the agents' point of view, it was only commented as an observation that every day there is an increasing number of plastics everywhere.

Synthesis of the groups

In order to put the issues that emerged through the observational experience of the focus group participants into a shared context, a synthetic framework was developed to promote a better understanding of the perceived problem (Figure 7.7, see also Supplementary Materials Table S7.1.: Annex F).

The themes were categorized according to the areas to which they belonged on the basis of the observations and experiences developed by the participants. In total, four shared central themes were extracted that it would relate the general view on plastic problems: Social causes, Management causes, Environmental consequences (impacts) and Socio-economic consequences (impacts).

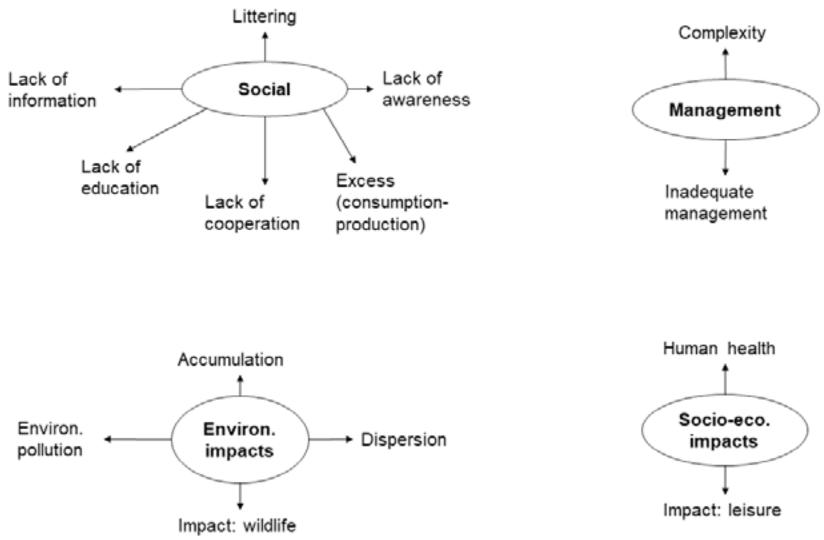


Figure 7.7. Synthetic framework of reference from the perception of the problems of plastics from the three stakeholders analyzed.

7.4.3. Synthetic problem statement including relationships

Although the elucidated observations among the groups made it possible to facilitate the context of the problems perceived by the participants, the relations between the emerging themes could differ among them and therefore their general conceptualization of the problem. In this sense, the third main research question offers an approach to the statement of the plastic problematic that emerged from the focus groups of the participants' perspective. With the objective of representing the relationships described among variables, the framework developed in previous sections were used to represent them (Figure 7.8; see also Supplementary Materials Table S7.1.: Annex F).

These relations facilitated the final declaration of each group on the problem of plastics, allowing to draw several hypothesis-proposals from the observations of the participants that allowed to limit this problem.

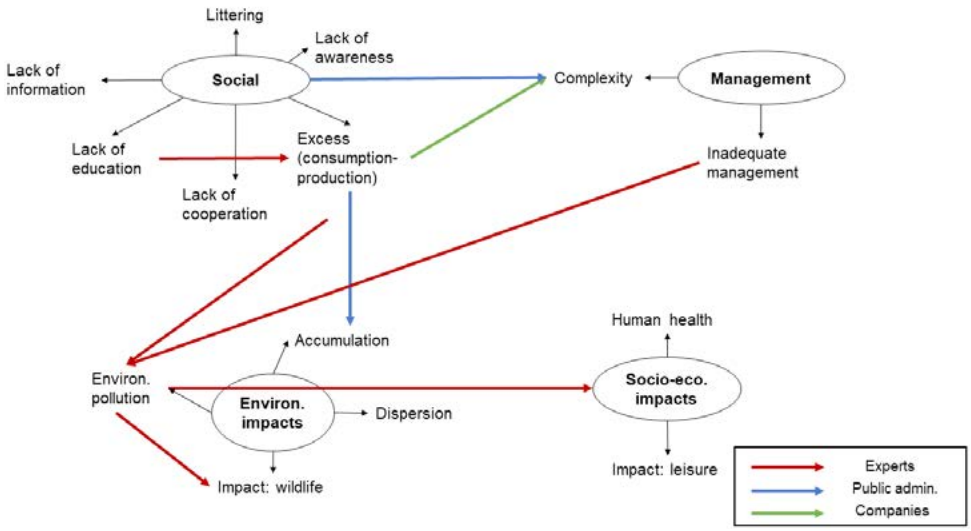


Figure 7.8. Synthetic framework of reference combined from the perceptions of the three stakeholders analyzed. *Relationships were developed through relational analysis carried out in the different focus groups.*

Definition and relations by experts

The experts were able to link all main thematic clusters by offering a response with a high degree of integration of the issues generated by plastic waste. The definition of the problem from the experts' point of view was literally defined as follows:

"Plastic pollution is a global problem with a particular impact in certain environments. It negatively affects to wildlife organisms and the socio-economic activities. Its source is the industry and the consumer, aggravated by the lack of education and proper management" (Group of Experts)

The relationships of variables defined by the point of view of experts offered a series of hypotheses/proposals aimed at reducing or mitigating the problem of plastics:

-Hypothesis/proposal 1: The increase of educational programs could lead to an improvement of habits to reduce the excess of plastics.

- Hypothesis/proposal 2: The adaptation and improvement of current management systems to the problem of plastic waste would reduce its entrance into ecosystems.

Definition and relations by public administrators

The general definition of the plastic problem by public administrators related the perceived main problem (excess) and management problems resulting from the misuse of current management systems, which leads to favoring the accumulation in the environment. The literal definition was as follows:

"Plastic excess in production, distribution and consumption, causes its accumulation in different environments, especially on the coast, as well as crowds of people which hinder its management." (Group of Public administrators)

In this case, the administrators related three of the four central themes, which in their union offer two main proposals to the problem:

- Hypothesis/proposal 3: The restriction of excess plastic could revert to its less accumulation in the environment.

- Hypothesis/proposal 4: The cooperation between all sectors of society seems to be a necessity to mitigate the problem of plastics.

Definition and relations by company agents

Finally, company agents also reflect the beginning of their definition by causes, encompassing society in this beginning. However, it seems to reflect part of the solution through cooperation. The literal definition was as follows:

"We (population) *have created a system that has led us to overuse plastic, that also difficult to manage it when becoming waste, system which should be restructured through awareness."* (Group of Company agents)

The main proposal based on the relationships between variables explicitly defined by the agents would be reflected in:

- Hypothesis/proposal 5: The reduction of excess plastic would facilitate the decrease of complexity in management systems (especially in waste management systems).

In addition, a solution to the general problem is spelled out that would add a proposal already in itself:

- Hypothesis/proposal 6: The improvement of awareness of the problem of plastic seems to be a fundamental factor in changing the current paradigm.

7.5. Discussion

Current research related to the extent of the effects of plastic waste on ecological systems has increased significantly in recent decades. However, this study focuses on analyzing the perception of key stakeholders, due to the importance of understanding the factors that direct the causes of the problem to guide towards effective policy measures to mitigate the problem (Pahl and Wyles, 2017). The qualitative empirical mixed-methodology approach used in this study confirmed the broad perception of problems caused by plastics in social-ecological systems from the key stakeholders' perspective. Here, we found clear evidence of perceived problems from the observations of participants, encompassing aspects from the different steps of the plastic life cycle.

7.5.1. Main problems of plastics perceived by key stakeholders

In general, social causes were defined by users as the most pressing problems of plastics. Regarding the causes, participants focused on the fundamental issues of plastic debris in these factors. The excess of plastic used in the consumption and the production processes were assessed commonly as the central problem of plastics (see also Table 7.1). This result was similar to the described by STAP (2011) study, that pointed out the growing plastic production and consumption particularly in the end-of-life plastics. In this sense, the lack of awareness, education and information were factors perceived.

The problems arising from plastics produced during the management processes were also among the main ones considered by the participants. The identification of plastic litter as an element that saturates management systems in the face of the quantity and diversity of waste, it is coupled with the necessary identification of the difficulty involved in the removal of abandoned plastic debris from the environment (e.g. Ariza et al., 2008; NOAA and UNEP, 2011). The accumulation and dispersion factors that can affect waste once it enters the environment were also commented. These factors suggest a broad view of plastic since it becomes waste and the problems it entails at every point of current waste management, which is further influenced by the lack of cooperation between all actors.

The findings also revealed a high perception of the consequences of plastic waste in natural environments but especially in marine ones, which demonstrate the high influence of the coastal context in which the members are located, and their observational experience related to their habits. Several studies showed this public association of plastic debris with marine ecosystems where there was usually a robust contextual component of the participants (e.g. Anderson et al., 2016; Hartley et al., 2015; Wyles et al., 2015). However, although experts delved more deeply into issues of specific impacts on marine wildlife, common to many perceptions from natural scientists (Rochman et al., 2016a), the groups developed the interconnection between ecosystems.

Other major perceived problems were those related to adverse effects, albeit to a lesser extent than those of causal origin. This fact could suggest an acceptance by users of the inherent anthropic nature of the problem itself. The responses reflected a higher perception of the harmful effects caused to organisms that have been broadly defined in current research (e.g. Alomar and Deudero, 2017; Cole et al., 2011; Deudero and Alomar, 2015; Fossi et al., 2014) and also in effects that could affect the socio-economic systems and that in recent years their concern for them is increasing. (Mouat et al., 2010; Newman et al., 2015).

Finally, the development of a large number of ideas during brainstorming reflects the high compression on the problems derived from plastic. These results ‘open the door’ to future social-ecological studies to explore the issue on a higher level of abstraction.

7.5.2. Main differences and similarities perceived

The main difference found among the groups seemed to reflect the absence of perception of the adverse effects produced by plastics (i.e. environmental and socio-economic) between public administrators and company agents. This difference suggests a lack of conceptualization of impacts produced by plastics that could affect the sectors they represent. Some of the consequences in the public and private sectors such as tourism, are being reported in the last years, showing a significant impact on public management sectors and private sectors such as tourism (e.g. Leggett et al., 2014; Mouat et al., 2010; Newman et al., 2015), with high importance on the island of Mallorca.

On the contrary, other differences found between the groups based on the same thematic points that were approached from different points of view. This fact is not necessarily a disadvantage since it offers a broader perspective of the same problem. For example, the slight differences found between the issues of lack of awareness among scientists, where there is a large number of how awareness raising can influence aspects of littering behaviors (Schultz et al., 2013); whereas the point of view of business agents seems to be driven by uses and changes introduced in companies in the markets and accepted by them. It can also be used for the rest of shared topics such as cumulation or management processes. Therefore, in this respect, the integration of perceptions and opinions from a greater number of stakeholders suggests a better approach to the identification and possible resolution of problems generated by plastics.

Regarding the similarities, it was widely reflected that excess is the main problem and concern of the stakeholders who participated in the study. This observation seems logical as it demonstrates the continuous development of industry and current uses towards a model where plastic material predominate and, for the moment, the legal measures adopted do not seem to adequately mitigate the problem (Gold et al., 2013).

7.5.3. Proposals for problem statements and their relationships

The definition of the problem of plastics reflected, in a synthetic way, the general perception of the participants on the problem of plastics. Based on the definitions, some hypothesis-proposals were developed on the perceptions obtained which are not exclusive and can be compatible between themselves:

- Hypothesis/proposal 1: The participants observed in the lack of education one of the topics that favors the problem of plastics. In this sense, improvement in education could make it possible to reduce plastic problems from the social point of view. In this regard, recent studies confirm that education is a fundamental step to raising public awareness, and reflects a high degree of effectiveness in childhood stages (e.g. Eastman et al., 2014; Hartley et al., 2015). Therefore, these improvements could have an impact on a medium- to a long-term solution, but it is clearly needed.

- Hypothesis/proposal 2: The management of plastics has not adapted to the massive amount of waste generated daily in our societies. There is also a significant imbalance in management systems that depends mainly on the economic status of each region (Hoornweg and Bhada-Tata, 2012). In this regard, authors such as Coe and Rogers (1997) recommended the improvement of waste management systems to prevent the abandonment and entry of plastics into ecosystems. But the ongoing research on plastic pollution is revealing new challenges that had not been previously detected, as is the case of microplastics removal and/or retention (e.g. Mintenig et al., 2016). Therefore, it is recommended that this proposal should be based on consensus solutions and a revised strategic plan to address current and future challenges in preventing the entry of waste into ecosystems.

- Hypothesis/proposal 3: Following the previous proposal, it should be accompanied by other additional solutions that do not focus exclusively on the final stages (i.e. when plastic becomes waste). The routes that plastic waste follows since it is abandoned, intentionally or unintentionally, are widely known and often result in accumulation areas distant from disposal areas (e.g. Galgani et al., 2015; GESAMP, 2015; van Sebille et al., 2012). For this reason, the limitation of plastic produced currently, especially single-use plastics which in Europe supposes around of 40% of plastic production (PlasticsEurope, 2018), would facilitate the reduction of the intensity with which this material reaches ecosystems.

- Hypothesis/proposal 4: Although the concern in recent decades has favored the development of various treaties and strategies at the international level (e.g. NOAA and UNEP, 2011; UNEP/MAP, 2015), the lack cooperation has been reported as one of the leading problems to achieve an adequate reduction of marine litter (Chen, 2015; Gold et al., 2013; Thompson et al., 2009). Moreover, these agreements have been limited to the implementation and establishment at smaller scales, which is revealed as a necessity according to the group's observations. Collaboration is, therefore, one of the fundamental guidelines in which all stakeholders at different organizational levels should be able to promote effective solutions to the problem of plastic pollution (Baztan et al., 2015; MICRO2016, 2016).

-Hypothesis/proposal 5: Plastic material, despite its ubiquitous daily presence, is generally considered as a unique element; however, there is a wide variety of polymers and additives that generate an extensive amount of different plastics as an 'end-product'(e.g. Shashoua, 2008; Vegt, 2005). In this sense, the high diversity of plastic implies an inherent complexity in waste management systems, which under the optimal conditions is usually incorporated into a broad category such as 'packaging'. Moreover, it must be added the difficulty of managing other plastic hazardous waste (i.e. sanitary or polluted), the poorly selected and the abandoned. The reduction of the excess could make it easier to manage plastic waste in terms of a scenario with a lower volume of debris to deal with in a given time frame.

-Hypothesis/proposal 6: Highly related to the first proposal, raising awareness of the effects caused by plastic debris is one of the leading recommendations that could be effective in mitigating the problem (Marin et al., 2009; Pahl and Wyles, 2017; Wyles et al., 2014). Nevertheless, it should be borne in mind that people have a limited level of concern for the large amount of social and environmental issues (Anderson et al., 2016), so effectiveness will depend on each personal circumstance and the degree of importance that people attach to each problem.

7.5.4. Implications

The findings of this study reveal the complexity of the interrelationships generated by the problems of plastics along their life cycle through the perceptions of key stakeholders in Mallorca. Although it is estimated that the awareness of marine litter has increased in recent years (e.g Gelcich et al., 2014; Wyles et al., 2014), it is urgently necessary to reinforce information-education about plastic pollution and continue to emphasize awareness raising (Jacobs et al., 2015a, 2015b; Veiga et al., 2016) and ensuring the knowledge of the problem and its consequences in order to adopt practices that promote a change towards a more sustainable behaviors. However, it is a necessary analysis of the social environment where it is intended to establish the measures to ensure their effectiveness (Thomas et al., 2016).

Currently, the participation of experts in the policy-making processes is increasingly demanded to solve the plastic issues (Baztan et al., 2015; Rochman et al., 2016b). However, due to the intricate and extent of the problems of plastics, integrative cooperation and coordination between the stakeholders are urgently required to address them in all their stages from the production to the impact, according to the focus groups participants. From this perspective, the gaps inherent in each stakeholder could be resolved, with the aim of promoting policies that are capable of efficiently mitigating plastic waste. Our results confirm and support many of the aspects extracted in the 'The Honolulu Strategy framework' (NOAA and UNEP, 2011); although, it is necessary to further deepen the opinions of all stakeholders in order to provide a broader view of the causes of the plastic residue problem, as well as an analysis at different organizational levels. Examples such as the STAP (2011) or the MARLISCO project (Veiga et al., 2016) in Europe, establish an extensive study of stakeholders and public perception of marine litter that favor bottom-up recommendations that should also be deepened at local-regional levels and extendable to other topics.

7.5.5. Methodological limitations and future research

This study only analyzed the participant' perceptions to explore the problems of plastics and their relations which findings, generated detailed and valuable information for the development of valid constructs based on the different methodologies used, following evidence-based methodological principles (Krueger and Casey, 2014). Although due to the nature of the qualitative analysis used where the number of participants was limited, and their viewpoints could be inherently biased, the responses were not formally extrapolated to the populations of interest. We could present the results to the focus groups in order to gain feedback, as well as replicate the groups of interest to increase the validity of the study, according to Yin (1994). However, the results showed consistency between the problems perceived in this analysis and several issues reported in previous research (e.g. Lee et al., 2015; NOAA and UNEP, 2011), allowing us to explore the views and connections of the problems generated by plastics for influential groups in decision-making processes, established in our aim.

Future research focused on exploring, identifying and analyzing differences in all administrative levels (i.e. from international to local levels) as well as the inclusion of all stakeholders, is urgently needed. Nor should it be forgotten that the analysis of the possibilities of reducing the current production of plastic for more sustainable alternatives should be deepened, without neglecting the improvements in waste management systems that cover current needs and establish future mechanisms. Moreover, the temporal variability should be explored in order to determine the evolution of the perceptions.

7.6. Conclusion

This work reinforces and expands the existing knowledge by examining and eliciting models of the plastic issues and their connectivity based on the detailed responses of experts, public administrators and company agents with some influence in the decision-making processes. Through a qualitative empirical and integrative approaches, perceptions and insights from stakeholders have been contextualized, situated and related, where we found that the excess of plastic use in the industry and consumption was the primary perceived problem associated with the problem of plastics. There was general agreement among participants about the social causes driven the problems; however, the consensus of the rest of causes was more disputed between the groups. The cooperation and responsibility of all stakeholders were deduced as the most urgent need to address the issues related to plastic waste.

Plastic pollution is a social problem driven by the insights, attitudes and behavioral responses of people, which would have to be analyzed and considered for the establishment of effective long-term solutions (e.g. Pahl and Wyles, 2017). Our approach provides a vision of the plastic problem from different points of view that we hope will contribute to the next integrative processes based on the hypotheses and proposals put forward.

During the work carried out by Archduke Ludwig Salvator in the Mediterranean region, he established synergies with experts, administrators, citizens and connoisseurs in each location he visited. This allowed him to obtain an overview of the studied reality. Today, the need to establish these links of cooperation between the various social entities has been reinforced in order to understand and tackle new challenges effectively.

The social dimension of the problem of plastic debris

Chapter 8

The problem of plastic debris: exploring beach users' perceptions, attitudes and motivations

Abstract

Plastic debris represents one of the most important fractions of marine litter accumulated on coastal ecosystems. Beach users recognized these debris as one of the main generators of litter in situ. In this study, we used a survey (n = 629) to investigate beach users' perceptions, awareness, attitudes and motivations of plastic debris in the coast of Mallorca (Spain). The initial approach of the respondents showed a relationship between plastic and concepts such as waste, pollutant or unsustainable; and almost 95% of the people surveyed considered plastic debris as an important problem to the environment. Marine and coastal wildlife were perceived as the main components affected by the consequences of plastic debris, while plastic excess and lack of awareness were seen as their main origin causes. Despite the certain difference between interested and uninterested users in the problem regarding the use of plastic containers, there was a clear rejection of plastic debris in the environment and a high selection of the environment depending on the absence of this litter; while there was a preference for measures to avoid the introduction of new taxes. These results contribute to deepening the social perception of plastic pollution, revealing important implications for the socio-economic sectors involved in these ecosystems.

8.1. Introduction

8.1.1. Background

The works carried out by Archduke Ludwig Salvator more than a century ago did not rely solely on contributions from the upper echelons of society, but instead on the importance of all population to obtain a complete insight. In this sense, the decision-making processes have been carried out fundamentally ignoring the vision and concerns of all the sectors of the population, particularly citizenship. In recent years, due to the need to develop solutions that prove to be more efficient in management processes, the opinions of a greater part of society to build bottom-up relationships have been explored and incorporated. These gradual changes give rise to the implementation of the vision that the Archduke already integrated into the different works he carried out.

Ecosystem goods and services that marine environmental provide to humans are increasingly needed to sustain the growing global population (Beaumont et al., 2007). Its deterioration is a clear sign of the human increased pressure on ecosystems (Waters et al., 2016). Consequences of our impacts have been widely reported (e.g. Chilvers et al., 2014; Halpern et al., 2008), and plastic pollution poses a new challenge that has been revealed as emerging threat in the last decades (Avio et al., 2016). Therefore, many international organizations are increasingly putting the focus of attention on this kind of waste (e.g. Charta

Smeralda, 2017; UNEP/MAP, 2015; UNEP, 2009, 2005; World Economic Forum, 2016; World Economic Forum and Ellen MacArthur Foundation, 2017).

Scientist have reported adverse consequences originated from plastic litter to natural ecosystems (e.g. Browne et al., 2013; Rochman et al., 2013; Wilcox et al., 2015), affecting especially to wildlife (e.g. Alomar et al., 2016; Deudero and Alomar, 2015; Fossi et al., 2017; Orós et al., 2005; Provencher et al., 2010; Tourinho et al., 2010) in marine and coastal habitats. Coastal areas are the interface between marine and land ecosystems, where the largest input of plastic debris enter the ocean with an estimation of 4.8 – 12.7 million MT each year (Jambeck et al., 2015). Hence, plastic fragments are currently among the most widespread marine debris in coastal ecosystems (e.g. Ariza et al., 2008; Hidalgo-Ruz and Thiel, 2013; Kiessling et al., 2017; Liebezeit and Dubaish, 2012; Martinez-Ribes et al., 2007; Poeta et al., 2016), where the human activities established in coastal areas contribute to the generation and accumulation of plastic litter in these zones (Galgani et al., 2010).

The exploration of public perception, awareness and behavior on effects and consequences due to human-derived marine pressures has been studied extensively, reporting a public growing concern on such type of pressures (e.g. Gelcich et al., 2014; Schultz, 2001). However, although plastics are one of the major compounds of marine debris (Barnes et al., 2009), the awareness related with plastics and especially microplastics seems to be low (Anderson et al., 2016; Chang, 2015; Jacobs et al., 2015). Despite the increase of studies related to marine litter perception, awareness and behavior over the last decade, there is still limited knowledge about plastic litter views and attitudes. These issues need to be further explored to promote the proper application of risk rules (Hartley et al., 2015; Pahl and Wyles, 2017).

Ecosystem services provided by coastal environments favor the well-being of users, while the presence of litter leads to a worsening of their perception and therefore, for their welfare. (e.g. Wyles et al., 2016, 2015, 2014). Traditionally, beach users have associated the main source of litter in the coastal to the users themselves who come to these places, but it is not common for respondents to admit their littering behavior (Campbell et al., 2014; Santos et al., 2005; Slavin et al., 2012). The motivations and attitudes that drive littering or other actions as recycling suggest a dependence of contextual and personal factors (e.g. Cialdini, 2003; Cialdini et al., 1990; Ojala, 2008; Schultz et al., 2013). There is evidence of the effect on public awareness from in-situ experiences (i.e. beach clean-up campaigns, beach awareness programs) (e.g. Cingolani et al., 2016; Hidalgo-Ruz and Thiel, 2013; Wyles et al., 2016), as well as positive results in the education of children in marine litter issues (Hartley et al., 2015).

In recent years, there has been a considerable increase of news in the media as well as environmental campaigns related to plastic pollution. These contributions have made the problem of littering by plastics better known to the public that could serve to raise their awareness. Precisely, engaging and raising this public awareness are seen as fundamental tools to promote changes towards more sustainable behavior and an essential component on integrated environmental management processes (e.g. Areizaga et al., 2012; Ariza, 2011; Marin et al., 2009; Roca et al., 2009). Despite that public participation is frequently encouraged by treaties or even international and international laws, public opinion explorations of their active involvement are rarely taken into account in decision-making processes (Areizaga et al., 2012; Roca and Villares, 2008).

8.1.2. Study site and objective.

The Balearic Islands are an important national and international tourist destination in the Mediterranean Sea (Garín-Muñoz and Montero-Martín, 2007; UNWTO, 2015). As many tourists and local people are using its well-known beaches, we decided to select one of its most visited island (Mallorca) to carry out a survey for the analysis of the plastic litter problem on coastal marine waters. Ten beaches were chosen (Figure 8.1): *Cala Barques, Port de Pollença, Port d'Alcudia, Platja de Muro, Colonia Sant Pere, Cala Millor, Can Pere Toni, Platja de Ciutat Jardí, Cala Estancia and Platja de Palma* beaches. We explored beachgoers perception and awareness of the problem of plastic debris.

Questionnaires had four differentiated sections related to the analysis of the perception and awareness of beach users, plus a fifth section for classification variables (see section 6.3 of methods – Chapter 6). The questionnaires were distributed in both English and Spanish due to the high presence of international tourism (see Supplementary Materials Figure S8.1.: Annex G).

The main aim of this chapter was to explore the views of beach users, in order to identify their main priorities and particular requirements that could facilitates a better management of the issue of plastic pollution. This study deepens the understanding of (1) the initial cognitive association of users and plastic material, (2) users' perceptions and awareness of the causes and impacts of plastic debris, (3) the beach users' perception of the present conditions of Mallorcan coastline and its future evolution, and (4) the attitudes and motivations of users in the context of the coastal environment.

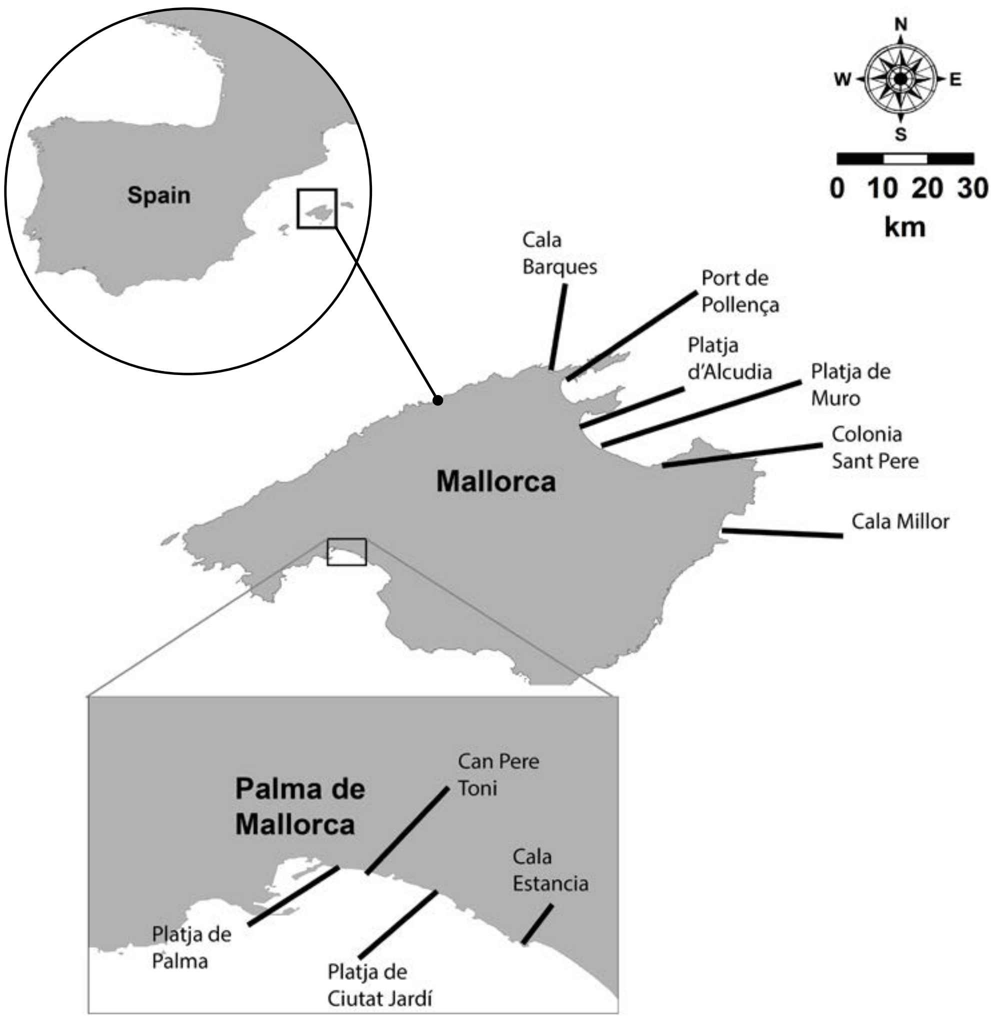


Figure 8.1. Location map of the ten beaches assessed in this paper located in Mallorca (Balearic Islands, Spain)

8.2. Results

A total of 629 useful questionnaires were collected in Mallorcan beaches, where 231 corresponded to domestic users (Spanish citizens) and 398 to international users. The results allowed the description of users' profiles, the initial cognitive status, perceptions, attitudes and motivations. Due to perception and awareness are critical factors for a change in the current situation of the plastic waste problem (e.g. Coe and Rogers, 1997), it is also important to know how much of the population is interested in the problem to analyze the attitudes and motivations that will favor an effective change.

8.2.1. Users' profile

The 62.52% of respondents were foreign (i.e. international users) followed by people from Mallorca (20.31%) and rest of Spain (16.06%) both groups considered as domestic users, the other 1.11% were not useful. From the foreign respondents, European constituted 88% of its total, having people from all other continents except Oceania in the other 12% (Figure 8.2a). The mean age of all participants was 41.80 ± 13.67 *s.d.* years old, where most of the interviewed users were in the range of 35-59 years old (56.22%, see Figure 8.2b). Main aggregated data from precedence, age, educational level and employed can be seen in Figure 8.2.

8.2.2. Initial cognitive status

Users were allowed to express the first single word to associate with the concept of "plastic". The responses obtained, explored the initial approximation of participants to the concept during their stay in the coastal ecosystem. 'Waste' was the most frequently word mentioned (23.68 % in average) from all users. The second word more answered was divided between the words 'bottle' (13.44%) and 'pollution' (13.12%) (Figure 8.3). In general, the main associated concepts were related to negative connotations (e.g. waste, pollution, problem), supposing the 48.02%, while only the 3.36% of interviewed responses were positive (e.g. useful or fantastic). Although there were relationships with

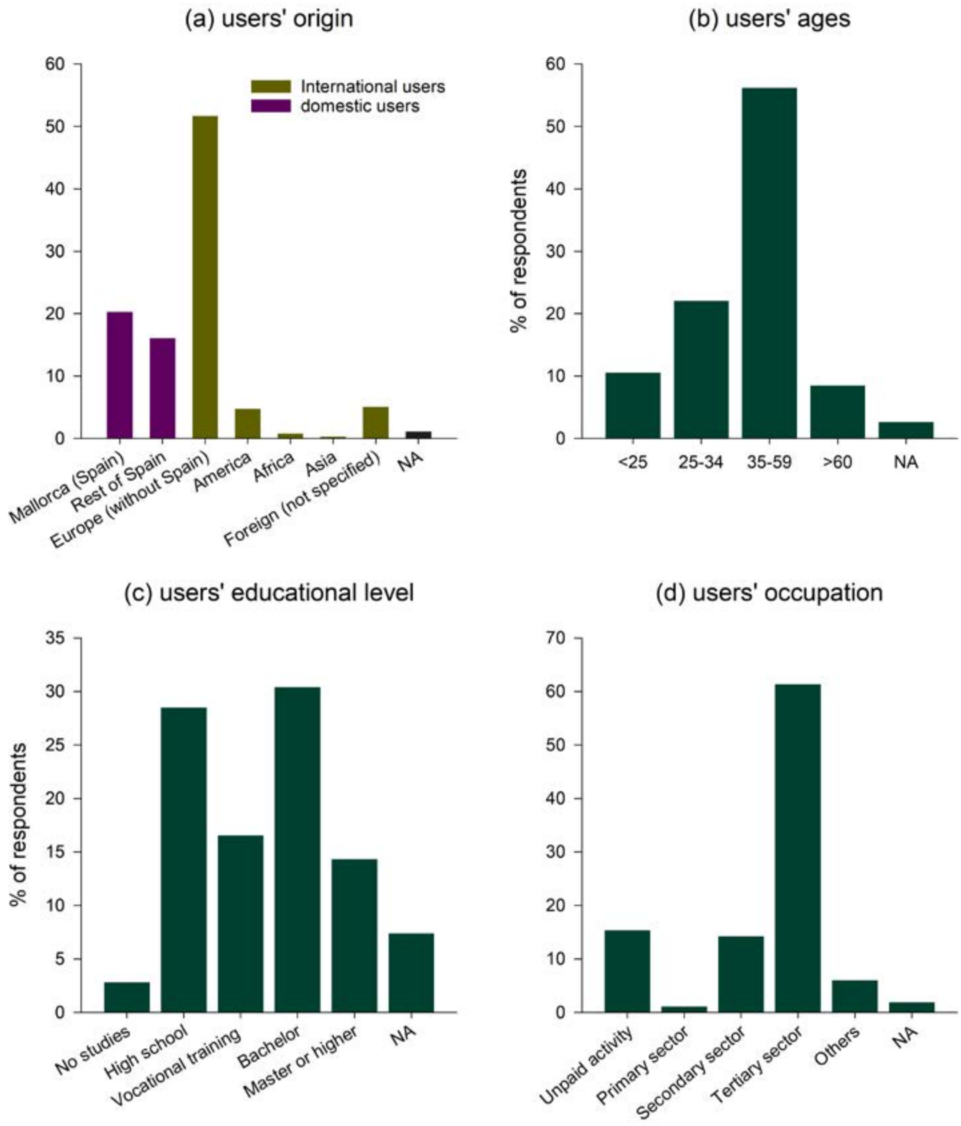


Figure 8.2. Percentage of respondents from 629 questionnaires of: *(a) Origin of the users, (b) Age of interviewed users, (c) educational level of the users, and (d) sectors of users' occupation. NA = no answers.*

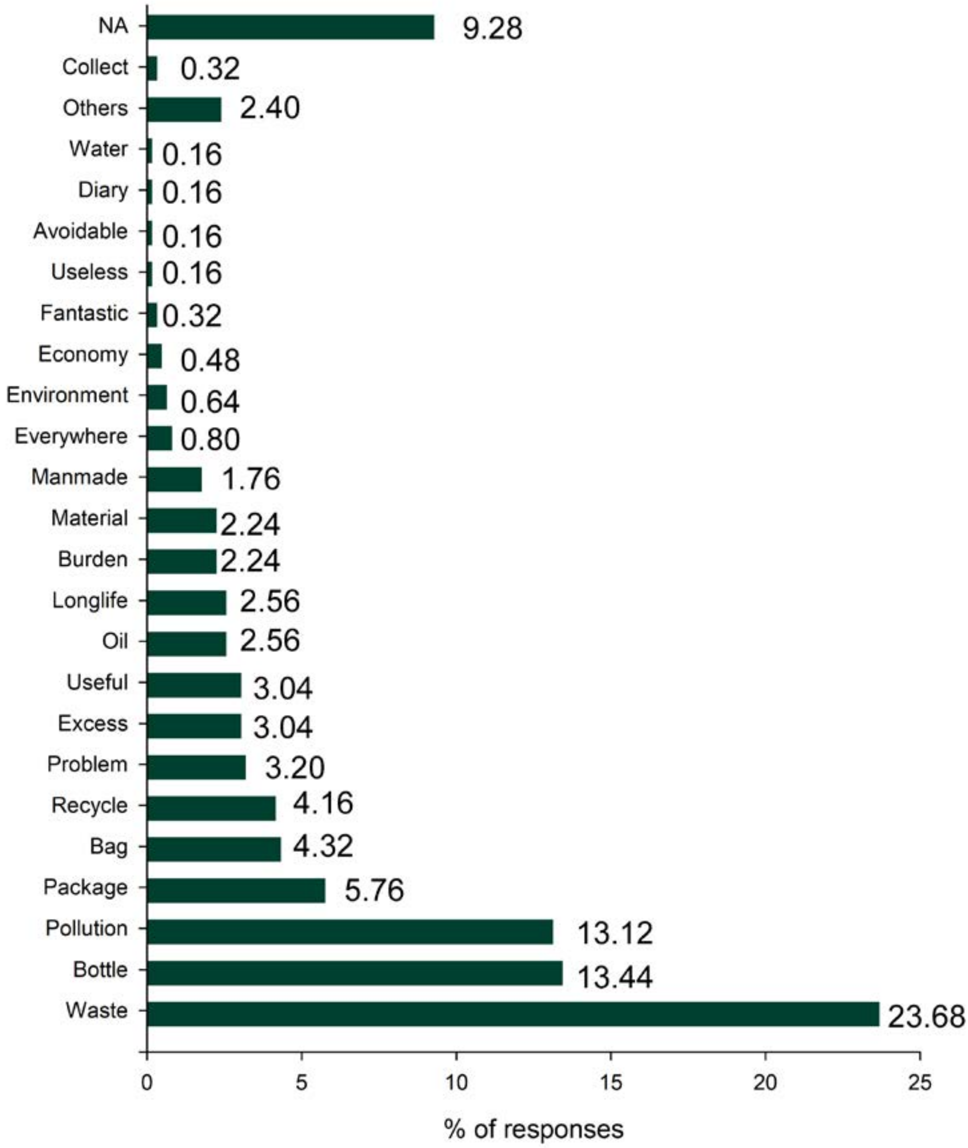


Figure 8.3. Initial cognitive associations with the word 'Plastic' for the beach users of Mallorca. *(n = 629). Side values represent the individual percentage of each concept. NA = no answer.*

environment and pollution concepts that could take minor specific conceptualizations of impacts, concepts associated with sizes or plastic fragmentation processes were not mentioned by the users. In the other direction, word associations with the advantages of plastic material (e.g. safety food, hygiene) were not specifically mentioned either.

Semantic differential allowed to explore the conceptualization of the plastic around opposite adjectives, to adjust the initial vision of the participant between two extreme points (Figure 8.4). The disambiguation between each pair of adjectives was decanted by the related adverse aspects (i.e. Pollutant, Excess and Unsustainable); however, between the couples 'Dirty-Clean' and the 'Useless-Useful' was revealed some degree of ambivalence.

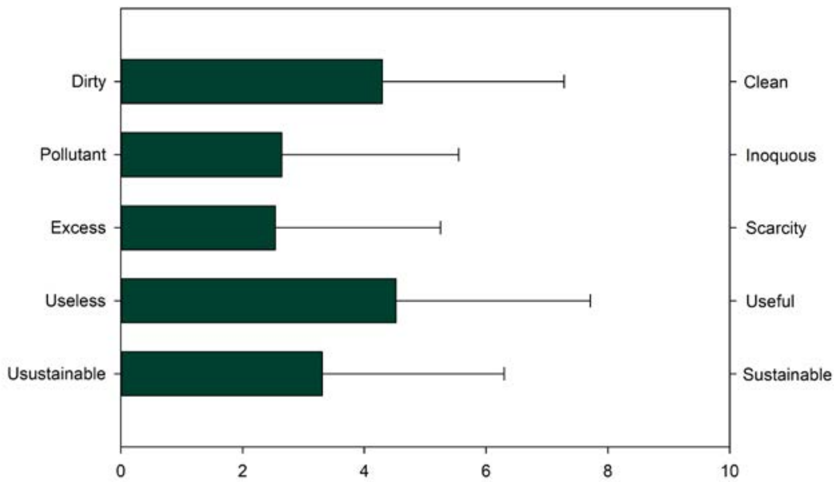


Figure 8.4. Semantic differential results in a ten-points Likert scale. *The bars represent the average values of a score from 0 to 10, where the results close to zero correspond with the adjectives on the left and close to 10 with the adjectives on the right. The average value 5 is considered not to favor any of the paired adjectives. Error bars represent the standard deviation.*

8.2.3. Public perceptions of plastic litter

The majority of the respondents (94.65%) considered the plastic litter as a harmful problem to the environment. Users' understanding was assessed based on main seven consequences and six causal parameters, which participants evaluated in a ten points likert scale (from 0 to 10) depending of the level of perceived harmful consequence and the factor that cause the plastic problem. Total Mean Importance score (TMI) was calculated based on the results of the Likert scale (Lozoya et al., 2014), to prioritize the perceived effects and causal parameters.

Environment related parameters (i.e. marine, coastal, land or landscapes) were perceived as the main affected by plastic debris (Figure 8.5a). Users classified “marine wildlife” and “coastal wildlife” as the most affected parameters (TMI = 4.56 & 4.54, respectively), categorizing them as *very harmful* by 70.24% and 68.82%. Within the environmental parameters, respondents considered less affected “land wildlife” (TMI = 4.46) than “landscape” (TMI =4.48). Despite plastic litter was showed as *very harmful* to the “human health” (TMI = 3.76) by the 34.04% of respondents, it was considered in a second level of concern. Analyzing the last effect parameters, users assessed leisure (TMI = 3.26) as more affected by plastic litter than economic activities (TMI = 3.20), classifying plastics debris as “*some harmful*” to these parameters by 27.72% and 27.24%, respectively.

Regarding the causal factors that could cause the problem of plastics (Figure 8.5b), the 74.80% of respondents considered the plastic “excess” (TMI = 4.31) of plastics as *quite* and *very probable*, while the 69.59% for the “lack of awareness” (TMI = 4.24). Analyzing the following factors, the “inadequate management” and “lack of information” were evaluated in a second order of probabilities (60.63% and 56.69%, respectively). “Properties of plastic” (TMI = 3.84) were the least considered to produce the impacts below the “economic model”.

Optional question favor that users could add some own perceived consequences and causal parameters. In the first case, respondents incorporated the following environmental issues: “CO_2 production” and “atmosphere”; social issues: “waste transfer to third world countries”; and economic issues: “agriculture” and “navigation”. While in the second case, users added “laziness” and “public civility” in relation to behavioral responses, and the “lack of alternatives” or the “media manipulation” themes.

Considering the coastal environment where respondents were surveyed, they were assessed for their perceived situation of the Mallorca's coast in relation to plastic pollution. The answers were equally divided among the categories *deficient* (19.53%), *neutral* (25.67%) and *good* (25.20%), see Figure 8.6.

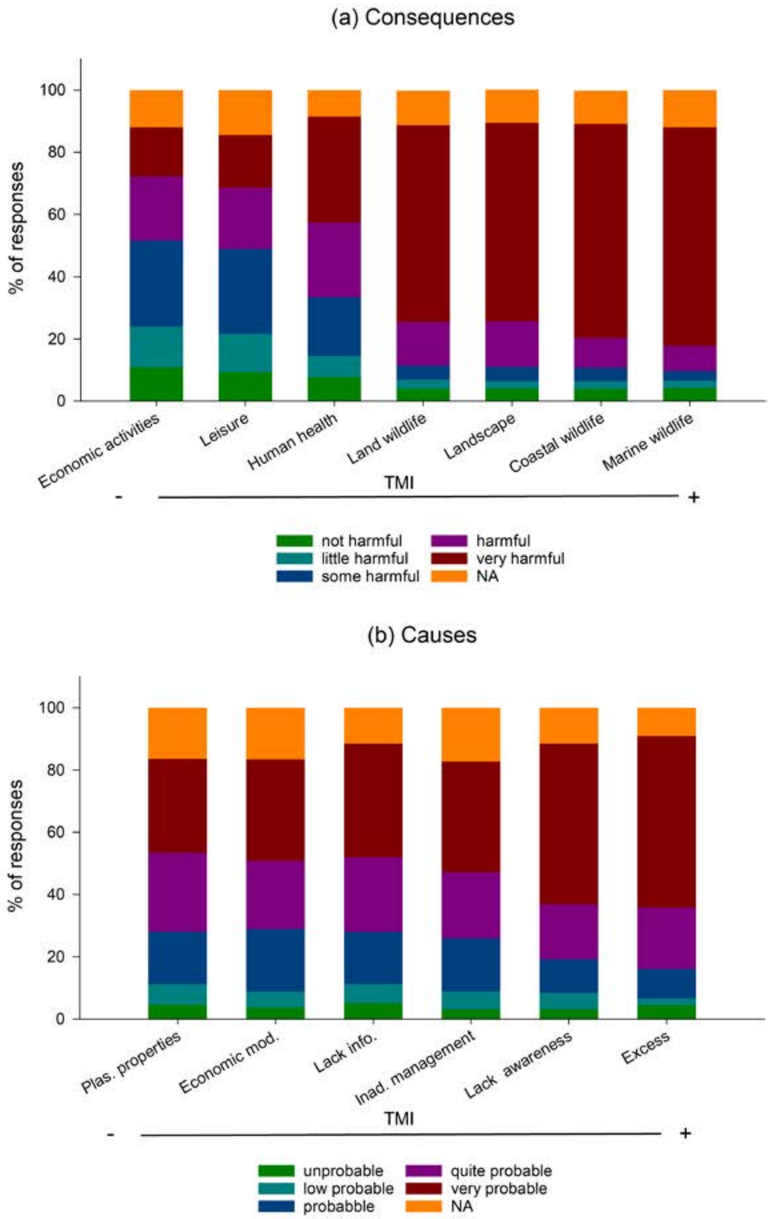


Figure 8.5. Users' perceptions of consequences and causes of plastic debris based on 13 parameters. *(a) graph represent the percentages of total responses in a likert scale in relation to the harmful consequences of plastics debris. (b) graph represent the percentages of total responses in a likert scale in relation to the causal parameters of plastics debris. A Total Mean Importance (TMI) was calculated to prioritize impacted systems.*

Calculating the average value of the answers to this question, International users (5.64) approved the coastal state of Mallorca, while Domestic respondents (4.61) did not reach the average level of satisfaction. In order to confirm these observations, significant differences between the users' origin were found ($\chi^2 = 50.03$; $p\text{-}values < 0.001$).

To further explore perceptions of the Mallorca's coast, we asked participants to predict environmental conditions this coast for the future in 5 – 10 years and 20 – 30 years. As a general pattern, most of the answers were pessimistic about future conditions of the coastal waters for the islands. In the 5 – 10 years period, the perception of the participants suggested a situation *worse than the current* one (36.02%), followed by an insight of a *neutral* state (25.98%) (see Figure 8.6). Their evaluation of the second future period was characterized by two opposing views; a pessimistic perception of the situation (*Much worse than the current* = 36.60%) in the first peak, while the second one is driven by a positive vision (*better than the current* = 23.27%) (see also Figure 8.6).

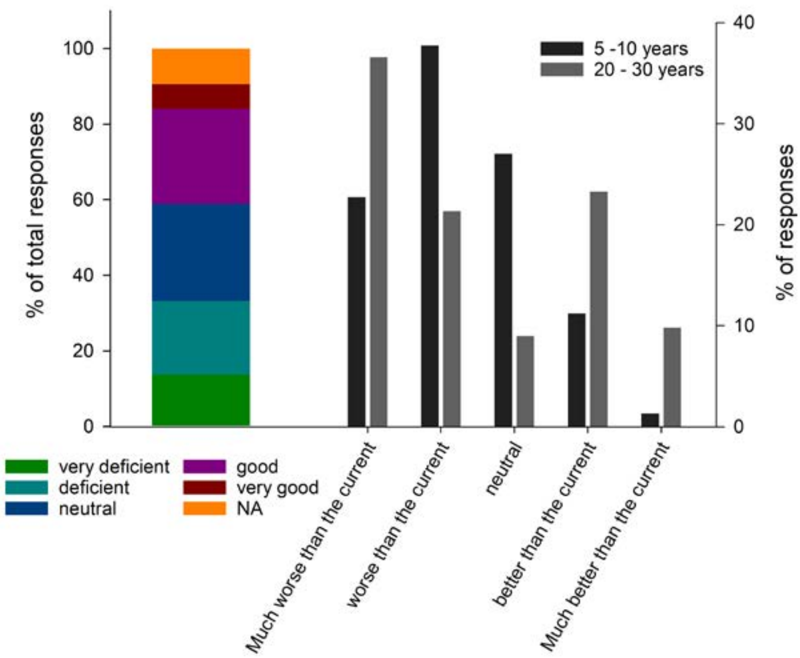


Figure 8.6. Perceived state of the coast of Mallorca and the evaluation of its future evolution. *The left side of the graph represents the percentages of total responses in a likert scale and the right graph represents the percentage of responses about the evaluation of the coasts in 5 – 10 years and 20 – 30 years.*

8.2.4. Users' evaluation about the information received and their attitudes and motivations

Information received

Interviewed users were asked about how they perceived the information given by manufactures and the administration on the life cycle and management of plastic products, where the 66.93% respondents considered this information *very deficient* and *deficient*, where it was noteworthy that the 42.33% of all responses evaluated this information as *very deficient*. In the case of information received from the public administrations concerning the planning and management of plastic waste, it was evaluated by the 52.91% as *very deficient* and *deficient* (Figure 8.7). The overall perception of respondents was unsatisfactory with a higher total mean evaluation for the public administrations (4.03) than for companies (3.34), away from the mean approval value 5.

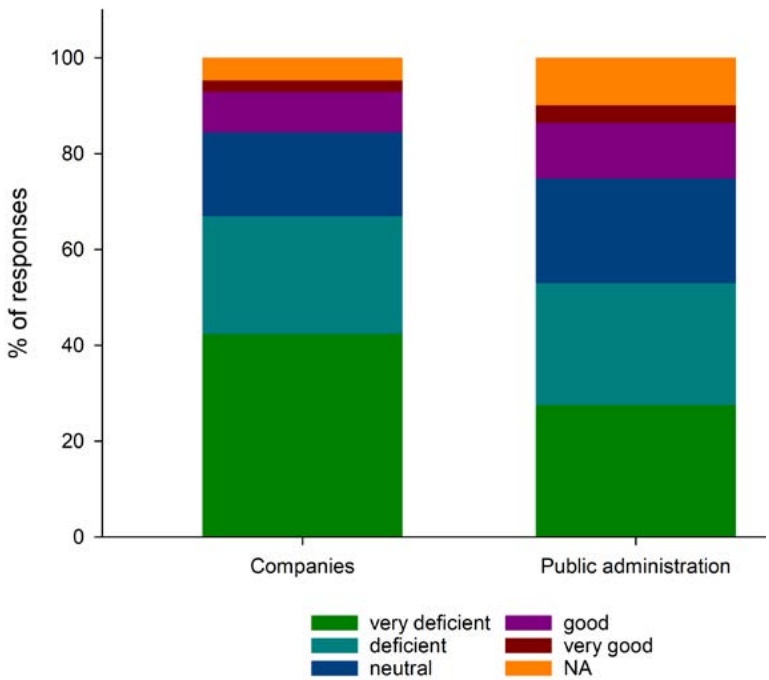


Figure 8.7. Perception of the beach users on the information received by the companies and the public administration. *Values are represented in the percentages of total responses.*

Attitudes

Beach users were asked about their degree of agreement on statements focused on the analysis of their attitudes. Only 17.01% ($n = 108$) of respondents were not interested in the environmental problem caused by plastics, while 78.43% indicated their interest in the problem. We note the extensive predominance of plastic litter rejection in the natural environments from the users' opinions (87.40% were strongly in agreement), causing a coastal selection (70.87% = *agree* and *strongly agree*) about the plastic waste in these environments (Figure 8.8). On the other hand, despite a certain hesitation to use plastic (average value = 7.04) that is reflected in its rejection (6.87), there was a wide neutral position (25.98% and 28.03%, respectively) which could be explained by the utilities associated with plastic products (Andrady and Neal, 2009; Richard C Thompson et al., 2009).

As expected, attitudes related with the rejection of plastic packaging as dislike it (77.5%) and refuse it (73.3%) showed the major differences between interested and non-interested users, where the comparison of column proportions indicated a significantly lower rejection of non-interested users (37.4%, $\chi^2 = 66.69$, p-value < 0.001; & 38.0%, $\chi^2 = 50.103$, p-value < 0.001; respectively) (Table 8.1). However, the relevant statements among interested users on plastic problem were the presence of plastics in the environment (98.0%) and the refuse a coastal environment full of plastics (81.5%); although there was significantly differences between the users, these were more reduced than in previous ones (86.1%, $\chi^2 = 31.67$, p-value < 0.001; & 67.7%, $\chi^2 = 13.19$, p-value < 0.001; respectively). The differences between the groups confirmed that the attitudes of interested respondents were significantly higher than the not interested users, through a post hoc comparison z-test (*p-value* < 0.05).

Motivations

Finally, respondents were asked about four reasons parameters to reflect their acceptance on measures that would help to mitigate the problem of plastic debris. 62.99% of interviewed users *strongly agree* with the implementation of return systems, 52.76% would introduce normative to reduce plastic excess and 42.68% *strongly agree* with measures that allow the reuse

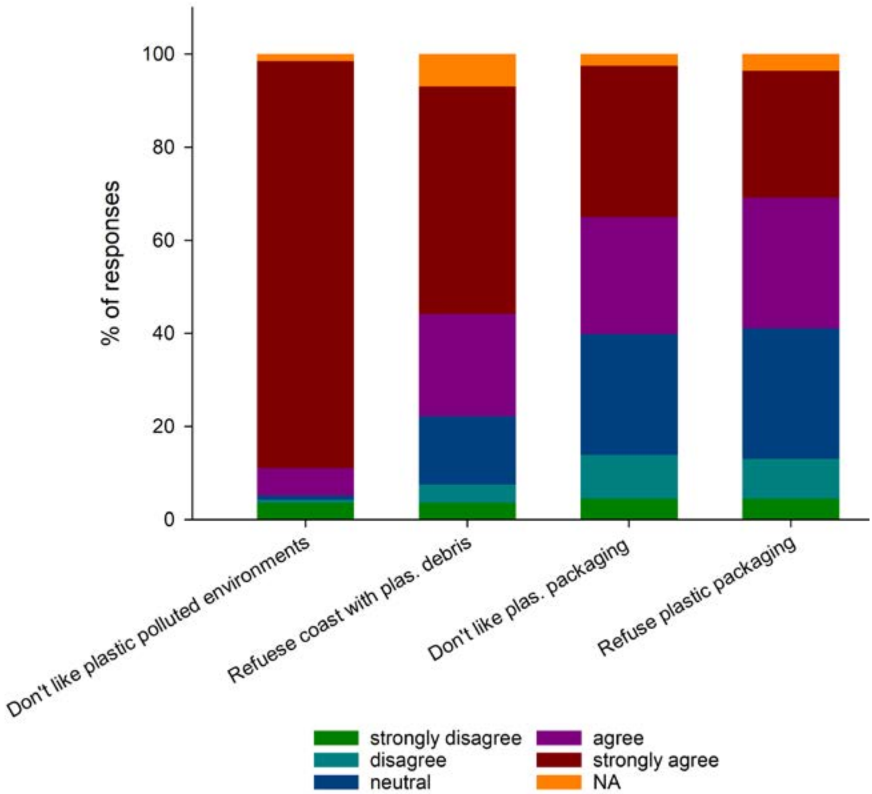


Figure 8.8. Beach user attitudes about the plastic pollution. *Values are represented the percentages of total responses.*

of plastic (e.g. bulk stores). Opinions of interviewed users about tax measures were more balanced, where only 30.39% *strongly agree* to adopt this option (Figure 8.9-left graph). Also, some measures were developed by the users in the optional open-ended question (Figure 8.9-right graph). Plastic substitution (i.e. alternative material) or the innovations was the most frequent topic, although other aspects related to fines, impact restoration and information (i.e. information, transparency or awareness) measures were also mentioned.

In order to compare interested and non-interested users, we also evaluated these motivation parameters (Table 8.1). Although, there were significant differences in all parameters, where measures to reduce plastic problems were proportionally higher in interested users. Return system were the most relevant parameter for 92.0% of interested and 75.0% of non-interested users

($\chi^2 = 25.99$, *p-value* < 0.001); however, establish additional taxes measure was less supported by the 69.5% of interested users and the expected lower proportions (38.9%) of non-interested respondent ($\chi^2 = 26.27$, *p-value* < 0.001). These results, together with the also higher values of return and reuse values among users, confirmed the initial motivation observations.

Table 8.1. Percentage of agreement for Attitudes and Motivations related with plastics for Non-interested/Interested beach users in plastic pollution problem. *Note: Different superscript letters indicate that column percentage differ significantly (p-value < 0.05; z-test for column proportions).*

		Non-interested	**Interested**
Attitudes	Don't like plastic in the environment	$86.1\%^{a}$	$98.0\%^{b}$
	Refuse coast with plastics	$67.7\%^{a}$	$81.5\%^{b}$
	Don't like plastic packaging	$37.4\%^{a}$	$77.5\%^{b}$
	Refuse plastic packaging	$38.0\%^{a}$	$73.3\%^{b}$
Motivations	Regulate excess	$65.7\%^{a}$	$88.8\%^{b}$
	Reuse	$63.9\%^{a}$	$81.3\%^{b}$
	Return	$75.0\%^{a}$	$92.0\%^{b}$
	Establish taxes	$38.9\%^{a}$	$69.5\%^{b}$

8.3. Discussion

The results of this survey provide an overview about the perceptions of beachgoers in Mallorca about plastic pollution consequences as well as public attitudes and motivations. Beach users showed a homogeneous negative perception of plastics with a high concern for marine and coastal ecosystems where the lack of awareness and the excess were perceived as the main drivers for this issue. The respondents also argued the low level of information received about these plastic problems, consistent with previous studies about perceptions associated to negative impacts in marine environment (Gelcich et al., 2014).

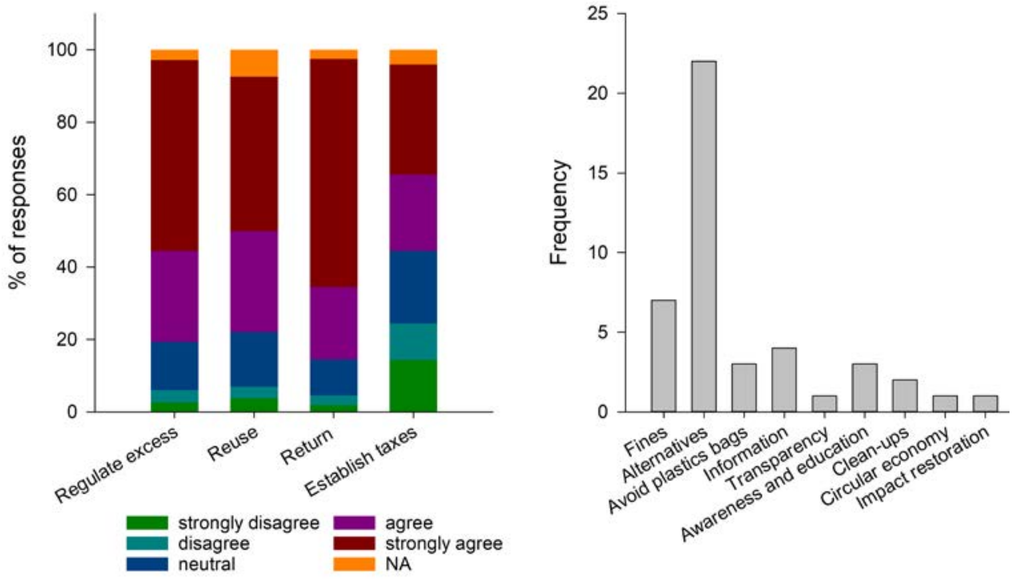


Figure 8.9. Public motivations to the problems of plastics. *Values are represented in the left graph are percentages of total responses in a likert scale. Right graph is the frequency of main themes added by participants in the open-question of the survey.*

8.3.1. Perception of the plastic problem

The initial cognitive status of respondents revealed the association of plastic with waste over the advantages of the material when participants are in coastal environments. A large majority responded to the harmful effects of plastic on the environment (94.65%), suggesting an increase in the awareness of beach users about the environmental impacts of plastic debris entering ecosystems. Although the absence of references related to particle sizes, such as microplastics, seems to suggest that beach users do not yet conceptualize this aspect of plastic contamination; similar to previous reported studies (e.g. Anderson et al., 2016; Chang, 2015; Jacobs et al., 2015; Kiessling et al., 2017).

The large and complex variety of packaging as well as the increasing individualization of the products lead to the overuse of the plastic (Hopewell et al., 2009), supported by the global annual increase of its production (PlasticsEurope, 2018) and the low effective recycling rates (Geyer et al., 2017; Lithner et al., 2011; Reisser et al., 2013); approximately the highest recycling rate worldwide in 2014 occurred in Europe with a value of about 30% (Geyer et al., 2017; PlasticsEurope, 2016). This excess was clearly perceived by the user, where 74.80% of respondents considered this excess as the main factor driving the plastic problem. However, despite users considered plastic as a major threat to ecosystems, they pointed out that the general lack of awareness (69.59%) was also another important causal effect. This duality between the appreciation of the problem and the lack of awareness seems to reflect the lack of responsibility of the respondents with respect to the rest of the users; supporting previous studies (e.g. Campbell et al., 2014; Santos et al., 2005; Slavin et al., 2012).

Regarding the consequences of plastics debris, marine and coastal ecosystems were clearly perceived as the most affected environments in contrast to land-based ones. Plastic adverse effects to marine and coastal ecosystems have been widely described in the literature (e.g. Avio et al., 2016; Cressey, 2016; Fossi et al., 2012; Law and Thompson, 2014), while terrestrial and remote ecosystems have become relevant during last years (e.g. Anderson et al., 2016; Cózar et al., 2017; Wagner et al., 2014). However, the image transferred to society (i.e. clean-up campaigns, news, NGO campaigns) are eminently marine, this suggest a clear prioritization of the users' concern towards these ecosystems based on the information obtained and the contextual factors where the survey were conducted. The consequences of the problem on social systems ranges broadly according to those reported in the last decades, such as tourism (Newman et al., 2015), aquaculture (Mouat et al., 2010) or the cost of cleaning (da Costa et al., 2016); while some research has analyzed the effects on human health there is still much controversy (e.g. Galloway, 2015; Van Cauwenberghe and Janssen, 2014). Public responses reflected this uncertainty about health, considered it less impacted than the ecosystems, while the initial cognitive views of cleaning and utility of the material were the best evaluated. Thereby, we could infer that users were in an ambivalent position between the consequences and benefits of plastics (e.g. food conservation or lightweight). However, the rest of social consequences could be gone unnoticed for most of the population.

8.3.2. Public attitudes and motivations

Regarding user attitudes, there was a widespread rejection of abandoned plastic debris in the environment, which seems to provoke the users' beach selection where coastal ecosystems are not affected by this debris. In this sense, *Cleanliness* is considered as one of the main drivers in beach selection (e.g. Krelling et al., 2017; Lozoya et al., 2014; Marin et al., 2009; Roca and Villares, 2008). Marine litter usually provoke changes in the perception of the beach status (e.g. Ballance et al., 2000; Rebecca Jefferson et al., 2014; Wyles et al., 2015); supported the general opinion obtained in our results. On the contrary, plastic packaging which actually supposes around the 40% of plastic production in Europe (PlasticsEurope, 2018), produced an ambivalence between the interested and non-interested users and reinforce their initial cognitive status. This suggest a certain confrontation between the advantages and consequences of plastic (e.g. Andrady and Neal, 2009; Thompson et al., 2009a), where undoubtedly the advantages of plastics dominance the opinions of non-interested users on plastic problems.

Deposit-return systems combined with a refund value have proven to be effective in increasing recycling rates (Andrady, 2003), although their implementation requires a previous analysis of the industrial-commercial and social environment in order to avoid rejection or inefficiencies (Hoornweg and Bhada-Tata, 2012). Our findings suggest, that beach users widely approve the introduction of this type of systems along with reused materials of plastics, substitution for more sustainable alternatives and the proposals of normative that regulate plastic excess. These results would reflect the change of vision of the users against the frequently unnecessary and excessive packaging of many of the products.

However, respondents were more reluctant to introduce tax measures that affect the final consumer. Regulations that limits the overuse of plastics together with fiscal benefits were prioritized against tax instruments. The payment of additional taxes or fees often entails a social rejection where users consider that they already contribute enough (Koutrakis et al., 2011; Lozoya et al., 2014), and could also be aggravated by the lack of information from the industry and the administration. According to users, only fiscal instruments on externalities or infringements would be considered as solutions against them.

8.3.3. Users' perception of the coastal status of Mallorca

Nowadays, the most frequent uses of the beaches are usually leisure and tourism, where the direct contact with a natural environments reports welfare to its users (White et al., 2010, 2013) and the aesthetics conditions may undermine the perception of coastlines (Wyles et al., 2015). In this sense, the users considered the Mallorcan coasts in a neutral state about the plastic pollution; however, according to Martinez-Ribes et al., (2007), the current state of the Mallorcan coasts about marine debris, resemble other international tourist destinations. These tourist places have remedial measures (i.e. public coastal cleaning service) that avoid the accumulation of marine debris abandoned on the beaches or those transported by the sea, which could be entailing a high economic cost similar to those produced in other regions (Mouat et al., 2010).

Nevertheless, a short-term (5 – 10 years) pessimistic belief about the plastic debris development in the Mallorcan coast, prevails in the assessment of users probably due to the inertia feeling and lack of performances with effective results at present. In the medium-term (20 – 30 years) a duality visioning aspect is considered between a progressive deterioration or an improvement was established. This double perception where the negative opinion could be due to the inherent comparison with other environmental problems (e.g. climate change) that seem to have a difficult solution, while the positive one might reflect some hope on the part of respondents.

8.3.4. Limitations to the study

The results of this study showed numerous strength focus on the current perception as well as the evaluation from the initial cognitive state to the attitudes and motivations of the beach users regarding the problem of plastic pollution. We also prioritize the general population sample in order to improve the external validity.

Firstly, beaches were not randomly selected. We selected beaches with high affluence of people and with global balanced representativeness of domestic and international users. The results may differ from other kind of beaches in Mallorca; however, we believe that the origin composition of users was similar across the Mallorcan beaches during summer season due to its international tourism character. Also, presenting the results as a single population sample allowed us to minimize these differences.

Secondly, the dates for conducting the questionnaires were not randomly selected, which could differ from the users' perceptions obtained throughout the year. Nevertheless, during the summer season we could increase the external validity through the sampling of larger population using the beaches.

Finally, the selection of non-beach users as control conditions it would be recommendable in order to define exclusive perceptions of beach users. However, due to the eminently coastal character of Mallorca, the limited distances between coastal areas and the high tourism rate, we believe that the variability in the region may be limited.

8.3.5. Implications

Our research has showed some important implications which add to existing evidence that users actively reject abandoned plastic debris on beaches, but also that a significant part of them begin to select beaches based on the non-presence of these materials there. For places such as Mallorca with a sectorial diversity that is fully focused on the tourism sector with an international relevance, factors that affect the selection of users as a holiday destination could mean great economic losses in the area (Newman et al., 2015). While in order to reduce the potential economic impact, management processes tend to rely upon remedial measures (i.e. coastal cleaning services) which represent a high annual cost supported by public money (Mouat et al., 2010).

The interviewed users showed a clear commitment to preventive measures that regulate the excess plastic used today, as well as the reuse and return of those plastic materials that have necessarily been used. However, because the problem of plastics also carries a significant social burden that the respondents also included, it is necessary to focus on measures that encourage the engagement and the raise social awareness. In this sense, the public sectors do not have sole responsibility; the results show a high demand from respondents to integrate these measures from companies and industry. According to other authors (e.g. Eastman et al., 2013; Wyles et al., 2014), programs that integrate environmental education and information together with clear regulation to the plastic material and its debris are urgently needed.

8.4. Conclusions

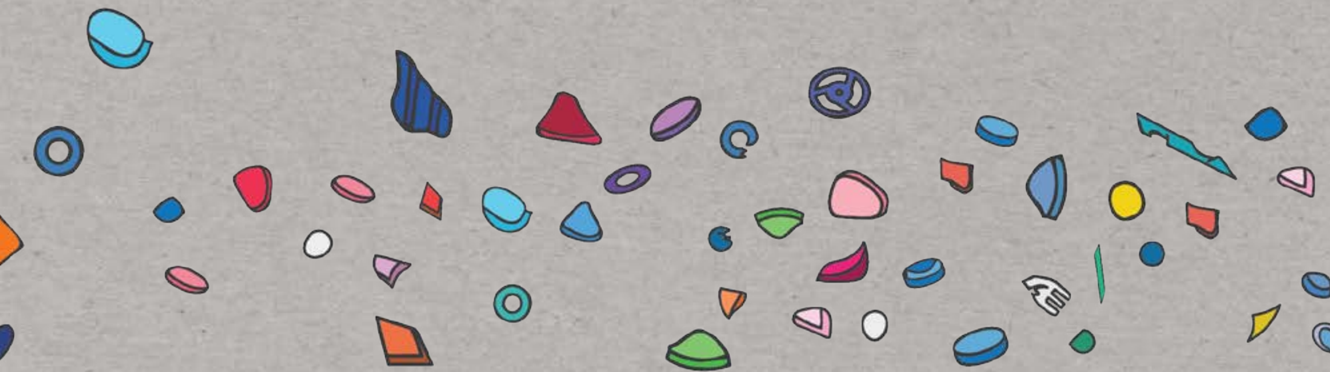
This study evaluates the beach users' perceptions and awareness of plastic debris as well as their attitudes and motivations regarding the problem. The results obtained confirm the growing concern of the beach users for the impacts produced by plastic debris, considering them as a global problem that affect to a widely environment ecosystems but specially to the marine ones. The attitudes demonstrate the rejection of this litter in coastal environments, where the adverse effects to the tourism sector and the costs involved in the management of plastic debris, could cause serious economic losses.

The global degree of perceived awareness by beach users seems to remain low. The importance of promoting information, education and knowledge to increase social awareness, as well as, the introduction of regulatory measures in coexistence with systems that allow the reduction of plastic excess should be fundamental steps towards the sustainable use of plastics in an integrated environmental management.

The integrated vision that the Archduke expressed in his work to offer a complete contextual vision of the environment remains today more necessary than ever. Societal point of view within the management of social-ecological systems are a clear requirement to achieve effectiveness in the problem of plastic debris.

Part III

A General Conclusion



Chapter 9

General Discussion and Conclusions

In the context of the increasing marine litter in the oceans, this thesis aims to contribute to the knowledge of this problem in the Mediterranean Sea addressing ecological and social issues. The first part focus on the analysis of the current state of floating plastic debris in the Mediterranean Sea. Due to the physical oceanographic processes and the population density in its shores, the semi-enclosed Mediterranean Sea has been shown as one of the waterbodies with more significant potential for the accumulation of plastic waste (e.g. Cózar et al., 2015; Eriksen et al., 2014; van Sebille et al., 2015). In the last years, both the scientific concern and the number of studies has increased the recognition of this litter problem considerably as one of the most important threats to marine ecosystems. Therefore, the first part of the main objective of this thesis was to provide information of the current floating plastic status through three different spatial and temporal scales, providing results of particle and weight distribution, size composition and kind of plastics in the surface waters of the Mediterranean Sea.

However, due to the broad social roots of the problem, it is also essential its analysis in order to understand insights and needs to help efficiently mitigate plastic pollution (Pahl and Wyles, 2017). In this sense, the second part of the main objective of this doctoral dissertation was to provide information on perceptions, awareness, attitudes and motivations from the social point of view. The insights and perceptions of several stakeholders were analyzed to evaluate points of reference and their relations about the problems generated by plastic material throughout its life cycle. In addition, public views, attitudes and motivations of beach users, as another essential stakeholder, were also evaluated to get a broad picture on the perception of plastic material and its adverse effects.

This thesis evaluates from a comparative work carried out by the Fundación Innovación, Acción y Conocimiento (FIAyC) on the travels through the Mediterranean of the Archduke Ludwig Salvator at the beginning of the 19th Century. Campaigns repeated Archduke explorations at a time in which semi-synthetic and synthetic polymers were discovered.

9.1. Part I: Current state of the floating plastic pollution in the Mediterranean Sea

As mentioned previously, the first part of the main objective of this thesis was to determine the current state of the Central and Western Mediterranean in relation to floating plastics pollution. In order to address this objective, three sub-objectives were identified. First, determine the spatial distribution of floating plastics; second, estimate the seasonal variability of plastics at the local scale; and third, characterize the plastic litter of the surface on the Mediterranean Sea.

9.1.1. Spatial distribution of floating plastic debris and its factors

During the last decade, exponential research of floating marine debris has been carried out worldwide and as well as, in the Mediterranean Sea. Using a manta net to collect plastic particles from the surface of the sea, we obtained a total of 139 samples in different spatial-temporal scales. Plastic fragments were found at all of them showing the pervasiveness of the problem in the Mediterranean (**Chapters 3-5**). Figure 9.1 provides a combined view of the distributions of plastic concentrations (weight and particle) on regional spatial scales.

In Chapter 3, we obtained random samples during research cruises to characterize the state at the regional macroscale. Plastic weight concentration reached 579.3 g(DW)·km^{-2}; while the two other large-scale surveys coincident

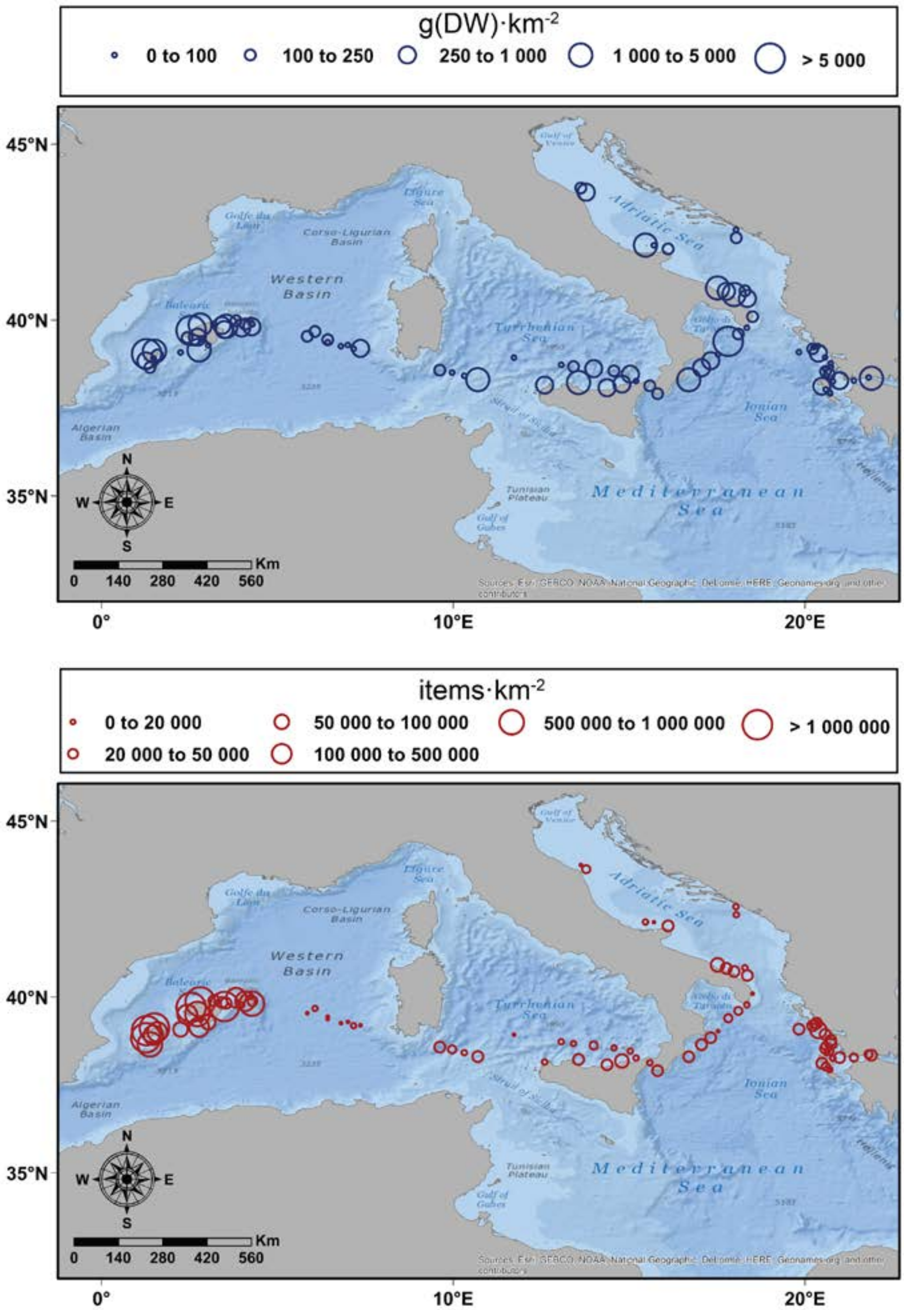


Figure 9.1. ***Floating plastic debris concentration of regional studies reported in this thesis.*** *Upper graph represents weight concentration (g(DW)·km^{-2}) and lower graph represents particle concentration (item·km^{-2})*

in time, reported similar values of 423 g·km^{-2} (Cózar et al., 2015) and 465.5 g·km^{-2} (Suaria et al., 2016). According with the recent study of Suaria et al. (2016), the similarities between the three weight concentrations confirming and support the current status of floating plastic debris in the Mediterranean Sea, as well as, one of the main areas of plastic accumulation along with the great oceanic gyres (Cózar et al., 2014) (**Chapter 3**). However, due to the different methodology used in the sampling and analysis between the studies of plastic pollution, the comparatives in terms of particle abundance are often complex. Recent Congress and scientific panels (e.g. GESAMP, 2015; MICRO2016, 2016) have advocated for the standardization of methodological processes, with the aim of improving the comparability and compatibility of results in this young field of pollution research.

At a large scale, we found a homogeneous distribution of floating plastics in the analyzed regional seas (**Chapter 3**). This suggests the absence of surface convergence hydrodynamic structures that produce stable accumulation zones similar to the great oceanic gyres (subtropical ocean gyres) due to the high variability of surface circulation in the Mediterranean; supporting previous reported (e.g. Cózar et al., 2015; Mansui et al., 2015).

Values were higher in coastal waters, where the results obtained showed maximum concentration values of 4,576,115 items·km^{-2} in the NW of Ibiza (Spain) and 9,298.24 g(DW)·km^{-2} in the Gulf of Taranto (Italy). The analysis between offshore and inshore waters defined by around 25 km off the coast, evidenced a decreasing concentration gradient of floating plastic particles with the distance from the land in the Central and Western Mediterranean Sea (**Chapters 3-4**). We confirmed the significative statistical differences between the plastic concentration in the coastal waters of the densely populated the Balearic Islands and the results of the regional macroscale of the Mediterranean (**Chapter 4**). We are aware that correlation is not a sufficient condition to derive causality between a pair of variables; but instead, we regard it as a necessary condition to promote hypotheses of causal processes. Pedrotti et al. (2016) also confirmed the importance of the first kilometers of coastal waters as an important accumulation area due mainly to the new inputs from land sources, while the results from the model produced by Fossi et al. (2017) in the Ligurian Sea (NW Mediterranean Sea) also reflected this higher coastal concentration of plastics.

Conversely, at a lower scale, hydrodynamic conditions have a substantial effect on the distribution of floating plastic debris. Most of the plastic debris in the marine ecosystems have been estimated that come from land-based sources (e.g. GESAMP, 2015; Jambeck et al., 2015; McIlgorm et al., 2011); but due to the unequal distribution of plastics in the Balearic Islands, suggested the strong influence of the hydrodynamic conditions in the redistribution of plastics from densely populated areas sources (**Chapter 4**). Therefore, through a first analysis of the prevailing currents in the Archipelago during the sampling period, different conditions were observed between the *Pitiusas* (Ibiza and Formentera) and *Gimnesias* (Mallorca, Menorca and Cabrera) islands acting synergistically. The first condition seemed to reveal a process of concentration in the inner of the mesoscale circulation from the Algerian sub-basin; the second one was influenced by the long-time residence waters at the north of the Balearic Promontory, reinforced by the contributions that crossed the Mallorca Channel. However, the seasonal variability of the surface currents in this area seemed to reflect substantial differences in surface concentration over some Balearic zones previously reported (Faure et al., 2015).

9.1.2. Seasonal variability of plastics in the Menorca Channel (local pilot study)

We also evaluated the seasonal distribution of floating plastics in the Menorca Channel's MPA against a high variability of coastal population density and the limited surface circulation in the Channel. Therefore, we tried to provide further insight into the sources and distribution of floating plastics debris, within this complicated scenario, forming an MPA with high plastic concentrations compared to other reported in the Mediterranean (**Chapter 5**).

The concentrations obtained during the four seasons of the year analyzed, reported variability of the values between 23,625 – 1,509,536 items·km^{-2} and 1.03 – 20,957.07 g(DW)·km^{-2} (**Chapter 5**). The estimated minimum and maximum values of the current state of floating plastic debris in the Menorca Channel's MPA, considering its declared surface area, amounted to 115,997,205 – 1,549,891,093 items·km^{-2} and 154,464.05 – 5,928,019.12 g(DW)·km^{-2}; however, if considering the area of the bays of *Pollença* and *Alcúdia* these values could rise to 273,829,364 – 2,372,244,482 items·km^{-2} and 228,139.62 – 20,112,875.04

g(DW)·km^{-2}. Therefore, the potential for accumulation plastic debris in the bays was reflected due to their proximity to the land-based sources and the reduced seawater circulation in comparison with the Channel itself (**Chapter 5**); with particular relevance in the mass of plastic particles.

The limited interaction between the Balearic density Front (characterized by higher salinity) and the mesoscale currents of the Algerian sub-basin determine the dynamics of floating plastic particles in this zone. Despite of this fact, the differences in observed particle and mass concentrations did not show significative seasonal variations in the Channel, suggesting the high complexity and coexistence produced by the oceanographic and demographic conditions that led to the distribution of floating plastic debris in the Channel (**Chapter 5**). On the contrary, the intra-seasonal variation reflected the differences in particle concentrations between the sampling stations located to the north and south of the Channel due to the balance in the convergence of an energetic Balearic Front and the mesoscale structures in the south (**Chapter 5**).

9.1.3. Characterize plastic litter: size and type of plastic particles

According to our lower limit of particle size (333 µm mesh size), microplastics were the predominant particles in the Central and Western Mediterranean Sea where sizes in the range of 1 mm^2 – 50 mm^2 were the most frequent ones (**Chapters 3-5**) (Figure 9.2). Regarding particle length, sizes from 0.5 to 1.3 mm were the particles with a higher presence in the coastal waters (**Chapters 4-5**). These results confirm and support the predominance of microplastics in the Mediterranean, supporting and expanding previous studies (e.g. Collignon et al., 2014; Cózar et al., 2015; Faure et al., 2015; Fossi et al., 2017; Suaria et al., 2016).

All plastic sizes were highly represented in coastal waters than in offshore waters excepting in the Menorca Channel; however, during autumn the presence of macroplastics rapidly increased in this area (**Chapter 5**). These facts suggest the efficiency of the coastal cleaning service in the Balearic Islands; when this service is suspended, the size frequency of floating macroplastics increased. This result could be considered that the coastal cleaning service is an adequate and sufficient measure for the remediation of plastic

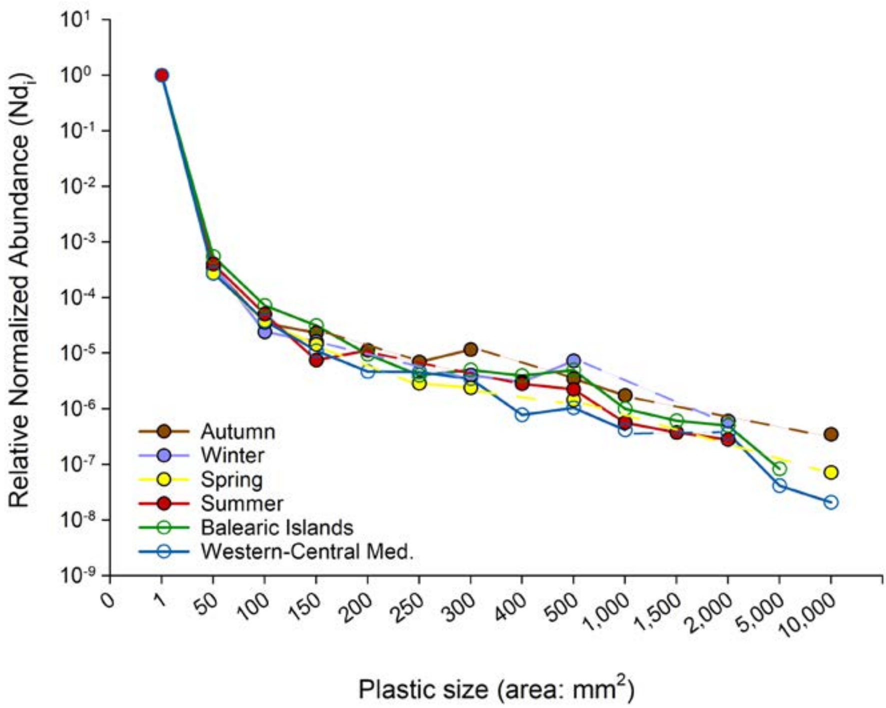


Figure 9.2. Plastic size (area) distribution of floating particles. *Values are in mm^2.*

pollution in coastal ecosystems. Nevertheless, the limited period of service operation (i.e. summer season), the rapid fragmentation of plastic debris entering marine ecosystems into smaller particles (e.g. Isobe et al., 2014; Pedrotti et al., 2016), as well as the redistribution of particles from the original sources, should promote preventive solutions to the entry of plastics into ecosystems in addition to the remediation ones.

The classification of plastic particles confirmed the persistence of hard fragments (**Chapters 3-5**). Films or flexible plastic fragments were usually the second most frequent compound observed (**Chapters 3-5**). The proportions found for these groups (~ 90% hard fragments and ~ 5% film fragments) appear to be generally repeated in the composition of floating plastics (Martí et al., 2016), where the polymeric composition of the floating fragments is usually constituted by more of the 60% of polyethylene (PE) in the Mediterranean according to recent studies (Fossi et al., 2017; Pedrotti et al., 2016; Suaria et al., 2016); see also General future perspectives section. Although, the proximity to the land-based sources favors the slight variation in the proportions of the plastic debris composition along the analyzed seasons (**Chapter 5**). The rapid increase of films particles during summer and autumn or the industrial pellets and foam fragments in winter, suggesting this variability linked to the consumption habits in the coastal of Menorca Channel and confirmed the lower persistence of these kind of plastics in the surface waters compared to hard ones (**Chapter 5**).

9.1.4. Study limitations

In the course of this research, some limitations were found.

A) The analysis of the surface plastics, by the features of the sampling tools (i.e. few draft centimeters), have been simplified to the use of surface measurements in most of the surface plastic pollution research. The presence of floating plastic debris is better expressed by volume of water filtered rather than the sampling distance due to the surface current variations (e.g. flow-back or vertical movements). Therefore, it is recommendable the use of a flowmeter to improve the accuracy of the study, according to recent reports (Suaria et al., 2016). However, in our Mediterranean regional study (**Chapter 3**), we were unable to use this device due to technical problems; hence, we utilized the GPS positions to derive the distance tows. In the rest of spatial-temporal surface analysis (**Chapter 4 – 5**), technical issues were corrected and volume values were obtained. We continued using surface units to compare all the data of this thesis and with other reported research, but also included the volume results.

B) Some coastal areas that were randomly selected to be analyzed within the course of the research NIXE III project had to be suspended due to the conditions. These conditions were presented in two main ways: firstly, the sea conditions, where wave height ~1.5 m and high wind conditions could produce gaps during the tows as the mouth of the manta net was exposed; while, secondly, the coastal sea traffic, especially in areas with a high density of recreational craft, could cause disturbances in the sea surface when navigating near the research vessel. Hence, we decided to eliminate those sampling points.

C) Finally, due to the complications to identify microplastics, the research is moving towards the characterization of the constituent polymer of the particles. In this thesis, it was not possible to characterize the plastic polymers, where we used the visual identification of particles. Suaria et al. (2016) reported in their study a certain misidentification of characterized plastic particles larger than 700 µm, but the error did not exceed 5% of total weight of their study. The concurrence of the results in weight concentrations obtained in the last large-scale studies in the Mediterranean (Cózar et al., 2015; Suaria et al., 2016), suggests that this error could be in the same range; however, we believe in the potential of polymeric characterization analyzes, especially for smaller particles where there is still a wide knowledge gap, and it could present themselves as a future opportunity (see General future perspectives section).

9.2. Part II: Public perception and awareness about plastic pollution

The implications of plastic pollution are not only limited to the natural environments, but social environments have also neither shown themselves unharmed to their impacts; nevertheless, the problem itself has a social and behavioral origin interrelated between all sectors. In the last decades, a considerable effort has been made to analyze the human perceptions and behaviors about the marine debris, but there is still a need for broader research of plastic issues (e.g. Anderson et al., 2016; Boudet et al., 2016; Pahl and Wyles, 2017). The second part of the main objective of this thesis was to study the social status of the problem of plastics. To address this objective, we identified two sub-objectives in this thesis: the first was to analyze three key stakeholders to obtain the perceptions of the problem of plastics, and the second was to examine the perception, awareness, motivations and attitudes of beach users in Mallorca regarding this issue.

9.2.1. Plastic issues from stakeholders' point of view

In **Chapter 7**, using a qualitative empirical mixed-methodology, we explored the emerged perceptions based on the observations from three influential stakeholders (experts, public administrators and company agents) in Mallorca (Spain). The qualitative social methodology has been proved effective for the initial exploring of emerging issues (e.g. Anderson et al., 2016; Pahl and Wyles, 2017), due in part to the facility of the free expression of participants.

The approach to the problem, based on participants' observational experience, reflected the convergence of the groups analyzed in the relevance of causal factors. The excess plastic used in both consumption and production was the crucial problem perceived of this material (**Chapter 7**), which collapses the management plastic debris systems due to the vast generation of plastic waste or their misuses, favoring the entry of plastics into natural ecosystems. This result is reinforced by the current growing plastic production, reaching 335 million metric tons (MT) in 2016, which the significant proportion of the annual plastic production in Europe is destined to the single-use plastics (e.g. packaging) (PlasticsEurope, 2018).

The rest of the themes and constructs that emerged in the study showed focal points related to the thematic areas of each group. The company agents developed detailed thematic issues related to management (e.g. waste management systems), the experts focused on adverse effects and consequences for social and ecological systems (e.g. human health, wildlife health), while the public administrations provided complementary visions between the other groups (**Chapter 7**). In this process, differences and similarities emerged between the observations of the groups that allowed the development of a framework of the problems of plastic material (Figure 9.3) and six different proposals covering the main problems identified (e.g. awareness, education, plastic reduction, cooperation) (**Chapter 7**).

The conformation of the framework of the plastic problem based on the observations of the participants suggested the urgent need to establish coordination tables that favor bottom-up interactions with suggestions and solutions of the whole set of stakeholders (**Chapter 7**). Some recent international measures have established such interactions among different stakeholders from which valuable recommendations have been released (Veiga et al., 2016); however, it is also needed the development of accounting models that cyclically assess the state of the problem within an ecosystem-based management system.

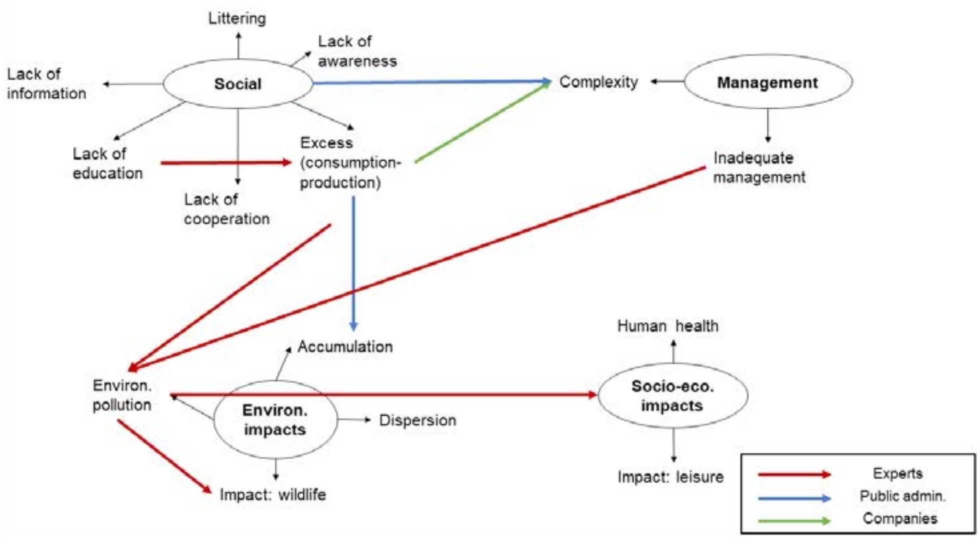


Figure 9.3. Framework combined from the perceptions of the three stakeholders analyzed.

9.2.2. Views of beach users on plastics

In **Chapter 8**, quantitative methods were applied through a questionnaire to obtain the beach users' perception and awareness of the problem as well as their attitudes and motivations, also showing the importance of users' opinions in addressing environmental problems. Initial results showed an elevated concern and awareness of beach users associating plastics with waste and perceiving it as a severe threat to marine and coastal ecosystems above the social and economic consequences. Also, the participants were broadly interested (78.43% of respondents) in the problems associated with this type of material.

Despite the initial perception, around 70% and 67% of beach users also pointed out the absence of awareness and information that together with the excess (74.80%) were considered as the primary problems related with plastics (**Chapter 8**). The respondents also considered that the information provided by the public administration is deficient (52.91% of responses), a fact that is aggravated if it is taken into account the information provided by companies (66.93% of responses) (**Chapter 8**). In this context, the absence of individual responsibility was reflected in which causes tended to be outsourced (e.g. rest of population, other sectors), but nevertheless also showed the limited effectiveness of the resources currently used by public managers and companies to transmit information on plastic waste (e.g. recycling campaigns, clean-up activities, advertisements).

The attitudes of most respondents reflected a rejection to the presence of plastics debris on the beaches and even expressed a selection or predilection for beaches where the presence of plastic litter was lower (**Chapter 8**). This result together with the perception of the current status of the Mallorcan coast and its future evolution, suggesting an important economic implication to large tourist sectors in the location of particularly affected areas. (e.g., Mouat et al., 2010). Regarding motivations of beach users (Figure 9.4), interested and non-interested users shared a general favor opinion to regulate the excess, reduce or return of plastics and their litter; although, the non-interested users showed a more conservative attitude in the use of plastic packaging (Chapter 8). These responses show the acceptability of the population by the implementation of measures that reduce the problem and that have repercussions throughout the life of the plastic, but that do not end up having an impact on the final consumer and that can cause a rejection and consequent effectiveness of the implemented measures (e.g. Koutrakis et al., 2011; Lozoya et al., 2014) (**Chapter 8**).

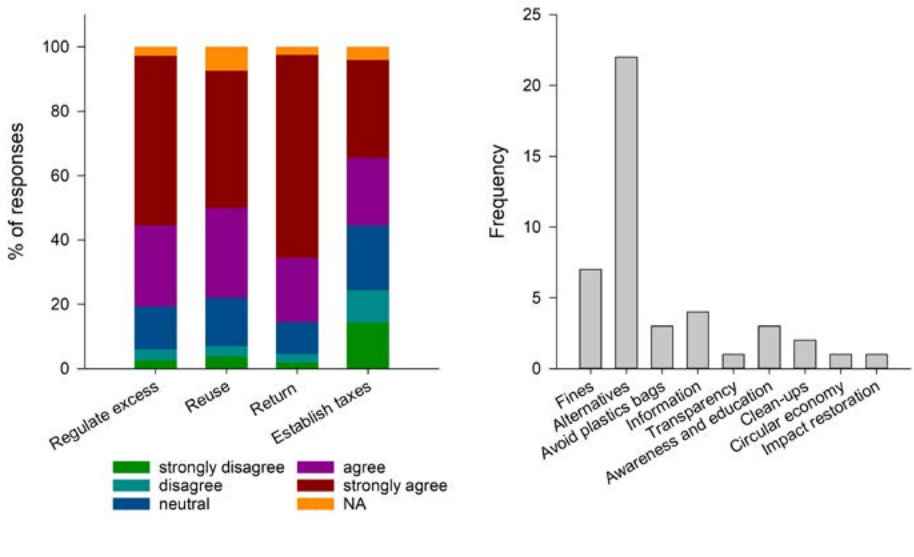


Figure 9.4. Public motivations of respondents to the problems of plastics. *Values are represented in the left graph are percentages of total responses in a Likert scale. Right graph is the frequency of main themes added by participants in the open-question of the survey.*

These results show the importance of analyzing users' perceptions due to the large implications for present and future scenarios. In this sense, options that allow bottom-up relationships to be integrated from a society that allows the integration of opinions and concerns to increase the effectiveness of policies and other solutions when it comes to mitigating plastic pollution.

9.2.3. Study limitations

In the course of this research, some limitations were found. A) Social research inherently has several limitations when analyzing the human variable thought it depends on personal factors (e.g. previous experiences, preconceptions) and the contextual situation in which the person is framed (e.g. Ojala, 2008; Schultz et al., 2013). In this sense, the qualitative social analyzes have demonstrated the detailed and valuable information that could be generated (e.g. Anderson et al., 2016; Pahl and Wyles, 2017), where the evidence-based methodologies had been followed to guarantee the validity of the results. The responses of this study could not formally be extrapolated to all population of interest due to the limited number of participants. It is common that depending on the nature of the issue to be addressed; there is an inherent bias among volunteers who choose to participate in these studies.

B) Questionnaire surveys allow a broader and more representative view of the population and the area of interest, where the large sampled population increased the external validity of our study. Although it would have been desirable to establish a comparison between the beach users and the rest of public, the eminently coastal character of Mallorca, as well as its extensive tourism, would hamper the approach in this study area (see General future perspectives section).

9.3. Main Conclusions

The distribution of plastics in all samples confirmed their ubiquitous presence in the surface waters of the Central and Western Mediterranean Sea.

- Similar values of weight concentration [579.3 g(DW)·km^{-2}] with other large-scale temporal confluent studies, confirmed the current state of floating plastic debris in the Mediterranean; where the estimated floating plastic accumulation extrapolated to its entire surface reached an average of 1,455 metric tons (MT).

- The diversity of methodologies used in the floating plastic research (e.g. different mesh sizes, manta net trawls-rectangular neuston net opening), cause that the variability in the range of the particle concentration between studies increase. However, the average results here presented (147,500 items·km^{-2}), are within the same order of magnitude in the large-scale reported studies.

- The maximum concentration values of floating plastics were found in the NW coast of Ibiza (4,576,115 items·km^{-2}) and the Gulf of Taranto (Italy) [9,298.24 g(DW)·km^{-2}]. The minimum concentration values were found in *S'Albufera des Grau* (NE Menorca; 7,199 items·km^{-2}) and the Menorca Channel [1.03 g(DW)·km^{-2}].

- The limited statistical differences among the areas analyzed in the Mediterranean Sea, confirm and support the absence of stable hydrodynamic convergence areas in the Mediterranean. However, incremental particle concentration with the distance to land was confirmed within data with the same low mesh limit (333 µm) in the Central and Western Mediterranean Sea. Where, also, the concentration of floating plastics on the coasts of the Balearic Islands (793 items·km^{-2}) was significantly higher than the compared results in other coastal waters of the Mediterranean western basin (367 items·km^{-2}).

- The distribution of plastic particles showed higher concentrations in the northern slope of the Balearic promontory in the Balearic Islands, reinforced by the results of the intra-seasonal north-south variation in the Menorca Channel. This supports the distribution model studies in this area.

- The high variability in the concentrations of plastic debris in the Menorca Channel did not show any significant differences between the sampled seasons; although, incremental evolution of the uncorrected wind-effect concentration of particles was observed.

- Despite the apparent relationship between the distribution of floating plastic waste and the oceanographic-demographic conditions analyzed, they were not significative correlated to determine particle distribution.

- Microplastics are the most widely present floating particles along the surface of the Mediterranean Sea (~ 95% of total particles), where the particles 1 mm^2 – 50 mm^2 of area and 0.5 mm – 1.3 mm of length were the most frequent sizes of those that were sampled.

- Hard fragments accounted for most of the composition of the sampled floating plastic debris in the Mediterranean Sea. Nevertheless, the composition of the plastic debris types with the lowest proportion reflected significant seasonal variation in the Menorca Channel.

- Qualitative social research provided an in-depth analysis of the insights, interrelations and deficiencies in the current social status of plastic debris problem, as well as, reducing biases in the global view of the problem by favoring the inclusion of different visions in the analysis.

- The causes of social-productive origin were perceived as the main problems of plastic over and above the social or environmental consequences. In this sense, the excess of plastic was categorized as the most worrying cause among stakeholder and beach users' perceptions.

- The improvement of awareness and education associated with plastic pollution were identified as fundamental social factors to combat the problem of plastic, while a breakthrough in current public-private management and cooperation systems was made for these same sectors.

- The lack of awareness and education continues to be perceived as an essential causal origin of the problem, which denotes a degree of awareness; nevertheless, the lack of awareness and education are still perceived as important causal origin of the problem.

- The presence of plastic debris on the beaches generates a general attitude of rejection that could result in a selection towards beaches without plastic debris, similar to other studies previously reported.

- The analysis of motivations of beachgoers reflected a preference to regulate the excess, reuse and return plastic compared to the introduction of new taxes, especially among non-interested in the problem of plastic.

- The socio-ecological study of problems with marked behavioral origins, as in the case of plastic pollution, is corroborated as fundamental to know and understand the status of the affected ecosystems, as well as to understand their causal origins to start building proposals and effective solutions that allow reducing this problem.

9.4. General future perspectives

Since the commercial expansion of plastic materials, the fast increase of this waste in the marine ecosystems at their end-useful life places them in one of the most widespread pollutants in the world. In the last decades, the scientific community concern has addressed the problem to reveal its dimension. We hope that both the data and results provided in this thesis will add another piece to the puzzle for the global contribution of knowledge about plastics pollution.

The spatial-temporal differences in the distribution of floating plastic floats analyzed in this thesis should motivate the proposals of new projects that improve the knowledge about the distribution, dynamics and trends of plastic waste in the entire of our marine ecosystems and also, in the fresh ones as well as to integrate data to come up with a better integrated picture in the accounts framework of the problem. This information is urgently needed for the adequacy of the necessary and positively invaluable floating plastic debris distribution models. We also believe in the importance of continuing to deepen on the characterization of plastics particles (e.g. molecular, size), where open, accessible and connected plastic repositories data from reported studies could favor the reduction of this knowledge gap, to improve the general and particular 'picture' of plastic pollution.

Plastic pollution has strong social and behavioral roots that are necessary to analyze better. Social research has the tools to analyze, evaluate, diagnose and deliver effective responses that would be integrated into legislation to assist management processes and mitigate the problems related to plastic materials. The next steps should focus on the investigation of contextual factors that drive the plastic littering behavior, as well as, the differences between the interior and coastal regions with the objective of generating valuable information to share with the decision-making processes.

Currently, some of the early efforts should focus on collaborative measures that include all stakeholders and the increase of social awareness, have been actively requested as reflected in the results of this thesis. Plastic is a valuable material, which as humans we have not been able to manage appropriately and where a cooperation exercise that integrates and prioritizes a broad integrative bottom-up vision, together with continuous education and open information, would be the key steps to start the change of current plastic waste paradigm. The development of Circular Economy concept (supported by the European Commission), based on the sustainability of limited natural stocks and the resilience of them, opens the new business models integrated into nature. Nevertheless, the change should not be directed solely at the economic model; the social model should also be redirected towards education in environmental values and opportunities. Science plays a fundamental role, where better communication of the science outreach could engage the society (stakeholders and users) and raise the awareness.

More than a century after the work of the Archduke Ludwig Salvator, the Mediterranean Sea faces new challenges. His conservative spirit led him to protect and value natural spaces, differentiating him from the rest of the society. Currently, diverse environments highlighted by the Archduke are considered unique; however, this differentiating character is nowadays, within reach of the small daily gestures that will make us evolve towards more responsible societies.

Chapter 10

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10.1 References by Chapter

Chapter 1

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10.2 Figure References or Authorship

Chapter 1

Figure 1.1. Archduke Ludwig Salvator of Austria (A) and his second steamboat the Nixe II (B).

A: https://commons.wikimedia.org/wiki/File%3ALudwig_Salvatorp.jpg. By Gaston Veuiller (Scanned and image processed by User: Anton) [Public domain], via Wikimedia Commons

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Figure 1.2. Main economic activities and their expected trends in the Mediterranean region.

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Chapter 2

Figure 2.2. Example of the tools used during sampling

A: Rafael Sardá

B: Luis F. Ruiz-Orejón

C: Greenpeace Handout/Pedro ARMESTRE. Luis Francisco Ruiz Orejón científico del CSIC/CEAB. (Consejo superior de investigaciones científicas) realiza muestreos a bordo del Rainbow Warrior.

D: Greenpeace Handout/Pedro ARMESTRE. Luis Francisco Ruiz Orejón científico del CSIC/CEAB. (Consejo superior de investigaciones científicas) realiza muestreos a bordo del Rainbow Warrior.

Figure 2.3. Example of flowmeter used in campaigns.

Luis F. Ruiz-Orejón

Figure 2.4. Example of calibrated photography to analyze particle sizes (area and length).

Luis F. Ruiz-Orejón

Chapter 6

Figure 6.1. Focus groups sessions.

A: Rafael Sardá

B: Rafael Sardá

C: Rafael Sardá

D: Rafael Sardá

F: Rafael Sardá

Figure 6.2. Example of interviewers explaining and preparing the questionnaire

Rafael Sardá

Chapter 11

Annexes and Publications

Annex A

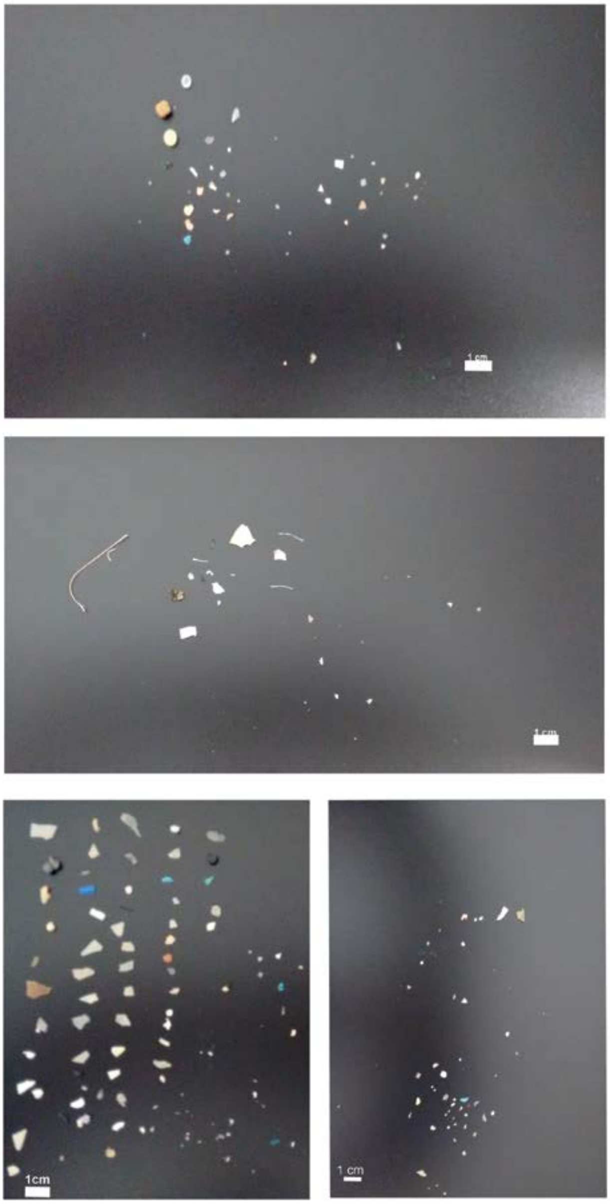

Figure S2.1. *Example of calibrated pictures for size analysis.*

Annex B

Figure S3.1. Representation of sampling points in the Northwestern and central Mediterranean Sea. *Different colors represent each survey campaign: Purple (2011), Green (2013). Background layer image form Esri servicices*

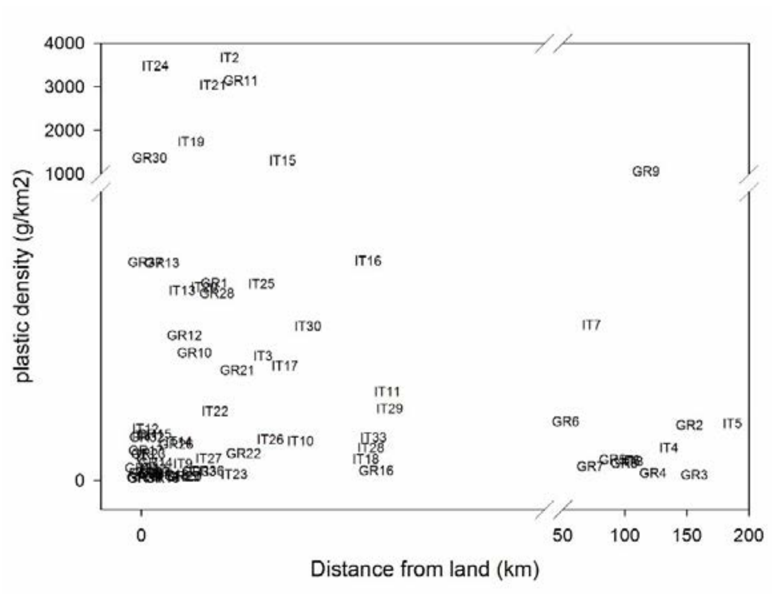

Figure S3.2. Plastic weight concentration versus distance to land with representation of sample identification.

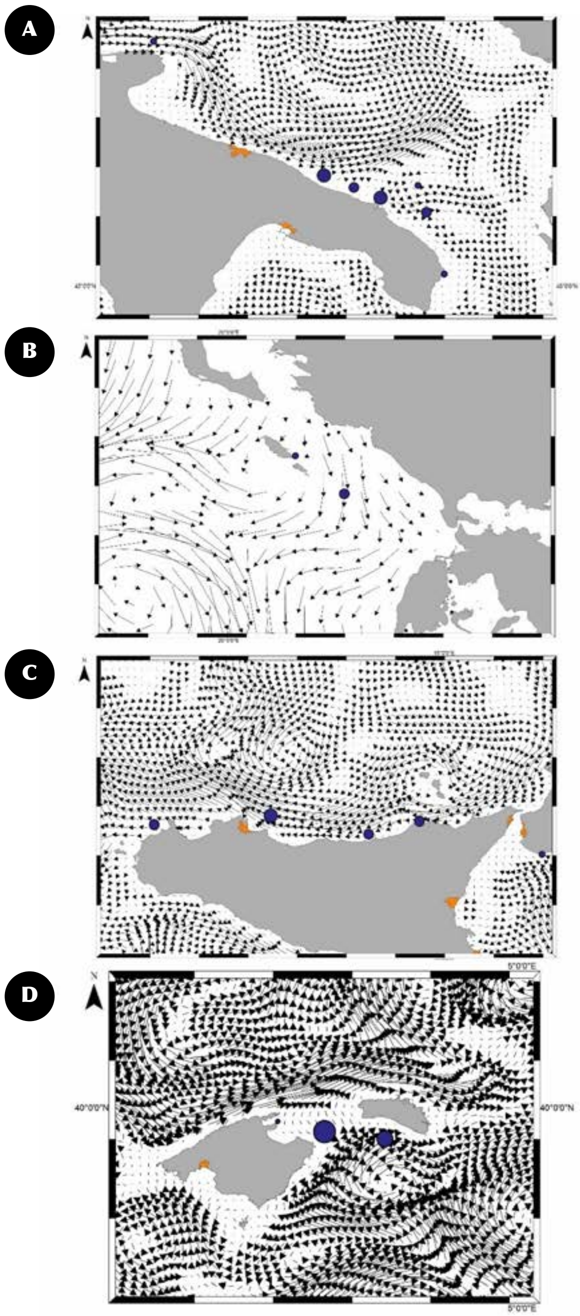

Figure S.3.3. *Plastic particle concentration in relation with sea surface circulation. (A) Otranto Strait at the Italian coast; (B) Northern Ionian Islands (Paxi, Antipaxi and Lefkada), Greece; (C) Northern coast of Sicily (Italy) and (D) Majorca and Menorca (Balearic Island, Spain). Yellow areas correspond to population centers.*

Table S3.1. ***Results of floating plastic concentrations in the North-western-central Med. Sea survey*** *Results of plastic weight (g(DW)·km⁻²) and particle (items·km⁻²) concentration, tar ball-pellet concentration (g(DW)·km⁻²) and wind (U_{10}) speed of each sample with starting coordinates. Plastic concentration are not wind-corrected.*

Sample ID	Coordinates (start)	Plastic weight concentration (g(DW)·km^{-2})	Plastic particles concentration (items·km^{-2})	Tar ball-pellets concentration (g(DW)·km^{-2})	Wind (U_{10}) speed (m·s^{-1})
IT1	N39 53.840 E3 12.100	80.68	122,284	0.000	1.84
IT2	N39 49.370 E3 32.370	3,656.17	209,383	12.599	2.77
IT3	N39 46.280 E3 59.380	430.65	35,397	0.600	3.58
IT4	N39 32.350 E5 51.300	112.19	16,799	0.000	3.42
IT5	N39 26.400 E6 26.200	196.60	8,999	0.000	3.46
IT6	N39 17.500 E7 00.500	67.67	18,599	0.000	3.88
IT7	N39 11.680 E7 22.000	538.70	17,399	0.000	4.26
IT8	N38 55.718 E11 43.714	64.90	11,313	0.000	7.05
IT9	N38 43.730 E13 04.286	57.38	29,398	0.000	6.44
IT10	N38 40.650 E13 25.400	135.95	32,997	0.000	3.61
IT11	N38 37.100 E13 59.800	307.84	90,593	0.003	4.35
IT12	N38 33.175 E14 34.361	177.27	31,797	0.001	3.04
IT13	N38 27.741 E15 02.142	657.07	44,996	0.004	2.05
IT14	N38 07.830 E15 35.340	133.31	28 198	0.000	0.60
IT15	N38 18.038 E16 41.966	1,301.48	238,781	0.019	0.95
IT16	N38 38.500 E17 03.675	760.80	170,986	0.005	1.08
IT17	N38 50.620 E17 19.330	396.15	152,388	0.000	4.20
IT18	N39 01.700 E17 31.820	73.07	16,199	0.000	4.10
IT19	N40 43.607 E17 59.168	1,728.94	231,582	0.011	0.88
IT20	N40 48.759 E17 45.942	669.25	137,989	0.005	1.59
IT21	N40 54.764 E17 31.121	3,030.00	982,121	0.063	1.66

IT22	N42 01.200 E16 06.625	239.38	437,965	0.005	2.76
IT23	N42 07.510 E15 42.363	20.22	15,599	0.000	2.17
IT24	N42 07.620 E15 28.010	3,481.28	47,996	0.000	4.08
IT25	N43 37.865 E13 46.870	681.19	88,791	0.000	4.30
IT26	N43 45.065 E13 37.730	140.99	15,599	0.000	3.42
IT27	N42 34.000 E18 02.360	74.87	22,798	0.000	3.11
IT28	N42 20.240 E18 02.827	112.61	35,397	0.002	2.52
IT29	N40 49.770 E18 17.720	248.26	46,196	0.004	4.10
IT30	N40 36.660 E18 21.852	534.26	134,989	0.125	4.35
IT31	N40 05.715 E18 30.770	153.89	14,399	0.000	5.48
IT32	N39 46.625 E18 20.970	39.90	32,397	0.040	2.45
IT33	N39 36.268 E18 06.526	147.77	59 395	0.001	1.99
IT34	N39 23.680 E17 49.275	9,298.24	85,193	0.007	2.48
GR1	N39 50.730 E3 25.660	682.67	330,397	13.085	2.66
GR2	N39 40.484 E6 04.399	190.05	20,421	0.000	3.09
GR3	N39 22.128 E6 26.055	18.30	12,773	0.000	3.58
GR4	N39 15.265 E6 48.530	24.54	12,773	1.562	4.6
GR5	N39 10.880 E7 10.250	71.54	22,964	0.000	4.95
GR6	N38 34.530 E9 37.300	203.38	190,270	12.046	4.01
GR7	N38 30.650 E9 58.310	47.34	64,547	0.453	4.12
GR8	N38 24.800 E10 19.075	57.94	46,848	3.123	3.38
GR9	N38 18.360 E10 42.100	1,048.63	123,049	13.429	3.24
GR10	N38 09.076 E12 36.094	442.17	32,348	0.000	6.55
GR11	N38 13.424 E13 33.960	3,132.43	106,570	0.934	4.52
GR12	N38 04.414 E14 22.560	502.17	459,563	19.246	2.51
GR13	N38 10.812 E14 47.825	754.01	617,351	73.644	2.62

GR14	N38 16.074 E15 11.990	60.48	28,198	0.822	3.9
GR15	N37 54.309 E15 48.690	159.73	323,411	7.970	5.69
GR16	N39 05.200 E19 49.780	32.94	122,390	36.198	3.7
GR17	N39 10.990 E20 13.220	102.83	321,274	43.970	3.73
GR18	N39 15.567 E20 21.827	7.95	44,996	1.725	3.73
GR19	N39 15.115 E20 19.835	20.73	136,789	0.996	2.45
GR20	N39 13.649 E20 15.206	14.06	59,995	28.126	5.61
GR21	N39 03.387 E20 22.959	381.42	1,164,282	625.821	2.57
GR22	N38 56.132 E20 34.409	91.88	15,1863	5.445	4.87
GR23	N38 45.940 E20 44.059	91.01	437,259	69.136	2.21
GR24	N38 39.953 E20 44.256	42.40	132,570	54.504	4.73
GR25	N38 36.251 E20 35.198	25.63	52,496	9.852	4.4
GR26	N38 32.171 E20 35.198	123.61	107,429	12.593	4.69
GR27	N38 24.862 E20 37.116	27.36	21,516	0.000	4.69
GR28	N38 16.540 E20 59.128	648.34	458,016	70.924	3.27
GR29	N38 16.540 E21 23.606	14.29	85,597	1.986	2.46
GR30	N38 20.574 E21 53.370	1,359.91	339,401	25.216	2.69
GR31	N38 22.075 E21 48.581	21.73	71,143	2.417	3.17
GR32	N38 28.069 E20 41.686	149.18	55,346	30.161	4.47
GR33	N38 15.382 E20 47.787	29.57	48,746	0.953	3.33
GR34	N37 54.871 E20 43.015	7.44	16,970	0.571	5.25
GR35	N37 56.074 E20 42.470	9.76	44,996	16.164	0.48
GR36	N38 01.347 E20 35.641	31.78	58,048	16.275	1.27
GR37	N38 06.999 E20 28.822	755.69	478,649	55.616	0.96

Table S3.2. R values from Spearman correlation test between sample composition. *(A) correlation data from both campaigns together and (B) separates. First campaign above the diagonal and second below the diagonal. Correlation data with p-values < 0.05 are in bold*

A	**Total Plastic**	**Micro-plastic**	**Meso-plastic**	**Macro-plastic**	**Tar Pellets**	**Paper**	**Vegetal**	**Animal**	**Other**
Total Plastic	1								
Micro-plastic	**0.881**	1							
Meso-plastic	**0.769**	**0.674**	1						
Macro-plastic	**0.813**	**0.597**	**0.475**	1					
Tar Pellets	0.110	0.219	-0.029	0.073	1				
Paper	0.000	0.000	0.000	0.000	0.000	1			
Vegetal	-0.114	-0.012	-0.221	-0.032	**0.507**	0.000	1		
Animal	-0.218	-0.115	-0.272	-0.167	**0.484**	0.000	**0.644**	1	
Other	0.017	0.130	-0.068	-0.072	**0.501**	0.000	**0.428**	**0.452**	1

B	**Total Plastic**	**Micro-plastic**	**Meso-plastic**	**Macro-plastic**	**Tar Pellets**	**Paper**	**Vegetal**	**Animal**	**Other**
Total Plastic	1	**0.818**	**0.700**	**0.770**	0.275	0.000	-0.156	0.086	0.067
Micro-plastic	**0.944**	1	**0.580**	**0.476**	0.169	0.000	-0.093	0.069	0.058
Meso-plastic	**0.751**	**0.688**	1	**0.362**	-0.044	0.000	-0.252	-0.113	-0.116
Macro-plastic	**0.805**	**0.701**	**0.543**	1	0.283	0.000	0.041	0.076	0.056
Tar Pellets	**0.436**	**0.566**	**0.379**	0.255	1	0.000	-0.063	**0.718**	**0.674**
Paper	0.000	0.000	0.000	0.000	0.000	1	0.000	0.000	0.000
Vegetal	**0.374**	**0.443**	0.320	0.257	**0.497**	0.000	1	-0.091	-0.091
Animal	**0.356**	**0.343**	**0.437**	0.165	0.034	0.000	0.271	1	**0.998**
Other	0.266	**0.353**	0.141	0.440	**0.414**	0.000	**0.470**	0.155	1

Annex C

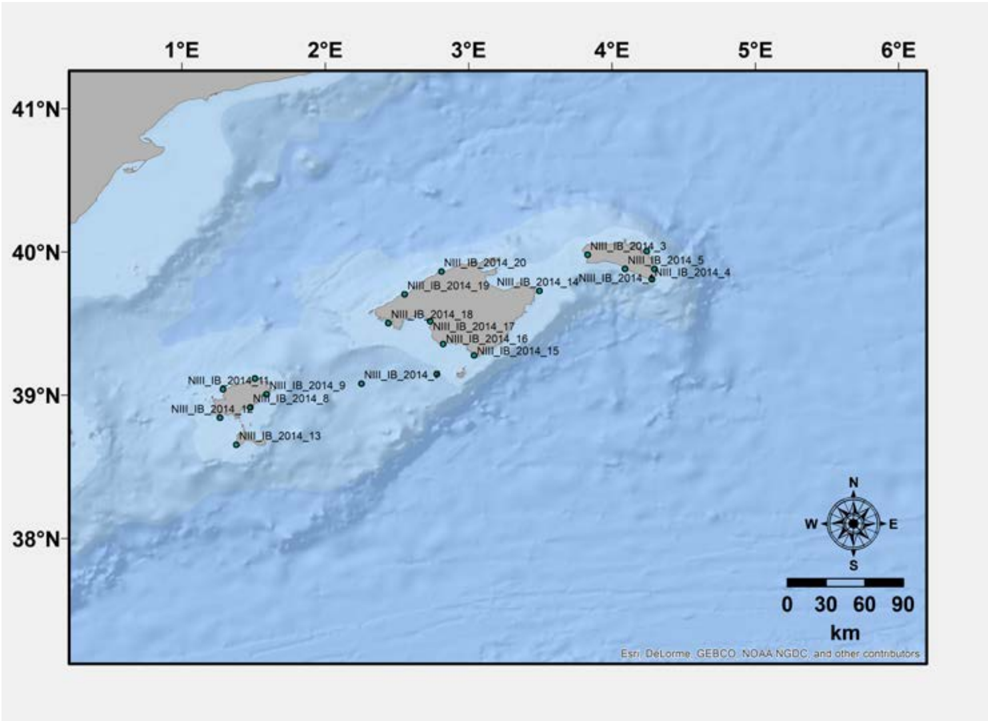

Figure S4.1. Study area of Balearic Islands survey with representation of sampling points. *Background layer image form Esri services.*

Table S4.1. Results of floating plastic concentrations in the Balearic Islands survey. *Weight concentration data in surface (g(DW)·km-2) and volume (g(DW·km-3) units. Particle concentration data in surface (items·km-2) and volume (items·km-3). Wind (U10) speed of each sample with starting coordinates. Plastic concentration are not wind-corrected.*

Sample ID	Coordinates (start)	Plastic weight concentration (g(DW)·km^{-2})	Plastic particle concentration (items·km^{-2})	Plastic weight concentration (g(DW)·m^{-3})	Plastic particle concentration (items·m^{-3})	Wind (U_{10}) speed (m·s^{-1})
NIII_IB_2014_1	N39 52.744 E4 17.825	61.485	43032.611	$2.89{\cdot}10^{-4}$	0.202	4.783
NIII_IB_2014_2	N40 00.316 E4 14.530	2.178	7199.424	$8,74{\cdot}10^{-6}$	0.029	4.848
NIII_IB_2014_3	N39 58.720 E3 49.829	230.465	265478.762	$9.88{\cdot}10^{-4}$	1.138	2.982
NIII_IB_2014_4	N39 48.446 E4 16.772	386.738	642291.474	$1.78{\cdot}10^{-3}$	2.956	4.030
NIII_IB_2014_5	N39 52.810 E4 05.519	127.065	357914.224	$2.85{\cdot}10^{-4}$	0.803	2.665
NIII_IB_2014_6	N39 08.716 E2 46.752	2533.123	105179.086	$1.09{\cdot}10^{-2}$	0.455	3.073
NIII_IB_2014_7	N39 04.776 E2 15.191	43.097	72160.126	$2.21{\cdot}10^{-4}$	0.370	4.135
NIII_IB_2014_8	N38 54.804 E1 28.731	78.884	429223.475	$3.38{\cdot}10^{-4}$	1.836	4.855
NIII_IB_2014_9	N39 00.333 E1 35.506	109.254	307582.536	$5.13{\cdot}10^{-4}$	1.445	4.171
NIII_IB_2014_10	N39 06.945 E1 30.594	1283.129	1446634.270	$5.67{\cdot}10^{-3}$	6.388	4.783
NIII_IB_2014_11	N39 02.393 E1 17.216	7420.765	2840687.030	$4.08{\cdot}10^{-2}$	15.621	4.444
NIII_IB_2014_12	N38 50.459 E1 16.011	498.448	1029292.660	$2.07{\cdot}10^{-3}$	4.273	1.896
NIII_IB_2014_13	N38 39.172 E1 22.826	232.825	762484.456	$1.11{\cdot}10^{-3}$	3.645	2.461
NIII_IB_2014_14	N39 43.643 E3 29.719	465.555	1297161.850	$2.00{\cdot}10^{-3}$	5.578	1.788
NIII_IB_2014_15	N39 16.642 E3 02.324	46.776	84336.110	$2.06{\cdot}10^{-4}$	0.371	4.694
NIII_IB_2014_16	N39 21.378 E2 49.388	1.413	14764.444	$7,22{\cdot}10^{-6}$	0.075	1.747
NIII_IB_2014_17	N39 30.898 E2 43.961	505.256	536871.336	$2.42{\cdot}10^{-3}$	2.569	2.624
NIII_IB_2014_18	N39 30.115 E2 26.422	183.297	326373.890	$8.17{\cdot}10^{-4}$	1.455	0.830
NIII_IB_2014_19	N39 42.191 E2 33.257	8102.939	2699784.020	$3.38{\cdot}10^{-2}$	11.269	0.970
NIII_IB_2014_20	N39 51.754 E2 48.639	1001.668	1191504.680	$4.32{\cdot}10^{-3}$	5.142	1.678

Table S4.2. ***R values from Spearman correlation test between plastic concentrations and the oceanographic variables in the Balearic campaign.*** *Correlation data with p-values < 0.05 are in bold*

	g(DW)·km^{-2}	Items·km^{-2}	SST (°C)	Salinity (psu)	Surface current	Wind speed
g(DW)·km^{-2}	1					
Items·km^{-2}	**0.928**	1				
SST (°C	0.412	0.383	1			
Salinity (psu)	0.110	0.065	0.340	1		
Surface current	-0.005	-0.055	-0.385	0.228	1	
Wind speed	-0.348	-0.285	**0.740**	-0.157	0.226	1

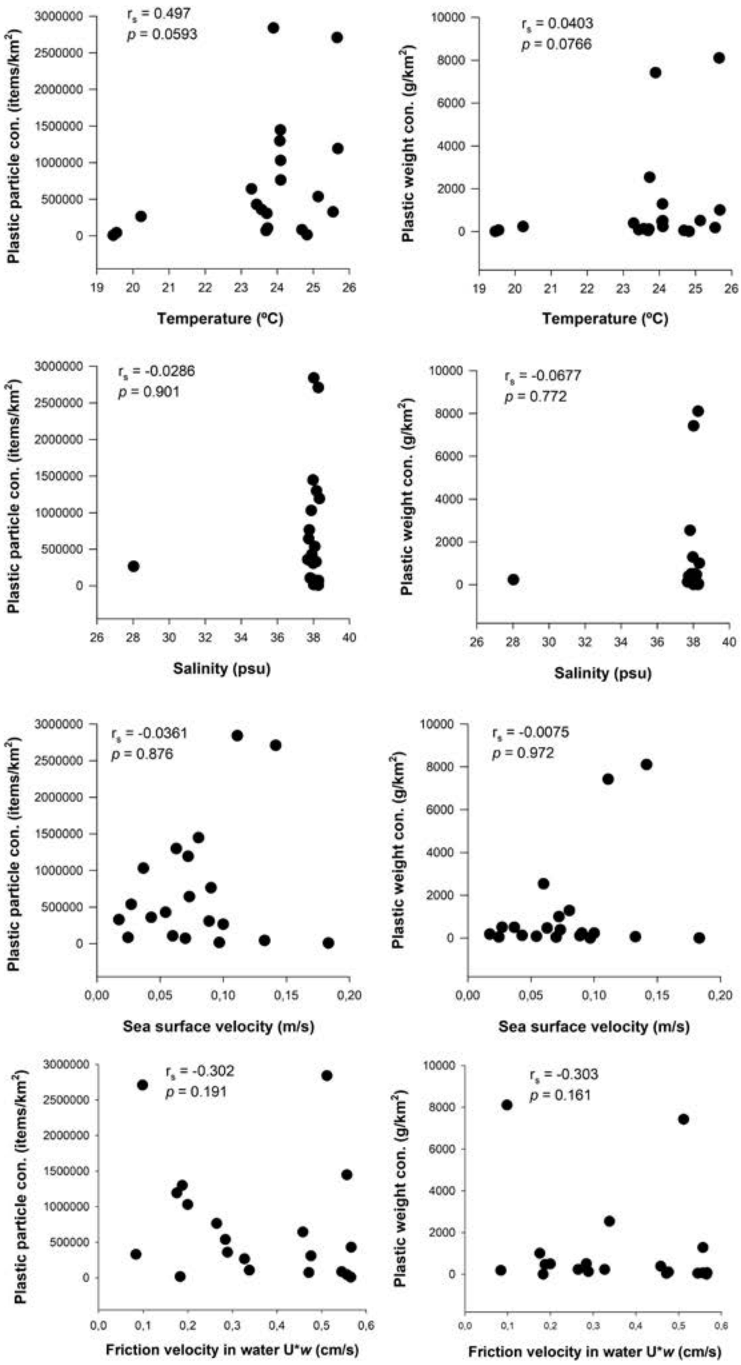

Figure S4.2. Effect of oceanographic variables on the concentration of particles. *Spearman's correlation coefficients (r_s) and p-values are shown in the top- left corner (n = 20).*

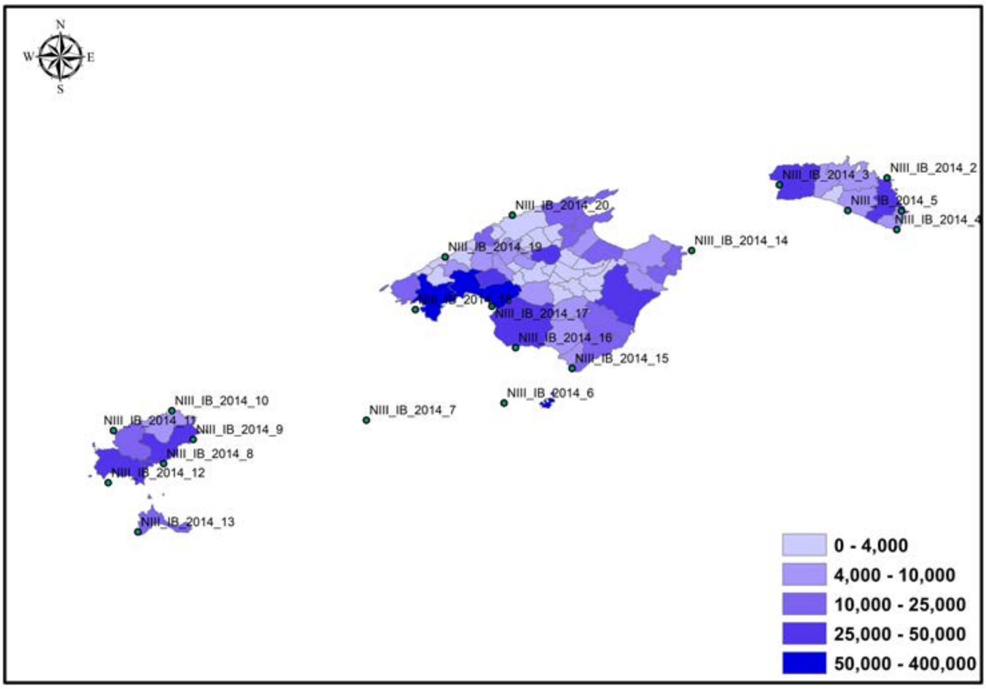

Figure S4.3. Population resident in the Balearic Islands during the sampling period. *Data extracted from the IBESTAT (see section 2.4. of methods – Chapter 2).*

Table S4.3. Number of residents in the municipal areas in the coastal sampling areas of the Balearic Islands. *Data extracted from the IBESTAT (see section 2.4. of methods – Chapter 2).*

Municipal area	Number of residents
Ibiza & Formentera	
Santa Eularia	36,189
Sant Joan	5,668
Sant Antoni	23,359
Sant Josep	25,362
Formentera	11,545
Menorca	
Maò	28,460
Ciutadella	29,282
Alaior	9,162
Sant Lluìs	7,472
Mallorca	
Capdepera	11,385
Santanyí	11,636
Llucmajor	34,602
Palma	399,093
Calvià	50,363
Valldemossa	2,558
Escorca	241

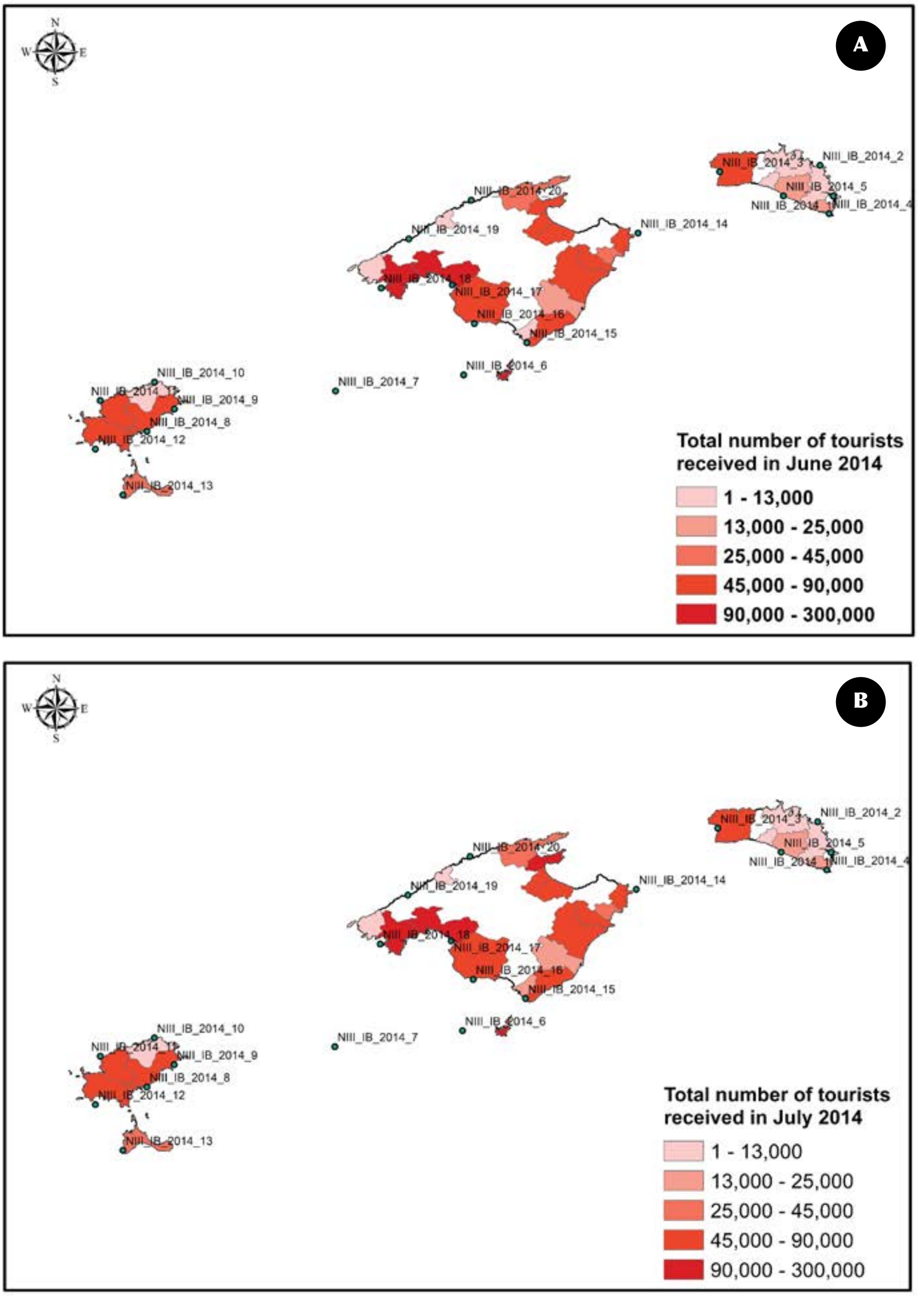

*Figure S4.4. **Tourist received in the Balearic Islands in June and July 2014.** Data extracted from IBESTAT (see section 2.4. of methods – Chapter 2).*

Table S4.4. Number of tourist received in the municipal areas of the Balearic Islands according to the sampling points. *The values include the hotel and tourist apartments offer. Data extracted from IBESTAT (see section 2.4. of methods – Chapter 2).*

Municipal area	Number of tourist recived	Month
Ibiza & Formentera		
Santa Eularia	64,008	June
Sant Joan	5,825	June
Sant Antoni	67,119	June
Sant Josep	75,909	June
Formentera	36,701	June
Menorca		
Maò	6,508	June
Ciutadella	65,374	June
Alaior	17,275	June
Sant Lluìs	16,443	June
Mallorca		
Capdepera	70,554	July
Santanyí	64,985	July
Llucmajor	63,708	July
Palma	236,798	July
Calvià	253,703	July
Valldemossa	ND	July
Escorca	ND	July

Table S.4.5. Data of the coastal cleaning service of Balearic Islands. *Kg of plastics collected in coastal surface waters by the coastal cleaning system of Balearic Islands during summer 2014. Source: Agència Balear de l'Aigua i la Qualitat Ambiental (ABAQUA).*

Service cleaning station	July (kg. of plastics)	August (kg. of plastics)	September (kg. of plastics)
Ibiza & Formentera			
Ibiza	46,41	98,94	71,91
Sant Josep	241,1025	511,241	417,3925
Sant Antoni	334,22	283,56	259,08
Sant Joan	89,301	108,953	156,349
Santa Eularia	60,792	142,9032	186,66
Formentera	46,98	151,61	107,46
Menorca			
Sant Lluis	4,6	68,425	7,4375
Mao	55,216	234,906	235,2644
Ciutadella	69,2835	255,816	289,0569
Es Castell	14,518	30,94	84,371
Es Mitjorn	5,508	19,992	48,144
Mallorca			
Capdepera	27,28	50,6	195,8
Santany	419,52	723,52	763,42
Llucmajor	56,42	58,28	24,49
Palma	57,35	346,32	167,24
Calvia	18,9	103,25	95,9
Valldemosa	23,31	44,73	35,28
Fornallutx	28,81	90,73	4,3

References

ABAQUA (Govern de les Illes Balears), 2014. Coordinació de Neteja del Litoral (C.N.L.), Recollides de les embarcacions temporada d'estiu 2014. Palma de Mallorca.

Annex D

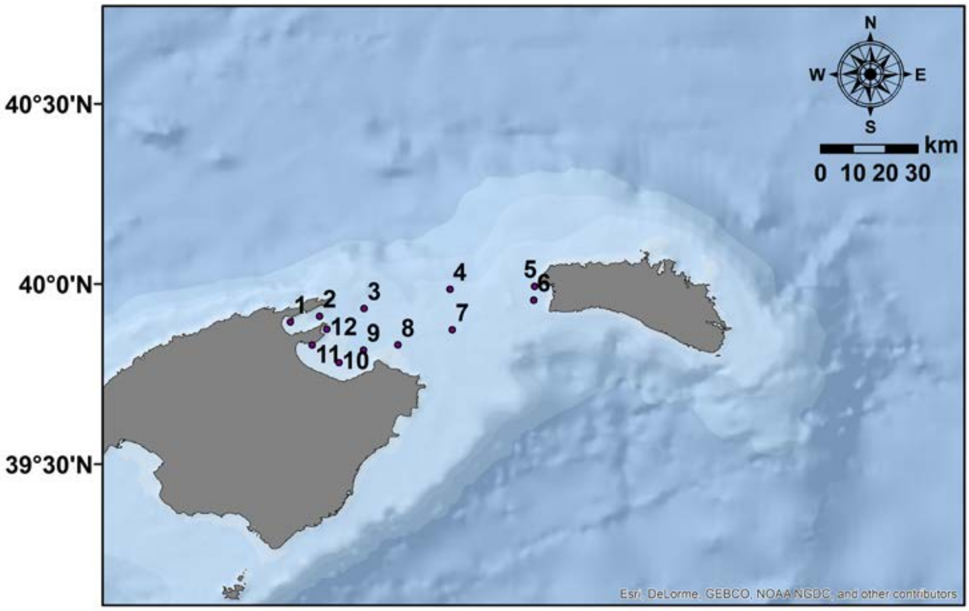

Figure S5.1. Study area of the Menorca Channel survey with representation of sampling points. *Background layer image form Esri services.*

Table S5.1. Results of floating plastic concentrations in the Menorca Channel seasonal survey. *Weight concentration data in surface ($g(DW)\cdot km^{-2}$) and volume ($g(DW\cdot km^{-3}$) units. Particle concentration data in surface ($items\cdot km^{-2}$) and volume ($items\cdot km^{-3}$). Wind (U_{10}) speed of each sample with starting coordinates. Plastic concentration are not wind-corrected.*

Sample ID	Starting Coordinates	Plastic weight concentration ($g(DW)\cdot km^{-2}$	Plastic particles concentration ($items\cdot km^{-2}$)	Plastic weight concentration ($g(DW)\cdot m^{-3}$)	Plastic particle concentration ($items\cdot m^{-3}$)	Wind (U_{10}) speed ($m\cdot s^{-1}$)
NIII_CM_2014_1_3	N39 55.890 E3 18.457	5.818	27,868.738	$2.25\cdot10^{-5}$	0.108	4.626
NIII_CM_2014_1_4	N39 59.109 E3 32.741	100.713	30,372.570	$4.07\cdot10^{-4}$	0.123	3.662
NIII_CM_2014_1_5	N39 58.711 E3 46.854	21.578	64,794.816	$1.02\cdot10^{-4}$	0.308	2.842
NIII_CM_2014_1_6	N39 57.285 E3 36.470	95.251	38,568.343	$3.22\cdot10^{-4}$	0.131	4.867
NIII_CM_2014_1_7	N39 50.002 E3 21.313	136.635	56,786.901	$5.21\cdot10^{-4}$	0.217	4.548
NIII_CM_2014_1_8	N39 30.283 E3 20.406	131.919	19,595.207	$4.87\cdot10^{-4}$	0.072	4.548
NIII_CM_2014_1_9	N39 48.972 E3 14.250	14,246.592	23,5025.841	$4.43\cdot10^{-2}$	0.730	3.650
NIII_CM_2014_1_10	N39 43.080 E3 14.250	128.397	127,114.831	$5.39\cdot10^{-4}$	0.534	3.650
NIII_CM_2014_1_11	N39 49.789 E3 09.783	12.228	40,496.760	$4.69\cdot10^{-5}$	0.155	5.229
NIII_CM_2014_1_12	N39 52.4628 E3 12.222	133.609	83,993.281	$5.70\cdot10^{-4}$	0.358	5.229
NIII_CM_2014_1_2	N39 54.604 E3 11.022	34.338	74,876.822	$1.49\cdot10^{-4}$	0.326	5.229

NIII_ CM_2014_1_1	N39 53.640 E3 06.180	80.551	203,538.404	$2.00 \cdot 10^{-5}$	0.929	5.229
NIII_ CM_2015_2_3	N39 56.741 E3 17.840	3,496.925	475,396.751	$9.61 \cdot 10^{-3}$	1.306	4.721
NIII_ CM_2015_2_4	N39 59.951 E3 33.932	687.830	131,989.441	$1.90 \cdot 10^{-3}$	0.364	4.056
NIII_ CM_2015_2_5	N39 58.200 E3 45.898	705.294	312,162.527	$2.29 \cdot 10^{-3}$	1.013	3.696
NIII_ CM_2015_2_6	N39 58.285 E3 36.470	130.970	50,395.968	$4.88 \cdot 10^{-4}$	0.188	3.696
NIII_ CM_2015_2_7	N39 50.002 E3 21.313	59.211	55,327.642	$2.58 \cdot 10^{-4}$	0.241	4.357
NIII_ CM_2015_2_8	N39 30.283 E3 20.406	11.271	18,619.200	$4.17 \cdot 10^{-5}$	0.069	5.009
NIII_ CM_2015_2_9	N39 48.972 E3 14.315	165.184	32,820.904	$6.23 \cdot 10^{-4}$	0.124	5.009
NIII_ CM_2015_2_10	N39 42.978 E3 15.282	8.686	25,546.343	$3.49 \cdot 10^{-5}$	0.103	5.009
NIII_ CM_2015_2_11	N39 49.315 E3 09.285	68.832	67,494.600	$2.61 \cdot 10^{-4}$	0.255	1.424
NIII_ CM_2015_2_12	N39 53.480 E3 12.720	21.486	65,244.780	$6.45 \cdot 10^{-5}$	0.196	1.424
NIII_ CM_2015_2_2	N39 54.604 E3 11.022	117.624	104,267.521	$6.10 \cdot 10^{-4}$	0.541	1.424
NIII_ CM_2015_2_1	N39 54.220 E3 06.700	24.433	73,119.151	$1.06 \cdot 10^{-4}$	0.317	1.424

NIII_ CM_2015_3_3	N39 56.500 E3 17.915	129.686	303,575.714	$5.64 \cdot 10^{-4}$	1.321	0.960
NIII_ CM_2015_3_4	N39 58.200 E3 31.806	111.103	98,701.781	$4.50 \cdot 10^{-4}$	0.400	1.224
NIII_ CM_2015_3_5	N39 59.311 E3 46.854	1860.845	515,530.186	$6.24 \cdot 10^{-3}$	1.729	3.560
NIII_ CM_2015_3_6	N39 57.700 E3 37.453	172.966	86,816.584	$6.55 \cdot 10^{-4}$	0.329	3.560
NIII_ CM_2015_3_7	N39 50.002 E3 21.313	9.989	23,623.110	$3.77 \cdot 10^{-5}$	0.089	3.325
NIII_ CM_2015_3_8	N39 30.283 E3 20.406	78.809	38,479.680	$1.68 \cdot 10^{-5}$	0.125	4.274
NIII_ CM_2015_3_9	N39 48.972 E3 14.250	169.522	321,574.274	$5.80 \cdot 10^{-4}$	1.099	4.274
NIII_ CM_2015_3_10	N39 43.080 E3 14.250	45.472	114,958.545	$1.94 \cdot 10^{-4}$	0.491	4.799
NIII_ CM_2015_3_11	N39 49.789 E3 09.783	5.841	12,773.172	$2.37 \cdot 10^{-5}$	0.052	5.846
NIII_ CM_2015_3_12	N39 53.218 E3 13.429	1.035	14,623.830	$5.12 \cdot 10^{-6}$	0.072	5.846
NIII_ CM_2015_3_2	N39 55.729 E3 11.915	5094.257	302,703.056	$3.43 \cdot 10^{-2}$	2.039	5.846
NIII_ CM_2015_3_1	N39 53.900 E3 07.203	544.480	471,562.275	$2.16 \cdot 10^{-3}$	1.874	5.846
NIII_ CM_2015_4_3	N39 55.158 E3 20.103	81.573	128,989.681	$3.74 \cdot 10^{-4}$	0.591	1.790

NIII_ CM_2015_4_4	N39 59.160 E3 34.033	213.723	116,581.583	$1.09 \cdot 10^{-3}$	0.595	0.751
NIII_ CM_2015_4_5	N39 58.300 E3 47.011	206.050	184,485.241	$8.56 \cdot 10^{-4}$	0.767	0.574
NIII_ CM_2015_4_6	N39 56.319 E3 36.077	180.790	326,091.560	$8.06 \cdot 10^{-4}$	1.454	0.716
NIII_ CM_2015_4_7	N39 50.719 E3 24.288	446.679	586,078.114	$1.96 \cdot 10^{-3}$	2.565	0.478
NIII_ CM_2015_4_8	N39 30.283 E3 20.406	317.802	330,941.267	$1.41 \cdot 10^{-3}$	1.466	0.753
NIII_ CM_2015_4_9	N39 47.509 E3 15.900	20957.073	482,586.393	$8.68 \cdot 10^{-2}$	2.000	0.753
NIII_ CM_2015_4_10	N39 44.800 E3 14.700	89.957	212,383.009	$3.42 \cdot 10^{-4}$	0.806	1.246
NIII_ CM_2015_4_11	N39 49.789 E3 09.783	180.367	241,392.453	$8.61 \cdot 10^{-4}$	1.152	2.945
NIII_ CM_2015_4_12	N39 52.970 E3 15.198	376.131	224,594.101	$1.60 \cdot 10^{-3}$	0.956	2.945
NIII_ CM_2015_4_2	N39 54.209 E3 12.318	1115.306	118,881.246	$5.45 \cdot 10^{-3}$	0.581	2.945
NIII_ CM_2015_4_1	N39 53.209 E3 05.318	34.458	55,441.993	$1.40 \cdot 10^{-4}$	0.226	2.945

Table S5.2. Number of tourist received in the municipal areas of the Menorca Channel according to the area of study. *Data extracted from IBESTAT (see section 2.4. of methods – Chapter 2).*

Municipal area	Autumn (n. tourist)	Winter (n. tourist)	Spring (n. tourist)	Summer (n. tourist)
Ciutadella	16,930	0	10,029	53,768
Pollença	16,254	0	12,384	20,125
Alcùdia	36,619	0	0	80,622
Muro	38,019	0	23,506	56,830
Santa Margalida	31,307	0	0	49,041
Total Mallorca & Menorca	906,060	181,437	760,222	1,963,136

Table S5.3. Percentage of hotel and tourist apartment occupancy in the municipal areas of the Canal de Menorca according to the area of study. *Data extracted from IBESTAT (see section 2.4. of methods – Chapter 2).*

Municipal area	Autumn (% hotel – % apartment)	Winter (% hotel – % apartment)	Spring (% hotel – % apartment)	Summer (% hotel – % apartment)
Ciutadella	47.6 – 27.2	0 – 0	ND – 57.5	71.4 – 94.7
Pollença	66.3 – 47.8	0 – 0	56.2 – 59.2	73.4 – 87.4
Alcùdia	64.8 – 63.1	0 – 0	29.4 – 0	80.9 – 90.9
Muro	65.7 – 43.1	0 – 0	0 – 62.6	85.6 – 91.2
Santa Margalida	56.3 – 31.0	0 – 0	ND	78.0 – 88.4
Artà	ND	ND	ND	ND

Annex E

Text S6.1.

This text refers to the transcripts of the focus groups sessions carried out to the key stakeholders in Mallorca (experts, public administrators and company agents). The documents do not include any personal references to the participants of the sessions, thus preserving their anonymity.

Due to the length of the transcripts, we did not consider it appropriate to include it in this document. However, you may request a copy of the transcripts justifying their use to the following e-mail address: luisf.ruizorejon@ceab.csic.es

(Language of text: Spanish)

Annex F

Table S7.1. Themes emerged from content analysis and selected verbatim. *Code between parenthesis correspond with its focus group participant. Colors represent the origin of theme in the focus groups sessions: green = affinity diagram, blue = brainstorming.*

Themes	Sub-themes				
	Excess (production-consumption)	**Awareness**	**Education**	**Information**	**Negligence (littering behavior)**
Social causes	*Now, the cup of coffee typical from New York is increasingly used here* (PA4) *It is easier to use things packed in plastic* (PA3) *I go to the supermarket and I see a large amount of plastic packaging used to wrap disposable products* (SN4) *Prioritize the plastic because it is a cheap material* (SN5)	*On the beach, many of the things you find are from the users that they have left them* (PA3) *In the mass residues* [general waste], *there are more than 10% that are containers* (C4)	[Example of a boy who throws a plastic] *But if you explain everything, this guy is going to be clear maybe it is lack of information or education* (SN1)	*Consumers do not have sufficient information to change the industry* (PA7) *Information on alternatives that already exist...we could create many things from materials that are biodegradable* (SN3) *We sell a finished product, but they do not tell the whole process of the product* (C6)	*Driving behind a school bus, I noticed that candy wrappers came out through the windows* (SN4) [recycling] *I believe that more than for lack of information or conscience is because they do not want.* (C5)
	Economic responsibility	**Lobbies**	**Cooperation**		
Economic causes	*The real cost would be to include the environmental costs, but economically it is*	*Is the pressure from the big lobbies that they were going to make change in a*	[plastics on food products] *I am required to put*		

Table S7.1. *(Continue)*

Table S7.1. *(Continue)*

Themes	**Sub-themes**				
	Economic responsibility	**Lobbies**	**Cooperation**		
Economic causes	*not feasible. But of course, this would dismantle the system by being based on unlimited resources.* (PA6) *Environmental costs are not internalized in the industry* (PA5)	*moment of the regulation…* (PA1)	*some things and I cannot deny. It must be a joint action to change this.* (C1)		
	Focused legislation	**Legal enforcement**	**Legal conflicts**	**Cooperation**	
Legislation causes	*Legislation that sets limit in production and consumption* (PA4) *It is a sector that changes a lot of regulation* (C5)	*Legislation, which is not well regulated.* (C4)	*They* [Administration-institutions] *demand me that I put some things [certain packaging] and I cannot say no. It must be a joint action to change this* (C1)	[plastics on food products] *I am required to put some things and I cannot deny. It must be a joint action to change this.* (C1)	
	Complexity	**Inadequate management**		**Cooperation**	
Management causes	*There are plastics that are not segregated because they are not packaging, (e.g. plastic forks)* (C3)	*In Palma* (Mallorca-Spain), *…, each time it reaches a cruise to the harbor appeared an abnormal amount of plastics in the coastal area, in addition also some kind of uncontrolled dumping* (PA6) *Frequently problems are derived, are sent to another country* (C1)		*We have denounced to the port authority, but they deny, every time a cruise to the port appeared an abnormal amount of plastics in the coastal zone* (PA6)	

Table S7.1. *(Continue)*

Themes	Sub-themes			
	Innovation	**Funding**	**Communication**	
Research causes	*Public and private initiatives to propose alternatives* (C2) *Lack of related studies* (SN1) *We do not know anything about the* [plastic] *pollution we do not have knowledge* (PA4)	*Lack of investment* (SN3)	*Lack of information on hazards, impact on health, bottled water in the sun...*(PA1) *Communication of the social impact of the problem* (SN5)	
	Dispersion	**Accumulation**	**Environ. Pollution**	**Wildlife health**
Environmental consequences	*Plastics dispersion is more wind theme* (PA1) *We found a beach plenty of plastic..., but I do not know how the currents supposedly take them right to this cove, because it was full* (SN3)	*Plastics in the gyres where these accumulate* (SN3)	*Pollute the environment* (PA5)	*A sea lion that had a plastic, a fishing net around its body* (disgusting) (SN3)
	Human health	**Leisure activities**		
Socio-economic consequences	*Unpredictable impact on human health* (SN8) *Many of the compounds forming plastic are transferred to hormonal level* (SN6)	*when fished with my father... something that has bitten and what we do is to see if it is a plastic or a fish, so that it speaks of the presence of plastic* (SN8)		

Themes	**Sub-themes**				
	Inexpensive	**Useful**	**Lightweight**	**Diversity**	**Durability**
Plastic properties	*The problem is that plastic is cheap, if were expensive we do not have this problem* (PA2) *Prioritize the plastic because it is a cheap material* (SN5)	*It is easier to use things packed in plastic* (PA3) *I do not like it either* [packaged products], *I like to buy a liter than three smaller ones, but it is that to see if there is to go hiking* (PA4)	*Near my house there is a landfill zone that is always full of plastics: bags, ... that fly from the landfill.* (SN6)	*I think the management of plastic is complex because there are many types* (C5)	*The problem is the life cycle, a life cycle that is long* (SN5) *The plastic is not reintegrated in the environment* (SN8)

Annex G

Figure S.8.1. *Questionnaires used to obtain beach users' perceptions in Mallorca. English version.*

Survey about Social Perception of Plastics in the Balearic Islands

Spanish National Research Council

We thank you in advance for your participation. We are requesting some of your time to answer this survey aimed to know the perception of people about the effects of plastic in the environment.
Approximate duration: 10-15 minutes.
Survey results will be used only for scientific purposes and they will be completely **anonymous and confidential**.
If you would like to receive the survey results, enter your e-mail:……………………………………………………

A. Cognitive phase of the problem

A1: If I tell you "Plastic", you respond to me: (Only one word)

……

A2: Tell me what a plastic material could be defined by you in these five rated gradations:

	0	1	2	3	4	5	6	7	8	9	10	
DIRTY, septic	○	○	○	○	○	○	○	○	○	○	○	**CLEAN**, aseptic
POLLUTANT, harmful	○	○	○	○	○	○	○	○	○	○	○	**INNOCUOUS**, harmless
EXCESS, abundance	○	○	○	○	○	○	○	○	○	○	○	**SHORTAGE**, scarcity, lack
ANNOYING, uncomfortable	○	○	○	○	○	○	○	○	○	○	○	**USEFUL,** beneficial
UNSUSTAINABLE	○	○	○	○	○	○	○	○	○	○	○	**SUSTAINABLE**

B. Evaluation of the perceptions

B1: EVALUATE: What extent the effects produced by plastics are harmful in each of the following topics?. (rate from 0 to 10, where 0 is "not harmful" and 10 "very harmful", N/A = No answer)

	NOT HARMFUL							VERY HARMFUL			
	1	2	3	4	5	6	7	8	9	10	N/A
Effects in leisure	○	○	○	○	○	○	○	○	○	○	○
Effects on economic activities	○	○	○	○	○	○	○	○	○	○	○
Effects on human health	○	○	○	○	○	○	○	○	○	○	○
Effects on the landscape	○	○	○	○	○	○	○	○	○	○	○
Effects on terrestrial flora and fauna	○	○	○	○	○	○	○	○	○	○	○
Effects on coastal flora and fauna	○	○	○	○	○	○	○	○	○	○	○
Effects on marine flora and fauna	○	○	○	○	○	○	○	○	○	○	○
Other (indicate):	○	○	○	○	○	○	○	○	○	○	○

B2: EVALUATE: What is your perception about the factors that cause the possible negative effects of plastic materials? (rate from 0 to 10, where 0 is "unprobable" y 10 "very probable", N/A = No

	UNPROBABLE							VERY PROBABLE			
	1	2	3	4	5	6	7	8	9	10	N/A
Plastic properties	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Excessive use of plastic	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Current economic model	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Lack of information	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Defects in management	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Lack of awareness	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Other (indicate):	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

B3: Do you believe that the arrival of plastic materials into the sea can harm the marine environment?

	1	2	3	4	5	6	7	8	9	10	
UNPROBABLE	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	**VERY PROBABLE**

◯ No Answer

B4: Overall, How would you assess the current situation of Majorcan coastline in relation to the problems of plastics? (Rate from 0 to 10, where 0 is "very deficient", 10 "Excellent" and 5 "Neither deficient/nor excellent")

	1	2	3	4	5	6	7	8	9	10	
VERY DEFICIENT	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	**EXCELLENT**

◯ No Answer

B5: How do you see the situation in 5-10 years and in 20-30 years?

5-10 years
- ◯ Much worse than the present
- ◯ Worse than the present
- ◯ Roughly equal
- ◯ Better than the present
- ◯ Much better than the present

20-30 years
- ◯ Much worse than the present
- ◯ Worse than the present
- ◯ Roughly equal
- ◯ Better than the present
- ◯ Much better than the present

C. Attitudes

C1: To what extent are you in accordance with the following statements?

I am interested in the issues related with the ENVIRONMENTAL problem of plastic materials

	1	2	3	4	5	6	7	8	9	10	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	**Strongly agree**

◯ No answer

a) I do not like plastic packaging

Strongly disagree	1	2	3	4	5	6	7	8	9	10	**Strongly agree**
	○	○	○	○	○	○	○	○	○	○	○ No answer

b) I dislike find plastic waste in natural areas: mountain, beach, sea, etc.

Strongly disagree	1	2	3	4	5	6	7	8	9	10	**Strongly agree**
	○	○	○	○	○	○	○	○	○	○	○ No answer

c) I choose the coasts where there is less amount of plastic to spend my free time: plastic absence both in the terrestrial and maritime beach.

Strongly disagree	1	2	3	4	5	6	7	8	9	10	**Strongly agree**
	○	○	○	○	○	○	○	○	○	○	○ No answer

d) I choose products that avoid excess of plastic packaging

Strongly disagree	1	2	3	4	5	6	7	8	9	10	**Strongly agree**
	○	○	○	○	○	○	○	○	○	○	○ No answer

D. Information and Motivation

D1: Think about the information you receive about plastic materials in your shopping and evaluate the following points (Rate from 0 to 10, where 0 es "very deficient", 10 "Excellent" and 5

a) The information you receive from companies about the origin, processes, compounds used in products.

VERY DEFICIENT	1	2	3	4	5	6	7	8	9	10	**EXCELLENT**
	○	○	○	○	○	○	○	○	○	○	○ No answer

b) Information about waste planning and management by the PUBLIC ADMINISTRATION

VERY DEFICIENT	1	2	3	4	5	6	7	8	9	10	**EXCELLENT**
	○	○	○	○	○	○	○	○	○	○	○ No answer

D2: Evaluate what actions would motivate you for reduce the use of plastic materials. (Rate from 0 to 10, where 0 is "strongly in against", 10 "strongly in favor" y 5 "Neither against/nor favor")

a) REGULATE and RESTRICT the use of plastic in products to the minimum required.

STRONGLY AGAINST 1 2 3 4 5 6 7 8 9 10 STRONGLY IN FAVOR

◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯

◯ No answer

b) INCREASE of bulk products with own filling packages. (Reduce)

STRONGLY AGAINST 1 2 3 4 5 6 7 8 9 10 STRONGLY IN FAVOR

◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯

◯ No answer

c) PROMOTE the return of packages (similar to the return of glass packaging or cans in markets)

STRONGLY AGAINST 1 2 3 4 5 6 7 8 9 10 STRONGLY IN FAVOR

◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯

◯ No answer

d) ESTABLISH higher taxes on products with more plastic.

STRONGLY AGAINST 1 2 3 4 5 6 7 8 9 10 STRONGLY IN FAVOR

◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯

◯ No answer

e) OTHER (indicate): …………………………………………….

STRONGLY AGAINST 1 2 3 4 5 6 7 8 9 10 STRONGLY IN FAVOR

◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯ ◯

◯ No answer

E. Classification Variables

E1. Are you? ◯ Man ◯ Woman

E2. Age in years:………………………

E3. What academic formation do you have?

- ◯ Uneducated
- ◯ Imcomplete primary school
- ◯ Graduate (primary or High-school)
- ◯ High school diploma, A levels
- ◯ Intermediate Vocational training
- ◯ Advanced Vocational training
- ◯ University studies: Bachelor's degree
- ◯ University studies: Master's degree or PhD.
- ◯ No answer

E4. Occupation

- ◯ Agriculture-farming and fishing
- ◯ Industry
- ◯ Service sector: commerce , tourism, education, health service, social service
- ◯ Without gainful employment: students, retired, unemployed,…
- ◯ Others. Specify………………………….

E5. Place of birth

◯ Mallorca/Majorca ◯ Rest of Spain ◯ Foreign. Country…………………………………

Thank you very much for your cooperation

Publications and participation in symposia

Publications in peer-reviewed journals, book chapters & symposia proceedings:

Ruiz-Orejón, L.F., Sardá R., Ramis-Pujol, J. In preparation. *The invisible plastics around the Balearic Islands (Spain): floating plastic debris in the coastal waters of the archipelago.* [In preparation]

Ruiz-Orejón, L.F., Ramis-Pujol, J., Sardá, R. In preparation. *The social dimension of the problem of plastic debris: exploring the perceptions of Mallorca's stakeholders that influence in decision-making processes.* [In preparation]

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J. In preparation. *The problem of plastic debris: exploring beach users' perceptions, attitudes and motivations.* [In preparation]

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J. *The invisible plastics around the Balearic Islands (Spain): floating plastic debris in the coastal waters of the archipelago.* Mar. Pollut. Bull. [under review]

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2016. *Floating plastic debris in the central and western Mediterranean Sea.* Mar. Environ. Res. 120, 136–144. doi:10.1016/j.marenvres.2016.08.001

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J. 2016. *A social-ecological approach to the problem of Floating Plastics in the Mediterranean Sea.* Proceedings of the MICRO 2016. Fate and Impacts of Microplastics in Marine Ecosystems. From the Coastline to the Open Sea. Pages: 65. 25 – 27 May, 2016.

Ruiz-Orejón, L.F., Ramis-Pujol, J., Sardá, R. 2016. *Floating Plastics in the Sea: People's Perception in the Majorca Island (Spain).* Proceedings of the MICRO 2016. Fate and Impacts of Microplastics in Marine Ecosystems. From the Coastline to the Open Sea. Pages: 153. 25 – 27 May, 2016.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J. 2016. *Plastics in the Mediterranean Sea surface: from regional to local scale.* Proceedings of the MICRO 2016. Fate and Impacts of Microplastics in Marine Ecosystems. From the Coastline to the Open Sea. Pages: 153 – 154. 25 – 27 May, 2016.

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J. 2016. *Plásticos en el Mar Mediterráneo: de escala regional a local. Seminarios* CEAB-CSIC. 22 June, 2016.

Ruiz-Orejón, L.F., Ramis-Pujol, J., Sardá, R. 2017. *The social dimension to the problems of plastics: exploring the stakeholders and public perceptions in Mallorca (Spain).* I Jornada de Investigadores Predoctorales (JIP). Centro de Estudios Avanzados de Blanes (CEAB-CSIC). 22 June, 2017.

ATTENTION ¡

Pages 386 to 394 of the thesis, containing the article

Ruiz-Orejón, L.F., Sardá, R., Ramis-Pujol, J., 2016. Floating plastic debris in the central and western Mediterranean Sea. Mar. Environ. Res. 120, 136–144. doi:10.1016/j.marenvres.2016.08.001

are available at the editor's https://www.sciencedirect.com/science/article/pii/S0141113616301325

Notes

Plastic debris has spread to all the oceans until it reaches their most remote extremes. The Mediterranean Sea is not an isolated case to this problem, which could also be reinforced by the scarce renewal of its waters and the high anthropogenic pressure to which it is subjected. This thesis presents and assesses the current state of the problem of floating plastic litter in the Central and Western Mediterranean in both ecological and social systems. From the ecological point of view, the omnipresence of plastic waste, especially microplastics, in surface waters was estimated from a spatial-temporal analysis with important concentration points in coastal areas. From the social point of view, the analysis of key stakeholders in the decision-making processes and the insights of the beach users, showed the limited awareness and an absence of information as the main causes that favor the greatest considered problem of plastic, the excess.