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Marine Litter in the Algarve Coast: Main sources and Distribution using a modelling approach

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Master in Marine and Coastal Sciences

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DECLARATION OF AUTHORSHIP OF WORK

I declare to be the author of this work, which is original and unpublished. authors and works consulted are duly cited in the text and are included in the list of references.

Eu declaro ser a autora deste trabalho, que é original e inédito. autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

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ABSTRACT

Anthropogenic litter, mainly plastic, can be found in all the oceans -since the most populated coastline to the most remote - it impacts on marine habitats, fauna and sea ongoing economic activities such as tourism, fishing and aquaculture, are negative. Qualitative and quantitative information about marine litter in our seas and oceans is required for policy development aiming to reduce marine litter and/or to assess effectiveness of existing programmes of measures. This work provided an overview of the Algarve beaches monitoring using OSPAR standardize guidelines for the 2013-2017 period, available by DGRM. Analysis of the two beaches litter surveyed data was performed using the tool Litter Analyst. The data shows an increasing trend in average item counts per year for all beaches aggregated of 11 items per year. In the period 2013-2017, plastic/polystyrene accounts for 37.3 % of all litter items found.

The top-80% shows that most of the items that are included in the paper category are cigarettes buts which have a high probability to originate from the tourism sector, whilst most of the items that are included on plastic and polyester categories are plastic pieces less than 50 cm, nets and ropes. Also, the data showed increasing trends for all source categories, except for ‘others’ and shipping where decreasing trends were found. The largest increasing trend in average item counts per year is from tourism (17 counts/year).

Numerical modelling is also one of the key tools with which it can gain insight into the distribution of marine litter. Over the past decade, a series of numerical simulations have been constructed that specifically target floating marine litter, based on ocean models of various complexity. This project provided an initial step in identifying available information on litter and developing preliminary analysis of its sources and distribution at the Algarve coast, using the Algarve Operational Modelling and Monitoring System (SOMA).

Results showed the coastal circulation plays a fundamental role in the dynamic of floating marine litter and its accumulations on the Algarve beaches, which showed be higher during winter scenario and lower during the upwelling scenario. Also, the simulations indicate that both particle velocity and the rate of floating marine litter accumulation along the Algarve coast increase when an extra wind force is assumed. Accumulations of beached floating marine litter were fond mostly on beaches located at the southwestern region of Algarve, as well as Faro beach.

Key words: Floating marine litter, Beach litter, Algarve coast.

RESUMO

Lixos antropogénicos, principalmente plásticos, podem ser encontrados em todo o mundo - desde os litorais mais populosos até os mais remotos - e seu impacto no habitat, na fauna e nas atividades econômicas costeiras e marítimas como turismo, pescas, aquacultura, são negativas. A região do Algarve apresenta uma economia regional completamente ligada ao mar, e também abrange importantes parques naturais, e atualmente, informações sobre as principais fontes, distribuição e acumulação de lixos são desconhecidas para esta região.

Informações qualitativas e quantitativas sobre o lixo marinho são fundamentais para o desenvolvimento de políticas que visam reduzir o lixo marinho e/ou avaliar a eficácia dos programas existentes. Neste trabalho foi apresentado uma visão geral do monitoramento de praias do Algarve usando as diretrizes padronizadas da OSPAR para o período 2013-2017, disponíveis pela DGRM. As análises dos dados levantados sobre as duas praias Algarvias foram realizadas utilizando a ferramenta Litter Analyst. Os dados mostram uma tendência crescente na contagem média de itens por ano para todas as praias agregadas de 11 itens por ano. No período 2013-2017, plástico/poliestireno foi responsável por 37,3% de todos os itens coletados.

Método Top 80% (principais lixos) mostrou maioria dos itens incluídos na categoria de papel são cigarros, mas com alta probabilidade de originar-se no setor de turismo, enquanto a maioria dos itens incluídos nas categorias de plástico e poliéster são peças de plástico com menos de 50 cm, redes e cordas. Também, os dados mostraram tendências crescentes para todas as categorias de origem, exceto "outras" e navegação onde foram encontradas tendências decrescentes. A maior tendência crescente na contagem média de itens por ano é do turismo (17 contagens /ano).

A modelagem numérica também é uma das principais ferramentas com as quais pode obter informações sobre a distribuição de lixo marinho. Na última década, uma série de simulações numéricas foram construídas visando especificamente lixo marinho flutuante, com base em modelos oceânicos de várias complexidades. Neste projeto, utilizou-se a modelagem hidrodinâmica e Lagrangiana para prever pela primeira vez o destino de lixo marinho flutuante originados de fontes terrestres e marítimas na costa do Algarve em diferentes cenários oceanográficos. Utilizou-se o Sistema Operacional de Modelagem e Monitorização do Algarve (SOMA) e acrescentou um coeficiente de deriva do vento e um fator de encalhe (beaching).

Os resultados também indicaram que a velocidade das partículas e a taxa de acumulação de lixo marinho na costa do Algarve aumentam quando uma força extra do vento é adicionada na simulação. Altas concentrações de lixos foram encontradas depositados principalmente na parte sudoeste da costa do Algarve, conhecida como barlavento, e nas praias de Faro.

Palavra-chave: Lixos marinhos flutuantes, Lixo de Praia, Algarve.

List of Acronyms

CSM- Cape St Maria

CSV-Cape St Vincent

EMODNET - European Marine Observation Data Network

FRS - Flow Relaxation Scheme

GES - Good Environmental Status

GOTM – General Ocean Turbulence Mode

GPML - Global Partnership on Marine Litter

IBI-ROOS - Iberia Biscay Ireland Regional Operational Oceanographic System

IPC - Iberian Poleward Current
MOHID - Hydrodynamic model

IST- Instituto Superior Técnico

MARATEC- Marine and Environmental Technology Research Centre

MSFD - Marine Strategy Framework Directive

NOAA - National Oceanic and Atmospheric Administration

OBC – Open Boundary Conditions

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

PC – Portugal Current

PCC -Portugal Costal Current

SKIRON - The Regional Weather Forecasting System

SOMA- Algarve Operational Modelling and Monitoring System

SST – Sea Surface Temperature (ºC)
DGRM- Portuguese National Directory of Marine Resources

UNEP - United Nations Environmental Program

FML- Floating marine litter

1.Introduction

1.1 Context

Over the past century, plastic has becoming an increasingly common and convenient manufacturing material, replacing more traditional materials, such as glass, paper, aluminium and natural fibres. Consequently, the proportion of plastic-based items entering in the waste has increased, nowadays it is estimated that more than 5 trillion of plastic litter pieces are circulating in our oceans (Eriksen et al., 2014), and humans are adding another 8 million metric tons of plastics to the ocean every year (Jambeck et al., 2015). Due to the low manufacturing cost and the longevity of the material, great amounts of plastic can remain in the ocean for long periods of time. In addition, most plastics are less dense than sea water, being easily transported by sea surface currents, winds and waves. Many studies recognized that floating marine macro litter is an important threat to the marine ecosystems and can be found with remarkable densities from oceanic subtropical gyres to inner seas (Constantino et al., 2019,), urban beaches (Kako et al., 2014; Martins & Sobral, 2011; Poeta et al., 2016; Rosevelt et al., 2013), as well as in remote islands (Barnes 2002).

Marine litter can enter into the ocean in many ways, deliberately disposed or accidently discharged by land or sea-based activities. It can travel large distances by ocean currents and winds till deposit on sea floor or land on beaches or to accumulate on open oceans. Marine litter pollution accumulation on the coastline may affect tourism and fishing revenue, coastal habitats and can cause damage to individual animals via entanglement and ingestion of litter. Cooperative efforts and activities among the neighbouring countries are needed to protect coastal and ocean areas from marine litter (Plan, N. P. A 2017).

Marine litter is an emerging threat to the ecological, economic and social value of the coast, and currently information on sources of litter, how it is transported and where its deposits are largely unknown. Understanding the source and fate of marine debris in the Algarve coast is thus important to develop new effective measures, previous studies have been using hydrodynamic model with high resolution, to track marine litter in coastal area (Chritchell et al., 2016; Chritchell and Lambrechts, 2015).

1.2 Objetives

The purpose of this work is to explore the dispersal and accumulation of macro plastic pollution at a local management relevant scale using the Algarve Operational Modelling and Monitoring System (SOMA) and OSPAR beach monitoring data.

a. Assess how the met-ocean conditions of the region (atmospheric and hydrodynamic condition) affect the trajectories and accumulation areas of floating marine litter originating from diverse sources.
b. Investigate the main sources of floating marine litter of the Algarve region.
c. Analyses the composition of litter (by item category, material, pathway and origin) from two Algarve beaches.

2 Background

2.1 Marine Litter and its characteristics

Human activities are responsible for a major decline of the world's biological diversity, in the oceans, the threat to marine life comes in many forms, such as overexploitation, harvesting, dumping of waste, pollution, alien species, dredging and global climate change. Recently, one particular form of human impact is having increasing attention due to their major threat to marine life: the pollution by marine litter (Derraik J., 2002). Marine litter is nowadays commonly observed across all the oceans, as they can be transported over long distances (Ryan, 2015). With the breakdown products, meso-litter (5-2.5 cm) and microliter (< 5 mm) they have become more numerous and dangerous to the marine ecosystem (Barnes et al., 2009).

Marine litter is defined as ‘‘any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment” (Cheshire et al., 2009). Floating marine litter can be considered as ubiquitous, occurring even in the most remote areas of the planet such as the Arctic (Bergmann and Klages 2012).

Plastic has become abundant and forms sometimes up to 95 % of the waste that accumulates on shorelines, sea surface and the seafloor (Derraik J. 2002). Litter item such as plastic bags, food and beverage containers, cigarette stubs and other plastic items were the most common items and constitute more than 80 % of litter stranded on beaches according the International Clean Up (Figure 2.1). In the North Sea beaches, small and medium plastic pieces string and cord items and plastic caps/lids were the most abundant items collected during OSPAR beaches surveys (Addamo et al., 2017).

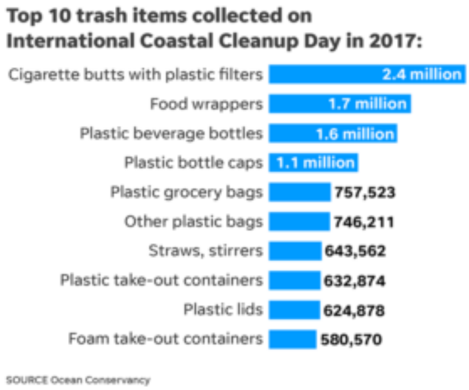

Figure 2.1. The top 10 litter items most collected during the International Coastal Cleanup during 2017. Source: Ocean conservancy.

Plastic is a synthetic material that is made by polymerizing molecules of monomer, materials that are derived from coal, petroleum or natural gas (Selukar et al., 2014). At present, plastic has achieved a crucial status, with extensive commercial and industrial, applications, therefore the demand is considerable; annual plastic production has increased dramatically from 1.5 million tonnes in the 1950s to more than 350 million tonnes in 2015 (Figure 2.2) (Europe P., 2015). In Europe, more than a third of plastics produced each year is used to make disposable items of packaging or other short-lived products that facilitate the transport of a wide range of food, drinks and other goods which are discarded within a year of manufacture (Hopewell et al., 2009).

Plastics items are lightweight, strong, durable and cheap, characteristics that make them suitable for the manufacture of a very wide range of products. These same properties happen to be the reason why plastics are a serious hazard to the environment (Laist, 1987). Many plastics contain a range of additives for various purposes, for example to improve ultraviolet (UV) resistance, plasticity, colour, impact resistance, and fire retardation. These may influence the physical characteristics of the plastics and their potential impact on marine organisms (Kershaw & Lebreton, 2016).

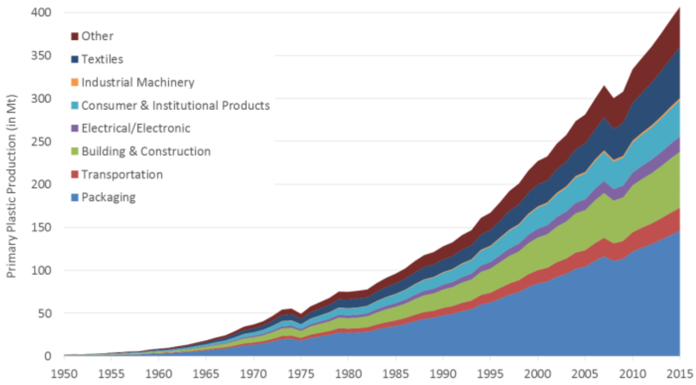

Figure 2.2.Global primary plastics production (in million metric tons) according to industrial use sector from 1950 to 2015. Source: Geyer et al. (2017).

Plastic items can slowly break down into smaller particles (microplastic) by exposure to ultraviolet (UV) radiation, and consistent mechanical abrasion from wave action (Brandon et al., 2016). Recently, microplastics (plastic particles < 5 mm in size) start be recognized as a globally ubiquitous contaminant and have received an increasing amount of research and policy attention over the last decade, due to their detrimental impact to a wide range of species and habitats, including humans. Microplastic can be ingested by multiple trophic levels, such as plankton, mussels, fishing and cetaceous. In addition, microplastic can have the ability to adsorb POPs (Persistent Organic Pollutants) that are both toxic for the organisms themselves, and for those who feed on them, including the human being (Gallo et al., 2018).

2.1.1 **Marine Litter Sources**

Marine litter results from human actions and behaviour, whether intentional or unintentional, and is the product of poor waste management, inadequate infrastructure and lack of public knowledge about the potential consequences of inappropriate waste management (UNEP 2009). Around 60-80% of marine litter comes from land-based sources such as land-fills, rivers and floodwaters, industrial outfall, storm water drains, untreated municipal sewerage and littering of beaches/coastal areas from tourism (Mouat et al., 2010). At the sea, abandoned, lost or discarded nets, ropes and floats and sewage from fishing, merchandize shipping, cruise shipping and oil rings and other activities are furthermore contributed to marine litter. Abandoned and derelict fishing gears is a significant and serious form of marine litter resulting in consequent injuries and deaths of marine organism. Once in the oceans, marine litter go through various transport pathways including degradation from macro to micro-litter, floating at the surface, vertical mixing in the water column, beaching and settling into sediment and occasional resuspension, and drifting at sea, as well as biological interactions (Figure 2.3). In Lachmann F.A (2016), approximately 70% of marine litter sinks to the seabed, 15% floats in the water column and 15% washes up on shore.

Floating marine litter (FML) is found in all oceanic water (Gregory and Andrady, 2003). FML constitutes the fraction of debris in the marine environment, which is transported by wind and currents at the sea surface and is thus directly related to the pathways of litter at sea. Synthetic polymers, such as polyethylene and polypropylene have lower densities than seawater, thus constitute the major part of floating marine debris (Andrady, 2015). For example, plastic pieces comprise around 80% of floating debris in the Mediterranean Sea (Suaria and Aliani, 2014), and in the SE Pacific off the Chilean coast (Thiel et al., 2003). Furthermore, the role of rivers as transporters of plastic is significant as they carry their litter load from urban areas to the oceans.

Higher abundances of FML are often reported from principal shipping routes and coastal waters adjacent to major urban regions and/or are related to the principal ocean current systems (Kubota, 1994). Their fate depends on their physics-chemical properties and the environmental conditions. Therefore, they float until they are washed ashore or sink because changes on the density due to biofouling and leaching of additives.

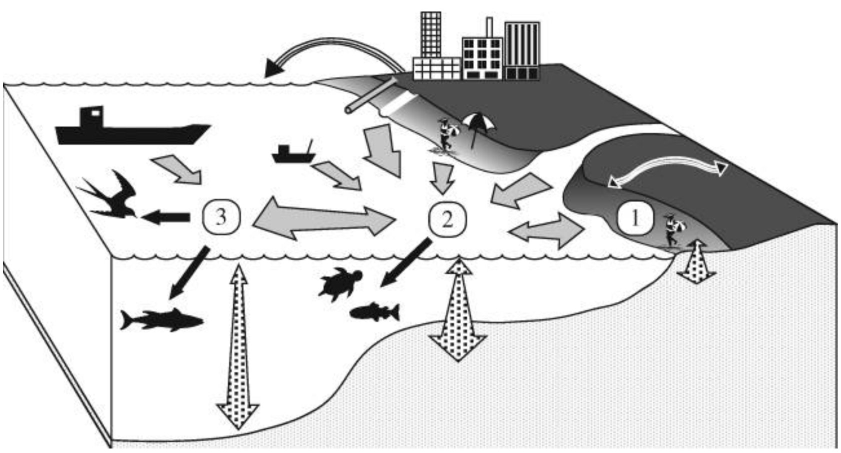

Figure 2.3. Schematic diagram showing the main sources and movement pathways for plastics in the marine environment, with sinks occurring (1) on beaches, (2) in coastal waters and their sediments and (3) in the open ocean. Source: Ryan et al. (2009).

Abundance of litter in the marine environment may vary widely with factors such as proximity of urban activities and coastal uses, degree of fishing effort and concentration of shipping traffic, as well as environment factor such as wind, tides, currents, coastal morphology, occurrence of heavy rain and flood events (Galgani et al., 2015). All those factors and the lack of standardized monitoring litter makes difficult the comparation of litter concentrations spatially and temporally. Nevertheless, a number of consistent patterns indicate the prevalence of plastics, greater concentration on beaches adjacent urban areas, touristic regions and shipping routes (Barnes et al. 2009).

In 2016, Sá et al. (2016) assess the Portuguese offshore water and observed that higher densities of litter were found in the north sector, probably as a result of the high number of navigation corridors and fisheries operating in that sector. Same pattern was observed in a 10 years beach assessment done by Coastal Watch along the Portuguese's beaches, where beaches in the northern regions, with higher population density appear to have more litter than the central and southern regions, with dominant types of litter recorded were plastic pieces and fishing gears (Candeias, J. M. P. B., 2015).

2.1.2 Litter Impact in the marine ecosystem

Marine litter is recognized to cause negative ecological, economic and social impacts (UNEP, 2006). Marine debris and particularly plastic litter represent a major threat for ecosystems, human health and the economy (Figure 2.4). Impacts may include such as, alteration, damage and degradation of benthic habitats, and the transport of alien invasive species (Katsanevakis, 2008). Nearly 700 marine species are reported with fatal entanglement in and ingestion of marine litter, however sadly this number continues to rise (Gall and Thompson, 2015). The majority of reported litter-related incidents affecting individual marine organisms involve plastic items. In terms of plastic litter or use, ropes and netting accounted for 57% of encounters in 2012, followed by fragments (11%), packaging (10%), other fishing-related litter (8%) and microplastics (6%) (CBD, 2012).

Ingestion can cause harm physically through choking, obstruction of the gastrointestinal tract leading to starvation or malnutrition, or internal injury and infection. It can also cause harm through chemical contamination, as certain items of marine litter, especially plastics, may contain toxic substances which cause death or reproductive failure in certain marine organisms (Mouat et al., 2010). Currently an emerging area of concern is the ingestion of microplastic (< 5 mm), due to their size. They are available to a wide range of organisms, including bottom feeders, filter feeders and scavengers (Thompson et al., 2004). When ingested, plastics release chemicals, together with adsorbed hydrophobic pollutants such as polychlorinated biphenyls (PCBs) and Dichlorodiphenyltrichloroethane (DDT) that may be transferred to organisms, hence raising concern as to their subsequent adverse effects (Teuten et al., 2007). The ingestion of microplastic material could be a route for chemicals to pass from plastics to the food chain.

Figure 2.4. Ecological and environmental impact of litter in coastal and marine environmental.

2.1.3 **Socio-economic and Economic Impact of Marine Litter**

Marine litter can cause serious economic damage: losses for coastal communities, tourism, shipping and fishing. Potential cost across EU for coastal and beach cleaning was assessed and almost €630 million is used per year to clean Europeans shores. Only Algarve municipalities spent around €2 million per year to clean their shores (Manhã C., 2009). Marine litter is considered a serious threat for tourism and local beach-goers, as litter reduces the attractiveness of littoral leading to lower beach user enjoyment and consequently reducing tourism revenue and the surrounding property values (Mouat et al., 2010). Leggett et al. (2014) found that if marine litter concentration was reduced in Orange County beaches, the residents could have an increase of 53 million of dollar in benefits.

The cost of marine litter to the fishing industry could amount to almost €60 million, which would represent approximately 1% of total revenues of the EU fishing fleet in 2010 (Marine litter GES, n.d). The fisheries sector is both responsible for and negatively affected by marine litter, hence increasing cost to fishing vessels (repairing damage to the vessel and equipment including disentangling fouled propellers), as well as reducing potential catches and replacement of lost gear (Werner et al., 2016).

For recreational as well as commercial vessel operator, entangled propellers and rudders are the most common issue, and can seriously damage vessels result in expensive repairs, crew downtime and safety concerns for the crew (Hall K., 2000; Mouat et al., 2010). Trash on the sea also represents a danger to swimmers and divers, as people can become entangled in submerged debris, and impact public health on shore (Cheshire et al., 2009).

2.2 Implement Legislation and Enforce Regulations

A wide range of international agreements and legislation both directly and indirectly address the problem of marine litter. Some of the instruments serve as a global guiding, encouraging regional bodies and countries to follow them. The most renowned are: Global Partnership on Marine Litter (GPML), the Honolulu Strategy, the G20 and UNEP Regional Sea Program. The major instrument addressing ocean-based litter pollution from ship is the Annex V of MARPOL 73/78.

In European level, there are numerous EU legal instruments already in operation that could have a role in tackling marine litter, addressing litter sources from a diversity of sectors. One directive can be considered as 'core' to the EU's efforts to tackle marine litter is the Marine Strategy Framework Directive (MFSD). The MSFD is the primary driver of targets and actions on the issue, marine litter is categorized as the tenth of eleven qualitative descriptors to achieve Good Environmental Status (GES), as "Properties and quantities of marine litter do not cause harm to the coastal and marine environment".

Additionally, there is a large suite of other pieces of EU legislation which may not have explicit marine litter in its objectives, or may not even make specific mention of marine litter, but nevertheless have vary levels of potential impact on the generation or clean-up of marine debris, such as the "European Strategy on Plastic Waste in the Environment" that regulates the aspects of plastics production, use, waste management, recycling and resource efficiency. Packaging and Packaging Waste Directive as the potential to have a high impact on marine litter, given that packaging comprises a large proportion of marine litter. Recently, this directive created new targets, establishing that by 2030, 70% of the packaging waste will be recycled or re-used regarding some specific materials contained in packaging waste (Circular Economy Strategy - Environment - European Commission., n.d.).

Regional instrument mostly serves as a platform for the states concerned to engage in coordination and cooperation in marine litter issues (Chen, C. L., 2015). The Regional Action Plan (RAP) for Marine Litter of OSPAR, which contains collective and national actions that aim to address both land-based and sea-based sources, as well as education and outreach and removal actions. One of those actions is the implementation of a guideline for monitoring marine litter on the beaches in the OSPAR Maritime Area, providing a standardized methodology and a photographic guide. In addition, in 2010 OSPAR started promoting Fishing for Litter schemes within the North East Atlantic. This simple yet effective scheme had two main goals; remove litter from the marine environment and to raise awareness of marine litter issues within the fishing industry (Regional Action, n.d.)

2.3 Prevention, Reduction and Control of Marine Litter.

Like other environmental problems, marine debris can be prevented and controlled through an effective collaboration of education, legislation, and innovation (Chen, C. L., 2015). Therefore, a combination of actions, focusing on reducing the rate at which waste is produced, increasing recycled waste and ensuring that appropriate management measures for the safe disposal of material that cannot be reused, or recycled need be applied by the state and municipalities. In addition, whenever possible, debris that already contaminates sea water should be removed (CBD, 2012).

Taxation and prohibition of plastic items are instrumental that aim changing consumer behaviour towards plastic consumption. Since tax on plastic bags came into force, some countries reported significant reduction of plastic bag consumption, Portugal reported a reduction of around 90% (‘Plastic bag use plummets a year after tax introduction - The Portugal News’, 2016), 95 % in Ireland (Summer C., 2012) and 70% in Sao Paulo city (Reis V., 2016). Some countries take it further such as France, United State, Canada, United Kingdom banned microplastic in health and cosmetic products. Europe Union plan to ban single used plastics such as plastic cotton buds, cutlery, plates, straws, drink stirrers and sticks for balloons (European Commission, 2018).

A waste management system based on the principles of polluter pays and driven by effectiveness and efficiency objectives can increase the amount of waste diverted toward recovery and recycling. The adoption of an effective schemes, such as Deposit return and restoration (Figure 2.5) has been showing to be an effective measure in preventing waste generation, in the United States, states that add this system increased the recycling rate between 66 to 96% depending on the deposit value (Gitlitz and Franklin, 2006).

Figure 2.5. Two different national and local initiatives to reduce litter. **a**. Circular economy and. the deposit refund container in Kooringal, New South Wales, Australia. Source: Google, 2019.

Long-term sustainable solutions are moving from a linear economy towards a circular economy. The circular economy scheme involves waste reduction, more sustainable production and consumption patterns (Figure 2.5.). Veiga et al. (2016) suggested that the marine litter problem may stimulate sustainable economies and lifestyles, generating multiple economic opportunities such as, new jobs creation, reductions in greenhouse gas (GHG) emissions, etc.

A move towards sustainable and resilient societies may need increased awareness about the threats of marine litter, changing behaviour and introduce a more responsible attitude towards protecting the environment. Currently, great number of educational materials have been produced by government agencies, schools' systems and non-profit organizations, for example, U.S National Oceanic and Atmospheric Administration, Ocean Conservancy, Open University of the Netherlands and United Nations Environment developed a Massive Open Online Course on Marine Litter (MOOC), Fishing for litter.

2.3.1 Monitoring of Marine Litter

To combat marine litter pollution effectively, it is crucial to have reliable information regarding the quantities, the potential sources and transport mechanisms of marine litter in a given area to implement effective management and mitigation measures (Galgani et al., 2013). Therefore, implement monitoring programs to quantify and characterize litter in marine ecosystems is vital to fully assess the ecological and socio-economic impacts of plastic pollution in marine ecosystems and to provide effective measures targeted at reducing emissions (Galgani et al., 2013). However, with the lack of harmonized protocols and general agreements, the information available is still scarce and geographically dispersed. Within this context, the MSFD recommends develop coordinated monitoring and assessment programs based on existing relevant programs and activities developed by the Regional Sea Conventions (RSCs).

Beach litter surveys are well-known technique for gathering information on the status of anthropogenic litter, both for the beaches themselves, and as an indicator for the wider marine environment (Nelms et al., 2017). OSPAR has been monitoring 70 beaches in the North East Atlantic follow standardized monitoring guidelines since 1998. These beaches are surveyed four times a year (at three-month intervals) and the numberof litter items per 100 m of coastline recorded. The monitoring records litter in 112 predefined litter items in 11 types (plastic, paper and other materials). The collection of data on marine beach litter aim provide information on amounts, trends and sources of marine litter, which can be used to focus on effective mitigating measures and to test the effectiveness of existing legislation and regulations (OSPAR, 2010).

The abundance of floating litter at sea can be estimated either by direct observation of large debris or by net trawls for smaller items. Over the past 10 years, a large number of studies have investigated the distribution and abundance of floating macro litter in the Mediterranean Sea (Suaria and Aliani, 2014), the Pacific Ocean (Pichel et al.,2007; Thiel et al., 2003), Atlantic Ocean (Sá et al., 2016; Ryan P.G., 2014; Chambault et al., 2018). Despite the few studies conducted in the different oceanic basins, the distribution and composition of macro litter remains poorly described in remote areas. Floating litter surveys are time demanding, expensive, and limited in coverage, therefore many of floating litter surveys have been performed with other activities. In order to reduce monitoring cost, researchers have also been developing new methodologies such as the use remote sensing methods (Topouzelis et al., 2019; Goddijn-Murphy et al., 2018), drones and modelling dispersal of plastic litter in aquatic systems from local to global.

2.4 Modelling Marine Litter

Ocean modelling has enormous advantage in enabling to counter balance the lack of in situ observations in some locations. Combination of ocean circulations and a particle tracking method, e.g Lagrangian tracers, can provide useful information on the transport, accumulation zones and potential origins of debris at different scales. For long time, these models have been widely applied to track the transport of different kinds of passive drifters in the marine environment, such as oil spill pollutants, fish eggs and larvae, marine debris. However, only in 1994 Kubota performed simulations in the North Pacific using a simple model combining conditions of climatic forcing, geostrophic current, Stokes drift and Ekman flow conditions and observed an accumulation area of marine litter in the North Atlantic. Maximenko et al. (2012), Lebreton et al. (2012) and Van Sebille et al. (2012) ignored atmosphere drag (referred to as “wind drift”) and wave transporting on floating plastics in global scales and observe 5 oceanic accumulations zones (Figure 2.6).

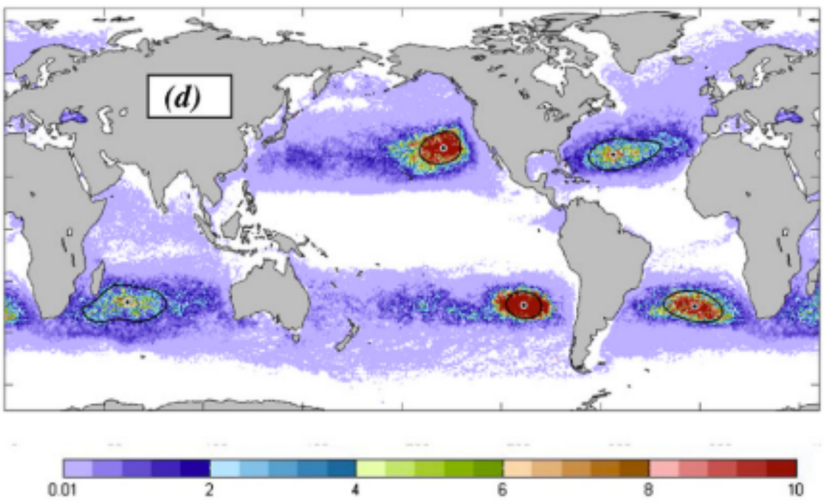

Figure 2.6. Model prediction of the five oceanic areas with highest concentration of floating litter, the subtropical gyres, also known as the world’s “ocean garbage patches”. Source: Maximenko et al., 2012.

Recently, with the rapid developments in the field of data acquisition and computational methods, enhancing the capabilities of operational systems for coastal regions, has enabled modelling marine litter at finer scales, predicting areas of accumulation at a beach scale. Examples of small-scale studies, focusing on a single coastline, with variable resolution are those of the Queensland Coast (Australia) in Critchell et al. (2015) and the Gulf of Mexico in Nixon and Barnes (2010).

Most of the marine litter studies describe as the Lagrangian approach as a more adequate (e.g. Maes & Blanke, 2015; Isobe et al.,2009; Kako et al., 2014; Neumann et al., 2014; and Carlson et al., 2017), in addition most of the projects use Lagrangian in offline mode, using stored pre-computed velocity fields to force the Lagrangian model. However, the distribution of any particles in an environmental fluid can be described generally by two approach, either in the Eulerian (fixed point), based on the integration of the advection-diffusion equation with maps of concentration of outputs, or through Lagrangian process (following the substance parcel), based on the integration of stochastic models describing the trajectories of particles.

The effect of wind drift on floating litter is directly linked to the litter item geometry exposed to the wind, which is dependent on its buoyancy, controlled by its density, shape and size. As an example, plastic bottles with air trapped inside and fishing buoys tend to travel faster and have a higher impact in their direction by the wind than subsurface litter (e.g. fishing nets), not being exposed directly to the wind but transported mainly by surface currents (NOAA Marine Debris Program, 2016). Unfortunately, appropriate wind drift factors are hard to specify and differ a lot among different buoyant items (Neumann et al., 2014). In studies that include wind drift, the value of the wind drift coefficient varies from of 0.01 to 0.05 (Carson et al., 2013; Critchell et al., 2015; Critchell et al., 2016; Neumann et al., 2014; Yoon et al., 2010).

The wind force depends on the drag coefficient C_D, the exposed area A and the kinetic energy of the wind:

$$F_w = A \cdot C_D \cdot \frac{1}{2} \rho_{air} {v_w}^2$$

(Equation 1)

Wave transport could be relatively important, particularly near coastal regions where it is consistently towards shore and thus transports material out of the marine environment.

Wind waves induce a net transport in the direction of the wave propagation, known as Stokes Drift (Stokes G. G.,1880). However, calculation of the Stokes drift for objects that partially protrude from the water surface is challenging, as these items will be subject to forces by wind, currents and Stokes drift. In most cases, it is reasonable to assume that the Stokes drift is in the same direction of the local wind (Van Den Bremer and Breivik, 2017). Lebreton et al., (2012) and Kubota (1994) in order to simplify used a Stoke drift proportional to the wind components multiplied by 0.01.

Many studies combine in the high-resolution ocean model with Markov chain, which could separate the marine litter input according their sources (land and sea-sources) and the population size, making the litter input close to the reality (Carson et al., 2013; Maximenko et al., 2012; Zambianchi et al., 2017). In 2016, Liubartseva et al. (2016) used Jambeck et al. (2015) estimation as input in their model to identify source-receptor relationships in Adriatic Sea, and also assumed that 40% of the particles enters through river, 40% coastal urban population and 20% from shipping lanes.

In order to increase model utility and confidence in results, researchers should aim to validate models with independent litter data, thus increasing our understanding of uncertainty (Hardesty et al., 2017). The main source of validation for the marine litter models come from survey carried at the shorelines, sea surface and seabed. Beach litter monitoring is a well-developed monitoring tool to determine trends of litter in the environment, detailed information on composition and amount of litter, which can provide an indication of sources of litter and the potential impact of measures. Most often, monitoring and beach surveys of litter remain one of the easiest and most cost-effective means of providing an information of marine litter. However, data can raise a number of issues. Often beach litter surveys are done by non-governmental organization that have the focus on cleaning and raising awareness of the population, thus missing proper classification and quantification of litter items. In general, methods that are used for estimating amounts of marine litter on beaches are considered cheap and fairly reliable, compared to the floating and seabed methods, but it is not clear how it relates to litter at sea. Furthermore, in some coastal habitats, litter maybe of terrestrial origin and may never actually enter the sea.

3 Study Area

Algarve is located in the South of Portugal and South-West of the Iberian Peninsula. It presents a coastline that stretches about 160 kilometres from the westernmost tip to the Spanish border (Figure 3.1). The study region exhibits diversified coastal systems, classified by high lithologic diversity, with two major types of shorelines; rocky-cliffs and sand beaches. The coastal area is populated by topographical structures, such as prominent capes, promontories and submarine canyons, whose spatial scales are tens to hundreds of kilometres and encompass important Natural parks (Janeiro et al., 2012). For example, Ria Formosa is one of the most important wetlands of the Portuguese territory, with extensive marshes and tidal channels (total area of 18000 ha) that maintains connections with the sea through six inlets, which guarantees daily renewal of water at the pace of tides. It hosts a remarkable diversity of habitats and biodiversity, and it is of fundamental importance for numerous species of migratory (Moura et al., 2019). The Natural Park do 'Sudoeste Algarvio e Costa Vincentina' stretches along 100 km of coastline and is one of the best-preserved coastal areas in Europe. In the Algarve, the Park covers the counties of Aljezur and Vila do Bispo, with a wide biodiversity with different species and natural habitats ('Classificação e Caracterização – ICNF', n.d).

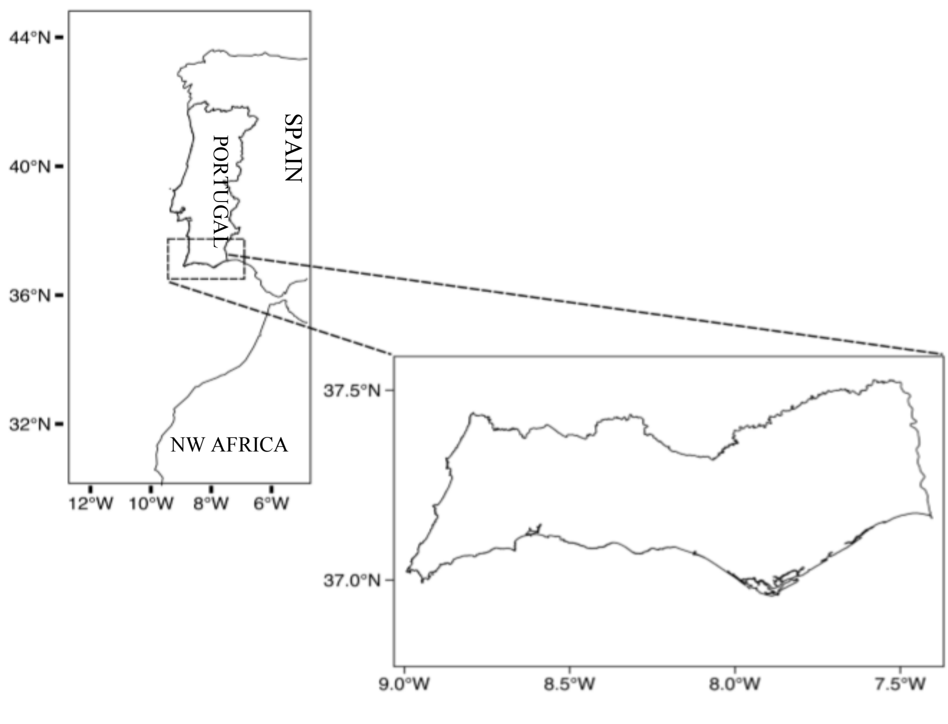

Figure 3.1. Geographic location of Algarve.

Algarve coast also encompass transient coastal water bodies, the two main estuaries in the region are the Guadiana and the Arade. These are critical to area development, providing areas for transport and trade, aquaculture and fisheries, breeding grounds for birds, salt production, recreation (Moura et al., 2017). The Guadiana river drainage basin is the fourth largest on the Iberian Peninsula, with a length of 810km and an area of 66.960 km^2. The estuary is located at the southern border between Spain and Portugal (Figure 3.2) and extends for about 80 km (Garel et al., 2009). It is subjected to semidiurnal, mesotidal tides, and it is usually well mixed in its upper section and partially stratified in its middle and lower sections, depending on river flow and tidal stage (Barbosa et al., 2010). According to Garel et al. (2009), the river inputs that flow into the Guadiana estuary are highly variable; at a seasonal and inter-annual scale, they produce severe droughts and episodic floods in the river basin. After the construction of the Alqueva Dam, the river flow has been strongly regulated (Sampath et al., 2015). Currently, the Guadiana river discharge into the estuary is less than 10 m^3/s in summer and about 20 m^3/s in winter (Sampath et al., 2009). In addition, Guimarães et al. (2014) observed that the estuary is under high human pressure, including effect of dams and different types of pollution, urbanization, agriculture, cattle breeding and olive oil production.

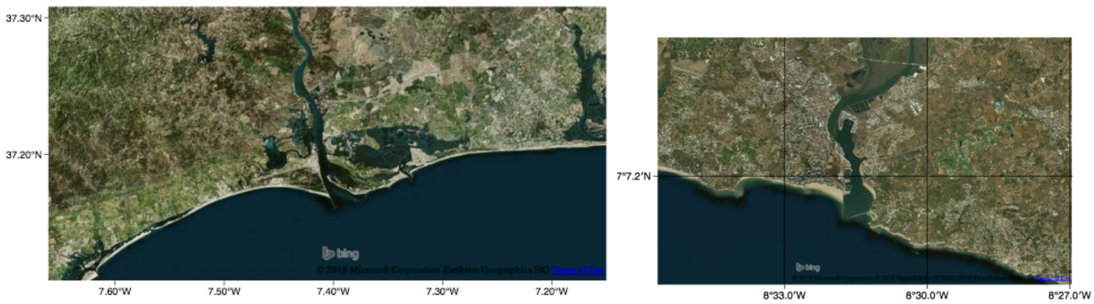

Figure 3.2. The two main estuaries in the region are the Guadiana and the Arade. Guadiana River located on the southern border between Portugal and Spain (Left) and Arade river discharging on Portimão coast (right).

Arade estuary is located in the centre-west of Algarve. The river's course takes it through the municipalities of Silves, Lagoa and discharge into the Atlantic Ocean in Portimão, east of Praia da Rocha (Figure 3.2). Its hydrographic basin has approximately 996 km^2

with a seasonal discharge around 10 m^3/s being at present the second largest estuary of the Algarve, after the Guadiana (Ferreira A.., 2006). Currently, it is under increasing anthropogenic pressure due to the existence of a large fishery harbour, aquaculture activities, recreational marinas, cruise terminal and waste-water effluent inputs (MARETEC, 2014).

3.1 Economy

Algarve has 4.996,8 Km^2 with 400.000 inhabitants distributed in 16 municipalities, and it is one of the most important touristic regions of Portugal and Europe. In 2017, it was reported that around 4 million of tourist visited Algarve, attracted by the beaches and Mediterranean clime (Região do Turismo Algarve, 2017). The economy of the region relies mainly on the tourism, especially in the coastal area, that represent directly 44.7 % of the regional Gross Domestic Product (GDP) and a key source of employment in the Algarve. Fisheries represent 3.7 % of the regional employment against 0.7 % at national level (Janeiro J., 2012). During 2017, the Algarve aquaculture represented 53% of the national production in marine or brackish waters, producing 4.620 tons. Regional fishing however has a small representation of the total Portuguese fishing (INE,2018).

Off the south of Portuguese coast important fishing grounds for local artisanal and industrial fleets are observing, operating different equipment and targeting several species. The most used fishing methods in this coast are: surface and deep water longlines, purse-seine, gill nets, trammel nets, pots and traps, finfish and crustacean bottom trawls. In addition, this area is also part of important maritime corridors linking the Mediterranean and North Africa to Northern Europe (Oliveira et al., 2015).

3.2 Climate and Ocean

The Algarve area is characterized by a Mediterranean climate. The mean annual air temperature is 16 °C, with a minimum in January (9°C) and a maximum in August (23°C), with warm dry summers (June to September) and wet winter (October to February) (Serpa et al., 2005). The coast is characterized by semi-diurnal with a tidal cycle of approximately 12h30m (corresponding to about two high and low water levels every day), and mesotidal with mean tidal range of 2 m of amplitude, the largest tidal ranges correspond to spring tides (2.6m with maximum of 3.44 m) and the lowest to neap tides (1.28 m) (IH, 2009).

The wave climate of the area is characterized as moderate to high (Costa et al., 2001). The mean waves height is between 1.7 and 2.2 meters with peak periods of 9 and 13 seconds for summer and winter periods. Wave regimes in Algarve coast differ markedly between western and southern area. In south coast the dominant waves reach from westerly to south-westerly direction, while the western littoral is exposed to the North Atlantic swell and storms presenting dominance of waves approaching from north-westerly to westerly, with high energy condition and seasonality in wave climate (Costa et al., 2001).

The oceanography of the region is largely dominated by medium size structures, time scales of a few tens of days explain more than 70% of the variability of the coastal alongshore wind stress, a major factor governing the coastal circulation (Alvarez-Salgado et al., 2003). The observed oceanographic patterns in the Iberian system reveal a conspicuous succession of mesoscale structures such as jets, meanders, ubiquitous eddies, upwelling filaments and counter-currents, superimposed on the more stable variations at seasonal timescales (Relvas et al., 2007)

The upwelling season is well-defined between April and begging of October (Fiúza A.F., 1983, Haynes et al., 1993), based on the seasonal wind regimes associated with the zonal displacement of the Azores high- and Icelandic low-pressure systems. During the upwelling season, strong northerly winds blow along the West Iberian coast, while westerlies and south westerlies prevail in winter (Garel et al., 2016).

When northerly winds blow along a meridional coast, coastal waters are transported offshore through an Ekman layer, and are replaced by rising of subsurface upwelled cold waters (Figure 3.3). Equatorward flow develops in geostrophic balance parallel to the front between coastal cold upwelled waters and the offshore warmer waters (Ambar I., 1994). The Portuguese upwelling zone is defined by front of strong temperature contrast that can reach 30-50 km offshore in weak upwelling event, and 100-200 km in strong event (Fiúza A.F, 1983).

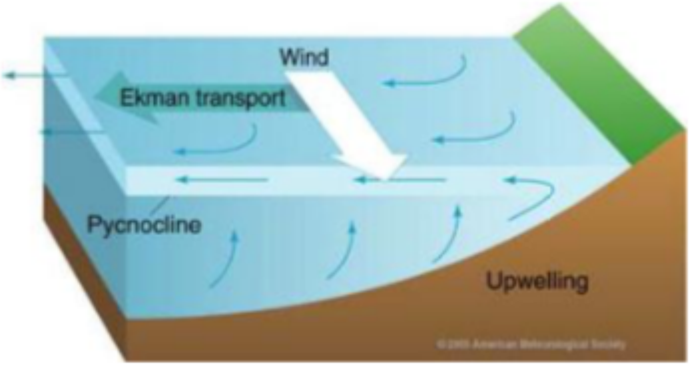

Figure 3.3. Scheme of Ekman transport and consequently upwelling effect occurs in the coast. Source: NASA, n.d.

Local topographic features, such as mountains chains located in Faro, occasionally divert the northerly wind direction to westerlies in the south coast, developing conditions for upwelling in the south coast of Algarve. Under the upwelling conditions, the coastal flow along the southern Algarve is towards east, as a result of west coast upwelling or of locally induced upwelling, while warmer oceanic waters lying offshore of the Algarve continental shelf flow westward. Upwelling in this area is more frequently during late spring/summer season, with intensity and frequency decreasing from west to east along the Algarve coast (Relvas and Barton, 2005).

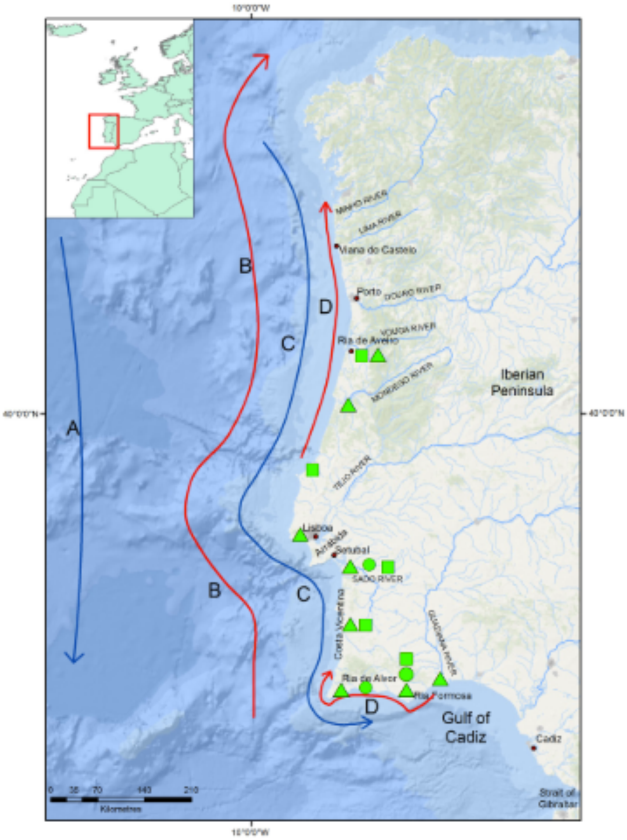

Figure 3.4.Sketch of the sea surface circulation off Western Iberia. (A) Northern segment of the Canary Current, the eastern branch of the North Atlantic gyre. (B) Poleward flowing Iberian Poleward Current (IPC). (C) Equatorward cold jet that develops during the upwelling season, and underneath the poleward flow remains. (D) Inner shelf poleward warm counter currents that develop during upwelling relaxations. Source: Cardoso et al., 2019.

Coastal circulation of the study region during summer is rather complex, dominated by the alternation of warm-cold-warm along the south Portuguese coast. Warm counter flow is associated with periods of weakening or relaxation of upwelling favourable winds, occurring a predominance of easterly and westerly winds (Relvas et al., 2007). This counter flow runs opposite to the typical upwelling coastal circulation, bringing warmer waters from eastern Gulf of Cadiz to the southwest coast of Iberian Peninsula (IP) (Teles-Machado et al., 2007).

Counter current flow shows to have an ecological consequence by preventing the transport between the inner shelf and the outer shelf, so an alongshore dispersion and consequent retention of larvae stages, phytoplankton, and detritus prevail over the inner shelf. Furthermore, the nearshore region assumes an exceptional importance as it represents the interface between the Portuguese populated coastline and the open sea (Cardoso et al., 2009).

During the winter the dominant wind direction to southerly and westerlies changes and poleward flow becomes a conspicuous feature at all levels between the surface and the Mediterranean water at ~1500 m, along the west Portuguese coast. The surface poleward flow carries relatively warm and saline water (Frouin et al., 1990; Haynes and Barton, 1990; Peliz et al., 2005, Isemer and Hasse, 1987). Poleward flows, ubiquitous and occasionally dominant features of eastern boundary upwelling systems, are important as they are strongly implicated in the onset of harmful algal blooms with significant economic repercussions for local fisheries and aquaculture (Relvas et al., 2007).

Winter upwelling events are unusual in the area since northerly winds prevail mostly during summer, however they do happen and are some studies addressing them (Alvarez et al., 2003). The upwelling events observed in winter are driven by the same mechanism, namely, by northerly winds along the adjacent coast. Nevertheless, the thermohaline properties of the water are different then (Alvarez et al., 2003).

4 Methodology

4.1 Beach Survey

Over a period of 4 years, Praia Batata and Faro Island beaches were sampled for litter four times each year (winter, spring, summer and autumn) acquiring information on amounts and sources of marine litter in the area (Table 4.1). On each survey, 100 meter transects were select and marked, using permanent references points on the beach to ensure that the same site was monitored in all subsequent surveys (OSPAR). All campaigns were organized by the Portuguese National Directory of Marine Resources (DGRM) and many surveyors were volunteers. All surveys were also conducted in accordance with the OSPAR Guidance for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area protocols for the 100 meters stretch (Figure 4.1).

Table 4.1. The APA survey period in Praia da Batata and Praia de Faro.

Survey Window	Survey period
Winter	Mid-January - February
Spring	April - Mid-May
Summer	Mid-June-mid-July
Autumn	October-Mi-November

During the survey all visible to the naked eye litter found in each transect was identified, counted (number of items per 100 m transect (N/100 m)), and registered on the survey forms according to the ‘Guidance for Monitoring Marine Litter on the Beaches in the OSPAR Maritime Area’. On the survey forms, each item is given a unique OSPAR identification number. The surveys classified the litter per types (plastic/ polystyrene, metal, paper and cardboard, wood, sanitary waste, cloth, rubber, glass, pottery/ceramics, medical waste and Faeces), and according to the activities that generates them (tourism, fishing, shipping, sanitation and other). In this project, medical and faeces litter were not considered.

Figure 4.1. Picture of the monitoring beaches organized by the Portuguese National Directory of Marine Resources (DGRM), displaying the location of the 100 meters transect. Source: Portuguese National Directory of Marine Resources, 2017.

4.1.1 **Data Analysis Procedures**

The results of Batata beach and Faro Island beach surveys carried out in the period 2013 to 2017 were evaluated using the Litter Analyst Software, which is a Windows program aimed for the statistical analyses of beach litter data. A full description of the software is given in its user manual in Van der Meulen and Baggelaar (2018) and Schultz et al. (2017).

Litter Analyst is able to read the data-exports from OSPAR beach litter data and perform trend analysis on individual litter items and total items with Mann-Kendall. Outputs are evaluation tables of items, sources and materials, but also a data series plot, boxplots, a table of data series and data density matrix can be created and saved externally (Van der Meulen and Baggelaar, 2018). For the analyses in this report, the following settings in Litter Analyst were used:

1. Aggregation condition 80%; minimum percentage of counts of items in the top-X list, hereby 10 items.

In this project, trend analysis is performed on the total items counts, litter material and sources, as well as on the top-80% items. The top-80% is defined as the list of most abundant items that during a six-year period constitutes on average at least 80% of the total counts. In the current beach analysis, the dataset of 5 years (2013-2017) was used.

In this project, the averages of total items and sources were calculated to total items from individual beach surveys, and not for annual averages. The total counts of beach litter surveys were calculated using 5 years arithmetic averages and median values to describe total abundance of litter on both sites.

It is important to connect monitoring results to the litter source in order to understand where, by whom and why litter is released from these systems and how it enters the marine environment. To help establish appropriate operational targets and to design, implement and monitor effective management and mitigation measures. For this project the assignment of sources categories to litter items by Litter Analyst, which are: Tourism, Shipping, Fishing, Others and Sanitary waste. A relative contribution of each source is provided as an average and trend analysis performed of the total abundances of items (period 2013-2017).

It is also essential to connect monitoring results to the litter material composition. Especially the fraction of plastic/synthetic items is of interest for MSFD policy makers, in light of the increased awareness and attention on plastic in the seas and oceans. A relative contribution of each litter material is provided as an average and trend analysis performed of the total abundances of items (period 2013-2017) which have been assigned with sufficient confidence to either of the following material categories: Plastic/polystyrene, Rubber, Sanitary, Paper/cardboard, Wood, Glass, Cloth/textile, Metal, Ceramic/pottery, and Medical.

4.2 Numerical modelling

For the modelling activities the MOHID water modelling systems was used. MOHID (derived from the Portuguese abbreviation of “MOdelo HIDrodinâmico” (Hydrodynamic Model)) is an open-source water modelling system continuously being developed by Marine and Environmental Technology Research Centre (MARETEC) at the Instituto Superior Técnico (IST) in Lisbon University. It can be used for open and coastal waters (MOHID Water) as well as in watersheds, rivers and soils (MOHID Land). Furthermore, it allows the simulation of the main physical, chemical and biological processes that occur in the marine environment. It uses an object-oriented programming philosophy and the FORTRAN 95 features. It is also organized in modules (or classes) that connect each other in a way that allows the transference of information from among them.

MOHID Water model is able to simulate a broad range of processes and scales from coastal areas to open ocean. Therefore, it has been applied at different marine systems worldwide, in the framework of both research and consulting projects. Along the Portuguese coast, different contaminants have been studied, including nitrogen load (Saraiva et al., 2007), faecal contamination (Leitão et al., 2012), microplastic (Ballent et al., 2013), sardine larvae migration (Nogueira et al., 2013; Santos et al., 2005), oil spill (Fernandes R., 2013; Janeiro et al., 2017; Janeiro et al.,2012), and algae (Pinto et al., 2016).

4.2.1 MOHID Water

MOHID water can be applied to simulate water dynamics and dispersion phenomena using Lagrangian and Eulerian approaches, sediment transport, water quality and biogeochemical processes within the water column and exchanges with the bottom. The model can be subdivided in several modules, which can simulate different processes. Also, the model can perform different simulations (1D, 2D or 3D) and can be used in one-way nesting scheme.

In term of processes, the main modules relevant in this work are:

- Hydrodynamic module: Computes the non-turbulence flow properties, such as water level, velocities, water fluxes;
- Turbulence Module: Manage the turbulence flow properties, such viscosities, diffusivities, turbulent kinetic energy and uses the formulation from General Turbulence Ocean Model (GOTM)
- Water properties Module: Computes the transport of water properties processes, such as temperature and, salinity using Eulerian approach;
- Lagrangian Module: Computes the transport of properties such as oil or litter using Lagrangian formulation.

The following paragraphs briefly describe the characteristics of each MOHID module used in the hydrodynamic and marine litter modelling in Algarve coast. Further detailed descriptions of the structure can be found in Leitão et al. (2005), Braunschweig (2004), Neves, R. (2007) and MOHID website.

4.2.2 **Hydrodynamic Module**

This model computes flow properties (water level variation, velocities, water fluxes). It solves the Reynold averaged Navier–Stoker equations, considering hydrostatic equilibrium and Boussinesq approximations. The equations related to mass and momentum evolution in the system are:

$$\frac{\partial u_i}{\partial x_i} = 0$$

(Equation 2)

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_i u_1}{\partial x_j} = -f_{u2} - g\frac{\rho_n}{\rho_0}\frac{\partial \eta}{\partial x_1} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_1} - \frac{g}{\rho_0}\int_z^n \frac{\partial \rho'}{\partial x_1} dx_3 + \frac{\partial}{\partial x_j}\left(A_j \frac{\partial u_i}{\partial x_j}\right)$$

(Equation 3)

$$\frac{\partial u_2}{\partial t} + \frac{\partial u_i u_2}{\partial x_j} = -f_{u1} - g\frac{\rho_n}{\rho_0}\frac{\partial \eta}{\partial x_2} - \frac{1}{\rho_0}\frac{\partial p_s}{\partial x_2} - \frac{g}{\rho_0}\int_z^n \frac{\partial \rho'}{\partial x_2} dx_3 + \frac{\partial}{\partial x_j}\left(A_j \frac{\partial u_2}{\partial x_j}\right)$$

(Equation 4)

where u_i represents the velocity vector components in x_i directions; η is the free surface elevation; f is the Coriolis parameter; A_j is the turbulent viscosity coefficients; p_s is the atmospheric pressure; ρ is the density and ρ' is the density anomaly, which is defined as the mean density minus the density at a particular depth.

The vertical turbulence is computed by a one-dimensional model, based on the GOTM model while the horizontal turbulence is obtained from empirical formulation using the Smagorinsk scheme.

4.2.2.1 Spatial Discretization

The model uses the finite volume approach to discretize spatial equations. The discrete form of the governing equations is applied macroscopically to a cell control volume, solving the equations independently of the cell geometry and allowing almost all kind of shapes of the cell, since only fluxes among faces are required. Therefore, a complete separation between the physical variable and geometry is achieved (Hirsch, 1988; Janeiro J., 2006).

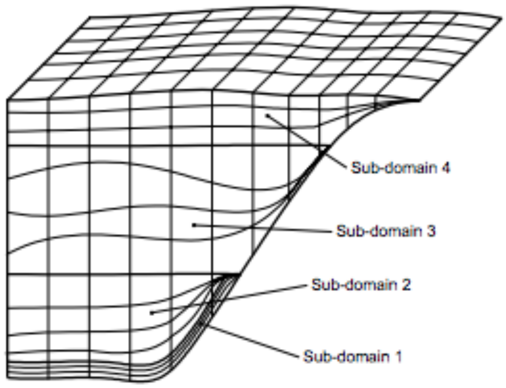

Figure 4.2. Illustrative grid showing the vertical discretization of the MOHID system. Source: Martins, F. (1999).

Cartesian or curvilinear coordinates can be used in the horizontal and a generic vertical coordinate with different sub domains can be used in the vertical (Figure 4.2), this way minimizing errors of some classical vertical coordinate (Cartesian, sigma and isopycnic) as mentioned in Martins et al. (2000).

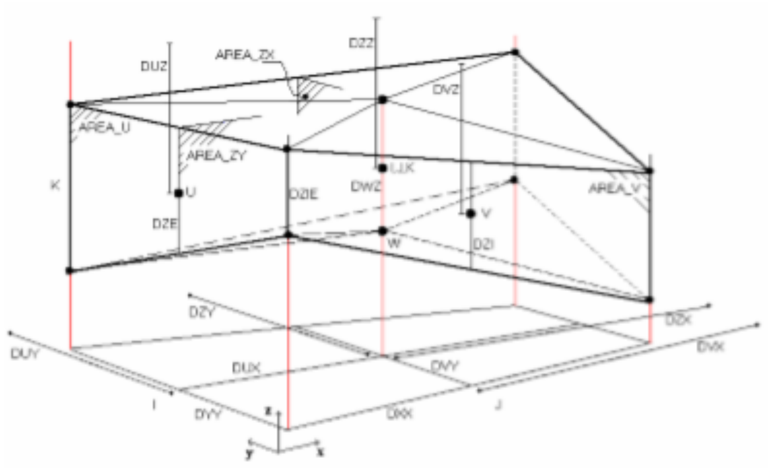

Figure 4.3. Volume element used in the discretization. Source: Neves R. (2007).

The grid is staggered horizontally using the Arakawa C concept, and a finite volume approach to calculate the velocities, the water level, and several scalar properties. In the Arakawa grid type C, the elevation, turbulent magnitudes and tracer are calculated at the centre of the grid cells, while the horizontal velocities and elevation is calculated in the centre of the west (u-velocities) and south (v-velocities) (Figure 4.3). The advection-diffusion of all properties can be discretized using centre differences for the diffusion term and upwind or TVD (Total Variation Diminishing) schemes for advective term.

4.2.2.2 Temporal Discretization

The temporal discretization is based on a semi-implicit ADI (Alternate Direction Implicit) algorithm. Therefore, MOHID computes alternatively one component of horizontal velocity implicitly while the other component is calculated explicitly. The resulting equations produce trigonal matrices that can be solved using the Thomas algorithm. Further full descriptions of the discretization can be found in Martins F. (1999).

4.2.3 Boundary Conditions

The model requires initial conditions and boundary conditions in the land, ocean and atmosphere interfaces to solve the differential equations. These boundary conditions can be provided at the surface and bottom of the domain, as well as on the lateral boundaries, and can be open, closed or mobile. Close to land (lateral closed boundaries), the cell faces in contact with land have null fluxes. At the free surface the model is forced by the wind surface stress, the energy and mass fluxes. At the bottom, boundary advective fluxes are null and the diffusive flux of momentum is estimated by means of a bottom stress law that depends on the near-bottom velocity.

Open boundaries are usually used to define interactions between the hydrodynamic module and external water masses, while closed boundaries are used to define the coastal line.

4.2.3.1 Open boundary condition

To prescribe coherent open boundary conditions (OBC), good external data are mandatory (Blayo and Debreu 2005). There are several sources of external solutions for coastal applications. Several global tidal solutions became very common approximately 15 years ago. The MOHID system has the necessary software tools to generate the external solution from the FES2004 tidal SSH atlases (Lyard et al. 2006). Pre-operational models have been made available over the last years (Mercator, HYCOM-US, Topaz and FOAM), providing a best estimate on the current state of the ocean low frequency processes.

To prescribe coherent open boundary condition (OBS), good external data are mandatory, which can be obtained by three ways: measurements, simplified solution of equations or using nested models (or sub-models). There are several sources of external solutions for coastal applications. The MOHID system has the necessary software tools to generate external solution from the FES2004 tidal. Pre-operational models have been made available over the last decades (Mercator, HYCOM-US, IBI, and others), providing a best estimate on the current state of the ocean process. The MOHID system allows the users to construct a tree of one-way nested models with no limitations on the number of nesting levels from a software perspective. By default, for each nesting level the external data for the OBS is extracted from the upper level nesting levels. However, the user also can use another solution linearly to the upper nesting levels. This nesting approach allows overlapping different scales in an efficient way to study local process.

Open boundaries in MOHID system use the flow relaxation scheme (FRS) developed by Martinsen and Engedahl (1987) provides a good method for handling the open boundary condition (OBC) in nesting approach. This scheme was originally designed to relax external solutions (ES) from a large area model towards solutions in a limited area model with a fine mesh and takes place within specified margin zones applied along the open boundaries. In the FRS zones the variables (tide, salinity, temperature) are redefined or relaxed by s relaxation parameter which varies from 0 to 1 within an FRS zone. It is equal to 1 at the outer edges of the zones, and decreases down to zero at the edges facing the MD. The FRS has shown to have the ability of filtering noise from the ES and leave the internal solution almost undisturbed without differ significantly the physical nature from the ES (Engedahl H., 1995). However, the major drawbacks for the FRS method are the required extension of the computer-space and -time (Martinsen and Engedahl, 1987).

4.2.3.2 Moving boundary

Moving boundaries are closed boundaries that change position in time. For example, if the domain has inter-tidal zones, some points can be alternately covered or uncovered depending on the tidal elevation (Neves R., 2007). Detailed description of the algorithms used in MOHID can be found in Martins et al. (1999).

4.2.4 Water Properties Module

This module computes the transport and evolution of water properties (e.g. temperature T, salinity S) in the water column using Eulerian approach and by solving the general advection-diffusion equations. The temperature and the salinity changes are due to the transport patterns of the flow from punctual discharges, surface fluxes like heat fluxes (solar radiation, infrared radiation, latent, and sensible heat in the case of the temperature) and mass exchanges (evaporation and precipitation in the case of the salinity).

The horizontal and vertical terms of these equations may be resolved by using an explicit or implicit approach. The advection term may be resolved by various discretization schemes, such as the centred differences, upwind, and TVD schemes.

The density is calculated based on the state equation for temperature, salinity, and pressure from UNESCO (1983). Currently, MOHID can simulate diverse different water properties, such as, temperature, salinity, phytoplankton, zooplankton, particles and dissolved organic phosphorus.

4.2.5 Lagrangian Module

This module uses the concept of trace, which is based on the simulation of the particle movement in the water column in a Lagrangian referential. The great advantage of its application is that this approach avoids the instability problems from explicit resolution of the advective transport term equation and can be applied to areas with complex features and abrupt gradients. The tracers are characterized by their spatial coordinates (x, y and z), volume and vertical/horizontal velocity, settling velocity and mass of constituents (Neves R., 2007).

Tracers are introduced at origins, they share the same list of properties and use the same parameters for random movements. These origins can release the tracers with different space and temporal approaches and may be compiled in groups in the output file facilitating the analysis. In space, the origins may release the particles as:

- "Point Origin" emits tracers in a given point;
- "Box Origin" emits tracers spread over an area;
- "Accident Origin" emits in a circular form around the point.

While, in time, the tracers may be discharge as:

- "Continuous emission" releases tracers at regular time;
- "Instantaneous Origin" release tracers at one period.

The spatial coordinates are computed by the velocity:

$$\frac{dx_i}{dt} = u_i(x_i, t)$$

(Equation 5)

This equation is solved by an explicit method:

$$X_i^{t+\Delta t} = x_i^t + \Delta t \cdot u_i^t$$

(Equation 6)

where u_i is the velocity and x_i for the position vector. In this formulation the velocity is evaluated at the beginning of the displacement (time t) and at the initial location x_i^t

Turbulent transport is responsible for dispersion of the particles, the effect of eddies over particles depend on the ratio between eddies and particle size. Eddies larger than the particle induces a random walk component in the displacement. The random walk is induced by the velocity field from the hydrodynamic module, wind from atmospheric module, spreading velocity and beaching from the oil dispersion module. The Lagrangian module may interact with other modules in order to simulate different processes (e.g. water quality, oil spill, sediment transport, marine litter pathway).

Each particle can have different grids associated to it instead of all particles being associated with only one grid. The user defines a list of domains ordered by descending priority in the input data file. The association between a particle and a domain is made via the particle position. After a particle position is initialized or changed it is associated with the domain with higher priority embracing the particle's position. It is critical to be able to develop tools that are able to use hydrodynamic solutions available and not be constrained to only one solution since that solution is limited in space and probably is not the best solution for the entire domain, thus the multi-mesh functionality allows particles to change between different model domains (Figure 4.4).

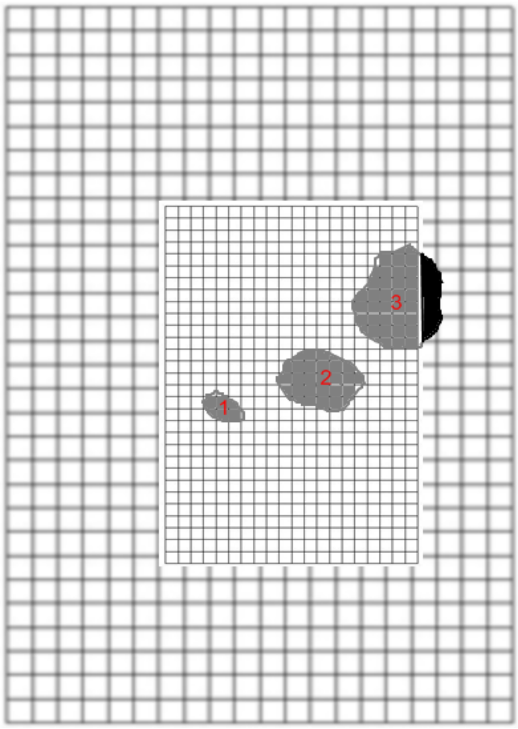

Figure 4.4. Schematic representation of 3 instants of a Lagrangian plume over coupled grids.

4.3 Modelling Marine Litter on the Algarve Coast

The marine litter in Algarve Coast was modelled using hydrodynamic results from SOMA (Algarve Operational Modelling and Monitoring System). This is a regional operational system developed primarily for forecasting oil spill trajectories in the Algarve coast (Janeiro et al., 2017). SOMA is based on MOHID modelling system, using downscaling methodologies. The system has the ability to reproduce the meteo-oceanographic features of SW Iberia to a good extend (Janeiro et al., 2017). For further detailed descriptions of the structure can be found in Janeiro et al. (2017).

4.3.1 **Initial Conditions**

All the simulations were run in hindcast mode. The model included a spin run of 8 days followed by 15 days run at time, with time step of 15 seconds. To determine the input time, it was performed a previous analysis of SST satellite images from MODIS aqua and wind data from Puerto del Estado, in order to observe and compare different scenarios of distribution of plastic pollution along the Algarve coast. According with Relvas et al. (2007), mesoscale processes, superimposed on the larger scale variability, are the major factor controlling the ecosystem functioning in the region, and it is possible to divide this circulation into a summer regime and a winter regime (Leitão et al., 2005). Winter surface circulation of Iberian coast is characterized by a narrow poleward warm water due to the seasonal reversal wind regime. Figure 4.5.a corresponds to a winter (January 2017) with the poleward flow. The most noticeable feature is the front evolving along 37°N separating colder waters to the north from southern warmer waters.

Summer regime reveal significant mesoscale activities, with thermal feature formed by a sequence of warm–cold–warm waters in the Algarve coast. The observation of September SST images (Figure 4.5.b) of a cold upwelled water band along the west coast, turning on Cape St Vincent and flowing eastward on the south coast is in close agreement with Relvas and Barton (2002) upwelling observation on Algarve coast. Furthermore, according with Relvas and Barton (2005) and Leitão et al. (2005), at the end of summer the wind regime changes to easterly on the Algarve coast and a warm coastal counter flow on the south coast can be observed, similar to the one displayed in Figure 4.5.c. After the pre-analyses, simulated period was setup in agreement with the different wind and circulation event, being than;

- 1-15 of January of 2017 (Figure 4.5.a);
- 15-30 of September of 2017 (Figure 4.5.b);
- 7-22 of October of 2017 (Figure 4.5.c).

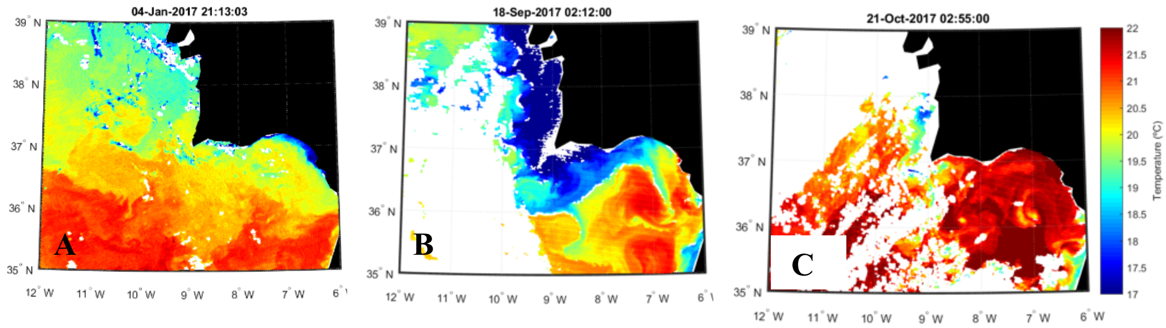

Figure 4.5. Events considered in the study derived from MODIS SST dataset. **A.** representation of winter sea surface temperature **B.** Upwelling event and **C.** downwelling event.

4.3.2 **Open Boundary Condition**

In order to obtain coherent open boundary conditions (OBC), a good reference solution is mandatory. The high resolution of the Northern Atlantic basin provided by the Iberia Biscay Ireland Regional Operational Oceanographic System (IBI-ROOS) is a reliable solution available. It provided data for temperature, salinity and current velocities with resolution of 3 km. The tide was forced in the boundary of the domain using the FES2012 global solution.

4.3.3 **Atmospheric forcing**

Atmospheric forcing conditions are supplied by The Regional Weather Forecasting System (SKIRON) developed by the Atmospheric Modelling and Weather Forecasting Group of the University of Athens for operational use at the Helenic National Meteorological Service (HNMS). It provides hourly data of wind U and V components, air temperature, specific humidity, total cloud cover, sea level pressure, total precipitation, upward and downward longwave flux, evaporation, latent heat flux and sensible heat flux at a resolution of 5 km. SKIRON results were firstly interpolated for the South Iberia and Algarve grid by before being used in the operational system as atmospheric forcing fields for the hydrodynamic and Lagrangian models.

4.3.4 **Spatial Discretization**

SOMA is constituted by three domains of increasing resolution. The bathymetric data used to build those grids were retrieved from the European Marine Observation Data Network (EMODNET).

Figure 4.6. Map displaying the grid level comprising the operational system. For the sake of scale Level 0 is not presented.

Level 0 is a two-dimensional model were tide is implemented and forced with FES2012 boundary conditions. Level 1 is a three-dimensional model, with a constant horizontal resolution of 3 km, 11 sigma layers in the first 20 m depth and a resolution of 75 cm at the surface layer. From the 20 m to the bottom 35 unevenly spaced Z coordinate levels vertically discretize the model. A time discretization of 30 s is used with this mesh. At the boundary, a Blumberg and Kantha (1985) condition is applied to the water level and a Flow Relaxation Scheme (FRS) is used for velocity, salinity and temperature. This allows a smooth forcing of the model and a weighting of internal and external solution to prevent an overshoot of the dynamic equilibrium. In the outer grid cells a sponge layer was applied to attenuate reflected spurious baroclinic flow oscillations.

Level 2 (Figure 4.6) is a three-dimensional model with a regular 1 km spatial resolution grid covering the Algarve coast. It has the same vertical resolution of Level 1 and a time discretization of 15 s. The communication between Levels 1 and 2 is made using FRS to relax the zonal and meridional horizontal velocity components, through an eight cells band adjacent to the lateral boundary (Janeiro J., 2017).

4.3.5 **Lagrangian scheme**

To track the movement of particles it was used the Lagrangian module, which was computed on-line coupled with the circulation model on S.O.M.A. Tracers were tracked online over a period of 15 days of January, September and October of 2017, with an hourly output of the tracers' positions.

Figure 4.7. Distribution of seeding location along the south Iberian coast, the blue boxes represent the shipping sources, red and yellow boxes represent litter discharged by fishing and aquaculture activities and pink boxes represent litter produced and released by land-based sources.

Macro plastic particles enter from diverse land and maritime-based sources, for this project it was released 10,000 particles instantaneous at the beginning of the simulation at each of the 23 source boxes. Land based sources included the major river systems flowing into the study region as well as the waterbody that drained Bordeira. This last one is likely an urban source of litter in the west coast of Algarve. These sources have a multitude of land uses, including urban, aquaculture and agriculture. Areas with high density population and a large tourist turn over, such as Portimão, Lagos, Albufeira, Tavira and Faro were considered. It was also considered the surrounding areas near the natural parks (Figure 4.7).

Sea based sources included fishing grounds and aquaculture sites between the coast and 150-meter depth areas, off the south coast of Portugal. These are the main fishing grounds for local artisanal and industrial fleets operating different metiers targeting several species: surface and deep water longlines, purse-seine, gill nets, trammel nets, pots and traps, finfish and crustacean bottom trawls (Gonçalves et al.,2015; Gonçalves et al.,2016). Offshore sources were randomly distributed along the offshore commercial shipping lane (Figure 4.8), that connects the Mediterranean Northern Europe. Since 2008, a Vessel Traffic Service (VTS) system has been monitoring the maritime traffic to 50 miles offshore mainland Portugal with an average of 800 vessels being tracked daily (MAMAOT, 2012; Oliveira et al., 2015).

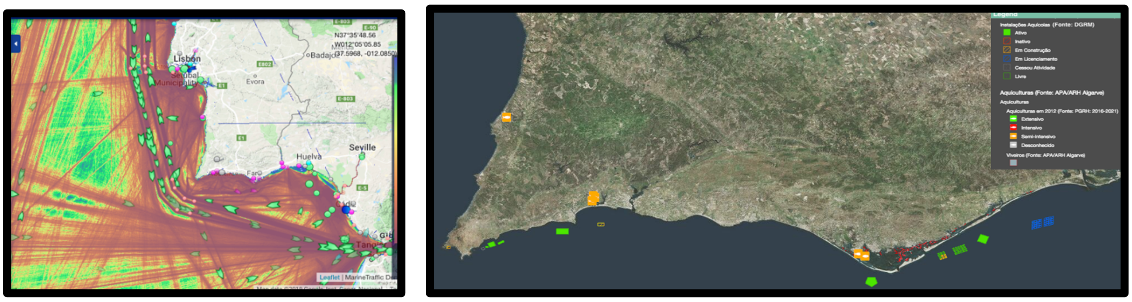

Figure 4.8. Location of maritime-based sources of Algarve. The main ship land and vessel traffic of the area is displayed in the sanapshot of MarineTraffic website (left figure), and the. locations of the aquaculture sites in Algarve according with DGRM. Source: ‘Geoportal PAqAT, n.d.

In order to focus on transport of floating marine litter, particles were forced to stay in the surface layer. The effect of wind was observed assuming a wind drift coefficient of 0.03, which means 3% of the wind at 10 m height, for each studied oceanographic scenario. Also, simulations without the wind drift was applied in this project.

Beaching parameter was assumed to simulate the dispersal, and eventual accumulation of macro plastic on the beaches. It was assumed that when particles reached 5 meters far from the coast, it has 50% of probability of be washed ashore or remain afloat in the coast. Others important parameters, informed by available literature were not able to use in this exploratory project, however it will be need considered on future works in the area.

5 Results

5.1 Descriptive and Trend Analysis

The average total item counts per 100-meter beach, trend and the significance of the trend are displayed in table 2 while 5-year arithmetic averages and median values are presented in Table 5.1. An increasing trend is found for both surveyed beaches, however the increase does not have statistical significance (p value 0.417 and 1.0). In 2017, between 589 (Batata) and 1153 (Faro) items were collected.

Table 5.1. Mean total items counts, trend and significance of the trend for Faro Island and Batata beach and for the two beached aggregated for the period 2013-2017.

Location	**Period**	**Mean total counts per survey**	**Trend** (counts/year)	**Significance of trend** (p-value)
Faro Island	01/01/2013-31/12/2017	245,5	27,9	0,417
Batata Beach	01/01/2013-31/12/2017	95,5	0,9	1,00
Batata Beach-Faro Island	01/01/2013-31/12/2017	186,3	11,3	0,399

Since this research aims to provide insight in the Algarve situation, results bellow was displayed as aggregated results for all two beaches. Trend analyses of litter material for the period of 2013-2017 are provided in the Table 5.2. The data shows a dominance of paper and plastic/polyester litter items on both beaches (51 % and 37.30 % respectively). Medical litters exhibited the lowest abundance on both surveyed beaches. For glass, ceramic/pottery, rubber and medical materials no trends were found. The largest increasing trend is for paper cardboard material (14.2 counts/year) following by plastic polystyrene (1.8 counts/year), both with no statistical significance. Only sanitary litter exhibited a trend increase of 0.5 litter item per year with statistical significance on both beaches.

Table 5.2. Mean total items counts, trend and significance of the trend for the two beached aggregated for the period 2013-2017.

Material category	Med. Count 100m	Aver. Count 100m	% of total counts	Trend (Counts year)	Significance of trend (p-value)
paper/cardboard	100,8	111,4	51,40%	14.2	0,381
plastic/polystyrene	66,8	80,9	37,30%	1.8	0,795
metal	9,3	10,5	4,80%	1.2	0,152
wood	4,3	4,8	2,20%	0.1	0,533
glass	2,3	2,8	1,30%	0	0,669
sanitary	1,8	2,5	1,20%	0.5	0,045
ceramic/pottery	1	1,8	0,80%	0	1
cloth/textile	1,3	1,3	0,60%	0	0,361
rubber	0	0,7	0,30%	0	0,44
medical	0	0,3	0,10%	0	0,617

Top-80% analysis has resulted in a top-10 for all two beaches for the period 2013-2017. The top-15 litter aggregated results for the two Algarve beaches are given in Table 5.3. Cigarette stubs rank as the number one most found item, followed by plastic polystyrene pieces smaller than 50 cm and nets and ropes. Together, they account for more than half of the total number of litter items found (60.2%). Plastic pieces smaller than 50 cm, nets and ropes and plastic caps showed a decreasing trend with no significative statistic, whilst cigarette stubs and other plastic litter exhibited a high increasing trend (12.1 and 0.9 counter per year respectively). The data shows increasing trends with a high ($p < 0.05$) significance for two of the top 15 items from the top 80% list.

Table 5.3. Top-80% of most found items along the Algarve coast, including median, average, percentage of total count, trend and significance of trend for the period 2013-2017.

Rank	Litter Category (OSPAR-100D)	Med. Count 100m	Aver. Count 100m	% of total counts	Trend (Counts year)	Significance of trend (p-value)
1	Paper: Cig_stubs	93,3	99,7	46,00%	12,1	0,299
2	Plastic polystyrene pieces < 50 cm	13,8	18,6	8,60%	-0,7%	0,697
3	Nets and ropes	7,8	12,2	5,60%	-0,3	0,82
4	Plastic: Other	7	8,2	3,80%	0,9	0,434
5	Plastic: Small_bags	6,5	7,9	3,60%	0,2	0,845
6	Paper: Other	4,5	7,6	3,50%	0,3	0,453
7	Plastic: Caps	5,8	7,4	3,40%	-0,1	0,794
8	Plastic: Cutlery	6,8	7,3	3,40%	0,7	0,135
9	Plastic: Crisp	3,8	4,6	2,10%	0,6	0,241
10	Metal: Caps	4,5	4,5	2,10%	0,8	0,047
11	Plastic: Food	1,8	4,3	2,00%	0	0,527
12	Metal: Foil	2,3	3,7	1,70%	0,4	0,281
13	Paper: Cig_packets	1	2	0,90%	-0,2	0,391
14	Plastic: Drinks	1,5	2	0,90%	0	0,793
15	San: Buds	0,5	1,9	0,90%	0,3	0,043

When comparing the results of the different surveys sites, the top 10 most found items are slightly similar, for instance the majority items on Top 15 most found items were plastic litter. There are some differences in the type and amounts of items found, like metal caps and ice cream woody stick were found frequently only in Batata beach whilst other plastic litter and paper litter items were collected with high frequency along Faro Island. Nets and ropes appear high on Top 15 most found items in Faro Island but not so in abundance in Batata beach.

OSPAR identified the following sources: fishing, shipping, tourism, sanitation and a category ‘other’ for unknown sources. The assignment of source categories to litter items is complex. In many cases, litter items can originate from different sources. Nets and ropes, for example, often originate from fishing vessels, but can also originate from vessels and recreational boats. In Table 5.4 the source allocation for beach litter in the Algarve period 2013 -2017 applying OSPAR classification is presented. Most sources of beach litter in the period 2013-2017 are allocated to the tourism (66.8%) and others (24.8%) followed by shipping (4.9%), fishing (2.2%) and sewages (1.3%).

Table 5.4. Sources trend analysis of litter items for both Algarve beaches, including trend in counts/year, percentage of total count, average and significance of trend for the period 2013-2017.

Litter Category (OSPAR-100D)	Med. Count 100m	Aver. Count 100m	% of total counts	Trend (Counts year)	Significance of trend (p-value)
Tourism	121,5	144,9	66,80%	16,7	0,217
Other	51,8	53,7	24,80%	-2,6	0,27
Shipping	8	10,7	4,90%	-0,5	0,697
Fishing	2,5	4,7	2,20%	0,2	0,647
Sanitation	2	2,8	1,30%	0,6	0,033

Litter originated from tourism activities show an increase of trend of around 16.7 items per year, while litter from “other” and shipping sources showed a decreasing trend of minus 2,6 and 0,5 of counts per year. Only one source showed trend increase with statistic significant, having a p-value smaller than 0.05.

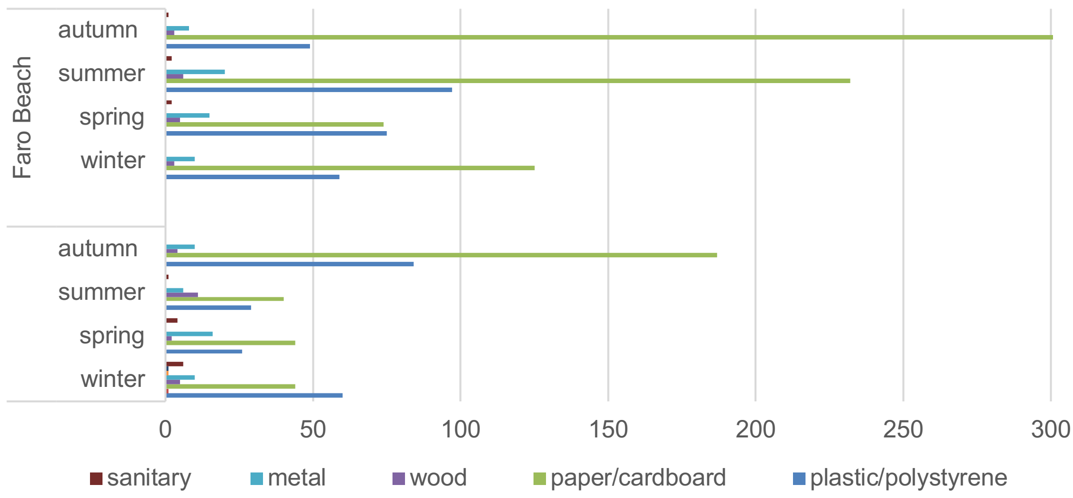

Figure 5.1. Number of litter items collected for both Algarve beaches, categorized by its material, during 2017 surveys.

During 2017, litter items were collected on both beaches, with a dominance of paper followed by plastic items on both surveyed beaches (**Erro! A origem da referência não foi encontrada.**), those items represent 92% of total litter collected at Faro Island and 85% of total litter collected at Batata beach during 2017 surveys. Plastic items were collected with higher abundance during spring (75 items) and summer (97 items) surveys, whilst on Batata beach occurred during autumn (84 items) and winter (60 items) surveys

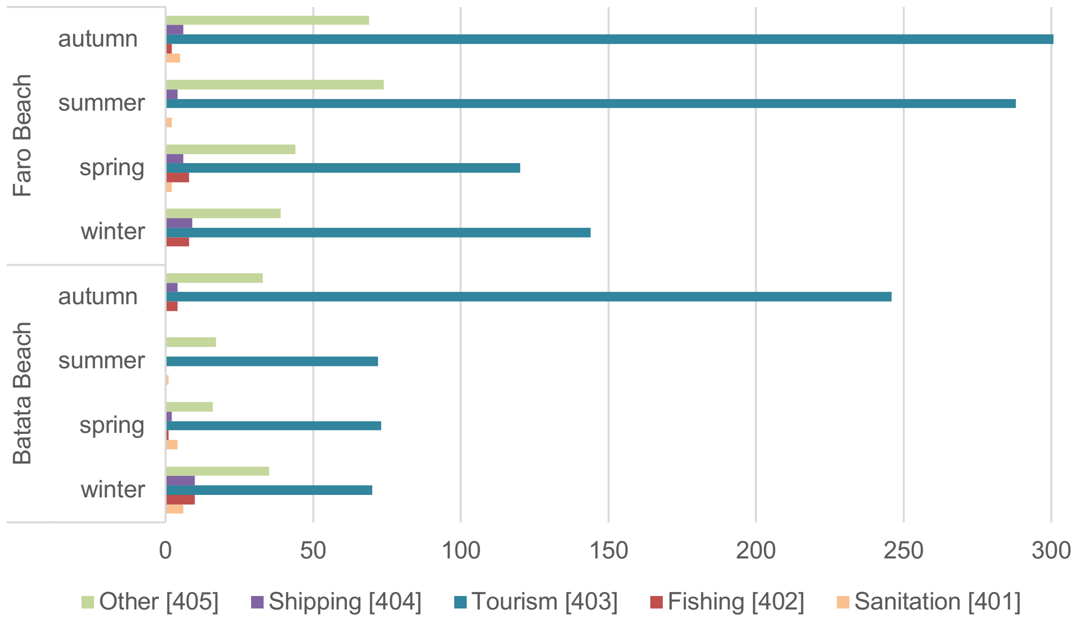

Figure 5.2. Number of litter items collected for both Algarve beaches, categorized by its material, during 2017 surveys.

Tourism activities were responsible for more than half of the litter collected on the beaches during 2017, followed by litter from unknown sources. Litter discharged by fishing, and commercial and recreational shipping reached with lower frequency Faro Island and Batata beach during 2017 (Figure 5.2). The field data showed that winter and autumn survey were the ones with higher concentration of litter originated from land and sea-based sources on Batata beach, whilst in Faro Island, litter originated from tourism and 'others' sources were found in higher concentration during summer and spring, while litter discharged by maritime sources were observed more during the winter survey.

5.2 Marine Litter simulations

5.2.1 Model assessment

Numerical model can be calibrated through the comparison of modelling results with field measurements and can be validated by reproducing an independent set of data. Although, there is no standard procedure for the calibration and validation of models available in the literature, therefore model calibration is done by qualitative comparison of short time series of parameters produced by the numerical model with field data for the same location and period of time (Cheng et al, 1991; Cheng et al. 1993).

The validation of the SOMA system was made by Janeiro et al. (2007) who followed O´Danncha et al. (2015) method. The SOMA validation included data from tide gauges, moored, buoys, vertical profile (CTD, XBT, Argos), ADCP, High Frequency Radar (HFR), remote sensing and drifter´s buoys. Therefore, validation of the model is outside the scope of this thesis, however a qualitatively assessment of model to observe the ability to correctly reproduce the events simulated was accessed comparing the sea surface temperature of the Level 2 with satellite images from METOP-A in three different studied seasons (winter, summer, autumn) during 2017. METOP data was retrieved from OSI-SAF webpage with SST images with 1 km of resolution for the period of interest. For the error analysis this was made by three different methodology.

The Mean bias error (MBE) is the average of the errors of a sample space. Generally, it is a good indicator of the overall behaviour of the simulated data with regards to the regression line of the sample. Positive values mean that the model under-predicts measured data, and a negative one means over-prediction, the results of the model being better the smaller the bias. A measure of the average errors is estimated according to the equation:

$$MBE = \frac{\sum_{i=1}^{n}(x_{model} - x_{obs})}{n}$$

(Equation 7)

Root mean square deviation (RMSD), also called the root mean square Error (RMSE), is a frequently used measure of the difference between values predicted by a model and the values actually observed from the study area.

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(x_{model} - x_{obs})^2}{n}}$$

(Equation 8)

Efficiency criteria of the model was measured by the coefficient of determination (R^2). It was applied for testing the proportion of variance in the measured data explained by the model and is defined as the square of the coefficient of correlation (r) according to Pearson Correlation Coefficient. The mean of the predicted value with values close to 1 indicates very good agreement and values approaching zero reflecting very poor agreement.

To evaluate the model performance for wind prediction, relative and absolute error were considered as suggested by O' Donncha et al. (2015) and Janeiro et al. (2017). The RMSD and Willmott (1981) model skill score (MSS) were used to access the wind results from the model and Cadiz buoy.

$$MSS = 1 - \frac{\sum_{i=1}^{n}(x_{model} - x_{obs})^2}{\sum_{i=1}^{n}\left(|x_{model} - \bar{x}_{obs}| + |x_{obs} - \bar{x}_{obs}|\right)^2}$$

(Equation 9)

x_{model} and x_{obs} are the model predicted and observed values respectively, while $\bar{x}_{obs}$ is the mean of observed values. The MSS provide a deeper understanding into the predicted abilities by overcoming the sensitivity of the correlation statistic to differences in the predict mean and variances. MSS varies between 0 (total disagreement between model and observed) and 1 (total agreement) (O' Donncha et al. (2015) and Janeiro et al. (2017)).

Table 5.5. Sea Surface Temperature model errors for each model period.

Period	**MBE**	**RMSD**	**R^2**
January (Winter)	-0.615	0.775°C	0.604
September (Upwelling)	-0.89	1.72°C	0.568
October (Counter Current)	-0.27	1.09°C	0.653

The error methodologies described in this project were applied to qualitatively validate the physical properties of the model by comparing simulated SST with remote sensing data were displayed in the Table 5.5 and Figure 5.3. The simulated and measured SST for the different studied oceanographic scenarios equally reflects the main feature of the temperature field described in Sanchez et al. (2006), Peliz et al. (2005), Relvas and Barton (2002), Relvas and Barton (2005), Sanchez and Relvas (2003).

In Figure 5.3.a, along the south coast, a cool water signal is noticeable along the coast, from the Gulf of Cadiz till Lagos. The model succeeds in reproducing the winter pattern although shows positive bias was observed (r^2= 0.60). Also, in this period, the simulation exhibited the lowest RMSD, with 0.77ºC.

In upwelling event the METOP image gives a clear picture of the upwelling jet flowing southward, meandering when it encounters CSV and creating a well-defined upwelling filament stretching westward. Part of the upwelling jet bends CSV reaching the south Portuguese coast as far as 8ºW. The model did succeed in reproducing the upwelling jet going southwards the west coast, although cold water along the south coast was not observed in the simulation. In addition, the warmer coastal water simulated was not observed in the satellite image (Figure 5.3.b). Therefore, this warmer coast in the south coast may explain the high RMSD value (~2ºC) and low coefficient of determination (R^2=0.57).

Finally, the counter current event studied, presents the evolution of the warm coastal counter current that is established when the relaxation of the upwelling favourable winds happens. There is a clear signal of warm from the Guadiana river to CSV, where it flows poleward after turning the Cape. In the model result, the same pattern can be observed, although an important difference in magnitude of the counter current in latitude and longitude exist. This differences in magnitude may explain the 1.1 error. Nonetheless, in this event the model exhibited the best agreement with the satellite image (R^2= 0.65).

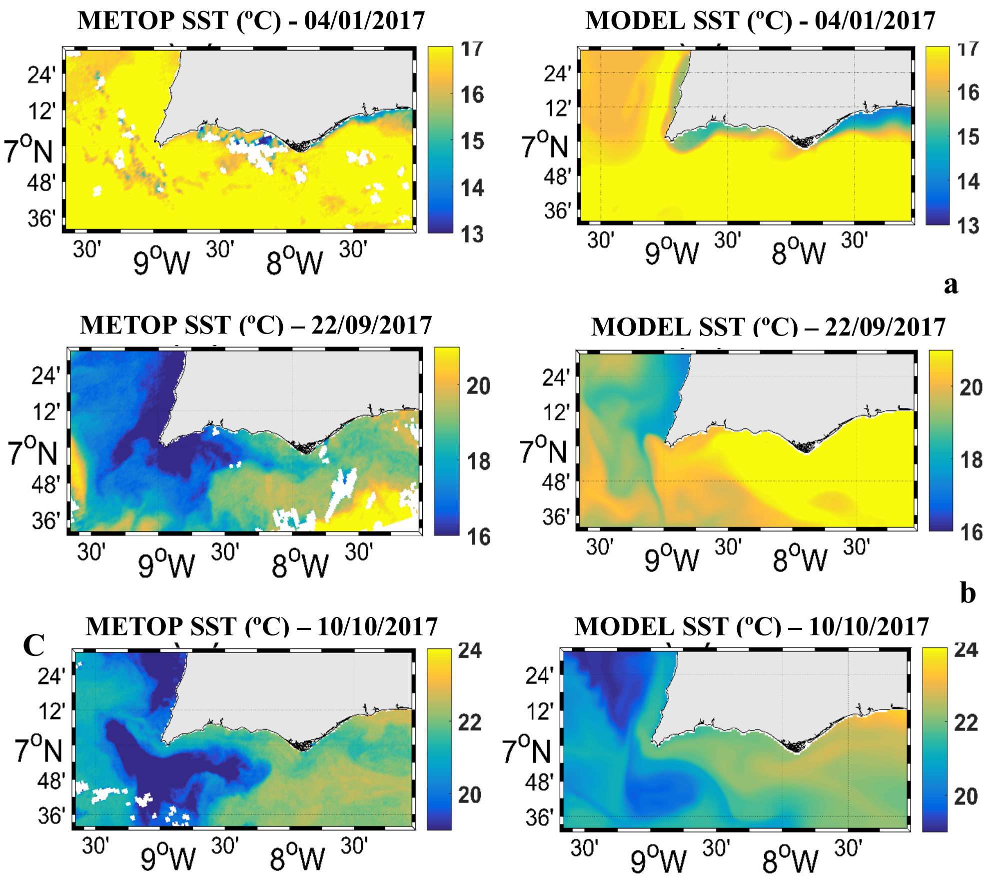

Figure 5.3. Mesoscale events considered in the study derived from METOP SST dataset. For each particular event, model results are displayed in the right while SST image in the left. a) Winter b) Upwelling event c) Counter current event.

Table 5.6. Wind velocity and direction MSS (model skill) for each model period.

Parameter	Period	Skill
Wind Velocity	January (winter)	0.97
	September (Upwelling)	0.89
	October (Counter current)	0.62
Wind Direction	January (winter)	0.62
	September (Upwelling)	0.94
	October (Counter current)	0.46

To explore the role of atmospheric boundary conditions in the quality of the simulated events, the SKIRON historical forcing conditions for each event were compared with the Gulf of Cadiz dataset for specific times. To estimate the quality of the comparations, quantifications of the differences were performed for both wind velocity and direction using MSS. The results obtained were displayed in the Table 5.6.

The results show a better correlation between wind speed while a poor correlation for wind direction. Counter current model showed the lowest correlation with the buoy of Gulf of Cadiz in order of direction and speed of wind, whilst January atmospheric results showed a great agreement between the wind velocity and significant correlation with the wind direction observed.

5.2.2 Hydrodynamic results

In this section the results obtained for the Algarve hydrodynamic are presented. As mentioned earlier, the surface circulation of the Iberian coast is characterized by well-defined seasonality related to wind climatology. The three studied events were considered capable of transporting the floating litter northward (S and E wind event) or southwards (N and NE wind events) along the west Portuguese coast.

5.2.2.1 Upwelling surface circulation

The upwelling conditions are seasonal along the west Portuguese coast, occurring mostly between July to September as a consequence of the intensity and persistence of northerly winds from June to August (Fiúza et al., 1982). Figure 5.4 shows that a persistent southward wind was blowing along the west coast, with velocities over 6 m/s were common in the west coast. In the south coast, at Faro, a more variable wind regime was observed. Typically, the summer wind pattern is affected by a thermal low over the Iberian Peninsula, forcing the northerly wind circulation along the west coast of Portugal to turn eastward at the latitude of the Algarve, as seen in the Relvas and Barton (2002).

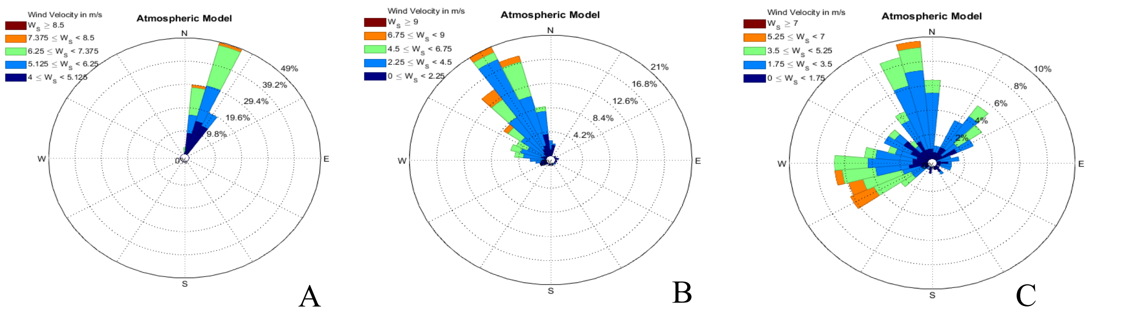

Figure 5.4. Distribution of wind speed and wind direction (where the wind comes from and how intensely) at the (a) west; (b) south west; and (c) south east coast during the upwelling event modelled.

Figure 5.5 and Figure 5.3.b shows the circulation output of the September simulation. The spring-summer flow system in the upper layer of Cape St Vincent (CSV) is extensively addressed (Sanchez and Relvas, 2003, Relvas et al., 2007, Fiúza et al. 1983, Leitão et al., 2005, Sanchez et al., 2006), especially the equatorward cold upwelled water along the Portuguese coast. A southward inshore flow turning cyclonic with higher velocities (> 0.2 m/s) on CSV and eastward along the Algarve coast was observed in figure 5.4. The main features of the circulation found in this simulation (Figure 5.4) are comparable with the spring–summer climatological analysis of the study area by Sanchez and Relvas (2003) and Relvas and Barton (2002).

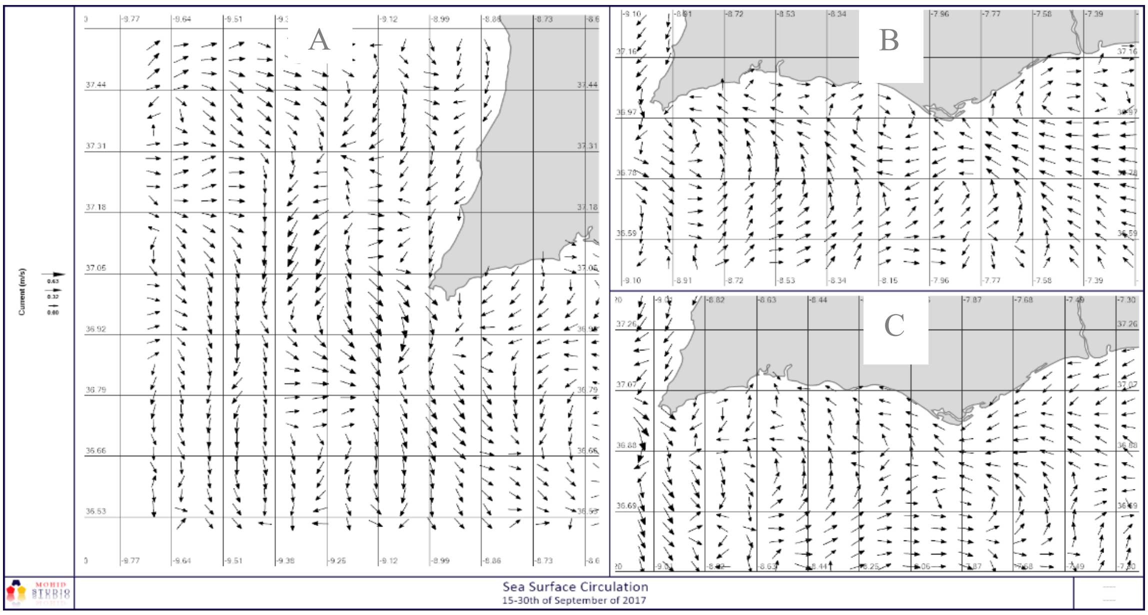

Figure 5.5. Simulation of Algarve sea surface circulation during the last fifteen days of September 2017. a. Equatorward water and jet of water entering in the Gulf of Cadiz after

4 simulated days. b. Eastward circulation along the south coast and formation of anticyclonic eddies in the inner shelf after 2 simulated days. c. Westward flow onshore after the northerly wind weakling.

Figure 5.5.c shows the eastward flow being by the westward flow over the south inner shelf, due to the northerly wind relaxations, however this brief wind change was not strong and long enough to observe the counter current turning northward on the Cape St Vincent. Fiúza (1983), using wind data and SST images corresponding to the summer of 1979, correlated the occurrence of upwelling off the southwest coast of Iberia with westerlies winds and the development of a warm coastal counter current stretching east–west with easterlies winds.

5.2.2.2 Counter current surface circulation

Results of simulation of 7-22th October 2017, display variation of intensity and direction of wind (Figure 5.6). Predominance of easterly winds was observed along the south Iberian coast in the early period of the model event, which favour the warm counter flow along the south coast, however, after 10 simulated days the wind direction changed, blowing from west (Figure 5.6.c). This phenomenon was also observed in the last days of Relvas and Barton (2005) oceanographic cruise.

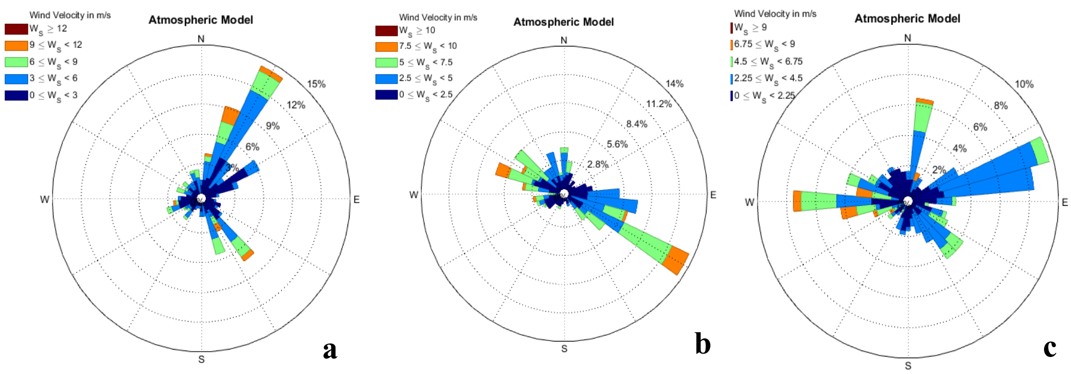

Figure 5.6. Distribution of wind speed and wind direction (where the wind comes from and how intensely) at the (a) west; (b) south west; and (c) south east coast during Counter current event modelled.

Figure 5.7 and Figure 5.3.c show circulation outputs of 7-22th October simulation. The model results include some of the features described in many studies (Relvas and Barton, 2005, Garcia-Lafuent, 2006, Relvas et al., 2007), namely the warm coastal counter flow and upwelled waters offshore the west coast. The counter flow has been observed off Portugal associated with a period of upwelling relaxation. Off SW Iberia, sea surface temperature imagery in Figure 5.3.c show the progressing of the warm counter current over the inner shelf from Guadiana river and turning poleward around the Cape St Vincent, with sea surface temperature values between 22 and 24 ºC.

During this simulation, the coastal warm counter flow corresponds a period of moderate predominant easterly winds (around 4 m/s at south and 3 m/s at west coast). The warm feature turns poleward around the cape crossing the bathymetry and carrying colder water offshore. Coastal counter current velocities in the south coast are around 0.2 m/s and after turning around CSV, the counter current gets more intense, reaching around 0.5 m/s west of CSV (Figure 5.7). This value is comparable with that observed near CSV in a cruise in June 1994, during an episode of the counter current (Relvas and Barton, 2005).

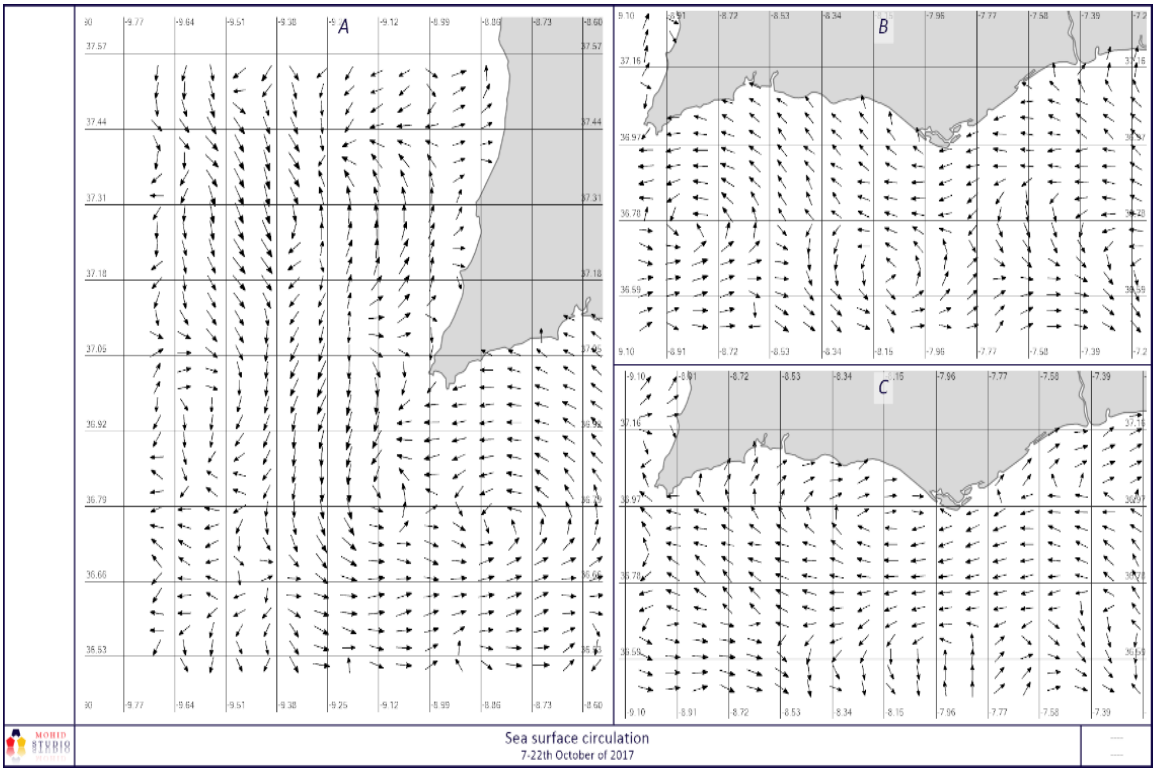

Figure 5.7. Simulation of Algarve sea surface circulation between 7 to 22 of October of 2017. A. Westward flow turning poleward flow on the Cape St Vincent after 2 simulated

days. B. Westward circulation along the south coast and the presence of anticyclonic eddies off the Cape. C. Eastward current after the presence of W winds.

5.2.2.3 Winter surface circulation

During winter model the southern Portuguese shelf is influenced by diverse wind directions. Nonetheless, Isemer and Hasse (1987) suggest that that predominant winds in the west coast of Iberian Peninsula during winter (October-March) are mainly south-westerlies. In some years the presence of episodic atmospheric anticyclonic circulation (the Azores High) could give rise to northerly wind events during winter (Relvas et al., 2007). In Figure 5.8, it is possible to observe strong southerly winds with maximum speed of 7-14 m/s, easterly winds and strong northerly winds in the west coast of Algarve.

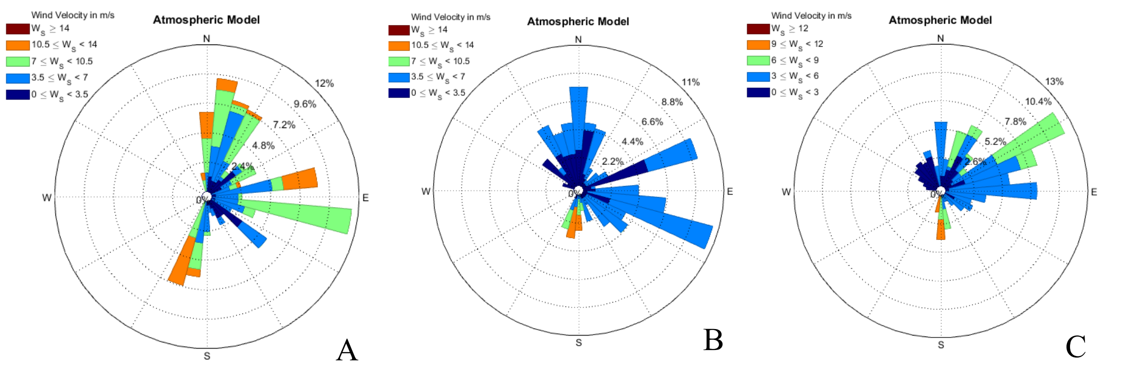

Figure 5.8. Distribution of wind speed and wind direction (where the wind comes from and how intensely) at the (a) west; (b) south west; and (c) south east coast during January simulation.

Wind blowing from south established a counter current regime on the shelf, resulting in northward flow in the winter over the inner shelf of the Portuguese coast with velocities close to 0.2- 0.3 m/s (Figure 5.8). These values were equivalent with Haynes and Barton (1990) and Frouin et al. (1990) observation on the northern part of the western Iberian shelf. It was possible to notice that the winter circulation results present in Figure 5.9, showed a similar zonal pattern to the counter current model, agreeing with Peliz et al. (2004).

At the end of the simulation, wind shift to southwards, the favourable upwelling winds. Despite, northerly wind is typical during summer periods, upwelling events on winter season has been documented along the Algarve coast by Haynes and Barton (1990), Vitorino et al. (2002), Torres and Barton (2006), as in some years the presence of episodic atmospheric anticyclonic circulation (the Azores High) could give rise to northerly wind events during winter.

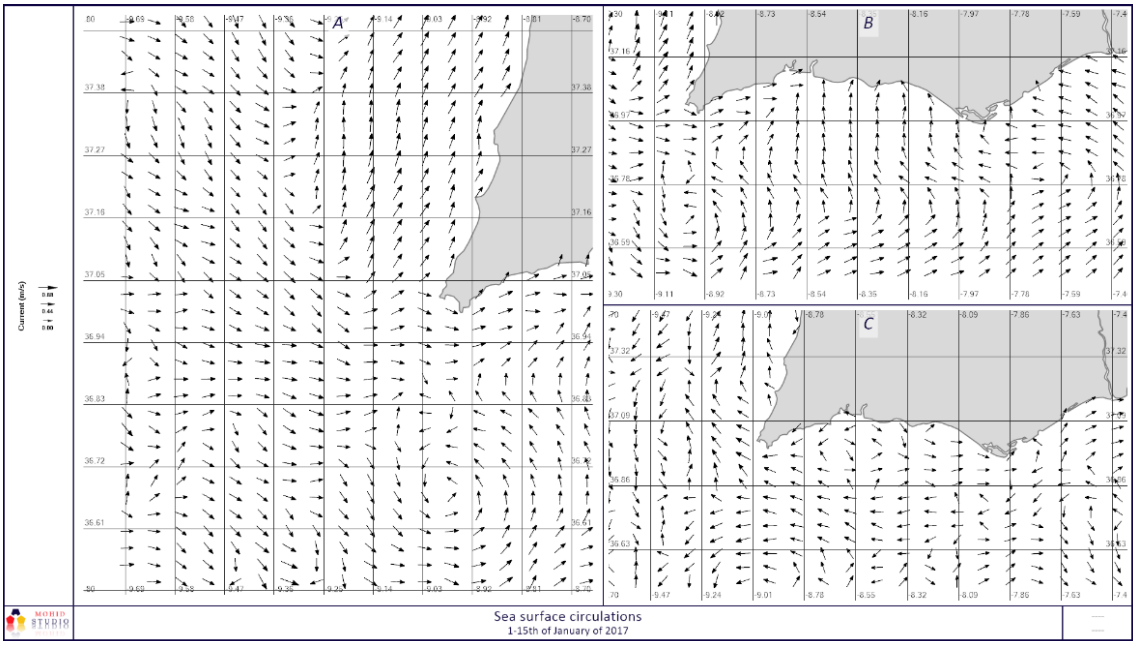

Figure 5.9.Simulation of Algarve sea surface circulation during the first fifteen days of January of 2017. A. Northward flow near the coast and southward current offshore is displayed. B. Westward circulation along the south coast and formation of anticyclonic eddies in the inner shelf after 2 simulated days. C. development of eastward flow onshore due to the northerly winds.

5.2.3 **Marine litter Modelling**

To investigate the potential trajectories, accumulation areas and dominant sources of macro plastic along the Algarve coast the hydrodynamic field obtained was used to force the tracers in three different meteo-ocean conditions. Wind drift coefficients of 3% and no wind drift, as well as beaching parameter were considered has hypothesis.

The three meteo-oceanographic scenarios studied resulted in different spatial patterns of distribution and accumulation for macro floating marine litter. However, similarities can be observed during January and October simulations results.

5.2.3.1 Floating marine litter trajectories

During the winter (Figure 5.10.a) and counter-current simulations (Figure 5.10.b), the westward flow drives the macro plastic along the south coast, this flow eventually turns north on the Cape St Vincent, carrying few macro floating marine litters to the west coast, and collaborating to the northward spreading along the west coast, for instance, particles sourced off the west coast of Algarve were transported further distances, reaching Sines coast. However, in the winter simulation, winds shift to southward carrying many of the macro plastic off the south coast.

In October simulation, easterly winds regime and strong westward counter-current led to a higher geographical dispersion of floating marine litter and more near to the coast, comparing with winter distribution. For example, macro plastic discharged near Guadiana rivers were carried to further distances till reaches Albufeira beach (Figure 5.10.b) while during winter accumulated along Olhão and Tavira coast (Figure 5.10.a).

During the summer model, upwelling jet coupled with the southward winds transport most of the floating litter far from the coast southward (west coast) and eastward (south coast of Algarve). However, a cyclonic circulation in the western region could be observed at the end of the simulation, transporting many floating litters toward the west (Figure 5.10.c).

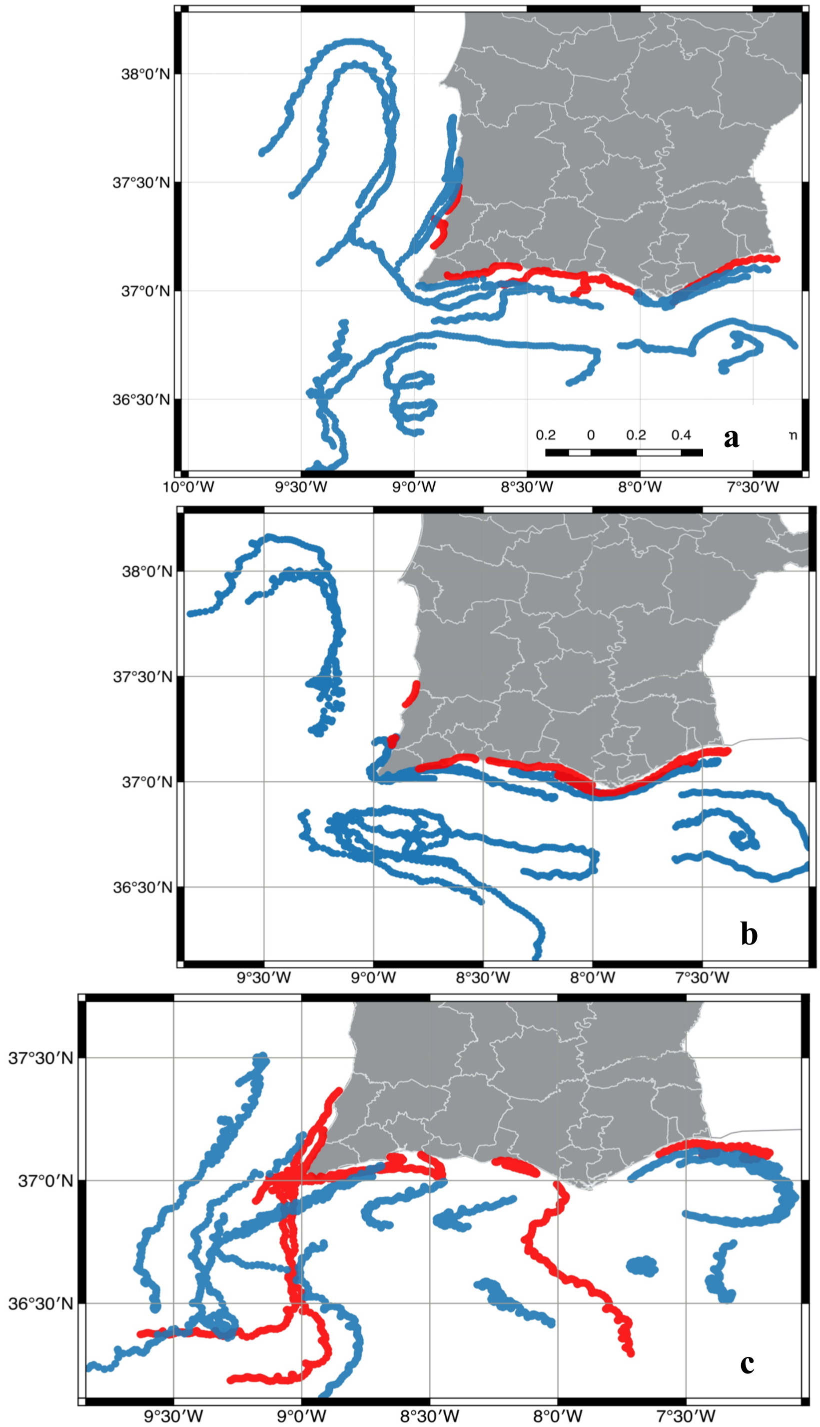

Figure 5.10. Mean trajectories of floating marine litter from land (red dots) and sea-based sources (blue dots) without the wind drift and beaching effect during the (a) winter, (b) counter current and (c) upwelling simulation.

5.2.3.2 Effect of the wind drift coefficient

Turning to results for floating marine litter with wind drift assumed, macro plastics were advected considerably faster due to the increasing pressure of the wind variable, for instance in Figure 5.11, it is possible observed that floating litter with high buoyancy were closer to the shore than the ones with low buoyancy, due to the increasing pressure of the southerly winds.

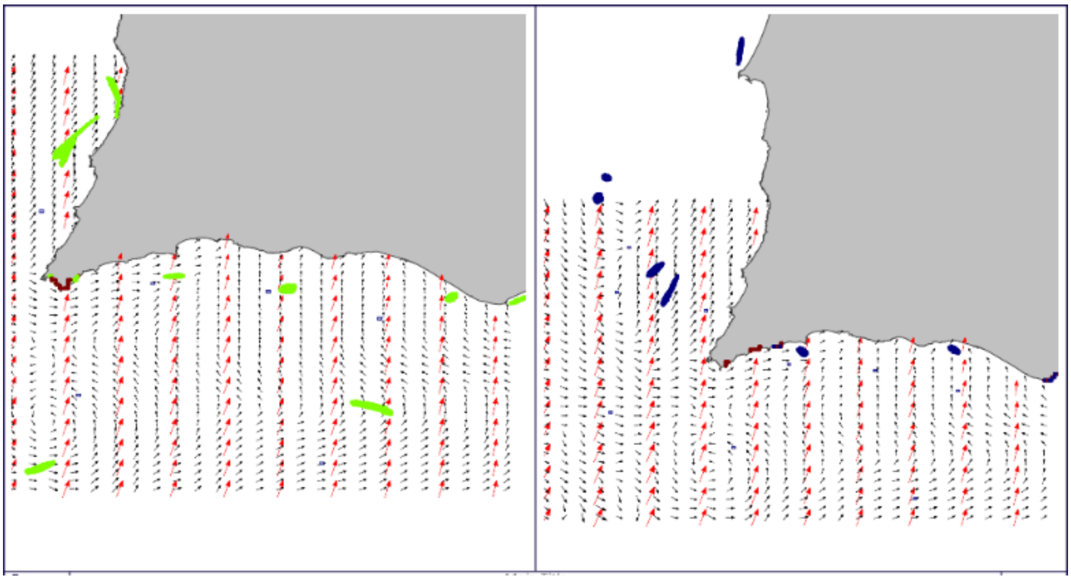

Figure 5.11.Tracers trajectories after three simulated days during the January event with no wind drift (green) and wind drift of 3% (blue particles).

In all the simulations where the wind drift coefficient was assumed, it was observed that increasing the wind drift coefficient from 0% to 3%, increased the particles at the extremes of the geographic spread along the west coast, whilst during winter and counter current simulation, macroplastic along the south coast were transported to beaches near its sources (Figure 5.12). During January event with the wind drift of 3% was assumed, great concentration of floating marine litter with high buoyancy in the shipping corridor were transported towards the coast by increasing pressure of the northward winds and being washing on Albufeira, Faro and Lagos shores (Figure 5.13.a). Figure 5.12.b showed that with increasing pressure of the easterly winds, macroplastic sourced offshore were transported further distances westward. In the upwelling event, floating marine litter were rapidly carried out by the increasing pressure of the southward wind of the shores towards the Gulf of Cadiz, leaving the Level 2 of SOMA model, in less than 5 days (Figure 5.12.c).

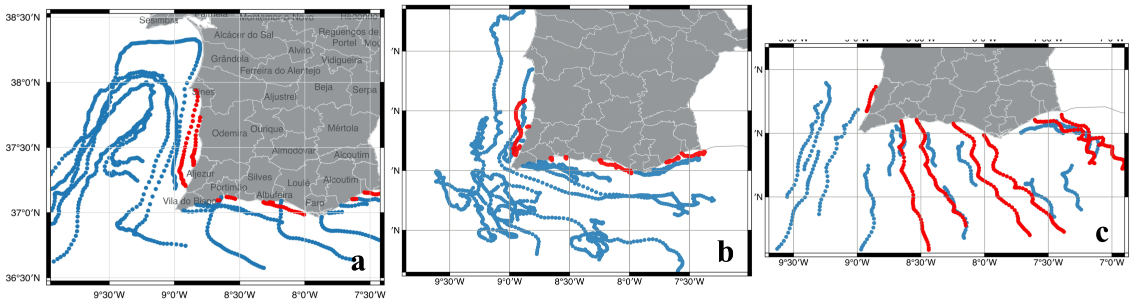

Figure 5.12. Mean floating marine litter from land (red) and sea-based sources (blue dots) trajectories with 3% of wind drift coefficient to (a) winter, (b) counter current and (c) upwelling event.

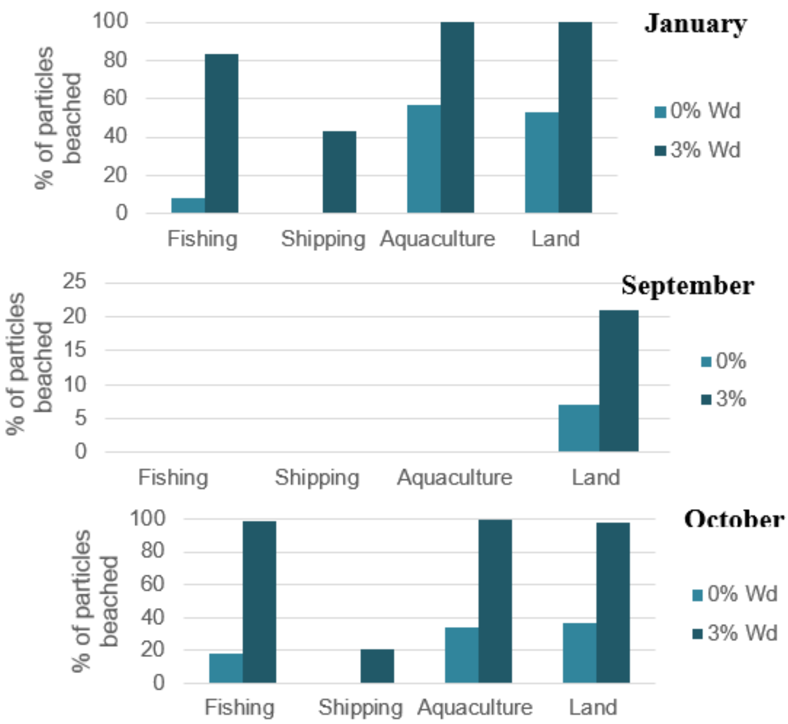

Figure 5.13. Proportion of tracers accumulated by each source category and wind drift coefficient during each study period

Figure 5.13 shows that the concentration of beached macro plastic varied according to the studied oceanographic scenario. Highest concentration of beached floating marine litters were observed during winter simulation, and lowest in the upwelling period. Also, increasing the wind drift coefficient from 0% to 3%, increased number of particles washed ashore, for instance, during the winter simulation, with 3% of wind drift assumed almost 50% of the offshore marine litter and 100% from land-based sources were washed on the Algarve shores.

5.2.3.3 Areas of shoreline affected by floating marine litter

All simulations showed a dominance of floating marine litter beached from terrestrial sources, however differences of litter beached from various sources varied according with the oceanographic scenario and beach location (Figure 5.13 and Figure 5.14). During winter and counter-current events, a great number of floating marine litter from sea ongoing activities (fishing, aquaculture and commercial shipping) were accumulated on Olhão, Faro, Vila do Bispo and Lagos beaches. During the upwelling scenario, only floating marine litter from land-based sources were beached and accumulated along the Aljezur shore (Figure 5.14.b).

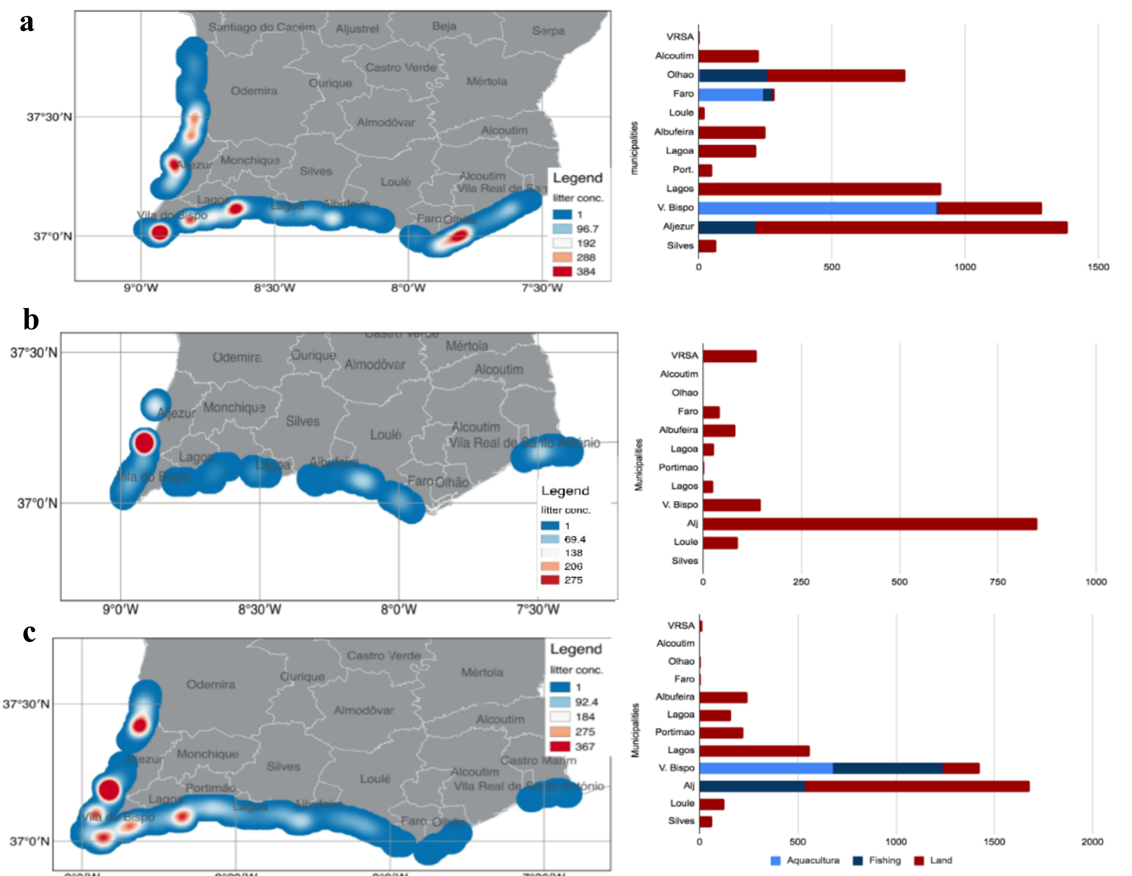

Figure 5.14.Seasonally averaged maps of the concentration of beached floating marine litter without wind drift along the Portuguese coast (left panel), and stacked bar graph

showing the relative tracers beached (%) in the major beaches of the area own terrestrial sources (red); from shipping lanes (grey); fishing activities (dark blue) and aquaculture sites (light blue), during a. winter, b. upwelling and c. counter current event.

The highest concentration of beached litter could be observed on Vila do Bispo, Aljezur and Lagos, however when wind drift coefficient is assumed the concentration is almost three times higher (Figure 5.13 and Figure 5.15). However, no significant differences on the areas of beached litter accumulation were observed between simulations without and with wind drift (Figure5.14 and Figure 5.15). Beaching litter results showed higher zones of accumulation along beaches located at the western region of Algarve.

Figure 5.15 showed floating marine litter with wind drift assumed from land-based sources seems to increase on Albufeira, Vila Real St Antonio, Portimão and Lagos beaches. Also, marine litter from merchandize vessels accumulated on Faro, Albufeira and Lagos during the winter event and on Vila do Bispo and Aljezur during counter current simulation.

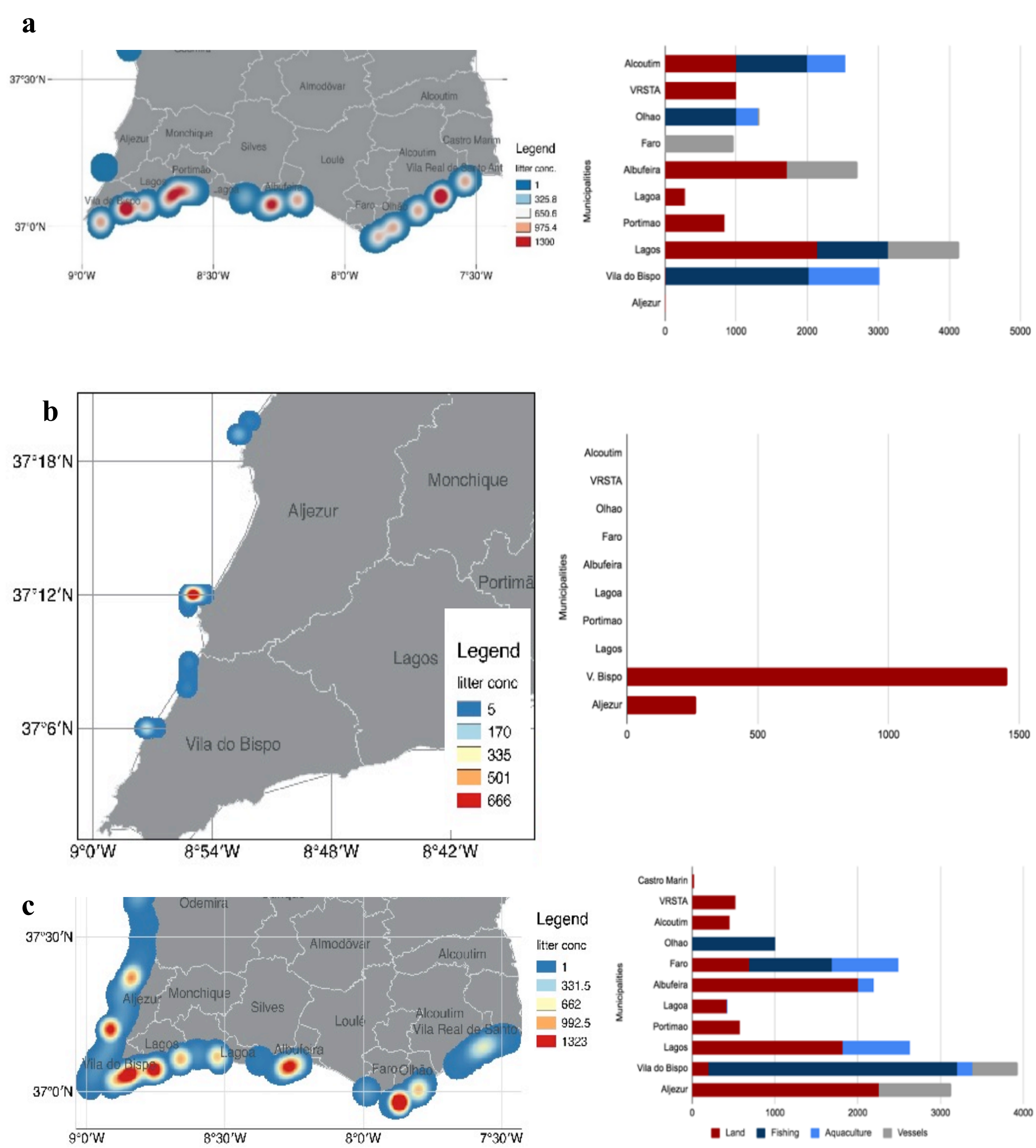

Figure 5.15. Seasonally averaged maps of the concentration of beached floating marine litter with 3% of wind drift along the Portuguese coast (left panel), and stacked bar graph showing the relative tracers beached (%) in the major beaches of the area own terrestrial sources (red); from shipping lanes (grey); fishing activities (dark blue) and aquaculture sites (light blue), during a. winter, b. upwelling and c. counter current event.

6 Discussion

In the present study, an online Lagrangian transport model based on the MOHID Water modelling was used to simulate the evolution of the 2-D surface transport pattern in the coastal area of the South Portuguese coast. The ability of IBI and SKIRON-forced Lagrangian model to reproduce the transports of floating marine macro litter located in the upper ocean layer was assessed using ocean sea surface satellite image and oceanographic buoy data. Differences in the magnitude and direction of each meteo-ocean condition studied were observed. However, the model reproduced significantly well the main oceanographic events observed, such as upwelling and counter current. Also, SKIRON results showed a better correlation for wind velocity than direction. Janeiro, J. (2014) once suggested that the wind direction difference was considered significant to influence the simulation.

The analysis of the floating marine litter simulations performed by SOMA in this study offers a first comprehensive description of the upper ocean layer transport patterns in the area and their potential impact on the distribution of Floating marine macro litter from land and sea-based sources. This study opens interesting opportunities, like the use of the SOMA model for long-term hindcast simulations of macro plastic dispersion, or its use for predicting macro plastic pathways in an operational and management context (prediction) for the Algarve coast.

During the upwelling event, the surface circulation advected mostly of tracers off the coast, preventing a great amount of marine macro-plastic from being accumulated on the shores. Upwelling-induced reduction in the concentration of floating litter in the NW Iberian coast has been documented by Gago et al., 2015 and Pereiro et al., 2019. In South Portuguese coast, the northerly and westerly winds can induce a southward and eastward flow along the coast and the consequent transport of floating marine litter towards the Gulf of Cadiz.

During counter current and winter, the prevailing southerly and easterly winds induce an eastward flow along the Southern Algarve and northward along the Portuguese coast. Under such conditions, an alongshore transport of floating marine litter to the south-western region of Algarve takes place from distant sources, such as fishing grounds and Guadiana rivers. Many macro plastics will be washed ashore after having travelled a long distance along the Southern Algarve coast. Simultaneously, counter-current favourable conditions increase coastal exposure to marine litter in the Natural Park of Sudoeste Algarvio and Costa Vincentina.

Therefore, variations in the concentration of floating marine litter in the Algarve water are a direct consequence of the wind-induced seasonality of the surface circulation in the South Iberian coast. However, short-time-scale variability of the wind, such as the coastal upwelling observed during the winter in response to brief episodes of northerly winds, may have a great influence on the drift of floating marine litter on daily to weekly timescales.

Wind can have a direct impact on surface trapped floating marine litter if they are not totally immerged, by adding an additional load on the emerged part. However, it is quite not straightforward to parametrise such a wind effect on floating marine litter. Indeed, height, density, proportion of immerged/emerged part vary with the litter type, composition and age. To better quantify the wind effect on macro plastic, additional observations are necessary, like e.g. massive drifting buoys experiments using devices of different density, volume, floating point. Most research that includes this parameter uses between 1% and 6% (Yoon et al., 2010; Ebbesmeyer et al., 2011; Hardesty and Wilcox, 2011; Carson et al., 2013; Critchell et al., 2015; Maximenko et al., 2015), and Neumann et al. (2010) and Yoon et (2010) concluded that 10% should be upper limit. Ideally is the wind coefficient should vary in time to reflect the change in floatability over time (for example, from degradation or biofouling).

Higher concentration of floating marine litter would be observed in the south-western region of Algarve, during the winter and counter current periods, therefore beach and floating litter clean ups and monitoring would be required in this area of the coast, as well as offshore of the Cape St Vincent. The beaching characteristics also strongly depend on the buoyancy ratio. In the case with the lowest buoyancy ratio, litter mainly beaches along the south west coast with maximum along the Cape St Vincent vicinity due to due to the strong eastward wind in winter and counter current event. However, including beaching factor it is necessary a very refined resolution of the nearshore area or a proper parametrization that can depend on various variables like e.g. beach type and slope, wind, wave or other hydrodynamic parameters (Declerk et al., 2018). Also, beached particles may be collected by cleaning services, or stay on the beach and be washed off again into the ocean.

The Algarve coast economy is linked with the sea, with tourism and fishing being the major source of economy. Therefore, floating marine litter can impact negatively on the local and regional economy. In Europe the stranded litter is considered by beach users to be one of the five most important aspects in relation to beach quality. Model showed the natural parks are highly vulnerable to this form of pollution. Impacts caused by macro plastic on the biota, especially on aquatic birds, along the Algarve has already been study. Nicastro et al. (2018) observed that the percentage of aquatic birds contaminated (21.5%) by plastic ingestion was almost the double than observed in others Portuguese coast by Bastos et al. (2019).

Currently, there are several local and regional efforts aiming at action for reducing and preventing marine litter and for mitigating its impacts along the Algarve. These include many clean up and monitoring programs organized by the municipalities and carried out by citizens volunteers. In Tavira, marine litter monitoring is carried out by students from diverse public schools, that seeks to bring awareness of the environmental, economic and social consequences of the increasing presence of waste in the marine environment. Fishing for litter (Pesca por um mar sem lixo in Portugal) is a good example of collaboration between the municipality of the island of Culatra and fisherman. This initiative does not only involve the direct removal of litter from the sea, but it also raises awareness of the problem in the fishing industry. Another great idea is the development of software applications, one such example is the lixomarinho mobile app. These technologies can help influence a change of behaviour, allowing us to be more mindful and to introduce a more responsible attitude towards protecting the environment.

Modelling with finer scales, predicting areas of accumulation at a beach scale, along with more regionally or locally focused assessments, can be used as part of a powerful tool to inform the public or authorities and encourage better management of litter. During the period of this study, any floating marine litter monitoring on the Algarve coast was carried out and few beach clean-up activities, such as Straw Patrol acquired beach litter data, however without a standardized method. Therefore, the only standardized data that could be used compare qualitatively the model results in this project was the DGRM.

Model results and beach clean-up data indicated that land-based sources, such as tourism, were the main sources of floating marine litter for the Algarve beaches. Beaching results showed that the model was adequate to predict higher concentration of plastic litter items along the Batata beach during the counter current event, as well as higher concentrations of plastic litter discarded from fishing activities, such as nets and ropes during January. Higher concentration of plastic in Batata beach were collect during the January and October surveys, which could indicate transport of litter by westward current, which was previously predicted.

The model did not predict a higher concentration of tracers on Faro Island during the upwelling event, which may suggest that this litter might be originated from the increase of beach goers during summer season in this area. Galgani et al (2013), observed that marine litter densities on beaches can be increased by up to 40 % in summer because of high tourist numbers. In some tourist areas, more than 75 % of the annual waste is generated in summer, when tourists produce on average 10–15 % more waste than the inhabitants; although not all of this waste enters the marine environment (Galgani et al. 2011).

7 Conclusion

A Lagrangian macro-plastic model was used to demonstrate the potential of such tools in support of response activities for plastic pollution. Results prove the adequacy of the method in supporting coastal pollution responses. Even though error parameters were observed in this project, the mesoscale features present in the region, observed and described by several authors, were identified by observing the remote sensing SST data with SOMA, being able to reproduce these features to a good extent.

The field data from APA and DGRM showed an increasing trend of litter items on the monitoring beaches during the 5 years. Cigarette stubs, plastic polyester pieces < 50 cm, and nets and ropes accounted for more than half of the total number of litters counts on both beaches analysed, it is a testament to the significance of this worldwide spread contaminant.

The accumulation zone and rate varied with the different meteo-ocean conditions simulated in this project, however some similarities between winter and counter-current event occured. This suggests that the surface flow temporal variability might play a role in shaping litter accumulation pattern; however, the structure of the model does not allow to assess such effects in the long term. The model results indicate that during winter periods with southerly winds great amount of plastics discarded onshore and offshore were carried towards the coast and spread along the coast, in the upwelling event macro plastic is cleaned off the coast, whilst warm counter current traps the plastic near the shore of the south-western and west coast.

Land-based sources, such as tourism, are probably the most important contributor to marine litter in the Algarve coast, especially litter released from areas of intense human activity can reach different locations along the studied coast and offshore areas. Some neighbouring areas, like the western Portuguese coast and southern Spanish coast, do appear to have the potential to contribute debris into the Algarve area, however this analysis was out of the project scope. Algarve also appears to be an exporter of litter for some neighbouring coastal regions and the Gulf of Cadiz.

Distinctive accumulations regions are found mainly on the south-western region, known as 'barlavento' with higher accumulation at Aljezur, Vila do Bispo, Lagos and Albufeira, while temporary plastics concentrations were exhibited offshore Cape St. Vincent. Moreover, no targeted litter observation campaigns have been yet carried out in the areas predicted with the higher concentration of litter, that anyway found some agreement with the very few available data. As far as seasonality in plastics accumulation onto coastlines is concerned, the highest seasonal is found in the winter, while upwelling period has the lowest beached floating marine macro litter.

Our results clearly indicate the need for a systematic floating and beach litter observation activity with standardizing method, that may shed light on the likely accumulation, main pathways and sources in the southern and southwestern Portuguese coast, the outcomes of this study lead us to strongly recommend the organization of regular, synoptic campaigns enabling the assessment of marine litter distribution over the whole Algarve coast, particularly on the barlavento region and on the natural parks preventing great environment and economic impacts.

8 Future Work

This work represents the beginning of the implementation of successful prediction tool to help coastal authorities dealing with marine litter pollution in the Algarve coast. However, many future work needs be implemented to improve the reliability of modelling the fate of floating litter in the study area. In this study once debris were landed, the tracers had the same probability to return to the ocean or stay beached, in order to mimic the reality, floating litter drifting close to the coast are likely to be washed ashore on beaches, and easily return to the ocean by tides and waves (Isobe et al., 2014). Waves are not currently included in the SOMA system. To do so would require coupling with a wave model, which is outside the scope of this thesis due to lack of reliable wave models in the study area. These site-specific processes, not included in the model, could influence accumulation of plastic debris on the surveyed beaches, and lead to a lack of agreement between model predictions and observed data.

While monitoring data on floating litter along the coastal area does not exist, model of litter dispersion and accumulation on beaches will remain qualitatively and the identification and qualification of the predominant sources will remain problematic (Critchell et al., 2016). The development of a Marine Litter Monitoring program focused on beaches and sea surface of Algarve coast need to be consider using a standardized method. Data on marine systems is notoriously difficult to collect, however, in the case of marine debris there is a significant opportunity to utilize data from volunteer beach clean-up, visual observations of floating litter using opportunistic vessels.

Another important development to gain insight of litter pollution in the area is understanding the distribution and fate of micro litter along the Algarve coast using oceanographic modelling, as according to Frias et al. (2016) microplastic were found in nearly of the 56% coastal sediment samples along the Southern Portuguese shelf, and the vast majority were microfibers and plastic fragments.

9 References

Addamo, A. M., Laroche, P., & Hanke, G. (2017). Top Marine Beach Litter Items in Europe, EUR 29249 EN.

Alvarez, I., DeCastro, M., Prego, R. e Gómez-Gesteira, M. (2003). Caracterização hidrográfica de um evento de inverno na Ria de Pontevedra (NW Espanha). *Estuarine, Coastal and Shelf Science*, *56* (3-4), 869-876.

Alvarez, I., DeCastro, M., Prego, R., & Gómez-Gesteira, M. (2003). Hydrographic characterization of a winter-upwelling event in the Ria of Pontevedra (NW Spain). Estuarine, Coastal and Shelf Science, 56(3-4), 869-876.

Ambar, I. (1994). Some features of the Portugal Current System: a poleward slope undercurrent, an upwelling related southward flow and an autumn-winter poleward coastal surface current. In *2nd International Conference on Air-Sea Interaction and on Meteorology & Oceanography of the Coastal Zone, preprints, September 22-27, 1994*. American Meteorology Society.Andrady, A. L. (2015). Persistence of plastic litter in the oceans. In Marine anthropogenic litter (pp. 57-72). Springer, Cham.

Aníbal, J., Gomes, A., Mendes, I., & Moura, D. (2019). Ria Formosa: challenges of a coastal lagoon in a changing environment.

Ballent, A., Pando, S., Purser, A., Juliano, M. F., & Thomsen, L. (2013). Modelled transport of benthic marine microplastic pollution in the Nazaré Canyon. *Biogeosciences*, *10*(12), 7957-7970.

Barnes, D. K. (2002). Biodiversity: invasions by marine life on plastic debris. *Nature*, *416*(6883), 808.

Barnes, D. K., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *364*(1526), 1985-1998.

Basto, M. N., Nicastro, K. R., Tavares, A. I., McQuaid, C. D., Casero, M., Azevedo, F., & Zardi, G. I. (2019). Plastic ingestion in aquatic birds in Portugal. *Marine pollution bulletin*, *138*, 19-24.

Bergmann, M., & Klages, M. (2012). Increase of litter at the Arctic deep-sea observatory HAUSGARTEN. *Marine pollution bulletin*, *64*(12), 2734-2741.

Blumberg, A. F., & Kantha, L. H. (1985). Open boundary condition for circulation models. *Journal of Hydraulic Engineering*, *111*(2), 237-255.

Brandon, J., Goldstein, M., & Ohman, M. D. (2016). Long-term aging and degradation of microplastic particles: comparing in situ oceanic and experimental weathering patterns. *Marine pollution bulletin*, *110*(1), 299-308.

Braunschweig, F., Leitão, P. C., Fernandes, L., Pina, P., & Neves, R. J. J. (2004). The object-oriented design of the integrated water modelling system MOHID. In *Developments in Water Science* (Vol. 55, pp. 1079-1090). Elsevier.

Candeias, J. M. P. B. (2015). Marine litter occurrence patterns along the Portuguese coast in the past decade (Doctoral dissertation).

Cardoso, P. G., Dolbeth, M., Sousa, R., Relvas, P., Santos, R., Silva, A., & Quintino, V. (2019). The Portuguese Coast. In *World Seas: an Environmental Evaluation* (pp. 189-208). Academic Press.

Carlson, D. F., Suaria, G., Aliani, S., Fredj, E., Fortibuoni, T., Griffa, A., ... & Melli, V. (2017). Combining litter observations with a regional ocean model to identify sources and sinks of floating debris in a semi-enclosed basin: the Adriatic Sea. *Frontiers in Marine Science*, *4*, 78.

Carson, H. S., Lamson, M. R., Nakashima, D., Toloumu, D., Hafner, J., Maximenko, N., & McDermid, K. J. (2013). Tracking the sources and sinks of local marine debris in Hawai ‘i. *Marine environmental research*, *84*, 76-83.

CBD (2012) Secretariat of the Convention on Biological Diversity and the Scientific and Technical Advisory Panel GEF. Impacts of Marine Debris on Biodiversity: Current Status and Potential Solutions, Montreal, Technical Series No. 67, 61 pages.

Chambault, P., Vandeperre, F., Machete, M., Lagoa, J. C., & Pham, C. K. (2018). Distribution and composition of floating macro litter off the Azores archipelago and Madeira (NE Atlantic) using opportunistic surveys. *Marine environmental research*, *141*, 225-232.

Chen, C. L. (2015). Regulation and management of marine litter. In *Marine anthropogenic litter* (pp. 395-428). Springer, Cham.

Cheshire, A., & Adler, E. (2009). UNEP/IOC guidelines on survey and monitoring of marine litter.

Circular Economy Strategy - Environment - European Commission. (n.d.). Retrieved 24 June 2019, from https://ec.europa.eu/environment/circular-economy/index_en.htm

Classificação e Caracterização – ICNF. (n.d). Retrieved 15 January 2019, from http://www2.icnf.pt/portal/ap/pnat/pnsacv/class-carac.

Constantino, E., Martins, I., Sierra, J. M. S., & Bessa, F. (2019). Abundance and composition of floating marine macro litter on the eastern sector of the Mediterranean Sea. *Marine pollution bulletin*, *138*, 260-265.

Cordeiro, N. G. F., Dubert, J., Nolasco, R., & Barton, E. D. (2018). Transient response of the Northwestern Iberian upwelling regime. *PloS one*, *13*(5), e0197627.

Costa, M., Silva, R., & Vitorino, J. (2001). Contribuição para o estudo do clima de agitação marítima na costa portuguesa. *2ª Jornadas Portuguesas de Engenharia Costeira e Portuária*, 20.

Criado-Aldeanueva, F., García-Lafuente, J., Vargas, JM, Del Río, J., Vázquez, A., Reul, A., Sánchez, A. (2006). Distribuição e circulação de massas de água no Golfo de Cádiz a partir de observações in situ. Parte II da pesquisa do mar profundo: Estudos tópicos na oceanografia, 53 (11-13), 1144-1160.

Critchell, K. and Lambrechts, J. (2016). Modelling accumulation of marine plastics in the coastal zone; what are the dominant physical processes? *Estuarine, Coastal and Shelf Science*, *171*, 111-122.

Critchell, K., Grech, A., Schlaefer, J., Andutta, F. P., Lambrechts, J., Wolanski, E., & Hamann, M. (2015). Modelling the fate of marine debris along a complex shoreline: Lessons from the Great Barrier Reef. *Estuarine, Coastal and Shelf Science*, *167*, 414-426.

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. *Marine pollution bulletin*, *44*(9), 842-852.

Directive, S. F. (2013). Guidance on monitoring of marine litter in European Seas.

Engedahl, H. (1995). Use of the flow relaxation scheme in a three-dimensional baroclinic ocean model with realistic topography. *Tellus A*, *47*(3), 365-382.

Eriksen, M., Lebreton, L. C., Carson, H. S., Thiel, M., Moore, C. J., Borerro, J. C., ... & Reisser, J. (2014). Plastic pollution in the world's oceans: more than 5 trillion plastic pieces weighing over 250,000 tons afloat at sea. *PloS one*, *9*(12), e111913.

Europe, P. (2015). Plastics- The facts 2014/2015. *The unknown life of plastics*.

European Commission (2018, May 28). Single-use plastics: New EU rules to reduce marine litter. Recovered in August 24, 2018, from http://europa.eu/rapid/press-release_IP-18-3927_en.htm

Fernandes, R. (2018). *Gestão do Risco da Poluição Costeira dos Derrames de Petróleo Sustentados pela Modelação Numérica Operacional*

Ferreira, A. (2006). Impacte do Plano do Porto de Portimão na Hidrodinâmica do Estuário do Arade.

Fiúza, A. D. G., Macedo, M. D., & Guerreiro, M. R. (1982). Climatological space and time variation of the Portuguese coastal upwelling. *Oceanologica acta*, *5*(1), 31-40.

Fiúza, A. F. (1983). Upwelling patterns off Portugal. In *Coastal Upwelling its sediment record* (pp. 85-98). Springer, Boston, MA.

Gago, J., Lahuerta, F., & Antelo, P. (2014). Characteristics (abundance, type and origin) of beach litter on the Galician coast (NW Spain) from 2001 to 2010. *Scientia Marina*, *78*(1), 125-134.

Galgani, F., Hanke, G., & Maes, T. (2015). Global distribution, composition and abundance of marine litter. In *Marine anthropogenic litter* (pp. 29-56). Springer, Cham.

Galgani, F., Hanke, G., Werner, S. D. V. L., & De Vrees, L. (2013). Marine litter within the European marine strategy framework directive. *ICES Journal of Marine Science*, *70*(6), 1055-1064.

Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine pollution bulletin*, *92*(1-2), 170-179.

Gallo, F., Fossi, C., Weber, R., Santillo, D., Sousa, J., Ingram, I., ... & Romano, D. (2018). Marine litter plastics and microplastics and their toxic chemicals components: the need for urgent preventive measures. *Environmental Sciences Europe*, *30*(1), 13.

Garel, E., Laiz, I., Drago, T., & Relvas, P. (2016). Caracterização das contra-correntes costeiras na plataforma interna do Golfo de Cádiz. *Journal of Marine Systems*, 155, 19-34.

Garel, E., Pinto, L., Santos, A., & Ferreira, Ó. (2009). Tidal and river discharge forcing upon water and sediment circulation at a rock-bound estuary (Guadiana estuary, Portugal). Estuarine, Coastal and Shelf Science, 84(2), 269-281.

Gitlitz, J., & Franklin, P. (2006). The 10cent incentive to recycle. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:The+10-cent+incentive+to+recycle#0

Goddijn-Murphy, L., Peters, S., Van Sebille, E., James, N. A., & Gibb, S. (2018). Concept for a hyperspectral remote sensing algorithm for floating marine macro plastics. *Marine pollution bulletin*, *126*, 255-262.

Gregory, M. R., & Andrady, A. L. (2003). Plastics in the marine environment. *Plastics and the Environment*, *379*, 389-90.

Guimarães, M. H., Sousa, C., Dentinho, T., & Boski, T. (2014). Economic base model for the Guadiana estuary, Portugal an application for Integrated Coastal Zone Management. *Marine Policy*, *43*, 63-70..

Hall, K. (2000). *Impacts of marine debris and oil: economic and social costs to coastal communities*. Kommunenes Internasjonale Miljøorganisasjon.

Hardesty, B. D., Harari, J., Isobe, A., Lebreton, L., Maximenko, N., Potemra, J., ... & Wilcox, C. (2017). Using numerical model simulations to improve the understanding of micro-plastic distribution and pathways in the marine environment. *Frontiers in Marine Science*, *4*, 30.

Hardesty, BD and C Wilcox (2011) Understanding the types, sources and at-sea distribution of marine debris in Australian waters.

Haynes, R., & Barton, E. D. (1990). A poleward flow along the Atlantic coast of the Iberian Peninsula. *Journal of Geophysical Research: Oceans*, *95*(C7), 11425-11441.

Hernández-Molina, J., Llave, E., Somoza, L., Fernández-Puga, M. C., Maestro, A., León, R., ... & Fernández-Salas, L. M. (2003). Looking for clues to paleoceanographic imprints: a diagnosis of the Gulf of Cadiz contourite depositional systems. *Geology*, *31*(1), 19-22.

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2115-2126.

Huthnance, J. M., Van Aken, H. M., White, M., Barton, E. D., Le Cann, B., Coelho, E. F., ... & Vitorino, J. (2002). Ocean margin exchange—water flux estimates. *Journal of Marine Systems*, *32*(1-3), 107-137.

IH, 2009. Tabela de Marés, 2010, Volume I, Portugal, Ministério da Defesa Nacional, Marinha.

INE, I. P. (2018). Estatísticas da Pesca 2017.

INE,I. P. (2018).

Isemer, H. J., & Hasse, L. (1987). The Bunker Atlas of the North Atlantic Ocean. Vol. 2: Air–sea interac-tions. *Springer Verlag*, *252*, 819-836.

Isobe, A., Kako, S. I., Chang, P. H., & Matsuno, T. (2009). Two-way particle-tracking model for specifying sources of drifting objects: application to the East China Sea Shelf. *Journal of Atmospheric and oceanic technology*, *26*(8), 1672-1682.

Isobe, A., Kubo, K., Tamura, Y., Nakashima, E., & Fujii, N. (2014). Selective transport of microplastics and mesoplastics by drifting in coastal waters. *Marine pollution bulletin*, *89*(1-2), 324-330.

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., ... & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-771.

Janeiro, J. M. L. (2014). Development of an operational tool for oil spill forecast: application to oil exposed regions (Doctoral dissertation, Universidade do Algarve (Portugal)).

Janeiro, J., Fernandes, E., Martins, F., & Fernandes, R. (2008). Wind and freshwater influence over hydrocarbon dispersal on Patos Lagoon, Brazil. *Marine pollution bulletin*, *56*(4), 650-665.

Janeiro, J., Martins, F., & Relvas, P. (2012). Towards the development of an operational tool for oil spills management in the Algarve coast. *Journal of coastal conservation*, *16*(4), 449-460.

Janeiro, J., Neves, A., Martins, F., & Relvas, P. (2017). Integrating technologies for oil spill response in the SW Iberian coast. *Journal of Marine Systems*, *173*, 31-42.

Kako, S. I., Isobe, A., Kataoka, T., & Hinata, H. (2014). A decadal prediction of the quantity of plastic marine debris littered on beaches of the East Asian marginal seas. *Marine pollution bulletin*, *81*(1), 174-184.

Katsanevakis, S. (2008). Marine debris, a growing problem: Sources, distribution, composition, and impacts. *Marine Pollution: New Research. Nova Science Publishers, New York*, 53-100.

Kershaw, P., Lebreton, L. (2016). Chapter 7.1: Floating plastic debris. In IOC-UNESCO and UNEP (2016). Large Marine Ecosystems: Status and Trends. United Nations Environment Programme, Nairobi, pp 153-163.

Kubota, M. (1994). A mechanism for the accumulation of floating marine debris north of Hawaii. *Journal of Physical Oceanography*, *24*(5), 1059-1064.

Lachmann, FA (2016). *Detritos plásticos marinhos - fluxos, medidas de mitigação e avaliação ambiental* (dissertação de doutorado, dissertação de mestrado, Departamento de Ciências Biológicas e Ambientais da Universidade de Gotemburgo, Gotemburgo, Suécia).

Laist, D. W. (1987). Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Marine pollution bulletin*, *18*(6), 319-326.

Lebreton, L. M., Greer, S. D., & Borrero, J. C. (2012). Numerical modelling of floating debris in the world's oceans. *Marine Pollution Bulletin*, *64*(3), 653-661.

Leggett, C. G., Scherer, N., Haab, T. C., Bailey, R., Landrum, J. P., & Domanski, A. (2018). Assessing the economic benefits of reductions in marine debris at Southern California beaches: a random utility travel cost model. *Marine Resource Economics*, *33*(2), 133-153.

Leitão, P., Coelho, H., Santos, A., & Neves, R. (2005). Modelling the main features of the Algarve coastal circulation during July 2004: A downscaling approach. *Journal of Atmospheric and Ocean Science*, *10*(4), 421–462. https://doi.org/10.1080/17417530601127704

Leitão, P., Galvão, P., Aires, E., Almeida, L., & Viegas, C. (2012). Fecal contamination modeling in coastal waters using a web service approach. *Environmental Engineering & Management Journal (EEMJ)*, *11*(5).

Liubartseva, S., Coppini, G., Lecci, R., & Creti, S. (2016). Regional approach to modeling the transport of floating plastic debris in the Adriatic Sea. *Marine pollution bulletin*, *103*(1-2), 115-127.

Maes, C., & Blanke, B. (2015). Tracking the origins of plastic debris across the Coral Sea: A case study from the Ouvéa Island, New Caledonia. *Marine pollution bulletin*, *97*(1-2), 160-168.

Manha, C. (2009). Milhões em limpeza. Retrieved from http://www.cmjornal.pt/portugal/detalhe/milhoes-em-limpeza?v=cb.

Marine litter- GES (n.d) retrieved 10/04/2019, from http://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm

Martins, F. A. B. D. C. (1999). Modelação matemática tridimensional de escoamentos costeiros e estuarinos usando uma abordagem de coordenada vertical genérica. (Doctoral dissertation, Technical University of Lisbon (Portugal)).

Martins, F., Leitão, P., Silva, A., & Neves, R. (2001). Modelagem 3D no estuário do Sado usando uma nova abordagem genérica de discretização vertical. *Oceanologica Acta*, *24*, 51-62.

Martins, J., & Sobral, P. (2011). Plastic marine debris on the Portuguese coastline: a matter of size? *Marine pollution bulletin*, *62*(12), 2649-2653.

Martinsen, E. A., & Engedahl, H. (1987). Implementation and testing of a lateral boundary scheme as an open boundary condition in a barotropic ocean model. *Coastal engineering*, *11*(5-6), 603-627.

Maximenko, N., Hafner, J., & Niiler, P. (2012). Pathways of marine debris derived from trajectories of Lagrangian drifters. *Marine pollution bulletin*, *65*(1-3), 51-62.

Moore, C. J., Moore, S. L., Leecaster, M. K., & Weisberg, S. B. (2001). A comparison of plastic and plankton in the North Pacific central gyre. *Marine pollution bulletin*, *42*(12), 1297-1300.

Moriarty, M., Pedreschi, D., Stokes, D., Dransfeld, L., & Reid, D. G. (2016). Spatial and temporal analysis of litter in the Celtic Sea from Groundfish Survey data: Lessons for monitoring. *Marine pollution bulletin*, *103*(1-2), 195-205.

Mouat, J., Lozano, R. L., & Bateson, H. (2010). Economic Impacts of Marine Litter. KIMO International.

Moura, D., Mendes, A., & Aníbal, J. (2017). Guadiana River Estuary. Investigating the past, present and future.

National Oceanic and Atmospheric Administration Marine Debris Program, 2016. Report on Modeling Oceanic Transport of Floating Marine Debris. Silver Spring, MD. 21 pp

Nelms, S. E., Coombes, C., Foster, L. C., Galloway, T. S., Godley, B. J., Lindeque, P. K., & Witt, M. J. (2017). Marine anthropogenic litter on British beaches: a 10-year nationwide assessment using citizen science data. *Science of the Total Environment*, *579*, 1399-1409.

Nelms, S. E., Coombes, C., Foster, L. C., Galloway, T. S., Godley, B. J., Lindeque, P. K., & Witt, M. J. (2017). Marine anthropogenic litter on British beaches: a 10-year nationwide assessment using citizen science data. *Science of the Total Environment*, *579*, 1399-1409.

Neumann, D., Callies, U., & Matthies, M. (2014). Marine litter ensemble transport simulations in the southern North Sea. *Marine pollution bulletin*, *86*(1-2), 219-228.

Neves, R. (2007). Numerical models as decision support tools in coastal areas. In *Assessment of the Fate and Effects of Toxic Agents on Water Resources* (pp. 171-195). Springer, Dordrecht.

Nicastro, K. R., Savio, R. L., McQuaid, C. D., Madeira, P., Valbusa, U., Azevedo, F., ... & Zardi, G. I. (2018). Plastic ingestion in aquatic-associated bird species in southern Portugal. *Marine pollution bulletin*, *126*, 413-418.

Nixon, Z., & Barnea, N. (2010). Development of the Gulf of Mexico marine debris model.

Nogueira, J, Campuzano, F. J., Neves, R. (2013). Sardine larvae vertical migration and horizontal dispersion patterns related to light intensity in the dynamic western Portuguese coast: a numerical study. *Ocean modelling for coastal management*. Case studies with MOHID, Mateus, M. & Neves, R. (eds.), IST Press. pp 161-173.

O'Donncha, F., Hartnett, M., Nash, S., Ren, L., & Ragnoli, E. (2015). Characterizing observed circulation patterns within a bay using HF radar and numerical model simulations. *Journal of Marine Systems*, *142*, 96-110.

Oigman-Pszczol, SS, & Creed, JC (2007). Quantificação e classificação de serapilheira em praias ao longo de Armação dos Búzios, Rio de Janeiro, Brasil. *Jornal da pesquisa litoral*, 421-428.

Oliveira, F., Monteiro, P., Bentes, L., Henriques, NS, Aguilar, R. e Gonçalves, JM (2015). Lixo marinho no alto do desfiladeiro submarino de São Vicente (SW Portugal): Abundância, distribuição, composição e interações da fauna. *Boletim de poluição marinha* ,

OSPAR Commission. (2010). Guideline for monitoring marine litter on the beaches in the OSPAR maritime area. *OSPAR Commission: London, UK.*

Peliz, A. J., & Fiúza, A. F. G. (1999). Temporal and spatial variability of CZCS-derived phytoplankton pigment concentrations off the western Iberian Peninsula. *International Journal of Remote Sensing*, *20*(7), 1363-1403.

Peliz, Á., Dubert, J., Santos, A. M. P., Oliveira, P. B., & Le Cann, B. (2005). Winter upper ocean circulation in the Western Iberian Basin - Fronts, Eddies and Poleward Flows: An overview. *Deep-Sea Research Part I: Oceanographic Research Papers*, *52*(4), 621–646. https://doi.org/10.1016/j.dsr.2004.11.005.

Pichel, W. G., Churnside, J. H., Veenstra, T. S., Foley, D. G., Friedman, K. S., Brainard, R. E., ... & Clemente-Colon, P. (2007). Marine debris collects within the North Pacific subtropical convergence zone. *Marine Pollution Bulletin*, *54*(8), 1207-1211.

Pinto, L., Mateus, M., & Silva, A. (2016). Modelar as vias de transporte de proliferação de algas nocivas na costa ibérica. Algas prejudiciais ,

Plan, N. P. A. (2017). Understanding of Floating Marine Litter Distribution in the NOWPAP Region-MERRAC Technical Report No. 35.

Poeta, G., Conti, L., Malavasi, M., Battisti, C., & Acosta, A. T. R. (2016). Beach litter occurrence in sandy littorals: The potential role of urban areas, rivers and beach users in central Italy. *Estuarine, Coastal and Shelf Science*, *181*, 231-237.

Politikos, D. V., Ioakeimidis, C., Papatheodorou, G., & Tsiaras, K. (2017). Modeling the fate and distribution of floating litter particles in the Aegean Sea (E. Mediterranean). *Frontiers in Marine Science*, *4*, 191.

Regional Action Plan | OSPAR Commission. (n.d.). Retrieved 24 June 2019, from https://www.ospar.org/work-areas/eiha/marine-litter/regional-action-plan.htm

Reis, V. (2016). G1 - SP reduz em 70% uso de sacolinhas um ano após lei, diz associação - notícias em São Paulo. Retrieved 23 December 2018, from http://g1.globo.com/sao-paulo/noticia/2016/04/sp-reduz-em-70-uso-de-sacolinhas-um-ano-apos-lei-diz-associacao.html.

Relvas, P., & Barton, E. D. (2002). Mesoscale patterns in the Cape Sao Vicente (Iberian peninsula) upwelling region. *Journal of Geophysical Research: Oceans*, *107*(C10), 28-1.

Relvas, P., & Barton, E. D. (2005). A separated jet and coastal counterflow during upwelling relaxation off Cape São Vicente (Iberian Peninsula). *Continental Shelf Research*, *25*(1), 29-49.

Relvas, P., Barton, E. D., Dubert, J., Oliveira, P. B., Peliz, A., Da Silva, J. C. B., & Santos, A. M. P. (2007). Physical oceanography of the western Iberia ecosystem: latest views and challenges. *Progress in Oceanography*, *74*(2-3), 149-173.

Rosevelt, C., Los Huertos, M., Garza, C., & Nevins, H. M. (2013). Marine debris in central California: Quantifying type and abundance of beach litter in Monterey Bay, CA. *Marine pollution bulletin*, *71*(1-2), 299-306.

Ryan, P. G. (2014). Litter survey detects the South Atlantic 'garbage patch'. Marine Pollution Bulletin, 79(1-2), 220-224.

Ryan, P. G., Moore, C. J., van Franeker, J. A., & Moloney, C. L. (2009). Monitoring the abundance of plastic debris in the marine environment. *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, *364*(1526), 1999-2012.

Sá, S., Bastos-Santos, J., Araújo, H., Ferreira, M., Duro, V., Alves, F., ... & Vingada, J. (2016). Spatial distribution of floating marine debris in offshore continental Portuguese waters. *Marine pollution bulletin*, 104(1-2), 269-278.

Sampath, D. M., Boski, T., Loureiro, C., & Sousa, C. (2015). Modelling of estuarine response to sea-level rise during the Holocene: Application to the Guadiana Estuary–SW Iberia. *Geomorphology,* 232, 47-64.

Santos, A. J., Nogueira, J., & Martins, H. (2005). Survival of sardine larvae off the Atlantic Portuguese coast: a preliminary numerical study. *ICES Journal of Marine Science*, *62*(4), 634-644.

Saraiva, S., Pina, P., Martins, F., Santos, M., Braunschweig, F., & Neves, R. (2007). Modelling the influence of nutrient loads on Portuguese estuaries. *Hydrobiologia*, *587*(1), 5-18.

Schulz, M., van Loon, W., Frota, DM, Baggelaar, P. e van der Meulen, E. (2017). Método padrão OSPAR e software para análise estatística de dados de camas de praia. *Boletim de poluição marinha*, *122* (1-2), 166-175.

Selukar, N. B., Lande, C. V., & Ingole, C. G. (2014). Waste thermocol to adhesive for better environment. Int. J. Innov. Res. Adv. Eng, 1, 98-101.

Stokes, G. G. (1880). On the theory of oscillatory waves. *Transactions of the Cambridge Philosophical Society*.

Suaria, G., & Aliani, S. (2014). Floating debris in the Mediterranean Sea. *Marine pollution bulletin*, 86(1-2), 494-504.

Summer, C. (2012). What should be done about plastic bags? - BBC News. Retrieved 23 December 2018, from https://www.bbc.com/news/magazine-17027990.

Teuten, E. L., Rowland, S. J., Galloway, T. S., & Thompson, R. C. (2007). Potential for plastics to transport hydrophobic contaminants. *Environmental science & technology*, 41(22), 7759-7764.

Thiel, M., Hinojosa, I., Vásquez, N., & Macaya, E. (2003). Floating marine debris in coastal waters of the SE-Pacific (Chile). *Marine Pollution Bulletin*, *46*(2), 224-231.

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W., ... & Russell, A. E. (2004). Lost at sea: where is all the plastic? *Science*, 304(5672), 838-838.

Topouzelis, K., Papakonstantinou, A., & Garaba, S. P. (2019). Detection of floating plastics from satellite and unmanned aerial systems (Plastic Litter Project 2018). *International Journal of Applied Earth Observation and Geoinformation*, *79*, 175-183.

Torres, R., & Barton, E. D. (2007). Onset of the Iberian upwelling along the Galician coast. Continental Shelf Research, 27(13), 1759-1778.

UNEP (2009). Marine Litter: A Global Challenge. Nairobi: UNEP. 232 pp.

Van den Bremer, T. S., & Breivik, Ø. (2017). Stokes drift. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2111), 20170104.

Van Sebille, E., England, M. H., & Froyland, G. (2012). Origin, dynamics and evolution of ocean garbage patches from observed surface drifters. *Environmental Research Letters*, *7*(4), 044040.

Veiga, J. M., Fleet, D., Kinsey, S., Nilsson, P., Vlachogianni, T., Werner, S., ... & Sobral, P. (2016). identifying sources of marine litter. MSFD GES TG Marine Litter Thematic Report. In *JRC Technical Report* (p. 43).

Vitorino, J., Oliveira, A., Jouanneau, J. M., & Drago, T. (2002). Winter dynamics on the northern Portuguese shelf. Part 1: physical processes. *Progress in Oceanography*, 52(2-4), 129-153.

Werner, S., Budziak, A., van Franeker, J., Galgani, F., Hanke, G., Maes, T., ... & Thompson, R. (2016). *Harm caused by Marine Litter: MSFD GES TG Marine Litter-thematic report*. Publications Office of the European Union.

Yoon, J. H., Kawano, S., & Igawa, S. (2010). Modeling of marine litter drift and beaching in the Japan Sea. *Marine Pollution Bulletin*, *60*(3), 448-463.

Zambianchi, E., Iermano, I., Suaria, G., & Aliani, S. (2014). Marine litter in the Mediterranean Sea: an oceanographic perspective. In *CIESM Workshop Monograph 46: Marine litter in the Mediterranean and Black Seas* (pp. 31-41). Monaco: CIESM Publisher.