NET4mPLASTIC PROJECT

WP4 - Activity 4.2 Lab’s analysis on plastic and microplastic wastes on coastal and marine environments

D 4.2.1

Better knowledge on the transport processes during specific events and in particular on the distribution and quantification of plastic and microplastic occurrence in the pilot sites

August, 2022 – Final Version

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INDEX

1 Introduction

Results of transport are linked to WP 4.3, therefore all the discussions related to a better knowledge on MP transport is provided with numerical simulations and readers should refer to deliverables form WP 4.3 to better understand the dynamics of extreme events.

As a consequence, in this deliverable, results will focus on a bibliographic review - Italy will focus on river as a major source and harbour while HR will focus on wastewater discharge and industrial sources. The data collected within this Project will also be discussed. The results of this Project are discussed in more details in the Deliverables D.4.2.2 Collection of plastic and microplastic items and identification of the plastic and origin by characterization of the different plastic polymers and D.4.2.4 MP contamination and correlation between the presence of PCBs/Dioxins/PAHs and MPs in bivalves.

2 Possible sources of MP and transport processes

2.1 Possible sources of MP in the Adriatic Sea - in general (bibliographic review)

“Marine debris” is defined as anthropogenic, manufactured, or processed solid material discarded, disposed of, or abandoned in the environment, including all materials discarded into the sea, on the shore, or brought indirectly to the sea by rivers, sewage, storm water, waves, or winds. At a global level, plastic litter constitutes 83–87% of all marine litter. Land-based sources are estimated to be responsible for approximately 80% of marine litter. (Gomiero et al., 2018; Wagner et al., 2014) Plastic marine debris affects the marine environment globally.

The production of plastic items has grown dramatically from 0.5 million tons in the 40s to 550 million tons in 2018 (https://www. plasticseurope.org/en/resources/ publications/498-plasticseuropeannual-review-2017-2018). Plastic material has many good advantages. It can be shaped into many specific forms, and it has good chemical and physical properties like elasticity, hardness, lightness, transparency and durability but its good properties take on a negative aspect when we talk about environmental impact. Its low ability of degradation is resulting in accumulation of small plastic fragments in coastal and marine sediments, pelagic and benthic biota from coastal to open ocean areas at each latitude from the poles to the equator. Plastic fragments can be divided into two groups: primary and secondary plastics, according to the way they are created. Primary plastics are resulting from the direct input of freshly manmade plastic pieces to the environment. Major sources of primary plastics are: (A) polymers intentionally produced and used as such - personal care consumer products, industrial or commercial products and other specialty chemicals with plastic microbeads; (B) inherent collateral products of other industrial activities or (C) plastic sourced as accidental or deliberate spillage i.e., pellets loss from plastic factories and transport (Wright, 2013). In contrast, secondary plastics come from larger plastic items that undergo degradation and subsequent fragmentation that leads to the formation of smaller plastic pieces as they start to break down by photooxidative degradation followed by thermal and/or chemical degradation (Wright, 2013). Antioxidants and stabilizers used as additives inhibit the degradation of the polymer. Thus, degradation rates depend strongly on used additives and plasticizers (Gewert et al., 2015). In most cases these are well-known toxic chemicals capable of leaching out from the plastic during the degradation process. They easily enter into the aquatic environment representing a further point of concern for eco-toxicologists (Gomiero et al., 2018). Plastic debris is a mixture of molecules and chemicals, its size ranging from some meters to a few micrometers and probably nanometers. It is derived from a broad variety of origins, such as fishing gear, nets, bottles, bags, food packaging, taps, straws, cigarette butts and cosmetic microbeads and the associated fragmentation of all of these (Gomiero et al., 2018).

Changes in physical and chemical characteristics (loss of structural integrity, fragmentation and agregation, Andrady, 2017) as well as interactions with biota (Law and Thompson, 2014) largely affect microplastic transportation pathways (E.C. Atwood et al., 2018). Most synthetic polymers are buoyant in water. They float in seawater and are transported and potentially washed ashore. The polymers that are denser than seawater tend to settle near the point where they entered the environment; however, they can still be transported by underlying currents (Gomiero et al., 2018). Microbial films rapidly develop on submerged plastics and change their physicochemical properties such as surface hydrophobicity and buoyancy (Andrady, 2011; Engler, 2012). Plastic debris can be found everywhere in the environment, especially in the marine environment. It can be found anywhere from sediments to sea surface. The observed loadings floating in the ocean represents only a limited portion of the total input. It has been previously reported that most plastic litter ends up on the seabed with a remaining fraction distributed on beaches or floating on the seawater surface. This could lead to a significant underestimation of the actual amounts of plastics in aquatic environments if the litter from seabed is not taken into consideration (Raynaud, 2014).

With some of the most significant amounts of solid waste generated annually per person (208–760 kg/year), the Mediterranean Sea is one of the world's areas most affected by litter (Eriksen et al., 2014). The estimated amount is 62 million of macrolitter items floating on the surface of the whole basin (Suaria et al., 2016). Mean densities of floating microplastics in the Mediterranean Sea is more than 100,000 items/km2 (Fossi, 2012). This shows us how big is the threat for this basin and especially for the Adriatic Sea because of its unic oceanographic conditions as well as the high degree of anthropogenic pressure related to tourism, artisanal and industrial activities coexisting in a narrow area (Gomiero et al., 2018).

The Adriatic Sea is an elongated basin, located in the central Mediterranean, between the Italian peninsula and the Balkans, with its major axis in the NW-SE direction. The northern area is very shallow, gently sloping, with an average depth of about 35 m, while the central part is on average 140 m deep, with the two Pomo depressions reaching 260 m. The northern and central parts of the basin are affected by a great number of rivers along the Italian coast, of which the Po River is the most relevant. River discharge and wind stress are the main drivers of the water circulation (Gomiero et al., 2018). The general circulation of the Adriatic Sea is well described in the paper written by A. Artegiani et al., 1997. According to the authors the main currents affecting the Adriatic circulation are West Adriatic Current (WAC), flowing SE along the western coast, and East Adriatic Current (EAC), flowing NE along the eastern coast. The Bora wind (from NE) causes free sea surface to rise close to the coast enhancing the WAC and the Sirocco wind (from SE), which is the major wind affecting the Adriatic Sea, leads flood events in the shallow lagoons along the basin coast (Artegiani et al., 1997). The materials flowing from rivers and other water sources stay within the coastal area because of a vertical thermohaline front parallel to the coast which extends through the water mass and divides coastal waters from the open sea (Artegiani et al., 1997). During the summer stratification of water column appears separating the warmer surface waters with lower salinity from deeper, colder and more saline ones (Artegiani et al., 1997).

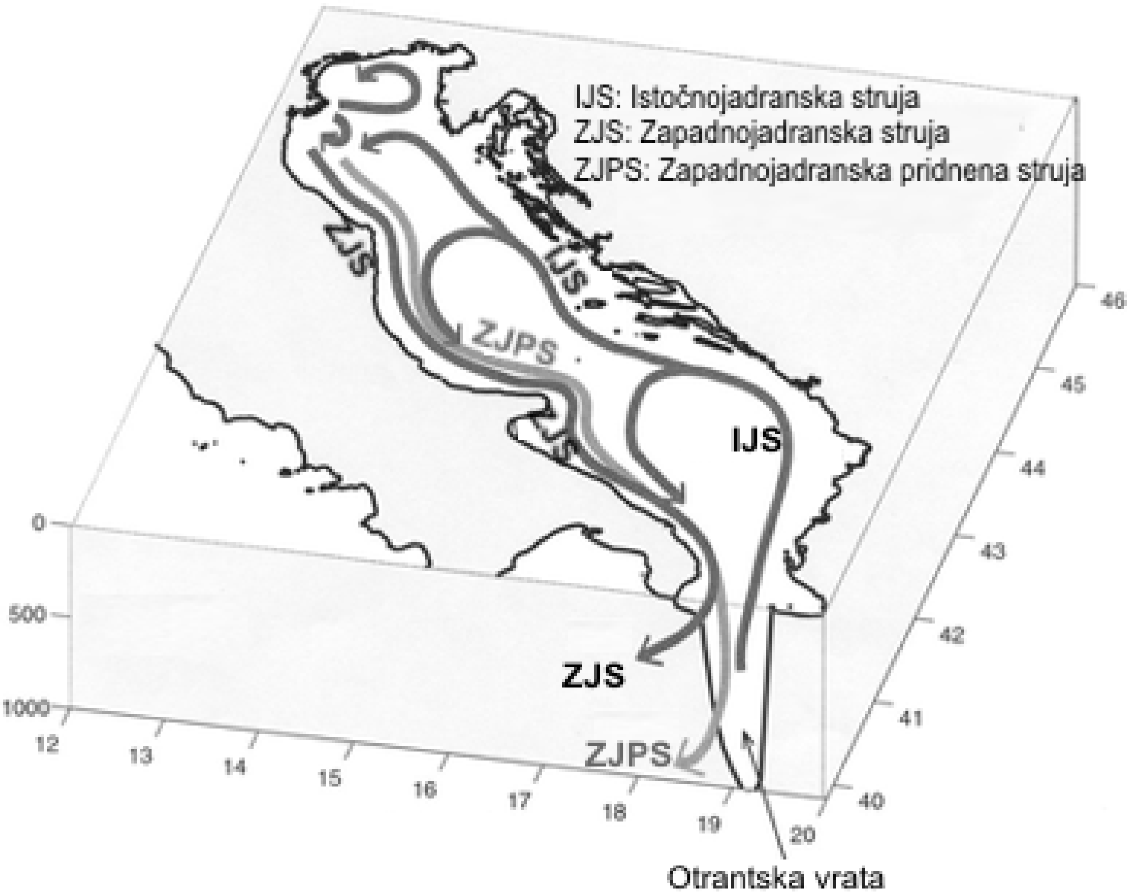

Figure 1: General scheme of sea currents in the Adriatic (from https://www.azu.hr/en/environment-protection/currents-in-the-adriatic-sea/).

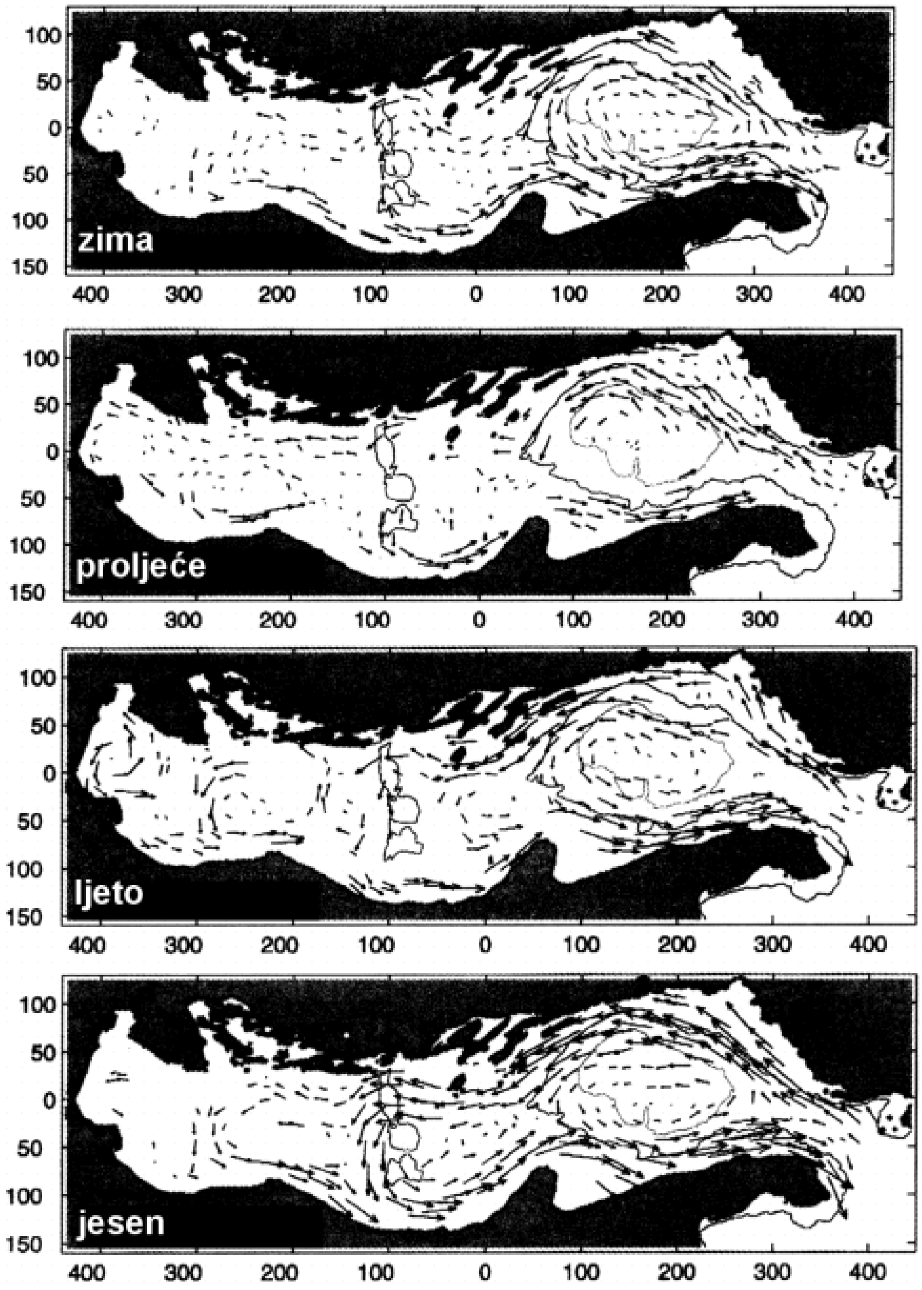

Figure 2: Seasonal distribution of surface sea currents in the Adriatic

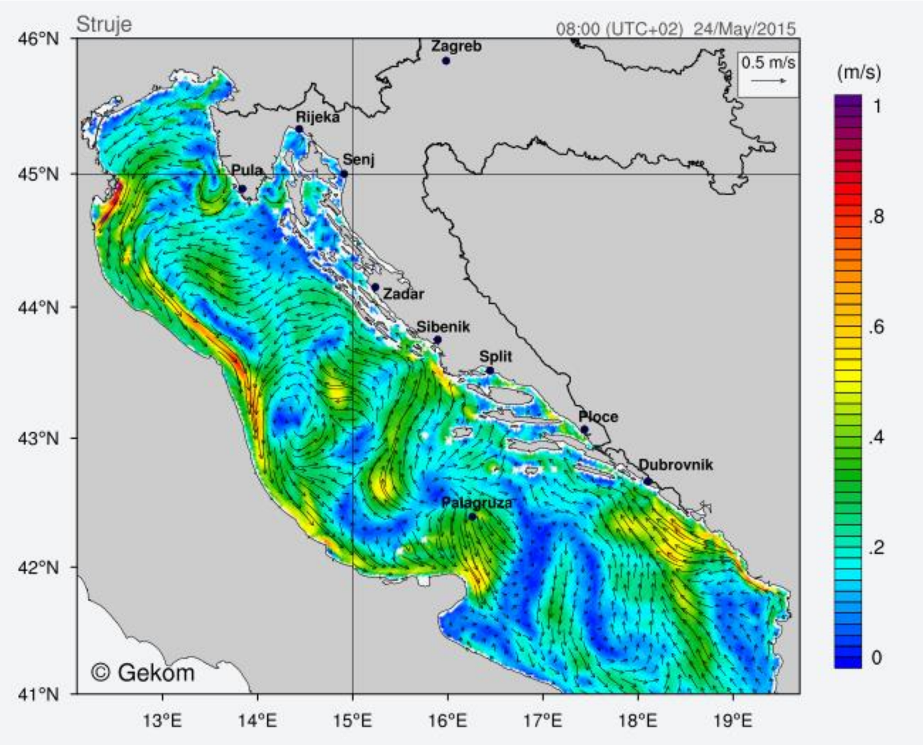

Figure 3: Sea surface currents on 24th May 2015.

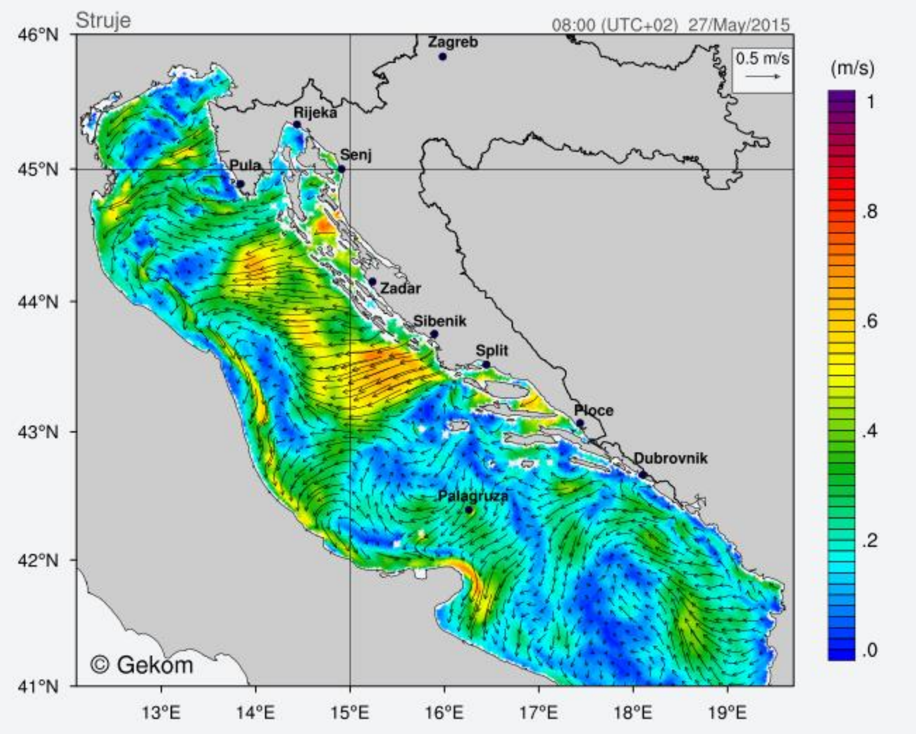

Figure 4: Sea surface currents on 27th May 2015.

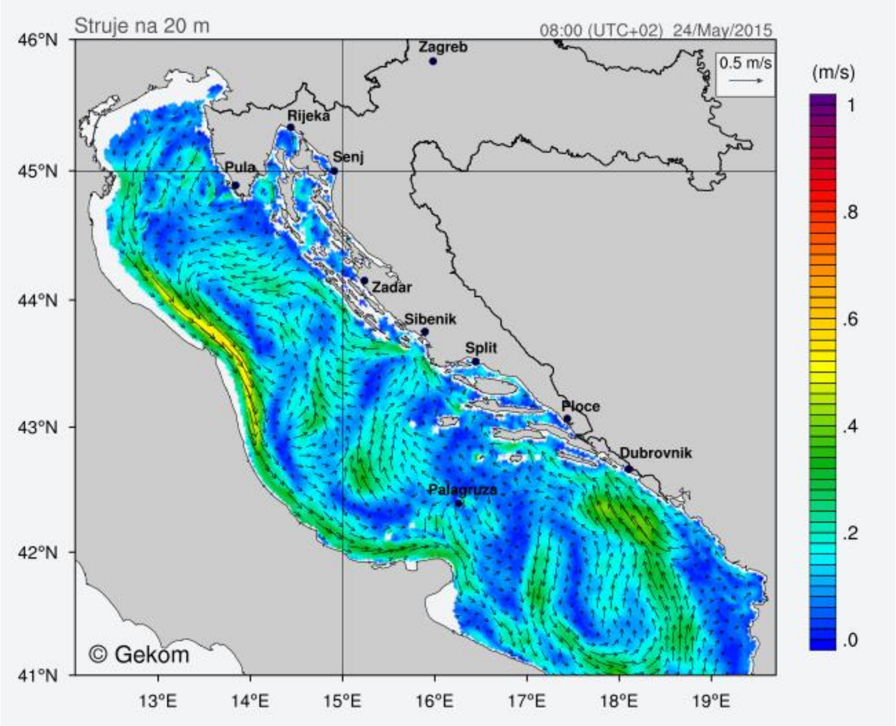

Figure 5: Sea surface currents on 24th May 2015, water depth 20 m.

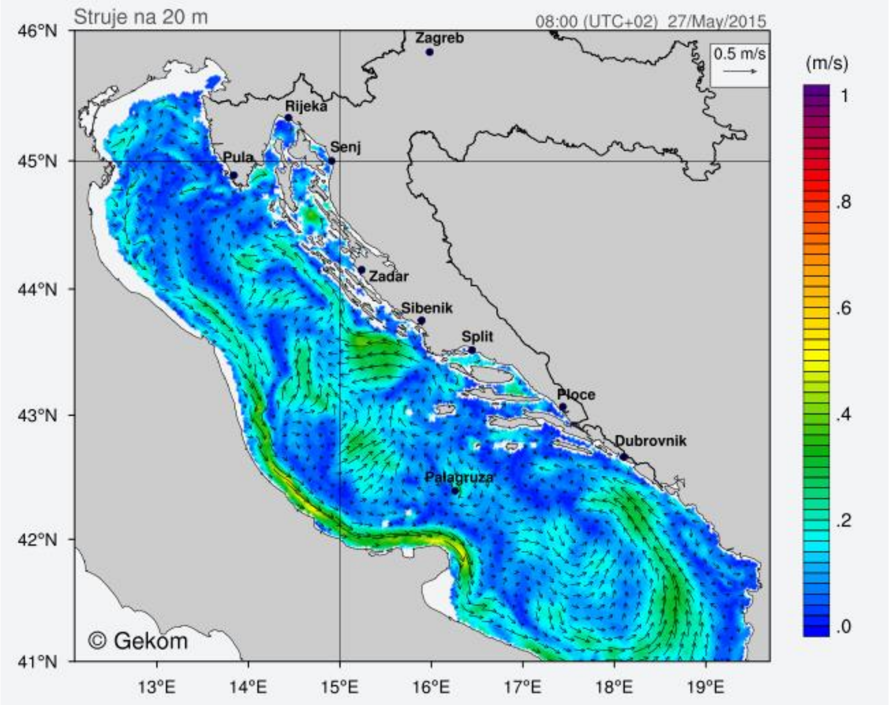

Figure 6: Sea surface currents on 24th May 2015, water depth 20 m.

2.1.1 Sources of plastic pollution in the Adriatic Sea: marine and land-based

Sources of plastic pollution in the Adriatic Sea can be divided into two main groups: marine sources of plastic pollution and land-based sources (Gomiero et al., 2019).

Marine sources of plastic pollution in the Adriatic Sea are:

a) Plastic products in aquaculture and fishery
b) Offshore oil and gas production activities
c) Decommissioning of ships and oil rigs
d) Transportation and logistics

Land-based sources of microplastics are:

a) Waste management
b) Sewage treatment plants
c) Agricultural production
d) City dust and road wear

2.1.2 Main pathways of the entry of marine plastic pollution into the Adriatic Sea

The main pathways of the entry of marine plastic pollution into the Adriatic Sea are (Gomiero et al., 2019): riverine, atmospheric and oceanic input.

2.1.2.1 Riverine input

The Adriatic Sea has a limited watershed. The largest rivers in the area are the Po, Adige, Tagliamento, and Arsa rivers. They are mostly located in the north. The Po River has the largest discharge with 1540 m^3/s followed closely by the Adige River with 235 m3 /s. Around 14 million people live in the Po basin which extends over 24% of Italy’s territory (Gomiero et al., 2018). It is expected that the input of microplastics through this pathway is very high.

2.1.2.2 Atmospheric input

It has been speculated that at the global level much fewer plastic debris is transported by wind than by rivers [UNEP, 2016; Cai et al., 2017), although this depends on the location. Wind transport of plastic debris may be significant, particularly in coastal areas dominated by strong periodic winds. Also, during intense storms wind can mobilize debris that would not normally be available for transport and carry it directly into rivers and the sea. (Gomiero et al., 2018). Atmospheric circulation is an efficient pathway for the transportation of floating microfibers and small plastic particles in the Mediterranean Sea as well as in other areas (Suaria et al., 2016; Ljubartseva et al., 2016). Some models, which include contribution of waves and wind in the surface plastic distribution, define the Adriatic Sea as a highly “dissipative” system with respect to floating plastics with a calculated half-life of floating condition of

43.1 days (Pasquini et al., 2016; Blašković et al., 2017). The authors say that by construction the Adriatic coastline may be responsible for the main sink of floating plastic debris.

2.1.2.3 Oceanic input

Oceanic currents can be responsible for movement of plastic pollution through marine environment. Sea currents with possibly any moving plastic pollution, from and to the Mediterranean Sea has recently been addressed by the modeling work of Liubartseva et al. (2016) and partially by the results of Pasquini et al. (2016) which pointed out the formation of an accumulation zone corresponding to the three well known gyres located northside, central and in the southern sector of the Adriatic Sea. Most of the litter coming from Ionian region ends up on the beaches of south Adriatc, but it can continue to move northwards, carried by the surface sea currents (Mokos et al., 2019).

2.2 Description of pilot sites

For the description of sampling locations see the Deliverable D 4.1.1 and D 4.1.2. Also, detailed description of reports of the results of previous EU projects on MPs and data collection in Adriatic basin is given in the Deliverable D 3.2.1. For the purpose of this Project two sampling locations were chosen in each Pilot site.

2.2.1 Italian sites

For the Italian Pilot site two locations were chosen – Po Delta and Pescara area.

Rivers are considered one of the main sources of plastic debris to the ocean (Jambeck et al., 2015; Lebreton et al., 2017). The River Po provides the largest riverine influx to the Adriatc sea. Average daily input of freshwater amounts 1500m^3/s with stremflow ranging between 100 m^3/s and 11500 m^3/s (Falcieri et al., 2014). River Po is the largest river in Italy. Its drainage area (74 000 km^2) encompasses much of the northern region of the country, with more than 20 million inhabitants, and includes many large cities as well as areas of intensive industrial and agricultural activities (Atwood et al., 2019). The river splits into many sub-rivers before flowing into the Adriatic Sea. The main sub-rivers are Po di Maistra, della Pila, delle Tolle, di Gnocca (or della Donzella) and di Goro (Atwood et al., 2019). This is way this location has been chosen as a pilot site for this study. It is under a great influence of the River Po so it is possible to measure the impact of the riverin input of microplastic to the Adriatic Sea. The authors (Atwood et al., 2019) published in their paper the results of their research of this area. In both Po River and Adriatic Sea, they revealed microplastic concentration up to 84 particles/m^3 and in beach sediment concentrations up to 78 particles/m^3. According to the authors Piehl et al. (2019) large microplastic abundance (particles 1-5mm) ranged from 2.92 to 23.30 particles per kilogram dry weight. The authors also discus high across- and along-shore variability of microplastic abundance. What is also interesting, the authors discovered that parking lots and harbours are large contributors to beach microplastic accumulation in this area (Atwood et al., 2019). Many authors have been investigating the patterns of accumulation of microplastic particles on the beaches under the influence of Po River (Falcieri, 2012; Falcieri et al., 2014; Spillman, 2007; Fiore, 2022; Carlson et al., 2017).

The second Pilot Site is located along the coast surrounding Pescara, in the south-western part of the Adriatic Sea. It is a site characterized by low sandy coasts with high human impacts due to big cities located along the coast and popular touristic locations.

2.2.2 Croatian sites

For the Croatian Pilot sites two locations were chosen – Rijeka area and Split area.

Bibliographic review and synthesis on the mechanism of municipal wastewater, maritime-oriented economic activities, oil industry, thermal power plants and tourism is discussed in this chapter (data from www.pgz.hr; www.ju-priroda.hr; https://zavod.pgz.hr/planovi_i_izvjesca/Prostorni_plan_PGZ for the Rijeka area).

The peculiarity of the coastal area lies in the contact of sea and land, the diversity of natural resources and economic activities. Numerous human activities in these areas and their intensity can lead to increased pollution of the sea water, overuse of resources, negative environmental impacts and, as a consequence, this can lead to reduced quality of life in this area.

In Rijeka area, in Kvarner catchment area, numerous human activities that take place that are permanent or sudden sources of pollution in north part of Croatian side of Adriatic, especially in highly urbanized or industrial zones. The main sources of pollution are the city of Rijeka with its municipal wastewater, followed by maritime-oriented economic activities (ports, shipyards, passenger and cargo terminals), oil industry (refinery, terminal, petrochemistry), thermal power plants and tourism as the most important economic branch in the coastal area. Significant sources of pollution on the islands are numerous hotels, tourist resorts, camps and nautical facilities (sports ports and marinas). In addition, sources of pollution in this area can be groundwater as well as the river Rječina and many torrents that appear after heavy rains. All of the sources mentioned could also be the sources of microplastics that goes directly into the Adriatic Sea. Possible source of MP could be sea currents, especially on the islands that are farthest from land.

In Kvarner bay there are differences between areas in relation to the possibility of causing marine pollution. The Opatija area from Brseč to Volosko is oriented towards tourism. The quality of the coastal sea, which is mainly used for rest and recreation, is dominated by communal and torrential waters, while there is no industrial activity. The most important source of microplastics in this area are households. The greatest danger to the marine environment comes from tourism.

In the narrower area of Rijeka ("Rijeka-center") from Preluka to the bay Martinšćica, the main sources of pollution are municipal wastewater of the city of Rijeka, including part of the industry. The City of Rijeka's public sewerage system is mixed, with only sand and grease traps in the wastewater treatment plant in Delta, and with a 500 m long subsea outfall at a depth of 40 m. This public sewerage system burdens the coastal sea the most with the amount of wastewater (14.559.177 m3 in 2020, Source: KD VODOVOD I KANALIZACIJA d.o.o. Rijeka) and the burden of discharged substances (suspended solids, organic matter, nutrients, hazardous substances). Also, there are shipyard and smaller facilities located along the coast. They have extensive drainage systems of technological water with discharge directly into the sea.

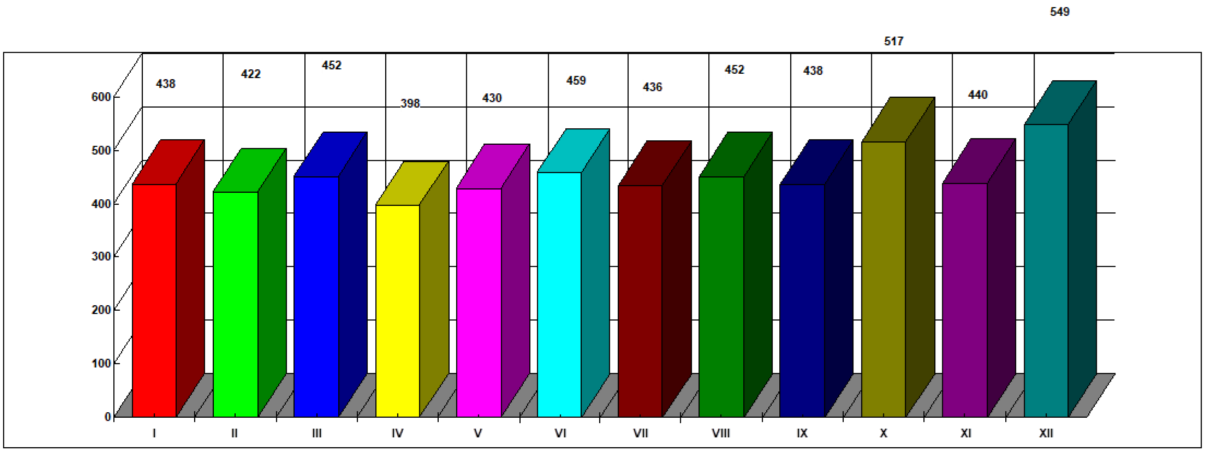

Figure 7: Average monthly wastewater flow through wastewater plant in Delta, in Rijeka, in 2020 (L/s). Source: KD VODOVOD I KANALIZACIJA d.o.o. Rijeka.

In the wider area of Rijeka ("Rijeka Ring"), the problem of sea pollution is concentrated on the northeastern side of the Gulf of Rijeka and the Gulf of Bakar. Most plants have independent discharges into the sea with wastewater treatment plants. Disruptions in the operation of wastewater treatment plants can be a major problem. The town of Bakar, the settlements of Bakarac and Kraljevica present a significant source of nutrient load on the Bakar Bay. This is highly industrialized area and more plants are under construction or are planned to be built here. Crkveničko-vinodolsko area is mostly oriented to tourism without major industrial pollutants. The islands in this part of Croatia are still sparsely populated. The predominant economic branch is tourism, with the exception of the northern part of the island of Krk, which is included in the spatial unit of the so-called "Rijeka Ring". It is important to say that nautical tourism is also an important growing industry.

One of the possible sources of microplastics and other kinds of pollution of the coastal sea from the mainland are certainly rivers. The biggest rivers in this part of Adriatic Sea are rivers Rječina and Dubračina. It could bring significant amount of microplastics into the sea, but further research is needed.

In the Split are, 4 rivers are present in the grid domain of PS4, the major of which is the Neretva, located in the southernmost part of the domain, the other rivers are the Jadro, the Cetina and the Zrnovnica all located in the northern coast, toward the city of Split. These rivers could be important sources of MPs for the Adriatic Sea, but further research is needed. In this area the main sources of pollution are municipal wastewaters, maritime-oriented economic activities (ports, shipyard, passenger and cargo terminals), industry and tourism which include hotels, tourist resorts, camps and nautical facilities (sports ports and marinas). Possible source of MP could be sea currents, especially on the islands that are farthest from land as in the Rijeka area.

3 Distribution of MP in the Adriatic

From the map it is visible that plastic litter has been found on many location across the Adriatic basin. Even through this Project, the microplastic particles have been found on every sampling location, in sea water, on the beaches and in the samples of mussels. This only confirms the theory that MPs are ubiquous and very much present in the Adriatic Sea. The results of this project are discussed in details in Deliverables within WPs 4.2 and 4.3.

Although there are many papers written on the subject of the MPs distribution across the Mediterranean and Adriatic Sea, there are still data missing (Guerranti et al., 2020).

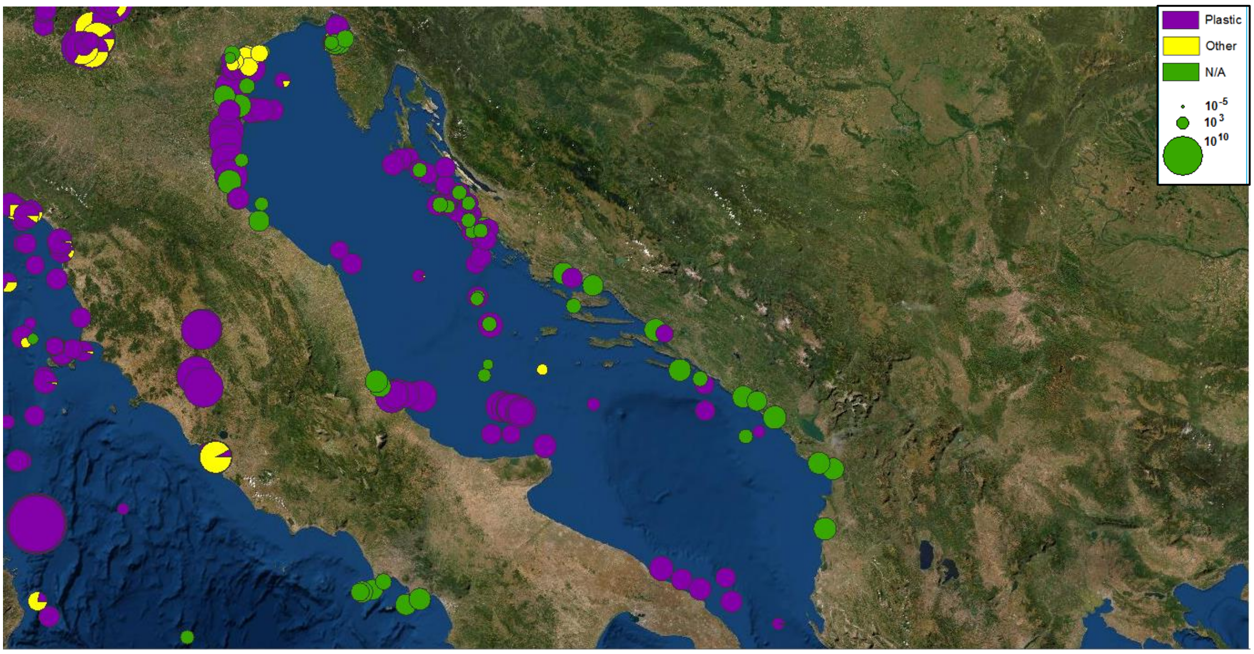

Figure 8: Distribution of litter types in the Adriatic basin. Tekman, M.B., Gutow, L., Macario, A., Haas, A., Walter, A., Bergmann, M.: Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research (from https://litterbase.awi.de/litter)

4 ML campaigns performed during specific extreme events

Current and waves associated with storms may deposit large amounts of plastic materials on beaches together with natural wrack (i.e., terrestrial plants, seagrasses, and algae). In addition, large rivers are considered as major entry points of litter transporting waste to the sea (Lebreton et al., 2017). Once in the sea, surface currents and winds can distribute the light floating litter items (mainly plastic) over wide areas. On the opposite, heavier, negatively buoyant items can be retained in coastal areas (Galgani et al., 2000). Sea state is among the possible factors contributing to determine litter distribution along coastal areas as reported by van Emmerik et al. (2019). Indeed, massive litter washouts have been observed during storm events with windy weather and extreme waves in combination with longshore currents (Menicagli et al., 2022). The same authors report that storms have also been found to affect littering indirectly by reintroducing in marine environments items exhumed from sediment in coastal areas subjected to erosion processes.

Boccasette beach is located in Porto Tolle municipality (Rovigo, Italy), on the north-western spit of Barbamarco lagoon system. The lagoon of Barbamarco belongs to the Po delta and is specifically located between the Po di Maistra and the Po Busa di Tramontana. The lagoon is separated from the sea by two spits and a barrier island. Our study focuses on the northern spit (about 4.4 km long, *Figure 9*), which is locally called Scanno di Bocassette. Boccasette is considered as a semi-rural area, and the main human activities are generally fishery and aquaculture, while local tourist activities occur only during the summer season.

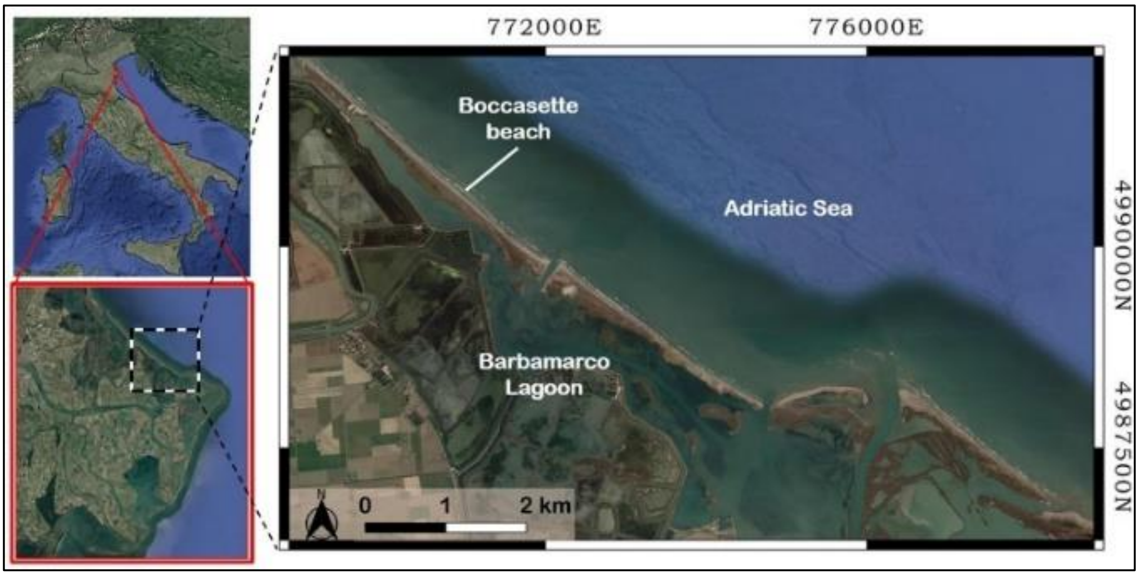

Figure 9: Study area (Map created using GIS tool: Google satellite).

In order to further understand the impacts of extreme events on the composition, distribution and accumulation of marine litter in coastal areas, three surveys were performed between November 2019 and February 2020 at Boccasette beach, with different meteorological conditions (*Table 1*). Considering that cleaning operations are generally performed by the local authorities, the first survey, realized the 14 November 2019, just at the beginning of an extreme sea storm associated to high-water conditions and fluvial flooding, while the second sampling operations has been performed three weeks later (06/12/2019), just after the previous sea-storm event. Finally, the third survey was performed the 20/02/2020 just after a sea-storm.

Table 1: General surveys information: cloud cover scale, Beaufort wind force scale and event notes.

Date	**Cloud cover**	**Beaufort scale**	**Event notes**
Nov 2019	Cloudy	7 – Near gale	At the beginning 1st sea-storm, high-water and flooding of Po
Dec 2019	Clear	4 – Moderate breeze	After 1st sea-storm; declining phase of high-water and flooding of Po
Feb 2020	Clear	4 – Moderate breeze	After 2nd sea-storm

The location of the sampling area was selected according to the following criteria (Vlachogianni et al., 2018): minimum length of 100 m longshore for a fixed 100-metre stretch; low/moderate slope (~ 1.5 – 4.5°); breakwaters or jetties absence; easy beach access guaranteed all year round; no/few additional human cleaning activities.

Therefore, the sampling area covered a 100 m long shore-parallel line, on-field divided in 10 transects (10 m wide) with a variable length depending on hydrodynamic conditions (min. 19.61 m; max. 47.46 m). The boundaries of the sampling site and of each transect were measured using a dGPS (Leica GS16) and geo-referenced in the coordinate system WGS 84 UTM 32N. In addition, a photogrammetric survey was carried out using an "Unmanned Aerial System Vehicle" (model 4 pro-obsidian DJI phantom multirotor drone equipped with a high-resolution camera - 20 Mpixel) in order to generate an orthomosaic image for each campaign. The geo-referenced orthophotos were imported in ArcGIS software to calculate the sampling area in order to relate the number of collected items to a defined surface (*Figure 10*).

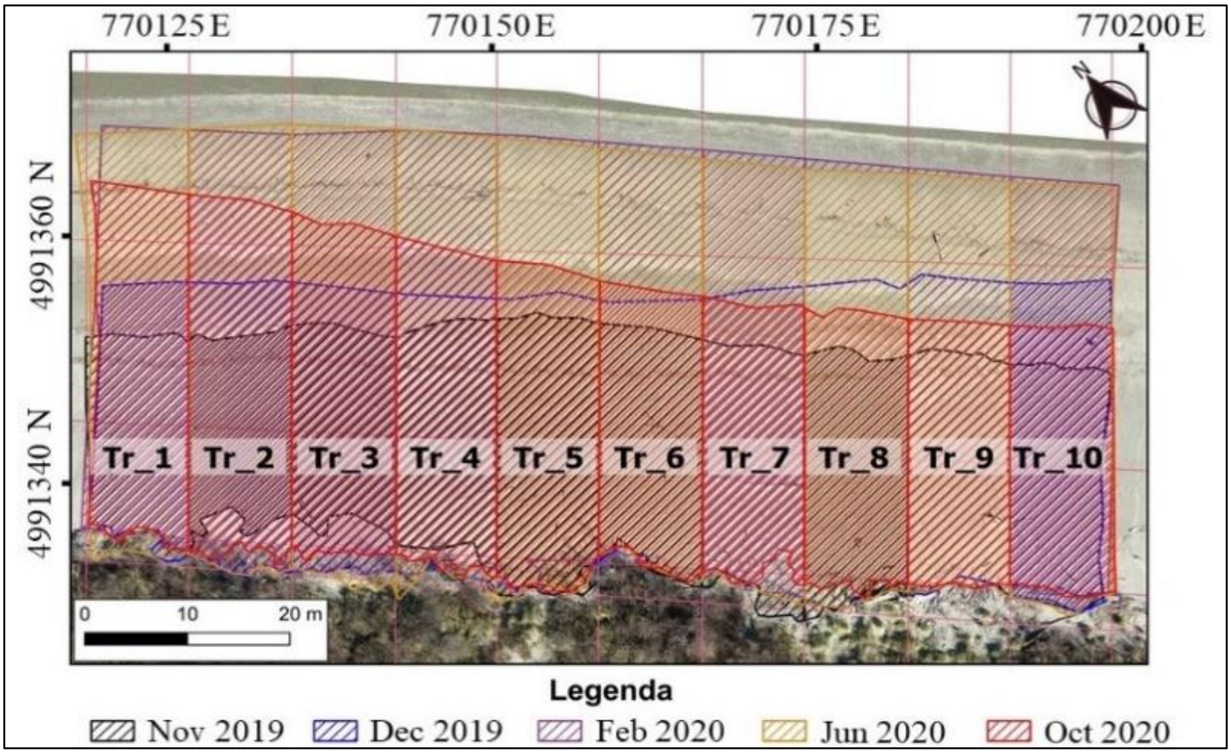

Figure 10: Transects and sampling site for each survey, highlighted by five different colours (on February 2020 orthophoto).

The analysis of the items should provide information regarding the impact of storm event and fluvial flooding event on macro-items accumulation (items ranging from 2.5 cm to 50 cm), while the impacts of extreme events on microplastic were assessed through numerical simulations realized within activity 4.3.

Adapting Palatinus et al. (2015), all stranded litter items were collected and classified according to the potential main sources of release and buoyancy properties (i.e. density, weight and surface-to-volume ratio). Furthermore, the density of marine litter items per m^2 (Lippiatt et al., 2013) was calculated and then the beach cleanliness status was evaluated using the Clean Coast Index (CCI, *Table 2*) (Alkalay et al., 2007).

Table 2: Clean Coast Index: value and definition for each quality class.

Quality	***Value***	***Definition***
Very clean	0 – 2	No litter is seen
Clean	2 – 5	No litter is seen over a large area
Moderate	5 – 10	A few pieces of litter can be detected
Dirty	10 – 20	A lot of litter on the shore
Very dirty	> 20	Most of the beach is covered with litter

In addition, we analysed the items according to their buoyancy properties and we also assessed the possible origin of the marine litter items using the method proposed by Tudor and William (2004). This method assigns each litter item to one specific source (e.g. Marine Conservation Society Beachwatch Surveys – MCS) (Anon. 2000). The attribution process is carried out by attributing all records (from a form) of a particular item to a particular source. It should be also noted that there is invariably a large category of non-sourced litter that consists of items which do not easily fall into specific source categories, e.g. plastic bags, caps/lids. These items have come from one source or another but there is no means of apportioning these to a specific source.

Furthermore, this method utilizes percentage allocation, where several input sources make a possible contribution to litter on a beach and are apportioned an appropriate allocation (e.g. Earll et al. 1999). The source categories considered by Earll et al. (1999) and in the present study, are:

- Tourism (beach users)
- Sewage related debris
- Fly tipping (which is waste disposed of illegally, often at the roadside or in rivers)
- Land (urban/rural) run off
- Shipping
- Offshore installations (e.g. oil rigs)
- Fishing related debris.

Furthermore, a score based on the likelihood (*Table 3*) that they originated from each source has been assigned to each item as reported in *Table 4*.

Table 3: Scheme of probability and percentage allocation of an item originating from a source (from Earll et al. 1999; Tudor and William, 2004).

Probability phraseology	***Probability score***	***Percentage allocation***
Very unlikely (UU)	0.001%	0%
Unlikely (U)	0.001-10%	0 to 10%
Possible (P)	50 – 50%	between 10 - 90%
Likely (L)	> 90%	over 90%
Very likely (LL)	100%	100%

Table 4: Scoring systems (A-E) – Likelihood of litter item originating from a particular source (from Earll et al. 1999; Tudor and William, 2004).

Probability phraseology	***A***	***B***	***C***	***D***	***E***
Very likely	4	9	16	16	16
Likely	3	7	8	4	4
Possible	2	5	4	2	2
Unlikely	1	3	2	1	1
Very unlikely	0	1	1	0.25	0.25
Not considered					0

4.1 Results

The number of items collected during the three surveys is reported in table 5. A total of 3296 items were collected, with a minimum of 1015 items (November 2019) to a maximum of 1203 items (December 2019). Therefore, in terms of number of marine litter items, we did not observe specific difference between the different surveys.

Regarding the number of items per m^2 (*Table 5*), our results are in agreement with other studies, and in particular with the study of Vlachogianni et al. (2018), who reported density ranging from 0.19 to 0.55 items/m^2 for the beaches of the northern Adriatic (Po Delta and Emilia-Romagna beaches). The beach generally appeared moderately clean or clean. However, our results reveal that a lower density of the survey of February 2020, which can be the result of a wider studied area (twice the area of the two previous survey). Considering that most of the items were found on the upper part of the beach, we believe that this difference is not relevant and cannot be related to different meteorological conditions. This result further suggests the need to modify the sampling methodology by dividing the beach wide in different sectors representing, for instance, the following morphological zones:

- Lower beach (below the ordinary berm)
- Beach (between the ordinary and storm berm)
- Upper beach (between the storm berm and the dune foot or the beach wrack
- The dune foot.

In addition, we suggest that the beach wrack should be sampled on its own in order to further understand the capacity of the beach wrack to capture marine litter items.

Table 5: Results of the three surveys (number of items and density).

	November 2019	***December 2019***	***February 2020***
Studied area (m^2)	2326.96	2912.59	4372.92
Number of items	1015	1203	1078
Density (items/m^2)	0.44	0.41	0.25
Clean coast index	8.59	8.01	4.63

By numbers, more than 90% of the beach litter consisted of plastic litter items, as clearly observed in *Figure 11* and *Table 6*. This result is in agreement with several studies, like for instance Pasternak et al. (2017), which reported that 90% of the beach debris collected in Israel were plastic. Similarly, Vlachogianni et al. (2018) observed that the majority of litter items collected on Adriatic and Ionian beaches were made of artificial/anthropogenic polymer materials accounting for 91.1% of all litter. Galgani et al. (2015) highlighted that plastics typically constitute the most important part of marine litter sometimes accounting for up to 100 % of floating litter.

Regarding the composition, the results highlight small differences between the three surveys. Indeed, the items observed during the first survey were mainly artificial/anthropogenic polymer material, with loss percentage for the other categories (less than 0.5% - rubber, wood, metal and glass items). Textile, paper and unidentified items were even absent. During the second survey, plastic items were still predominant, but an increase of processed/worked wood was observed (reaching 1.16% with 14 items). Finally, during the last survey, a small decrease of plastic items occurred while rubber (13 items), textile (21 items) and metal (20 items) items increased, reaching more than 1%. Such differences may be related to the different meteorological conditions. We believe that the increase of the woody items could be related to flooding event, which occurred after the first survey.

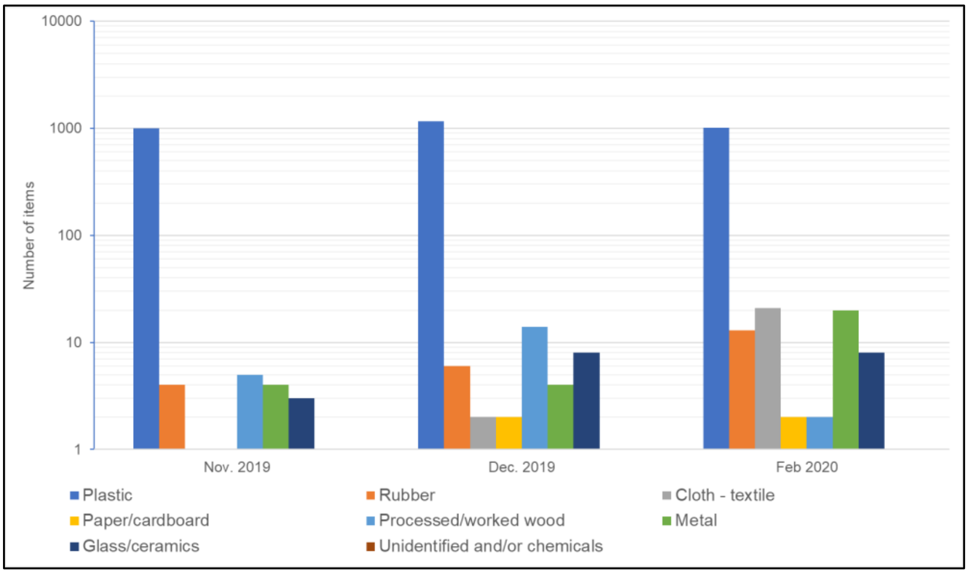

Figure 11: Composition of the marine litter items collected during the 2019-2020 winter season. Note the y-axis logarithm scale to represent the number of items.

Table 6: Percentage (%) of total litter items per category type (artificial/anthropogenic polymer material; rubber; cloth/textile; paper/cardboard; processed/worked wood; metal, glass/ceramics and unidentified and/or chemicals) collected during the 2019-2020 winter season.

	Nov. 2019	*Dec. 2019*	*Feb 2020*
Plastic	**98,42**	**97,01**	**93,88**
Rubber	0,39	0,50	**1,21**
Cloth - textile	0,00	0,17	**1,95**
Paper/cardboard	0,00	0,17	0,19
Processed/worked wood	0,49	**1,16**	0,19
Metal	0,39	0,33	**1,86**
Glass/ceramics	0,30	0,67	0,74
Unidentified and/or chemicals	0,00	0,00	0,00

Furthermore, the analysis of the 10 most frequent items (*Table 7*), accounting for 70 to 80%, indicates that plastic pieces or polystyrene pieces were the most frequent items during the two first surveys, while mussel nets were the most frequent during the last survey. Moreover, the different surveys are similar, and present only small differences. For instance, shotgun cartridges were only found during the first survey (November 2019) that is directly related to human activities and not to physical factors such as sea storms. However, the distribution of the floating and sinking items reveals a difference in relation to the different surveys (*Table 8*). Indeed, the first survey, which has been carried out at the beginning of the storm and flooding event, is characterized by a higher percentage of sinking debris items (60%) compared to the floating items, while a greater presence of floating items has been observed in the second and third surveys (after the storm events). As reported by different studies, once marine litter enters into the marine environment, the hydrographic characteristics of the basin may play an important role in the transport, accumulation and distribution of floating debris (Menicagli et al., 2022). Similarly, the predominance of sinking debris observed after storm events can be caused by erosive processes that can exhume plastics with age up to 40 years from foredune sediments (Turner et al., 2021; Andriolo and Gonçalves, 2022).

Table 7: The master list: the 10 most frequent items.

Items		***11-19***	***12-19***	***02-20***
G79	Plastic pieces 2.5 cm > < 50cm	**175**	86	95
G45	Mussels nets, Oyster nets	163	79	**220**
G95	Cotton bud sticks	101	101	59
G21	Plastic caps/lids drinks	89	124	36
G82	Polystyrene pieces 2.5 cm > < 50cm	88	**224**	59
G24	Plastic rings from bottle caps/lids	24	122	37
G5	Plastic bag collective role; what remains from rip-off plastic bags	14	84	110
G23	Plastic caps/lids unidentified	92	50	
G7	Drink bottles <=0.5l	16		
G8	Drink bottles >0.5l		92	22
G70	Shotgun cartridges	51		
G50	String and cord (diameter less than 1cm)	26		
G67	Sheets, industrial packaging, plastic sheeting		29	
G30	Crisps packets/sweets wrappers			40
G4	Small plastic bags, e.g. freezer bags, including pieces			37
G78	Plastic pieces 0 - 2.5 cm			37
	Percentage	82,7	82,4	69,8

Table 8: Composition of the marine litter debris according to their buoyancy properties (floating/sinking).

	11-19	***12-19***	***02-20***
Sinking	60%	46%	40%
Floating	40%	54%	60%

Finally, it should be mentioned that the source of plastic fragments is difficult to assess as they originated from the degradation of larger items present in marine environment for a long time. The polystyrene pieces collected during the different surveys, and in particular during the second survey, could derive from items used in fishing-related activities. In contrast, the abundance of plastic bags and small bags could be related to an improper waste disposal. The analysis of the marine litter source, applying the scoring system 'A' of the method proposed by Tudor and William (2004) is synthetized in *Table 9*, reveals that fishing activities are the main source of the marine litter, and tourism or improper waste disposal is the second source of marine litter.

In addition, we should mention that at Bocassette beach 50% of the marine litter originates from ocean-marine-based sources, which is in agreement with the main human activities of the study area.

Table 9: Source of the marine litter items applying the Scoring system 'A' proposed by Tudor and William (2004).

	Tourism Improper waste disposal	***SRD Sewage***	***Fly tipping - land***	***Land (run off)***	***Shipping***	***Offshore***	***Fishing***
Nov. 2019	20,3	12,8	2,0	13,8	13,6	6,9	30,6
Dec. 2019	21,3	13,3	4,4	14,6	16,7	7,3	23,4
Feb. 2020	18,8	9,7	6,7	11,8	13,3	5,1	34,5

5 Conclusion

Plastic litter in general and microplastic particles are present in the Adriatic Sea.

In terms of number of marine litter items in this study, specific difference between the different surveys at Bocassette beach was not observed. The beach Bocassette generally appeared moderately clean or clean. By numbers, more than 90% of the Bocassette beach litter consisted of plastic litter items.

The analysis of the 10 most frequent items, accounting for 70 to 80%, indicates that plastic pieces or polystyrene pieces were the most frequent items during the two first surveys, while mussel nets were the most frequent during the last survey. A higher percentage of sinking debris items (60%) compared to the floating items was observed at the beginning of the storm and flooding event, while a greater presence of floating items has been observed after the storm events.

The predominance of sinking debris observed after storm events can be caused by erosive processes that can exhume plastics. The source of plastic fragments is difficult to assess as they originate from the degradation of larger items present in marine environment for a long time. Fishing activities are the main source of the marine litter, and tourism or improper waste disposal is the second source of marine litter at studied beach. On Bocassette beach 50% of the marine litter originates from ocean-marine-based sources, which is in agreement with the main human activities of the study area.

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