Scalable full-cycle marine litter remediation in the Mediterranean: Robotic and participatory solutions

SeaClear2.0

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D2.1 Marine litter occurrence domains report

WP2 – Concept design & technical specification

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Deliverable description	*This report focuses on the litter occurrence in regard to specific environments such as highly frequented touristic regions, industrial ports, fishery, and aqua cultural sites as well as protected natural areas. Elaborating those specifics will shape and define further data acquisition measures and help to train the AI responsible for decision making process in litter collection, and distinguishing on marine wild life and waste fractions. (<=T2.1)*

1 R = Document, report, DEM = Demonstrator, OTHER = Software, technical diagram, etc., DMP = Data Management Plan

2 PU = Public, C-UE/EU-C = EU Confidential under Decision 2015/444, SEN = Sensitive

Document history

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Disclaimer of warranties

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Definitions

- **Beneficiary:** A legal entity that is signatory of the EC Grant Agreement no. 101093822.
- **Consortium:** The SeaClear2.0 Consortium, comprising the list of beneficiaries below.
- **Consortium Agreement:** Agreement concluded amongst the SeaClear2.0 beneficiaries for the implementation of the Grant Agreement.
- **Grant Agreement:** The agreement signed between the beneficiaries and the EC for the undertaking of the SeaClear2.0 project (Grant Agreement no. 101093822).

Beneficiaries of the SeaClear2.0 Consortium are referred to herein according to the following abbreviations:

- **TU Delft**: TECHNISCHE UNIVERSITEIT DELFT
- **DUNEA**: REGIONALNA AGENCIJA DUNEA
- **Fraunhofer**: FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
- **HPA**: HAMBURG PORT AUTHORITY
- **ISOTECH**: ISOTECH LTD
- **MDanchor**: M. DANCHOR LTD
- **Subsea Tech**: SUBSEA TECH SAS
- **TECNOSUB**: TÉCNICAS Y OBRAS SUBACUÁTICAS, SLU
- **TUM**: TECHNISCHE UNIVERSITAET MUENCHEN
- **UNIDU**: SVEUCILISTE U DUBROVNIKU
- **UTC**: UNIVERSITATEA TEHNICA CLUJ-NAPOCA
- **VEO**: VEOLIA PROPRETE
- **VLPF**: VENICE LAGOON PLASTIC FREE

Abbreviations

- **EC**: European Commission
- **GA**: Grant Agreement
- **WP**: Work Package
- **KPI**: Key Performance Indicator
- **ML**: Marine litter
- **ALDFG**: Abandoned, lost, and discarded fishing gear
- **MSFD**: Marine Strategy Framework Directive
- **GES:** Good Environmental Status

Executive summary

The current deliverable is part of WP2, the work package that aims to design the overall SeaClear2.0 concept, based on the research on marine litter occurrence in the proposed domains of activity. Through D2.1, marine litter analysis will be formulated, that will define the problem the SeaClear2.0 system needs to tackle. A marine litter occurrence analysis is conducted for each demonstration or pilot site within the project, including five countries with direct access to the Mediterranean Sea and one outside of its basin. Next, the marine litter hotspots and typology are discussed for each site. Further on, the findings in terms of litter typology and occurrence are grouped into the system validation domains, which are primarily used for showcasing the relevance of performing tests and demonstration with the SeaClear2.0 system within the scope of the project, but also for formulating the potential use-cases outside the envisioned test sites, through the addition of associated regions. Finally, the correlation with the MSFD descriptors and the envisioned validation tests performed by the SeaClear2.0 system throughout the project. The results of this work will also be used to formulate the system requirements for each test or demo site, and in turns, the technical solution to be developed.

1. Introduction

1.1 Overall objective

The SeaClear2.0 project will develop an integrated approach to address the entire cycle of marine litter (ML). The project focuses on reducing marine pollution, specifically from marine litter, in the Mediterranean. This will be achieved by using teams of autonomous, intelligent robots to monitor and collect marine seafloor and surface litter, and through participatory practices to identify site-specific measures for marine litter prevention and reduction. By identifying ways to valorise litter and extend policy-making, SeaClear2.0 will provide innovative solutions for effective marine litter management, further promoting the health of oceans, seas, and water bodies.

The main objective of this document is analysis of the marine litter typology and occurrence for the project demonstration and pilot sites, followed with the identification of project use cases, in order to define the problem that SeaClear2.0 system needs to tackle. This document gives an overview of the general situation of marine debris in the Mediterranean, with the most recent data and acknowledgments, followed by an overview of relevant environmental challenges for each project showcase domain.

SeaClear2.0 objective is contribution to all expected outcomes of the call "Mediterranean sea basin lighthouse – Prevent and eliminate pollution of our ocean, seas and waters". In order to follow up this objective and to qualify the SeaClear 2.0 system benefits, but also to identify the challenges, D2.1 gives a corelation of the project use cases with Marine Strategy Framework Directive (MSFD) qualitative descriptors. By answering the defined environmental challenges, consequentially, Good Environmental Status (GES) will be achieved, along with the direct contribution to MSFD.

Sea debris poses environmental, economic, health, aesthetic, and cultural threats, with huge degradation consequences for marine and coastal habitats and ecosystems that incur socioeconomic losses in marine-based sectors. It can be observed everywhere in the oceans, with the Mediterranean Sea being drastically impacted because of its specific geographical and oceanographic setting. Debris enters oceans from both land and water-based sources and can travel long distances before depositing on shores and seafloor. SeaClear 2.0 system will be challenged with various marine litter fractions and site conditions. Continuous removal of marine debris is a key factor in fighting this enormous environmental problem, where innovative solutions such as the SeaClear 2.0 robotic system (see Figure 1), plays the crucial role of solving the problem and mitigating the consequences of further accumulation of garbage in our seas, specifically on depths that are difficult to be reached by human divers.

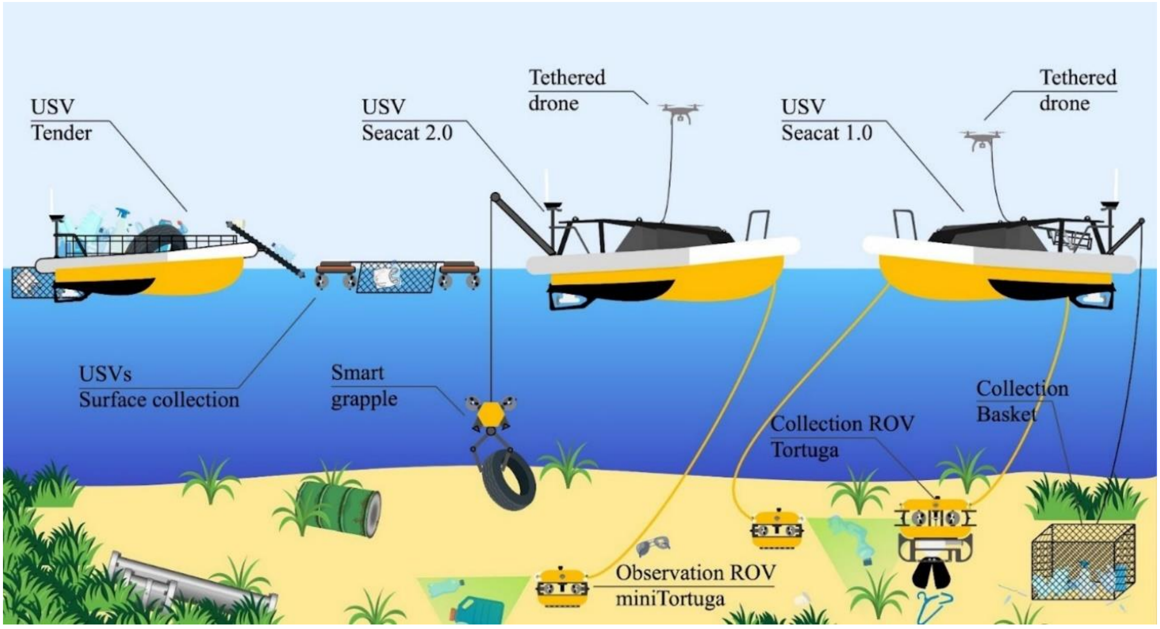

Figure 1. Concept of SeaClear2.0 robotic system (left + middle) working alongside the SeaClear1.0 system (right)

1.2 Deliverable structure

This deliverable is structured to primarily analyse ML occurrence for the project demo and pilot sites, with an overview of the general situation for the debris in the Mediterranean where the SeaClear 2.0 system can be transferred via associated regions inclusion. Chapter 2 describes the marine litter occurrence in the Mediterranean with identification of marine litter hotspots and marine litter typology, Chapter 3 focuses on project system validation domains and corresponding demo/pilot sites, with project showcase domains description and ML occurrence for each demo/pilot site. Chapter 4 focuses on challenges presented before the SeaClear 2.0 system and in what way the project use cases will try to answer them, in corelation with relevant MSFD descriptor.

2. Marine litter occurrence in the Mediterranean

2.1 Marine litter hotspots in Mediterranean

The Mediterranean Sea is the largest and deepest enclosed sea on Earth, while its shores are home to 7% of the world's population. It is a specific marine basin with limited connection with other oceans, with the main water exchange occurring in the west, through the Gibraltar Strait, where the Atlantic waters enter the Mediterranean. It has an anti-estuarine circulation that causes this basin to act as a trap for particles including pollutants and specifically, ML plastic. The Mediterranean Sea has highly developed tourism, with 30% of the world's maritime traffic passing through as a major shipping lane, with thousands of vessels traveling through the region every year. It is also a place with the highest percentage of municipal waste on an annual level per person (208 - 760 kg/year). This amount of waste increases up to 40% during the tourist season, precisely because of the large number of tourists in the summer months, causing more than 75% of total municipal waste. Taking all mentioned into consideration, the unique geography and oceanographic setting, along with its high population density and inefficient waste management, result that the Mediterranean Sea is identified as one of the world's most heavily affected areas for marine pollution, specifically marine litter [1].

The issue of marine litter and plastic pollution is high on political agendas, global but specifically European agenda. It is directly addressed by the MSFD, while the recent Zero Pollution Action Plan includes specific reduction targets for waste generation, plastic litter at sea and input of microplastics.

Hot spots – i.e., higher concentrations of marine litter, are observed in areas under high anthropogenic pressure and proximity to land-based sources of litter. Most of the marine litter in Mediterranean is made out of synthetic polymers, better known as PLASTICS. The root causes of rising plastic pollution are found in the increase of plastic use, unsustainable consumption patterns, ineffective/inefficient waste management and loopholes in plastic waste management [8].

The Mediterranean region is home to numerous coastal cities, tourism industries, fisheries, and shipping lanes, all of which contribute to the problem of marine pollution. The consequences of this pollution can be seen in the form of decreased biodiversity, altered food webs, and impacts on human health [8]. Coastal plastic pollution hotspots in the Mediterranean are presented in the Figure 2, along with SeaClear 2.0 demo sites and pilot sites.

The groundwork of the SeaClear 2.0 system development is based on and demonstrated at three key locations that are all Mediterranean litter hotspots: Marseille, Tarragona, and Dubrovnik, as well as via pilot tests in Venice, Ashdod, and Hamburg, altogether validating the system in a wide range of environmental conditions. To ensure the system applicability to the entire Mediterranean basin and beyond, at least five associated regions will be involved via a call for tender to prove feasibility, replicability and scale-up of the proposed robotic and participatory approach. These will be key partners to enable and achieve the project's outcomes as well as the mission's call, by specifically focusing on the pre-described scenarios of Each domain is connected to potential candidate locations and to a use case, both different from the project's given pilot areas and demo sites to prove replicability.

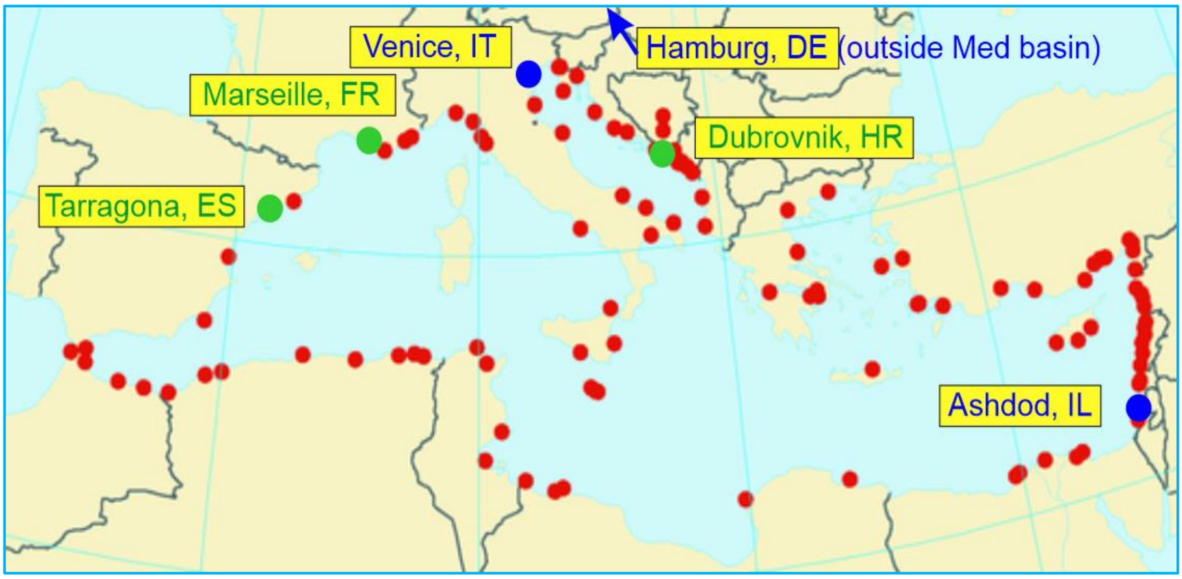

Figure 2. Coastal plastic pollution hotspots in the Mediterranean (European Environment Agency, "Pollution Hot Spots along the Mediterranean Coast," map, 2012)

green = SeaClear2.0 demo sites;
blue = SeaClear2.0 pilot sites;
red = all the other hotspots, where SeaClear2.0 results can be applied.

Considering the marine pollution sources in the Mediterranean Sea, major identified are *land-based activities*, which includes waste disposal, tourism, agriculture, and industrial activities that result in the release of pollutants into the sea. The major input of land-based point sources of contaminants is treated (or non-treated) wastewater discharges, followed by land-based run-off, and atmospheric deposition (wet/dry deposition and diffusive transport). Sea-based sources (i.e., direct inputs from maritime and industrial activities, such as shipping, fishing, oil refining oil and gas exploration and exploitation) may be permanent chronic sources of pollution in the marine environment, and include the potential for acute pollution events [8].

2.2 Marine litter typology in Mediterranean

Marine litter is a specific kind of waste, defined as any persistent, manufactured, or processed solid material discarded into the sea, rivers, or on beaches. It can be brought indirectly to the sea with rivers, sewage, stormwater, or winds, or intentionally discarded at sea. ML fractions are extremely diverse and depend directly on the human activities implemented, which, in the first case, caused the waste production. The waste fractions found underwater are subject to biofouling, and sometimes can even become part of the marine habitat itself, making the autonomous robotic collection even more challenging. ML can be found tangled in the protected *Posidonia* habitats, it can be hidden in underwater caves and even found on great ocean depths. Passive litter on the seafloor can cause chemical and physical pollution, but also "blanketing" and "suffocation" of marine habitats. In the case of plastic fractions, once enter the environment, they never cease to exist, becoming smaller and smaller particles called microplastic, and eventually even smaller particles invisible to the eye, called nanoplastic. The potentially harmful effects on marine ecosystems of this, so-called ML by-products, such is the microplastics, remain practically unexplored.

ML in the Mediterranean includes a wide variety of fractions and substances, encountered also in other marine and coastal areas of the world. In the Mediterranean basin, 80% to 90% of marine litter is made of plastic, and it is estimated that on a yearly basis 230,000 tonnes of land-sourced plastic leak into the Sea. The recreational use of Mediterranean beaches can generate up to half of the beach litter, while fisheries and aquaculture account for 2% to 15% of litter found on beaches, floating on the sea surface, or lying on the seafloor. Rough estimates show that shipping lanes can generate up to 20,000 tonnes of sea-sourced plastic litter every year [8]. According to the Marine Litter Assessment in the Mediterranean (UNEP/MAP, Athens, 2015), by far the No. 1 type of marine litter in the Mediterranean is cigarette filters (closely followed by cigar tips), which constitute a real menace to the region and can be found even in the most remote coastal areas.

In order to observe marine litter for the context of robotic innovative solutions and its work-scope, marine litter fractions, macrolitter and microlitter, have been divided and grouped by the location found, i.e., on the beach, seafloor, or sea surface.

- **Beach ML (macrolitter and microlitter)**
- **Seafloor ML (macrolitter and microliter)**
- **Sea surface ML (macrolitter and microlitter)**

Because of its specificities and severity of the damage it causes underwater, a marine litter fraction grouped as **ALDFG – abandoned, lost, and discarded fishing gear,** are described separately.

Detailed data on ML typology for Mediterranean from research done by Vlachogianni et al from 2019, Veiga et al. in 2022 and Ziveri et al. from 2023, are presented in Table 1.

LOCATION	***MARINE LITTER (ML)***	
	MACROLITTER	***MICROLITTER***
BEACH	*For the Mediterranean Sea, according to the research done in 2022., the general trend is a declining number of items found per 100 m of beach, from over 1,000 items per 100 m of beach to 325 items in 2019 [2]. Data on the composition of marine litter on Mediterranean beaches shows that plastic (bottles, bags, corks, etc.), aluminium (cans) and glass (bottles) make up 52% of the waste sorted by categories. Cigarette butts make up about 40% of the waste collected [4]. Smoking related waste seems to be an important problem in the Mediterranean. The International Cleanup Campaign in 2013 found*	*There are still no universally accepted statistics based on the analysis made on the beach microplastic data, since the methods used for the investigations, are not yet standardised. The results from recent studies show a relatively large variation from 0 to 2,175 microplastic particles per kg dry sediment or sand. The highest levels were found in the Venice Lagoon which is one of the project pilot sites, but no direct correlation was seen between rural or remote areas or beaches. Although, there is still a need for harmonisation and standardisation of analytical methods*

	that cigarette butts were the most frequent items found on Mediterranean beaches, with abundances ranging from 35-62% of the total items recorded [3].	*before a more detailed evaluation of results is possible, it can be noted that microplastics data are ambiguous in both coastal beaches and sediment in both urban, rural, and protected areas of the Mediterranean [2].*
SEAFLOOR	*Several studies used trawling to determine the amounts of macrolitter on the seafloor of the Mediterranean Sea. The number of items varied from 13 items to more than 1,000 items/ km², depending on the area sampled. The items consisted predominantly of plastic materials (60–80 %). On a weight basis, plastics were also the most abundant litter item followed by glass items. In the case of seafloor macrolitter, large variations were noted, but there is no decreasing trend in the period of last 15 years, which is the case with beach macrolitter [2]. Marine litter in general varies according to the location and the exact human activities conducted at the relevant coastline. In the case of intense mariculture activities, such are fish and shellfish farms, seafloor macrolitter identified are specific waste fractions coming mostly from the activities conducted. In areas with intensive and extensive aquaculture activities, mussel nets are among the most common items found. These waste fractions will be challenging items processed through the project showcases. The results obtained from the seafloor surveys show that litter from aquaculture accounts for 15% of total items recorder [5]. Besides the specific waste fractions from aquaculture/mariculture, waste from shipping is a subject that will also be given a focus through the project demo showcases. Despite the strict promotion of the waste delivery to port reception facilities and its international shipping regulations, it is estimated that up to one-third of the litter generated by merchant shipping is not delivered and could, instead, be illegally discharged into the sea. This is, however, difficult to assess*	*Studies on microplastics in the Mediterranean are showing that microplastics are abundant in the seafloor sediments, but that levels vary from 0.4 to 900 microplastics and fibres are the majority of the microplastics found [2].*

	reliably due to scarce information and up-to-date data [2].	
SEA SURFACE	*The composition of marine litter floating at the surface of the Mediterranean Sea or lying on the seafloor show a pattern where plastic items represent, respectively, up to 90% and 80% of the pollution [8]. According to the MEDSEALITTER project, a decreasing gradient was found from river mouths, coastal areas to the open sea where 1–10 items per km ² were observed. Another large-scale macrolitter mapping of the Mediterranean using both observations from the air and ships covering more than 27,000 km, reported averages of 0.80 and 1.13 items larger than 30 cm [2].*	*Recent studies, with method of analysis being the manta trawl with a mesh size of 300 µm, show microplastic levels from several 100,000 to over 1,000,000 microplastics in the South Adriatic Sea. The quality of the different studies varies largely in terms of confirmation of the microplastics found, especially in the case for fibres which could be synthetic or natural. Same as for the beach microplastic analysis, limited harmonised data is available, but in every part of the Mediterranean, more than 100,000 microplastics are found per square kilometre (0.1 item/m ²) [2].*
ALDFG – abandoned, lost, and discarded fishing gear	*As there is still limited information on the magnitude of ML on beaches and on the seafloor, while global estimations of the number of specific debris of lost fishing gear, i.e.,* ***ghost nets****, is even more limited. This is further pointed by the loss of gear at larger depths, mostly inaccessible to human research. That is why this specific waste fraction will be given a focus through the project showcases, using the autonomous robots where the “human hand” cannot reach. The correct impact of ghost fishing is difficult to quantify, as ghost fished individuals either die, are consumed by predators, or decompose without being recorded. The approx. estimations for the Mediterranean Sea, specifically along the Black Sea coast of Türkiye, calculated a log of 1,626.8 panels/year, which is 1.5 % of the overall panels in use. Also, ALDFG can become entangled amongst rocks, which stress, and damage sessile and suspension feeders, such as sponges and corals. According to recent research, approx. 78 % of litter items were identified as derelict fishing gear, the majority of which were longlines. Of these debris, 29 % had entangled corals. Lost fishing gear made of plastic continues its lifecycle under the sea surface, it degrades very slowly and never seizes to exist, becoming the microplastic problem of our oceans [2].*	

Table 1: Detailed ML typology for the Mediterranean Sea

3. Project system validation domains and corresponding demo/pilot site

3.1 Project showcases domains

As a distinct effort at the start of the project, project consortium refined the number of domains that illustrate the impact of SeaClear system. For each project showcase domain, specific environmental problem has been defined, along with ML typology estimation and possible robotic solution for the given problem. All details are described in the Table 2.

PROJECT SHOWCASE DOMAIN	SHORT DESCRIPTION	ENVIRONMENTAL PROBLEMS & DIGITAL- ROBOTIC SOLUTION	ML TYPOLOGY
Tourism in coastal areas and recreational freshwater lakes	*A marine and/or coastal area frequented by tourists and attracting visitors, often because of its scenery, objects of interest, or recreational activities, thus highly impacted by touristic activities on the site-specificity, environmental status, and stakeholder range.*	*Pressure on natural resources through coastal urbanization, over-consumption, massive tourism generating waste, causing increased pollution, natural habitat loss, and threatening endangered species. The tourism impact can be diverse – negative impacts of tourism development can gradually destroy environmental resources on which it depends. If the tourism industry is properly managed and controlled, it has the potential to create beneficial effects on the environment by contributing to nature protection and conservation. It is a way to raise awareness of environmental values and it can serve as a tool to finance protection of natural areas.* *Using robotic solutions, huge amounts of waste i.e., marine litter produced by tourism activities, can be continuously removed from the area, on lower cost and with reduced manpower. This would be an example of good practice in tourism management, where it can also be used as a visible tool for awareness raising on marine litter problematic.*	*Land-sourced waste from hospitality industry and activities (hotels, bars, restaurants, beach concessionaires, water sports, etc.): mostly plastic (bottles, food containers, cigarette butts).*

Ports (both small and large, including water transport)	*Extensive nautical activities, mooring, transfer of cargo and/or passengers - a pilot area with highly developed nautical activities, where boats and ships moor and transfer passengers and/or cargo, to/from land, thus creating area of specific ecosystem qualities, with specific environmental and waste issues, contemplating around specific stakeholders.*	*While efficient ports are vital to the economic development of their surrounding areas, the related ship traffic, the handling of the goods in the ports can cause a number of negative environmental impacts. Shipping has an environmental impact both in ports, as well as in the immediate vicinity of the ports. Examples of these impacts are changes of water quality impacting aquatic flora and fauna, coastal hydrology and bottom contamination, noise from ship engines and machinery possible toxins and alien species from the ballast water, etc. Public authorities at various administrative levels have put in place a wide range of policy instruments to limit negative environmental impacts.* *Specific port conditions, such resedimentation due to turbid currents, could be tackled with robotic solutions, as a continuous practice for mapping the seafloor and tagging the bulky waste fractions underwater, including potentially dangerous waste. This could significantly reduce operation cost and life threat to human handling and operating potential waste, including fractions on significantly high depth, on which cannot be reached by human power only. Robotic solutions in ports should be also used as a monitoring tool for water conditions (alarms set for increased pollution) and could be used to remove litter from the general area, thus preventing for the litter to be distributed by ocean currents and ships/boats in other marine environments where it could pose even greater threat to the ecosystem.*	*Marine-& land-based sources from port activities: mostly bulky waste (tires, large metal construction, machine parts, nautical equipment, and tools, UXO).*

Fisheries and aquaculture	*Industrial cultivation of fresh & saltwater species under controlled or semi-natural conditions or industrial near and offshore fishing activities and tradition. Aquaculture pilot area refers to area for cultivating freshwater and saltwater populations under controlled or semi-natural conditions while fisheries refer to area highly impacted by fishing activities and tradition.*	*Main environmental problem, i.e., impact from fisheries and aquaculture to be tackled through this project is specific waste production which poses extremely high threat to marine life. The culture equipment used in shellfish and fish farms is suspended in the water column from floating longlines and so is prone to snapping and falling to the seafloor during extreme weather conditions, or is just discarded in the sea due to bad management practices. This causes the creation of artificial sea floors and release of various pollutants in the environment, with microplastic being one of the most persistent issues. Abandoned, lost, or otherwise discarded fishing gear continues to "work" and trap marine life in their path long after its inadequate discharge. These abandoned nets are thus called "ghost nets" and are one particularly egregious part of the global fishing problem.* *Robotic solutions could be working continuously, covering the large aquatic areas affected by these specific waste fractions, removing it from the marine environment on depths where diver operations are limited due to the depths and weights of this type of marine waste.*	*Marine-based sources from mariculture industry, such as shellfish and fish farming construction pieces and equipment, mostly plastic and metal waste, bulky waste fractions, rubber, fishery equipment – "ghost" nets and other fishery material.*
Protected natural areas	*Nature reserves and protected areas with limited touristic and maritime activity, but exposed to litter and waste inflow due to currents - Showcase domain representing area of special nature protection, such are nature reserves and parks, national parks, natural monuments, natural resources*	*Some nature protected areas have more or less tourism and maritime activities developed, while continuously persisting on conservation of the area, considering that environmental problems know no administrative borders and boundaries. There are cases of huge marine litter problems coming from neighbouring areas and thus directly impacting the nature protected location. The challenge is to find the solution to preserve the area while also preserving the habitats and wildlife. Litter occurrence related to tourism and maritime activities and especially from neighbouring areas directly impacting the nature protected locations.* *Robotic solutions will help to pre-emptive monitor the marine environment conditions, mapping the seafloor and removing the litter from the seafloor while preserving protected habitats, specifically Posidonia oceanica beds.*	*Land-based and marine-based source marine litter coming mostly from other areas, driven by ocean currents; plastic waste, various waste fractions, depending on neighbouring activities.*

	protection areas, flora and fauna protection areas, sanctuaries etc.		
River and channels in urban areas	*Heavily frequented rivers and channels by fisheries, inland water transport, leisure, and recreational activity as well as connection to sewage and rainwater pipe systems.*	*Cities located along rivers and crisscrossed by channels are exposed to numerous industries such as local fisheries, inland water transport and local service providers for leisure and recreational activity aiming for residential and touristic clients. Their urban character and connection to sewage and rainwater drainpipe systems make them heavy carriers for waste.* *Robotic waterside maintenance will help avoid litter floating to open water, deterioration of waste to microplastics and exposing of toxic substances, preserve water quality and healthy environment and ensure safe ship traffic. Employing a robotic solution will tackle the problem from the source. Similar to port areas, the resedimentation problem can also be tackled in a robotic system and, additionally, benefit from the stability of measurements even in higher currents (3-4kn).*	*Large range of litter like food and beverage containers up to lost ship equipment and purposely discarded items, like e-scooters, shopping carts, wrongfully disposed vehicles containing motors, damaged batteries, and fuel tanks.*

Table 2: Overview of the SeaClear 2.0 showcase domains with its major environmental challenges, possible robotic solutions, and ML typology

3.2 Marine litter occurrence at project demonstrations and pilot sites

SeaClear 2.0 project covered the entire Mediterranean region area, with demo and pilot sites distributed along relevant coastal points, where ML hotspots can be observed. Each demo/pilot site covers respective project showcase domain and challenges of particular site conditions and marine litter occurrence. Overview for each demo/pilot site, corresponding project showcase domain and ML typology has been described in Table 3. This will be used as a comparison table of the wide spectre of conditions that the SeaClear 2.0 system will be facing. For each demo/pilot site, summary of specific ML fractions has been described, along with the estimations of the ML fractions size, graded according to the protocol defined in the Guidance on Monitoring of Marine Litter in European Seas (A guidance document within the Common Implementation Strategy for the MSFD) [16], which divides ML fractions in following categories: A. < 5cm*5cm = 25cm²; B. < 10cm*10cm = 100cm²; C. < 20cm*20cm = 400cm²; D. < 50cm*50cm = 2500cm²; E. < 100cm-100cm = 10000cm² = 1m²; F. > 100cm-100cm = 10000cm² = 1m².

DEMO SITES	Marseille site	PROJECT SHOWCASE DOMAIN COVERED	SHORT DESCRIPTION OF THE SITE
		Tourism in coastal areas and recreational freshwater lakes; Ports (both small and large, including water transport); Protected natural areas	Marseille coastal waters suffer from anthropic pressure with a lot of ML hotspots. We will carry out demonstrations within Marseille harbour, at the Arenc dock, and at the Corbières beach on the west of Marseille bay. The Aygalades rain water outfall reaches the sea in the Arenc and during storms litter is drained all along the outfall overpassing containment grids down to the dock. The Corbières beach is one of the most polluted beaches in the city. E.g., Both sites are thus excellent candidates for litter cleaning, and SST seaside facilities are located in between these two sites at just ½ hour sailing from one or the other. Demonstrations will also be carried in the protected area of Calanques. The cliffs of the Calanques are a natural wonder, a unique kind of geological formation made of limestone. They are big rocky coves forming a steep and narrow valley inland and are mostly found around the Mediterranean sea. The Calanques National Park is a protected and highly regulated area, stretching over 20 km from Marseille to Cassis, with 26 Calanques of various sizes (25 in Marseille and 1 in Cassis). Marine biodiversity in Calanques area is exceptional. This area is also under tourism impact, including nautical tourism, thus special care should be taken in order to preserve the area and achieve sustainable tourism with minimal waste impact. Recreational navigation and maritime transport of passengers are highly regulated. The transport of passengers requires prior authorisation from the Calanques National Park. The speed is limited to 5 knots within 300 metres of the shore. Yellow buoys mark out restricted areas. Some areas are forbidden to anchor.
		ML TYPOLOGY	

<table>
<tr><td></td><td></td><td colspan="2">For the Marseille site, research by Vlachogianni, Th. from 2019 and Bergmann et al from 2015, along with data provided by SST, has been analysed. For the beach litter data for the Marseille area, average litter density was calculated to be 1048 items/100m. The majority of litter items (82%) were made out of plastic, which is also a category of litter dominant on beaches all over the world. The second most abundant group of litter items found were glass/ceramics (7%) and processed wood (6%). Items made of rubber accounted for 2%, while metal for 1%, paper for 1% and cloth/textile for 1%. Plastic pieces < 50 cm accounted for the highest percentage 16.3% (4,012 items) of the total litter items recorded, followed by polystyrene pieces < 50 cm with 5.6%. The third most abundant items were mussel and oyster nets with 5% and unidentified plastic caps/lids with a 5%. Other identifiable plastic/polystyrene items, plastic drink bottles >0.5l, plastic caps/lids from drinks, other glass items, plastic drink bottles <=0.5l and other wood < 50 cm were among the top 10 items found [12]. In the northern Mediterranean Sea, in an offshore area of ca. 100 × 200 km between Marseille and Nice and also in the Corsican Channel, floating debris was quantified during marine mammals' surveys. A maximum of 55 pieces km² was recorded, with strong spatial variability. While plastic material accounted for the highest proportion (83 %) of the floating ML, textiles, paper, metal, and wood comprised 17 % [13]. According to the UNEP/MAP Marine Litter Assessment in the Mediterranean from 2015, for the southern France, ML density on seafloor for depths from 0 – 800m, accounts 76-146/ km² [1]. For the item compositions, plastic is predominant, accounting 60-80%. In 2021, during one clean-up action, altogether 480 kg of litter was collected. Specific is that heavier ML fractions are also observed, such as scooters and household appliances, and some of the fractions connected to the port activities.

<u>Summary of main ML fractions that will be subject of the SeaClear 2.0 use case:</u>
Sea surface – various floating plastic items.
Seafloor – heavier ML fractions, plastic, rubber (car tyres and similar), and metal, all connected to the port activities.
ML fractions size estimations: from A. < 5cm*5cm = 25cm² to F. > 100cm-100cm = 10000cm² = 1m²</td></tr>
<tr><td></td><td rowspan="2">Dubrovnik site</td><td>PROJECT SHOWCASE DOMAIN COVERED</td><td>SHORT DESCRIPTION OF THE SITE</td></tr>
<tr><td></td><td>Tourism in coastal areas and recreational freshwater lakes; Fisheries and aquaculture; Protected natural areas</td><td>Dubrovnik Neretva County (aquaculture, fishing, protected areas, tourism), situated at the southernmost tip of the Croatian Adriatic coast, is affected by oncoming marine litter from the Eastern and Central Mediterranean basins. Mali Ston bay is responsible for around 85% of total Mediterranean production of the European flat oyster. The area was declared a Special Natural Reserve in 1983 and is a part of the Natura 2000 ecological network. Unfortunately, all equipment used directly or indirectly for bivalve and fish farming has been prone to snapping and falling to the seafloor or just being discarded in the sea. The aim of our demos here is to find and collect lost and discarded fishing gear in the sea, illustrating the effectiveness of the SeaClear 2.0 system as a tool for supporting sustainable fishing and aquaculture and as a comparison to traditional methods of cleaning marine waste. We are planning to set demo sites at Mali Ston Bay and at specific fishing locations around Dubrovnik-</td></tr>
</table>

Neretva County. We will exploit the clear water to focus in particular on litter mapping and classification from visible-light cameras.

ML TYPOLOGY

The major area of Dubrovnik Neretva County is under influence of large amounts of ML. Because of its specific geographic location, being the southernmost county in Croatia, severe amounts of waste carried by marine currents and waves reaches the shores from neighbouring countries, usually occurring in autumn. Form total of 4 hotspots in Adriatic Sea, 3 are located in Dubrovnik Neretva County (Mljet, Korčula, Lastovo). Besides the ML from neighbouring countries, one of the most important sources are inland tourism activities. In SeaClear 2.0, Dubrovnik demo site will be subject to ALDFG litter and specific ML fractions from mariculture, i.e., shellfish farming activities in Mali Ston Bay. Official data on ALDGF litter in this area were not available, but because of specific oceanographic conditions and geographical configurations, due to the fact that the southern part of the Adriatic, where Dubrovnik site is located, has a depression in which the depths drop sharply and counting the maximum Adriatic depth of the 1233 m, it is to assume that huge amounts of ALDFG are being accumulated in the area. Two EU projects have conducted research in order to have an overview of the ML that can be found on the Dalmatia coastline, including the Dubrovnik Neretva sites. Project DeFishGear (2013 – 2015) and project ML-repair (2018-2019), implemented by experts from the Institute of Oceanography and Fisheries in Split, showed that the most common items found in the collected waste from the sea were pieces of plastic and Styrofoam measuring 2,5 - 50 cm, ear sticks, plastic plugs for all purposes and severe amounts of cigarette butts, especially in touristic areas. From the floating waste material, over 90% of the items found were of plastic origin, followed by paper items and those made of processed wood. On the seafloor, different metal objects could be found, along with accumulated plastic, trapped in the rocky coastline and seafloor, including protected areas of *Posidonia* beds along the Croatian coastline. As for the specific ML fractions in Mali Ston Bay that will be one of the SeaClear 2.0 showcase subjects, a recent overview of ML litter in Mali Ston Bay was observed through 2 clean-up actions done by DUNEA and UNIDU, through MARLESS project, all in 2022. For the 1st clean-up action, altogether 206,73 kg of waste was pulled out of the sea bottom on transect size of approx. 2000 m^2, counting 354 items in total, composed of plastic, glass, rubber and metal. Considering analysis by origin, majority of items was connected to the mariculture activities of the area, i.e., of sea origin, and the main item collected were plastic pergolars - shellfish farming "socks" used in oyster and mussel farming with more than 67 kg of wet weight belonged to this item fraction. Considering the total number of items collected, the most numerous waste fraction was glass, counting total of 244 items, followed by plastic items counting 55 items. In the 2nd clean-up action, altogether 217,75 kg of waste was pulled out of the sea bottom on transect size approx. 3000 m^2, counting 83 items in total, composed of plastic, glass, rubber and metal. Considering analysis by origin, majority of items was connected to the mariculture activities of the area, same as for the 1st clean-up action. The main items collected were also plastic pergolars - shellfish farming "socks" used in oyster and mussel farming with more than 105 kg of wet weight. The most numerous waste fraction was also plastic, counting 63 items and only 10 glass fraction items. The most numerous were smaller round plastic crates (15 items) and bigger square plastic crates (D < 50cmx50cm

		= 2500cm2, 20 items), all items used in shellfish farming. These fractions were in a really good condition, only covered in biofouling, with high potential to be reused. Summary of main ML fractions that will be subject of the SeaClear 2.0 use case: Sea surface – various floating plastic items, floating ML hotspots arriving from neighbouring countries in large patches during autumn period. Seafloor – various plastic items entangled in protected *Posidonia* meadows, specific ML from shellfish farms (oyster and mussel pergolars tangled in large patches, plastic crates from shellfish farming, farming construction pieces, etc.) and ALDFG. ML fractions size estimations: from A. < 5cm*5cm = 25cm² to F. > 100cm-100cm = 10000cm² = 1m²	
	Tarragona site	**PROJECT SHOWCASE DOMAIN COVERED**	**SHORT DESCRIPTION OF THE SITE**
		Tourism in coastal areas and recreational freshwater lakes; Ports (both small and large, including water transport)	Tarragona (ports, tourism, fishing) is a port city and a tourist attraction of the first order. The city houses the largest chemical hub in southern Europe. The Port of Tarragona plays a key role in the competitiveness of this hub. The combination of maritime traffic/port operations, tourism, fishing, and industrial activities gives rise to large amounts of marine litter and therefore is an opportunity for demonstrations/tests on different spots to cover all potentialities of SeaClear2.0. Industrial stakeholders: Besides Tarragona Port and Marina Tarraco, TECNOSUB will engage the Association of Chemical Companies of Tarragona, companies responsible for an important part of pollutants in the area, who already confirmed interest in the project. Touristic: Local and regional administrations will be invited with public organizations involved in touristic promotion of the area (Tarragona Tourism, Costa Daurada Tourism) and Local Federations of Hotels, Campings and touristic lodgement. Academic: Tarragona University, Catalonia Technological Research Centre. Environmental: Mother Earth Foundation Mediterranean.
		ML TYPOLOGY	
		According to data provided by TECHNOSUB, obtained from Tarragona's University research group and Tarragona Port Authority database, main contamination in Tarragona area are microplastics. 57% of them due to clothing fibres. By type of plastic: polypropylene (42%), polystyrene (37%) and polyethylene (16%). Regarding ML on beaches, according to Spanish Government reports, for the total of 70 km beach area, eight most abundant items that account for 62% of the total are: – plastic fragments not identifiable < 50 cm, 30.8% – shopping bags (or recognizable pieces), 7.6%, – small bags (bags for frozen fruit and similar) 5.2%, – fragments of expanded or extruded polystyrene between < 2.5 cm, 5.2%, – plastic caps, stoppers, and corks, 4.7%, – plastic ropes and ropes (diameter > 1 cm), 4.3%.	

As for seafloor ML, Saladie et al from 2021, reported that the biggest concertation of debris can be found on depths ≤100 m. The density of marine litter in the swept area of the Gulf of Sant Jordi was 130 items km². The vast majority of observed ML was made of plastic, 80% of the total. The most abundant objects were plastic bags and sanitary waste (mainly wet wipes), followed by plastic bottles (<2 L). Statistically significant differences were observed, both in the amount and characterization of the ML, considering the time of year the trawl collection was performed (summer vs. autumn) and the depth at which it was conducted (hotspots ≤100 m depth). The ML collected for the summer period accounted for 65.2% of the total, with the remaining 34.8% corresponding to the first month of autumn [15].

Summary of main ML fractions that will be subject of the SeaClear 2.0 use case:
Sea surface – various floating plastic items.
Seafloor – plastic items up to 100m depth, specifically plastic bags, and sanitary products. It is estimated that in the relative port area, heavier ML fractions, plastic, rubber (car tyres and similar), and larger metal items will also be found, all connected to the port activities.
ML fractions size estimations: from A. < 5cm*5cm = 25cm² to E. < 100cm-100cm = 10000cm² = 1m²

PILOT SITES

Venice site

PROJECT SHOWCASE DOMAIN COVERED	SHORT DESCRIPTION OF THE SITE
Tourism in coastal areas and recreational freshwater lakes	Venice Lagoon is the largest coastal transitional ecosystem in the Mediterranean and, at the same time, one of the UNESCO World Cultural and Natural Heritage sites. It is characterized by a maze of channels (maximum depth exceeding 15m), which cut across a large area of shallow waters (average depth of 1m), fens and salt marshes. It is founded in the 5th century and spreads over 118 small islands. Venice became a major maritime power in the 10th century. The whole city is an extraordinary architectural masterpiece in which even the smallest building contains works by some of the world's greatest artists. Venice has several factors playing a part in plastics pollution due to its unique features, in terms of morphological setting and density of resident (decreasing) and transient population (increasing). Ten rivers flow into Venice Lagoon bringing in the plastic litter along their path. Finally, Venice has its port that stretches over an area of more than 2,045 hectares, to 5% of the total surface of the Municipality of Venice. Within the port there are two very distinct areas, namely Porto Marghera- which hosts the logistics, commercial and industrial activities -, and the Port in Venice, which has mainly risen around the Marittima passenger port and minor berths where passenger services are organized and supplied to cruise ships, hydrofoils, and yachts. In 2022 Venice got 13 million tourists with an increasing trend. [17].

ML TYPOLOGY

For the Venice site, a paper from Madricardo et al from 2019 and paper from Renzi et al from 2020 has been observed, along with data provided by VLPF. Marine macro-litter is present throughout the floor of the channels though with highly variable concentrations mainly depending on the economic activities in the adjacent area. The average density amounted 7.5 items/km² and that the highest litter concentration occurred around the cities of Venice, Chioggia, and at the lagoon inlets. In particular, in the Grand Canal, the highest value of mean abundance of ML on the seafloor was found, counting 1161 items/km². The Grand Canal has never been dredged up until the research done in 2019, and it is estimated that it probably contains layers of waste dating back to the foundation of Venice. The abundance and distribution of ML on the seafloor is much less assessed than at the sea surface [9]. According to data provided by VLPF, in cooperation with H2020 project MAESLTROM, in one clean-up action carried out by the MAELSTROM robotic platform, 208 items were recovered from the seafloor, with most of it being pieces of glass items counting 108 items, followed by construction material various fractions. It is also noted that large amounts of car tyres can be found on the Venice lagoon seafloor. In Venice lagoon, recorded mean values of microplastic in sediments is 1445.2 items/kg. The literature highlights that rivers are an important source of microplastics in marine coastal sediments and in transitional water ecosystems. The high pollution levels have been recorded for the Venice lagoon, recording microplastics from all tested sampling sites and demonstrating a wide distribution of this type of pollution in lagoon ecosystems [10].

Summary of main ML fractions that will be subject of the SeaClear 2.0 use case:
Sea surface – various floating plastic items brought by river inflow.
Seafloor – various plastic items, metal and specifically glass bottles and glass fragments, car tyres.
ML fractions size estimations: from A. < 5cm*5cm = 25cm² to E. < 100cm-100cm = 10000cm² = 1m²

Ashdod site	PROJECT SHOWCASE DOMAIN COVERED	SHORT DESCRIPTION OF THE SITE
	Ports (both small and large, including water transport)	Ashdod is a city in the southern coastal plain of Ereẓ Israel. It is one of Israel's two industrial ports. Israel coastal waters have major litter hotspots. The location of Ashdod in the far east end of the basin adds regional diversity to the consortium that can clearly contribute towards the project due to its heavily polluted marine environment. A growing port infrastructure and increasing efforts to attract tourists to the area will likely worsen the current situation.
	ML TYPOLOGY	

<table>
<tr><td rowspan="4"></td><td></td><td colspan="2">For the Ashdod site, two papers were observed, Segal et al from 2022 and Segal et al from 2023. The most abundant ML fractions observed were plastic items (bags, cups, caps, etc.), found in all water depths. Metal products (drinking cans, aluminium cans, etc.) appeared in the shallow and deep stations and probably sank to the bottom close to their disposal point. On some of the plastic items, such as Yuta bags and big industrial bags, marine life has been observed, such as molluscs, Polychaeta, Cnidarian, and Crustacea. It is assumed that the litter coming from the shore was separated by the currents based on weight, where the lighter plastic products drift from the shelf to the slope and beyond, while the heavier waste stays close to the disposal site. Plastic is considered the primary element that composes litter in most beaches studied worldwide, which is also the case in Ashdod, with 85% of ML on beaches being plastic (70 ± 6% of the waste was made of plastic, and 9 ± 5% was made of metals). Beach litter concentration amounts 0.19±0.06 items/m^2 [7]. The seafloor macrolitter concentration was 115 ± 108 items/km^2 in the shallow station and 2885 ± 3397 items/ km^2 in the deep stations. Interesting information is that the hotspot was found at 200-500 m water depth, where litter concentration was 5797 ± 5752 items/km^2 at 200 m water depth and 4713 ± 3034 items/km^2 at 500 m water depth. At the closest stations to the beach (20-60 m water depth), the plastic comprised 84–85 % of the total number of items. The percentage of plastic products increased with depth to 92 % - 98 %. Considering microlitter, fragment debris was dominant in the shallow stations and reached up to 77 % of the samples in Haifa Bay in July 2021. Industrial plastic (pellets) and foam were found only in shallow stations and in rare cases, whereas cosmetic plastic (granules) appeared in the deep stations; most particles found during the investigation were opaque [6].

<u>Summary of main ML fractions that will be subject of the SeaClear 2.0 use case:</u>
Sea surface – various floating plastic items (bags, cups, caps, etc.)
Seafloor – various plastic items (Yuta bags and big industrial bags with possible marine life inside), metal items and specifically various plastic items heavily accumulated on depths 200-500 m. It is estimated that heavier ML fractions will also be found in near proximity of the port, such are various plastic and construction items, rubber (car tyres and similar), and metal, all connected to the port activities.
ML fractions size estimations: from A. < 5cm*5cm = 25cm^2 to E. < 100cm-100cm = 10000cm^2 = 1m^2</td></tr>
<tr><td rowspan="3">Hamburg site</td><td>PROJECT SHOWCASE DOMAIN COVERED</td><td>SHORT DESCRIPTION OF THE SITE</td></tr>
<tr><td>Ports (both small and large, including water transport); River and channels in urban areas</td><td>Hamburg, offers a different spectrum of requirements on SeaClear2.0 capabilities due to murky water conditions and the litter items found there, ranging from urban and touristic waste to naval equipment, construction items, e-scooters with batteries and UXO. Specifically, the last two pose a threat, e.g., leakages will harm water quality and marine species and uncontrolled explosions due to corroding ammunition can severely disturb port operations.</td></tr>
<tr><td colspan="2">ML TYPOLOGY</td></tr>
</table>

		For the specific Hamburg site – Hamburg port, the data was provided by HPA database. ML occurrence is relatively small in regards to the overall size of the Hamburg Port which spreads over 7,000 ha. Roughly 2,800 ha are considered water area, as the city is located at the Elbe river connecting it to the North Sea. Even though the river is in frequent use, ML occurrence in general and the amount are rather small. However, the litter that can be found, is there for different reasons. Some of it may be carried in by the respective river and tidal currents and other may be attributed to the urban environment, because the riverside is a popular place to spend time for tourists and residents. Wind, heavy rain and storm floods during late fall, winter and early spring time may cause debris inflow into the river as well as parts of the port are subject to flooding, that carries away loose objects. Other litter to be found can be considered historic remains from world war II, former ship building and fishing as well as goods handling activities in the area. Overall Hamburg does not have a waste problem, but contamination does exist. ML fractions that can be found in Hamburg port, ranges from large to small objects such as: – tools and equipment from operation and maintenance works on infrastructure and ships – vehicles, tires, machine parts, steel beams, scooters, and shopping carts – ammunition and unexploded ordnance – large pieces of wood – plastic bags, canisters, beverage cans and other plastic parts. These contaminations can essentially be detected on three levels. On the water surface, in an area of approx. 1.5 meters below the water surface and at the bottom of the Elbe. Exact information about the respective quantities, especially about the pollution underwater, can unfortunately not be given at present. The existence of these, however, is shown on the one hand by net bycatch from fishing and on the other hand by the salvaged material that comes to light during sediment sampling or during dredging. The latter is a constant process in the port of Hamburg in order to maintain sufficient water depth for the safe and secure passage of seagoing vessels. Hydrographic soundings have also yielded corresponding findings. Debris can be spotted in areas that dry off during low tide on a regular basis. Smaller quantities of floating litter wash ashore and partially submerged items reappear. <u>Summary of main ML fractions that will be subject of the SeaClear 2.0 use case:</u> Sea surface – various floating plastic items from the onshore activities. Seafloor – mostly heavy items (lost tools and equipment from operation and maintenance works on infrastructure and ships, tyres, etc.) ML fractions size estimations: from A. < 5cm*5cm = 25cm² to F. > 100cm-100cm = 10000cm² = 1m²

Table 3: Detailed description of each demo/pilot site with corresponding project showcase domain and ML typology

The majority of the ML fractions found in project locations are of plastic compound, followed by rubber, metal, and glass items; cloth, paper, and wood are rare. ML fractions on the sea surface that will be tackled by the SeaClear 2.0 system are various floating items. The lighter floating plastic items are prone to be carried away by the sea currents, depending on the oceanographic conditions of the area, and eventually sink on the seafloor. Thus, we have the example of the Ashdod area, where plastic items such are plastic bags, bottles, etc, are usually found accumulated at the highest depths, from 200 to 500 m, carried away by the ocean movements. It is concluded that the presence of plastic items does not have a strong dependency on human activities on the nearby shore area, i.e., the proximity of the waste source. For example, we have the Dubrovnik Neretva site where huge amounts of floating litter arrive from the neighbouring countries, carried away by the marine currents. In the case of the heavier macrolitter on the seafloor, such are heavier plastic items, rubber, metal, and glass fractions, unlike the lighter plastic items, accumulation directly depends on the human activities in near proximity. It is estimated that the litter is separated by the currents based on weight, where the lighter items drift away, in depths or in surface patches, while the heavier waste stays close to the disposal site. This is specifically the situation in shellfish farming areas, large beaches, and ports. In the case of ALDFG waste, once the fishing gear enters the oceans, it continues its movement in the depths and poses a great threat to marine life. We can find them freely floating in the water column but eventually trapped on the marine corals, rocks, and marine life in general. For the locating of ALDFG, the fishermen's boat routes should be examined.

In order to have a more detailed analysis of the litter that can be found in the different regional seas, according to the Master list of litter items defined in the Guidance on Monitoring of Marine Litter in European Seas [16], we listed 100 most frequent waste fractions, divided by composition, with a note if it can be found on the sea surface and/or seafloor, see Table 4.

MATERIAL	#	ITEM GENERAL NAME	MAX ESTIMATED SIZE CATEGORY*	LOCATION	
				sea surface	seafloor
PLASTIC	1	Shopping plastic bags	D	x	x
	2	Small plastic bags, e.g., free freezer bags, incl. plastic bag pieces	C	x	x
	3	Plastic bottles <=0,5 L	C	x	x
	4	Plastic bottles >0,5 L	D	x	x
	5	Plastic buckets	D	x	x
	6	Cleaner bottles and containers	D	x	x
	7	Food containers, incl. fast food containers	D	x	x
	8	Various cosmetic bottles and containers <=20 cm	C	x	x
	9	Various cosmetic bottles and containers <50 cm	D	x	x
	10	Engine oil bottles <50 cm	D	x	x
	11	Engine oil bottles >50 cm	E	x	x

	12	Various crates and containers	D	x	x
	13	Plastic cups and lids	A	x	x
	14	Various plastic items and fractions<=20cm	C	x	x
	15	Cutlery and trays	C	x	x
	16	Straws	C	x	x
	17	Cover/packaging	D	x	x
	18	Mussel/oyster nets - pergolars	F		x
	19	Synthetic ropes	E		x
	20	Fishing net < $1m^2$	E		x
	21	Fishing net > $1m^2$	F		x
	22	Fishing line	F	x	x
	23	Tangled nets	F		x
	24	Fish boxes	D		x
	25	Floats for fishing nets	C	x	x
	26	Buoys =>50cm	D	x	x
	27	Sheets, industrial packaging, plastic sheeting	D	x	x
	28	Car parts	E		x
	29	Hard hats/Helmets	D		x
	30	Shoes/sandals	D		x
	31	Traffic cones	D		x
	32	Foam sponge	C	x	x
	33	Telephone (incl. parts)	C		x
	34	Plastic construction waste	F		x
	35	Cable ties	F		x

	36	Sanitary towels/panty liners/backing strips	C		x
	37	Toilet fresheners	C	x	x
	38	Diapers/nappies	D		x
	39	Medical/Pharmaceuticals containers/tubes	C	x	x
	40	Flip-flops	D	x	x
	41	Sunbeds	F		x
	42	Styrofoam packaging (boxes, etc.) >50cm	D	x	x
	43	Cigarette butts and filters	A	x	x
	44	Various plastic fragments <20cm	C	x	x
RUBBER	45	Rubber gloves	C		x
	46	Balls	D	x	x
	47	Rubber boots (scuba diving bots)	D		x
	48	Bicycle tyres	E		x
	49	Car tyres	F		x
	50	Large industrial tyres	F		x
	51	Tractor tyres	F		x
	52	Rubber belts	F		x
	53	Various wheels	F		x
	54	Other rubber pieces <=50 cm	D		x
	55	Other rubber pieces >50 cm	F		x
CLOTH	56	Clothing (various clothes)	E		x
	57	Shoes	D		x
	58	Clothing rugs and towels	F		x
	59	Backpacks and bags	E		x

	60	Carpets and furnishing	F		x
	61	Ropes	F		x
	62	Other textile pieces >50cm	D		x
METAL	63	Aerosol/Spray cans industry	D	x	x
	64	Cans (beverages and food)	C		x
	65	Foil wrappers	C		x
	66	Disposable BBQ's	E		x
	67	Appliances (refrigerators, washers, etc.)	F		x
	68	Tableware (plates, cups & cutlery)	D		x
	69	Fishing related (weights, sinkers, lures, hooks)	C	x	x
	70	Middle size containers <50 cm	D		x
	71	Gas bottles, drums & buckets (> 4 L)	D		x
	72	Wire, wire mesh, barbed wire	E		x
	73	Barrels	F		x
	74	Car parts / batteries	F		x
	75	Cables	F		x
	76	Household Batteries	B		x
	77	Large metallic objects (various)	F		x
	78	Other metal pieces < 50 cm	D		x
	79	Other metal pieces > 50 cm	E		x
GLASS	80	Bottles incl. pieces	C		x
	81	Jars incl. pieces	D		x
	82	Light bulbs	C		x
	83	Tableware (plates & cups)	C		x

	84	Construction material (brick, cement, pipes)	F		x
	85	Glass buoys	E	x	x
	86	Glass or ceramic fragments >2.5cm	B		x
	87	Large glass objects >50 cm	E		x
PAPER	88	Paper/Cardboard	E	x	x
	89	Cardboard (boxes & fragments)	E	x	x
	90	Cups, food trays, food wrappers, drink containers	D	x	x
	91	Newspapers & magazines	D	x	x
	92	Cartons/Tetra pack Milk	C	x	x
	93	Other paper items =<20 cm	C	x	x
	94	Other paper items =<50 cm	D	x	x
WOOD	95	Corks	A	x	x
	96	Processed timber	E	x	x
	97	Crates	E		x
	98	Various boxes (fish boxes)	E	x	x
	99	Ice-cream sticks, chip forks, chopsticks, toothpicks	A	x	x
	100	Various processed wooden items >50cm	E	x	x

Table 4: List of 100 most frequent ML fractions divided by composition with a note if it can be found on the sea surface and/or seafloor

* A. < 5cm*5cm = 25cm²;
B. < 10cm*10cm = 100cm²;
C. < 20cm*20cm = 400cm²;
D. < 50cm*50cm = 2500cm²;
E. < 100cm-100cm = 10000cm² = 1m²;
F. > 100cm-100cm = 10000cm² = 1m².

It is estimated that all of these 100 ML fractions can be found all over the Mediterranean Sea. Approx. 45% of the items will be found in the floating ML patches, before settling on the seafloor. All of the marine litter will eventually reach the sea bottom, land on our shores and beaches, or unfortunately, end up in biota, ingested by marine mammals and turtles, entangled on sea birds. By analysing the approx. size grade for each item (max possible size), it is concluded that 32% of the items belong to grade D (< 50cm*50cm = 2500cm²), followed by items in size C (< 20cm*20cm = 400cm²) and F (> 100cm-100cm = 10000cm² = 1m²), see Chart 1. F size category is most diverse and here we rank all items that can be larger than 1m². In the F category, we grouped the specific ML fractions such are mussel/oyster nets (pergolars), pieces of shellfish farm constructions, and ALDFG items.

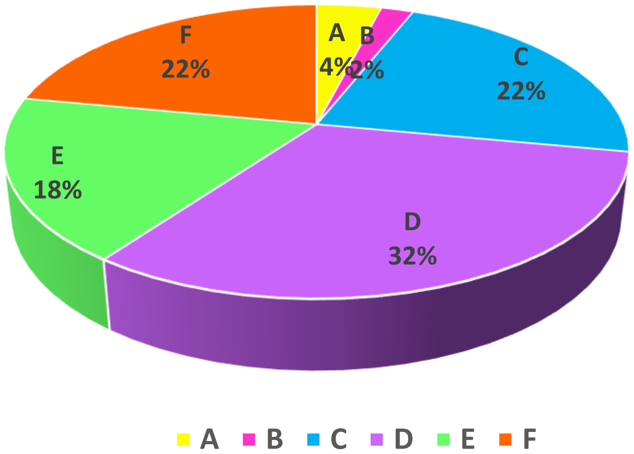

Chart 1: Percentages for each size grade for the list of 100 most frequent ML fractions *(A. < 5cm*5cm = 25cm²; B. < 10cm*10cm = 100cm²; C. < 20cm*20cm = 400cm²; D. < 50cm*50cm = 2500cm²; E. < 100cm-100cm = 10000cm² = 1m²; F. > 100cm-100cm = 10000cm² = 1m²)*

As for the analysis of the data on the density of items found on the seafloor (number of items per km²) for the depth from 0 to 100 m, the average density for the SeaClear 2.0 demo/pilot sites is 325,66 items per km². Data for the Venice site extremely vary depending on the location, i.e., the proximity of the urban area, with 7.5 items per km² being an average for the entire Venice lagoon area, but the extreme number of 1161 items per km² found in the Venice Grand Canal. As already mentioned, there is also an exception for the Ashdod site, where the ML density extremes are observed at the depths at 200 m, counting 5797 ± 5752 items/km², while density at depths up to 100 is more than twice lower. Data for the Hamburg port is not exact, but the estimation is to have 50 items per km². See the graphic overview in Chart 2.

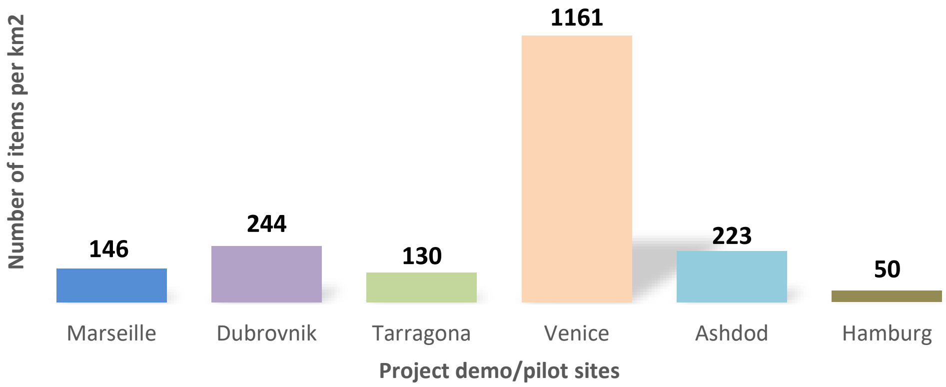

Chart 2: Density of ML items on seafloor for depths 0-100m

Plastic waste is as diverse as human cultures, customs, needs, and lifestyles. Most frequent items are plastic bags, bottles in various sizes, plastic packages, cigarette buts, and similar everyday items. For specific plastic waste connected to SeaClear 2.0 demo/pilot site, we have waste from shellfish farms, especially so-called *pergolars* (see Figure 3). They are long, tubular nets used in shellfish – oyster and mussel farming procedures, attached on ropes and placed under the sea surface, for the purpose of growing oysters and mussels to commercial size. In the clean-up actions, divers are finding these nets entangled and abandoned on the seafloor.

Figure 3. Pergolars – oyster nets from Dubrovnik Neretva Mali Ston Bay, from left with attached oysters for the farming, to the entangled patches taken by divers from the seafloor (photo source: DUNEA database)

Extremely hazardous plastic ML fractions are for sure ALDFG. There is no overall figure for the proportion of ALDFG in marine litter. According to FAO [17], negative impacts of this ML fraction, include navigational hazards and associated safety issues, the ability of ALDFG to continue to fish (often referred to as ghost fishing), with detrimental impacts on fish stocks, with no generation of economic benefits and with potential impacts on vulnerable or threatened species and on benthic and inter-tidal environments (see Figure 4).

Figure 4. ALDFG litter (photo sources: https://www.downtoearth.org.in/blog/pollution/plastic-waste-woes-a-primer-on-india-s-marine-litter-problem-87059; https://africaneyereport.com/wp-content/uploads/2023/07/loggerhead_turtle_trapped_in_a_net_in_the_mediterranean.jpeg; https://www.worldatlas.com/articles/what-are-ghost-nets.html; https://www.worldwildlife.org/stories/our-oceans-are-haunted-by-ghost-nets-why-that-s-scary-and-what-we-can-do--25)

As for the metal waste, the SeaClear 2.0 demo/pilot sites are facing the specific large metallic items connected to the port activities, which is not strange, since from a total of 6 demo/pilot sites, 4 sites are important ports (Marseille, Tarragona, Ashdod, Hamburg). According to the experience and data available to project partners coordinating these demos/pilots, SeaClear 2.0 sites are also subject to home appliances waste, abandoned transportation vehicles such are scooters, pieces of shellfish farm constructions, and similar large items (see Figure 5).

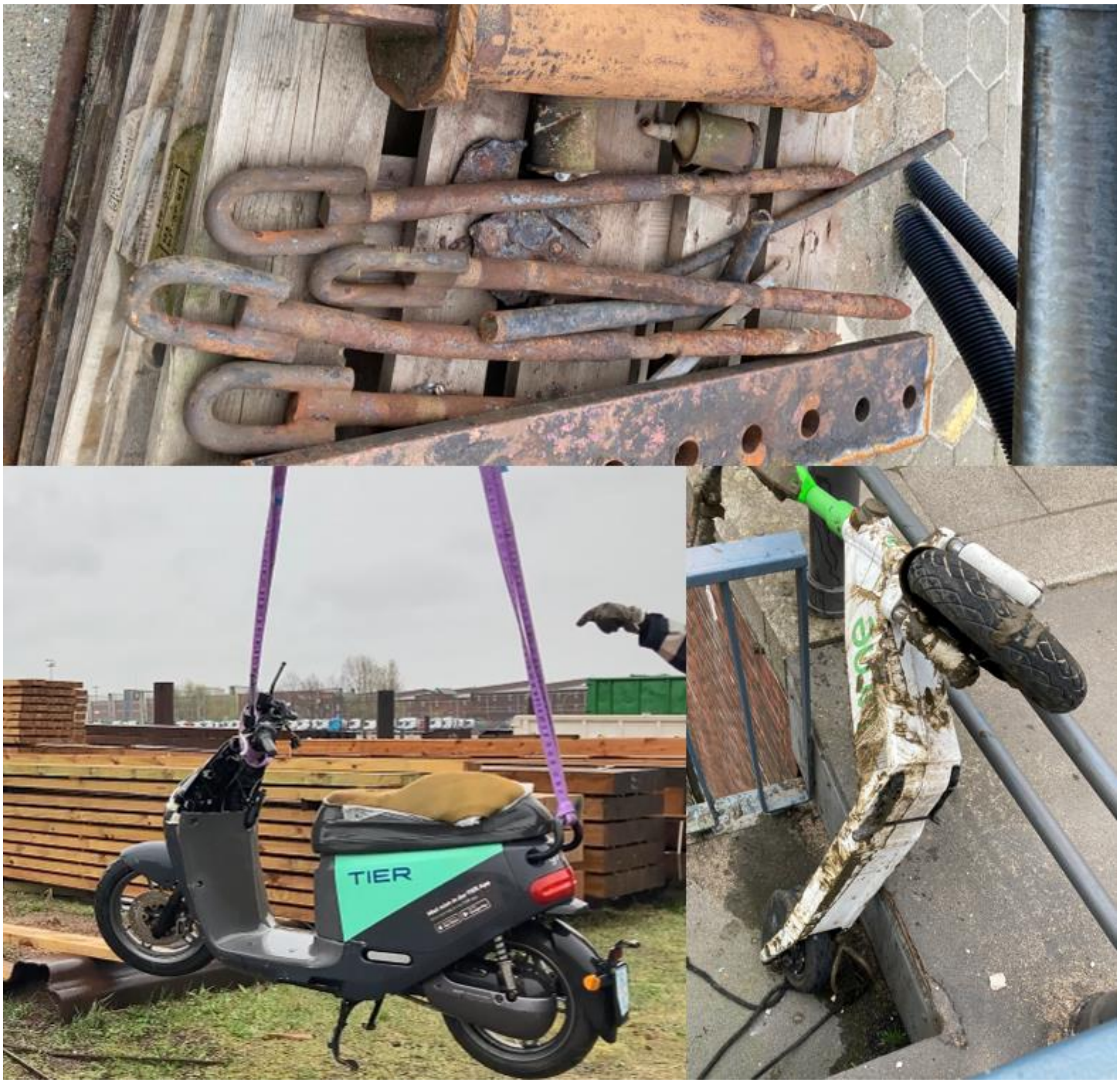

Figure 5. Large metal objects connected to the port activities (photo sources: HPA database)

In the case of rubber ML, project demo/pilot sites are mostly facing tyres of all sizes, from smaller vehicles wheel, to large industrial tyres (see Figure 6). In the case of shellfish farms, the tyres are used as shore fenders for vessels operating and monitoring the farming procedures.

Figure 6. Rubber ML – various size tyres (photo sources: HPA and DUNEA database)

Glass ML fractions are usually classified under the D category, meaning all items smaller than 50 cm in length, with the most frequent items being various glass bottles. It is presumed that the presence of glass bottles is directly connected to tourism activities on shore (hospitality industry, etc.), and nautical tourism, especially in the high-season touristic period. Paper, wood, and cloth ML, are not so frequent items to be found on the seafloor and sea surface. These materials do not pose such a threat to marine environment, as is the case with plastic waste.

Project demo/pilot sites cover a wide spectre of human activities producing different waste fractions, where the shape, volume, and weight of ML fractions will be one of the main bases in defining the final technical specifications of the SeaClear 2.0 system, in order for it to operate in various conditions.

4. Challenges for SeaClear 2.0 system for each project domain

4.1 Achieving GES – list of relevant MSFD descriptors

In order to qualify the SeaClear 2.0 system in the context of achieving GES, we have made a corelation between the project and MSFD qualitative descriptors. This analysis shows in what way the project corresponds to the EU holistic framework challenges, in achieving its objectives, to protect and conserve its coasts, seas, and the ocean. This also enable us to observe the challenges that will tackle the System. See Table 5.

MSFD DESCRIPTORS	RELATION TO THE SeaClear 2.0 PROJECT
D1. Biodiversity is maintained	By reducing the large amounts of marine litter from the seafloor, the system developed within SeaClear2.0 will allow for the seafloor biodiversity to be restored. Also, by answering to challenges of ALDFG, and reducing its amount, of litter it will prevent ghost fishing as another cause of reduction of biodiversity.
D2. Non-indigenous species do not adversely alter the ecosystem	Early detection of an invasive non-indigenous species can be incorporated into the AI-based SeaClear2.0 recognition subsystem used for differentiating litter vs sea life. Transport of invasive non-indigenous via ML fractions, will be significantly reduced with our system, thus helping in reducing spreading of these species.
D3. The population of commercial fish species is healthy	By reducing marine litter, the population of commercial fish will benefit from less pollutants in their environment, thus increasing the number of healthy species.
D4. Elements of food webs ensure long-term abundance and	Chemical substances, or microplastics that accumulate in marine organisms can be reduced by eliminating the amount of marine litter, thus the SeaClear2.0 project will directly address this MSFD descriptor, which will be achieved by

reproduction	fulfilling the project key objectives: – to reduce the pollution from litter and plastics in the Mediterranean sea basin and in regions outside the Mediterranean sea basin, – to engage stakeholders, transfer knowledge and empower the citizens through innovative, participatory activities that will build ocean literacy and provide opportunities for active participation in marine litter identification, collection, and monitoring, – to develop an upscaled technologically innovative solution, both by demonstrating multiple systems working together to multiply the area covered, and by increasing the capabilities of the individual system with better sensing, collection, and handling larger objects and depths, and – to outline the policy recommendations and a business plan to bring forth the innovative technologies for marine litter collection and reuse/recycling into everyday use.
D5. Eutrophication is minimised	Reducing human-induced eutrophication can be done through changes in legislation and raising awareness to sea pollution and how pollutants are introduced to marine environments. This will be addressed through key objectives: – to reduce the pollution from litter and plastics in the Mediterranean sea basin and in regions outside the Mediterranean sea basin, – engage stakeholders, transfer knowledge, and empower the citizens through innovative, participatory activities that will build ocean literacy and provide opportunities for active participation in marine litter identification, collection, and monitoring, – to outline the policy recommendations and a business plan to bring forth the innovative technologies for marine litter collection and reuse/recycling into everyday use.
D6. The sea floor integrity ensures functioning of the ecosystem	Our environmental WP8 will lead to decisions on whether to collect litter based on how risky collecting it would be in view of not harming marine flora, fauna, and environment which will be achieved, through key objective: – to reduce the pollution from litter and plastics in the Mediterranean sea basin and in regions outside the Mediterranean sea basin.
D7. Permanent alteration of hydrographical conditions does not adversely affect ecosystem	The SeaClear2.0 systems can also be used for monitoring the hydrographical conditions characterized by the physical parameters of seawater temperature, salinity, depth, currents, waves, turbulence, turbidity.

D8. Concentrations of contaminants give no effects	To monitor nutrient losses and pesticide concentrations, we will consider adding sensors including pH, ORP, conductivity, dissolved oxygen, turbidity, ammonium, chloride, nitrate, salinity, mV, ORP, TDS, or resistivity. Moreover, we specifically plan to raise awareness of this issue for relevant stakeholders through reduction of the pollution from litter and plastics in the Mediterranean sea basin and in regions outside the Mediterranean sea basin and while engaging stakeholders, transferring knowledge and empowering the citizens through innovative, participatory activities that will build ocean literacy and providing opportunities for active participation in marine litter identification, collection and monitoring.
D9. Contaminants in seafood are below safe levels	Microplastic ingestion by marine organisms is shown to cause the bioaccumulation of contaminants and their transportation up the food chain. By removing plastic litter from the marine environment SeaClear2.0 can contribute to the reduction of microplastics and thus the reduction of contaminants in seafood.
D10. Marine litter does not cause harm	Quantities of marine litter are reduced significantly by the SeaClear2.0 system by at least 57% over the area where it works, see our KPIs and key objectives.
D11. Introduction of energy (incl. underwater noise) does not adversely affect ecosystem	To prevent increasing harmful anthropogenic noise, we will focus on high-frequency sonars largely above 300kHz, typically 1.8 and 3 MHz, whereas fishes and marine mammals' hearing ranges lie largely below this value [HB17].

Table 5: List of MSFD descriptors in relation to the SeaClear 2.0

4.2 Definition of SeaClear 2.0 use cases in corelation with showcase domains and MSFD descriptors

The SeaClear2.0 platform will provide a new service of robotic underwater cleaning in variety of marine conditions, including the industrial and tourism value chains. In Table 5, the initial project use cases concept is described, all in corelation to the project showcase domains for the exact project demo/pilot sites and future associated regions. Definition of project use cases, is ground base for the formulation of the system requirements. For the details, see Table 6.

DOMAIN	CORRESPONDING PROJECT DEMO/PILOT LOCATION	POTENTIAL LOCATION FOR ASSOCIATED REGIONS	MSFD DESCRIPTOR (see Table 4 for details)	USE CASE
Tourism in coastal areas and recreational freshwater lakes	Marseille site; Venice site; Tarragona site; Dubrovnik Neretva site	Mediterranean Sea or nearby lakes (e.g., Greece, Turkey, Tunisia, Montenegro)	D1, D2, D6	Marine litter (especially plastic from land & water-based tourism activities) caught in protected habitats. Challenge: remove while protecting biodiversity and leaving habitats undamaged.
Ports (both small and large, including water transport)	Marseille site; Hamburg site; Ashdod site; Tarragona site	Mediterranean Sea - Northern Africa (e.g., Tunisia, Morocco)	D2, D11	Monitoring of the water quality in ports, detection and removal of bulky sea debris found in ports, at various depths, not removable with human divers.
Fisheries and aquaculture	Dubrovnik Neretva site	Scandinavia (e.g., Norway) OR United Kingdom	D3, D4, D7, D8, D9	Traditional aquacultural activities with extensive fish farming (freshwater and marine) facing challenges from lost fishing gear, aquacultural equipment and impacts of water quality (nutrients, microplastic). SeaClear 2.0 system challenge will be finding and the removal of ALDFG waste and specific waste from shellfish farms.
Protected natural areas	Dubrovnik Neretva site; Marseille site	Portugal - Azores OR Scotland-Faroe Islands or Rosemary Bank Seamount OR Alboran Sea	D1, D2, D4, D5	Natura 2000 areas, marine reserves, Volcanic Islands, marine debris is found here in demanding retrieval conditions; protecting ecosystems ranging from microorganisms to ocean mammals (whales, dolphins) and their habitat.
River and channels in urban areas	Hamburg site	Mediterranean Sea (e.g., Turkey, Greece) or Northern Europe (e.g., Belgium)	D4, D10	Urban canal system heavily used by public and touristic boats/ within a city, strong exposure to small to large scale litter (scooters/ bikes).

Table 6: List of project showcase domains, challenge of the use cases in correlation with MSFD descriptors

5. Summary

Through D2.1, marine litter analysis has been successfully implemented, as the basis for defining the problem the SeaClear2.0 system needs to tackle. SeaClear2.0 project aims to develop an integrated approach to address the entire cycle of marine litter on a wide spectrum of marine conditions and areas all over the Mediterranean region, altogether 6 demo/pilot sites. The guiding thought of the document was project showcase domains as system validation areas, and the correlation between the SeaClear 2.0 work scope, environmental challenges it will be facing, and the ML typology for each site. In this way, we were able to formulate possible robotic solutions for the given problems, i.e., environmental challenges. Investigations of relevant publications have been thoroughly carried out, obtaining the most recent data for the subject of sea debris' various fractions and their occurrence. This document gave a detailed comparison for each project demo/pilot site, with a summary of the main ML fractions that will be the subject of the SeaClear 2.0 use case. Besides the details description of the ML typology of project demo/pilot sites, D2.1 also described the marine litter occurrence in the Mediterranean region in general, with the identification of marine litter hotspots and marine litter typology. This will enable the transfer of knowledge further than the project's main scope itself and easily plan the inclusion of the associated regions that will benefit from the project and vice versa. In order to qualify the SeaClear 2.0 system in the context of achieving GES, we have made a correlation between the project and MSFD qualitative descriptors. This analysis shows in what way the project corresponds to the EU holistic framework challenges, in achieving its objectives, to protect and conserve its coasts, seas, and the ocean.

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