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	WP2: Concept and use cases	**Version:** V3
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SEarch, identificAtion and Collection of marine Litter with Autonomous Robots

SeaClear

https://seaclear-project.eu

D2.1
Use-case definition document
WP2 – Concept and use cases

Grant Agreement no. 871295

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Deliverable description	Deliverable 2.1 investigates and elaborates use case definition, the infrastructure requirements and describes exact test areas – demo sites for demonstrating the use cases. Concept will be validated in Task 2.3. Required inputs are expert knowledge from all partners and stakeholders.

[1] R = Document, report, DEM = demonstrator, DEC = Websites, patents filing, etc. OTHER: Software, technical diagram, etc. ETHICS = Ethics

[2] PU=Public, CO=Confidential, only for members of the consortium (including the Commission Services), CI=Classified, as referred to in Commission Decision 2001/844/EC.

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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. 871295.
- **Consortium:** The SeaClear Consortium, comprising the below-mentioned list of beneficiaries.
- **Consortium Agreement:** Agreement concluded amongst SeaClear Beneficiaries for the implementation of the Grant Agreement.
- **Grant Agreement:** The agreement signed between the beneficiaries and the EC for the undertaking of the SeaClear project (Grant Agreement no. 871295).

Beneficiaries of the SeaClear Consortium are referred to herein according to the following codes:

- **TU Delft:** Delft University of Technology.
- **DUNEA:** Regional Development Agency Dubrovnik-Neretva County - DUNEA.
- **Fraunhofer:** Fraunhofer Center for Maritime Logistics.
- **HPA:** Hamburg Port Authority.
- **Subsea Tech:** Subsea Tech SAS.
- **UTC:** Technical University of Cluj-Napoca.
- **TUM:** Technical University of Munich.
- **UNIDU:** University of Dubrovnik.

Abbreviations

- **EC:** European Commission.
- **GA:** Grant Agreement.
- **UAV:** Unmanned aerial vehicle.
- **USV:** Unmanned surface vehicle.
- **UUV:** Unmanned underwater vehicle.
- **ASV:** Autonomous surface vehicle
- **ROV:** Remotely operated vehicle
- **SRIA:** Strategic Research and Innovation Agency
- **JPI Oceans:** Joint Programming Initiative Healthy and Productive Seas and Oceans

Executive summary

The present document is a deliverable of the SeaClear project, funded by the European Commission's Directorate-General for Communications Networks, Content and Technology (DG CNECT), under its Horizon 2020 research and innovation programme (H2020), reporting the results of the activities carried out by WP2. SeaClear aims to develop an architecture of innovative technological components consisting of Unmanned, Underwater, Surface and Aerial Vehicles - UUV, USV, UAV- to find and collect litter from the seabed from the water column, focusing on coastal areas, where waste inflow concentrates.

Deliverable D2.1 gives a description of the chosen pilot locations, as well as, a thorough analysis of their characteristics. Furthermore, it presents a comparison of the different test areas. Finally, deliverable D2.1 documents an overall context of different robotic aided service use cases that can be developed to demonstrate the functionalities of the SeaClear infrastructure.

The main focus of the project is to develop an autonomous robot platform for underwater litter collection. The developed system will be based on the use cases analysis resulting from an iterative development process with participation of the relevant stakeholders. Finally, the use cases will be used for the evaluation of the technological components of the SeaClear system in terms of performance, reliability and adaptability.

1. Introduction

1.1 Overall objective

Deliverable 2.1 overall goal is to investigate and elaborate pilot locations, with an emphasis on how the locations were chosen, in order to have an overview of the exact situations in which the robotic systems will be demonstrated and verified. It describes general conditions of test areas, taking into account climate and weather, oceanographic conditions, seabed structure, including biodiversity impacts, marine litter occurrence and legal framework that is required to follow up during the demonstration phase. There is an exact description also of the available infrastructure on pilot areas. This deliverable elaborates the need for innovative solutions for marine litter problematics in the given areas. It will also elaborate different robotic aided service use cases for the waterborne transport and other sectors, taking account of stakeholder opinions. Methods used are stakeholder interviews stakeholders consulting, other projects results & literature and the jointly design of service use cases while considering feasibility and impact as well as project time and budget. Activities and needs for the pilot cases are aligned with the Waterborne Technology Platform and JPI Oceans strategy. Waterborne has been set up as an industry-oriented Technology Platform to establish a continuous dialogue between all waterborne stakeholders, such as classification societies, shipbuilders, shipowners, maritime equipment manufacturers, infrastructure and service providers, universities or research institutes, and with the EU Institutions, including Member States. The strategy of JPI Oceans is defined by its Strategic Research and Innovation Agenda (SRIA) which was published in May 2015 [1]. The SRIA presents ten Strategic Areas, developed and agreed by JPI Oceans as strategic priorities for marine and maritime research in Europe. SeaClear action directly corresponds to all ten JPI Oceans strategic areas:

1. exploring deep sea resources
2. technology and sensor developments
3. science support to coastal and maritime planning and management
4. specifically linking oceans, human health and wellbeing
5. Interdisciplinary research for good environmental status
6. Observing, modelling and predicting ocean state and processes
7. contributes to climate change impact on physical and biological ocean processes
8. effects of ocean acidification on marine ecosystems
9. food security and safety driving innovation in a changing world
10. use of marine biological resources through development and application of biotechnology. [3]

The concept developed in D2.1 will be validated in Task 2.3.

[3] http://www.jpi-oceans.eu/introduction

SeaClear system will be developed and used in four test sites where an autonomous robot system will be verified: one system for the purpose of cleaning ports in the Hamburg port area on two demo site locations with the end user Hamburg Port Authority (Germany), another one in the area of Dubrovnik, namely near Lokrum Island and one in the area of the Mali Ston Bay, with Regional agency DUNEA (Croatia) as end user for these areas. With these four demo sites, SeaClear covers completely different application areas, given the fact that it addresses the deployment in a port location emphasising the use in a maritime industries context on the one hand and the deployment in two other locations representing protected nature areas on the other: one with relevance for tourism and one with great significance for the maricultural sector, namely the shellfish industry. Given the mentioned areas, the SeaClear system will face different waste fractions, both from inland and sea origin, and various obstacles that need to be solved in order for such a system to be fully functional.

All four demo sites have been selected taking into consideration the following criteria: a minimum length of 100 m in order to allow a fixed 100-metre stretch to be surveyed; sites are characterized by a low to moderate slope (~1.5–4.5°); they have a clear access to the sea (not blocked by breakwaters or jetties); they are accessible to survey teams throughout the year; normally they are not subjected to manual clean-up operations. Furthermore, the selected areas are situated in the vicinity of ports or harbours, river mouths, coastal urban areas or tourism destinations; and in relatively remote areas. Surveys will be carried out at intervals of three months in autumn (mid-September – mid October), winter (mid-December – mid-January), spring (April), summer (mid-June – mid-July). For the survey method we are planning to follow the EU MSFD TG10 “Guidance on Monitoring of Marine Litter in European Seas”. We will deploy our robotic solution and evaluate its overall effectiveness, but also exploit the clear water to focus on litter mapping and classification from visible-light cameras.

General conditions presentation is needed in order to develop a SeaClear system that could operate in various settings. On the one hand there will be extreme conditions like the high turbidity in Hamburg, where HPA as partner is in absolute control over the locations for demonstrations. And, on the other hand, there are relatively favourable oceanographic parameters in Dubrovnik Neretva County, which is, however, highly impacted from nautical tourism, protected marine species and specific types of waste from the maricultural sector. Both settings present challenging but different conditions for the SeaClear System to operate autonomously.

1.2 Document structure

The remaining document is structured as follows: Chapter 2 provides a general overview of Dubrovnik Neretva County selected pilot cases, altogether two pilot cases with two demo sites. Chapter 3 presents the general conditions of Hamburg Port, altogether one pilot case with two demo sites. Chapter 4 gives a comparison of all four demo sites, presenting general data, from the basic site information, oceanographic parameters to legislation obligations of each location. In Chapter 5 use case ideas are presented for each pilot location and finally, in Chapter 6 general conclusions of this deliverable are provided.

2. Dubrovnik Neretva County general conditions

2.1 Project pilot locations - Dubrovnik Neretva County pilot locations

Dubrovnik Neretva County is the southernmost county in the Republic of Croatia. It can be defined as “the blue” county with more than 80% of the area being sea surface, having direct access to the Adriatic Sea, which represents a key environmental feature of the county. This semi-enclosed marine basin connected to the Ionian and Mediterranean Sea via the Otranto Gate (which is only 75 km wide), has been playing a significant role throughout history in the development of economy, cultural and social life of the project area. Marine litter problematics is considered as one of the main ecological threats in the area and needs innovative solutions for fighting the negative impacts of this type of waste, especially the marine litter on seabed. Given the fact that the only available option for collecting litter from sea bottom are clean-up actions with divers, autonomous underwater and surface vehicles that would continuously clean the ocean in coastal areas, would be an efficient solution for this huge problem. Sea currents entering the Adriatic through the Otrant gate circulate upwards along the Croatian (eastern) coast and exit along the Italian (western) coast. Because of its geographic location, Dubrovnik Neretva County is the first “line of defence” for incoming marine litter from the Eastern and Central Mediterranean basins. In order to cover the two different types of marine litter issues present in Dubrovnik-Neretva County (general cross-border marine litter and locally generated aquaculture and fishing-related litter) two demo sites were chosen:

- Island of Lokrum
- Mali Ston Bay

The Island of Lokrum (Figure 1) is located in the close vicinity of the city of Dubrovnik, 600 m off the coast. It is 1,5 km long with a surface of 72 ha and it hosts numerous habitat types on the island as well as in the marine area. Situated in front of the old town of Dubrovnik, it serves as a natural breakwater for the city. Its marine area extends approximately 150 m off the coast. Besides being an important natural habitat, it is also a valuable environmental and economic resource for the region. Use case tests will be performed in the island’s small harbour - the bay of Portoč (42°37'32.7"N, 18°07'23.4"E), which is open to southeast winds.

Figure 1. Island of Lokrum (source: http://www.lokrum.hr/blog/galerija/galerija-lokrum/)

Mali Ston Bay (Figure 2) is an area enclosed by Pelješac peninsula on one side and mainland on the other side, with specific properties of its ecosystem - mildly eutrophic, making it perfect for the shellfish industry. This area is the main mariculture site for European flat oyster (*Ostrea edulis*) exploitation since ancient times, with the first written records of farming dating back to the 16th century. It is one of the few remaining sanctuaries of this oyster species in Europe, with no recorded instances of shellfish diseases to date - culpable for mass mortalities and utter devastation of other European culture sites and natural populations. For this reason, Mali Ston Bay is nowadays responsible for around 85% of total Mediterranean production of the European flat oyster and may be key to future European flat oyster restoration attempts in the Mediterranean, in order to revive natural populations of this environmentally and economically valuable species. Technologies of cultivating oysters have changed over the years, with an increased use of plastic materials in the last 50 years. Initially, oysters were cultured suspended on ropes hanging from fixed wooden structures, of which some were later replaced with steel rails. Today, both can be found in the bay, although most farms now use floating longlines attached to plastic buoys with oysters suspended on ropes. Mussel (*Mytilus galloprovincialis*) farming was also popularized and performed in a similar fashion, although suspending mussel stockings or "pergolas" were used instead of ropes on the floating longlines. Different plastic substrates (e.g., nets, ropes, cups, etc.) have been used for collecting wild spat of both aforementioned species from the wild for stocking farms. In recent years, predation of the gilthead seabream (*Sparus aurata*) on all cultured bivalves has instigated the use of different types of protective netting and a range of different types of culture containers. Being suspended in the water column, the culture equipment used has been prone to snapping and falling to the seafloor or just being discarded in the sea, which makes mariculture activities one of the main marine litter sources in the area. Use case tests will be performed on the University of Dubrovnik's marine research concession situated in front of its Laboratory for mariculture in Bistrina (42°52'16.2"N, 17°42'04.3"E) - one of the most productive coves in Mali Ston bay.

Figure 2. Bistrina in Mali Ston Bay (source: http://old.dubrovniknet.hr/novost.php?id=64065#.Xv3DAW37SUk)

Tourism activities differ in both areas. **Lokrum island** is one of the main Dubrovnik tourist attractions, with a total of over a million visitors in the six years period from 2014 to 2019 and an average of about 175000 visitors per year, in private or agency organisations, according to the Public Institution Lokrum Reserve database. Overnight stays are not allowed on the island, so only day trips are possible. Besides these visitor numbers, since access is only by boat, locals have annual cards for Lokrum excursions and unlimited visits to the island. In the six-year period from 2014 to 2019, also according to the Public Institution Lokrum Reserve database, almost 4000 annual cards have been issued, with an average of 600 annual cards per year. **Mali Ston Bay** is a famous tourist destination known for its highly valued oysters. According to Dubrovnik Neretva County Tourist Board database, tourism data for this area, Pelješac peninsula with Ston, Janjina, and Dubrovačko Primorje municipalities, in the six-year period from 2014 to 2019, counts a total of approximately 250000 visitors (arrivals at the destination), with an average of 40000 visitors per year.

As for marine transport, **Lokrum island** abounds with water traffic, but due to the relatively shallow waters there is a limitation to only small boats and yachts and a few regular boat lines that offer public transport to the island or excursions. The test site is a bay where the island's main, although very small, port is located and so is frequented by most visitors. The bay is also a favourite anchorage for numerous local day-trippers during the summer months. **Mali Ston Bay** is limited to service vehicles related to shellfish farming (8-12 m in length) and very small boats. However, the test site is an area of sea under concession of the University of Dubrovnik so very little or no marine traffic is to be expected during on-site tests.

2.2 Climate and weather

The two demo sites chosen for use case Dubrovnik, **Lokrum island** and **Mali Ston Bay** generally have similar climate and weather conditions, as there is only about 40 km distance between the two locations. The area is characterized by a mild Mediterranean climate, rainy winters with gusts of cold wind and hot, humid and moderately dry summers. Air temperatures generally reach 30°C during the summer months, with the average warmest period in August. The coldest winter month is January and the average winter temperature is about 12°C. However, they differ greatly by the level of exposure to the open sea and associated harsh weather conditions. Lokrum island is highly exposed to open sea conditions while Mali Ston Bay is closed off. It is characterized by calm weather patterns, which allow for intensive shellfish farming activities.

2.3 Oceanographic parameters

The southern Adriatic is connected to the Ionian Sea through the Otranto Gate and includes the South Adriatic Pit, the deepest area in the Adriatic Sea (1200 m). It is a moderate warm sea with temperatures at even the deepest layers always above 10° C and a wide range of temperatures on the surface, from 3° C to 30° C. Temperature gradient in a water column, thermocline, occurs during the warmer months at 10-30 m, with warmer upper layers and colder lower ones. During the autumn, temperature of the water column equalizes, and the average temperature of the autumnal isothermal layer is 18° C - 19° C. The main nutrient sources are surface runoffs, underground waters and urban discharges, as well as aeolian inputs. From north to south of the Adriatic, a progressive decline in nutrient concentrations appears in the surface layer so the south part is characterised as oligotrophic sea. However, in some areas, like **Mali**

Ston Bay, specific ecological conditions appear. Higher nutrient concentrations in Mali Ston Bay are caused by the inflow of fresh water from the Neretva River and from numerous underground springs. **Lokrum island** has clear transparent water with visibility down to 25 meters, while the mildly eutrophic and silty bay of Mali Ston is often turbid with limited visibility. Even so, visibility in Mali Ston depends on current hydrometeorological conditions and seasonal changes in phytoplankton abundance (higher in spring/summer, resulting in lowered visibility). Annual water temperature oscillation loosely follows air temperature and have been measured in the range from 12 °C to 29 °C. Temperature, salinity, nutrients, dissolved oxygen, and chlorophyll generally show a pronounced seasonal cycle. For Lokrum island demo site, depth varies from minimum 2 m shallow waters to 19 m which can be seen in Figure 3.

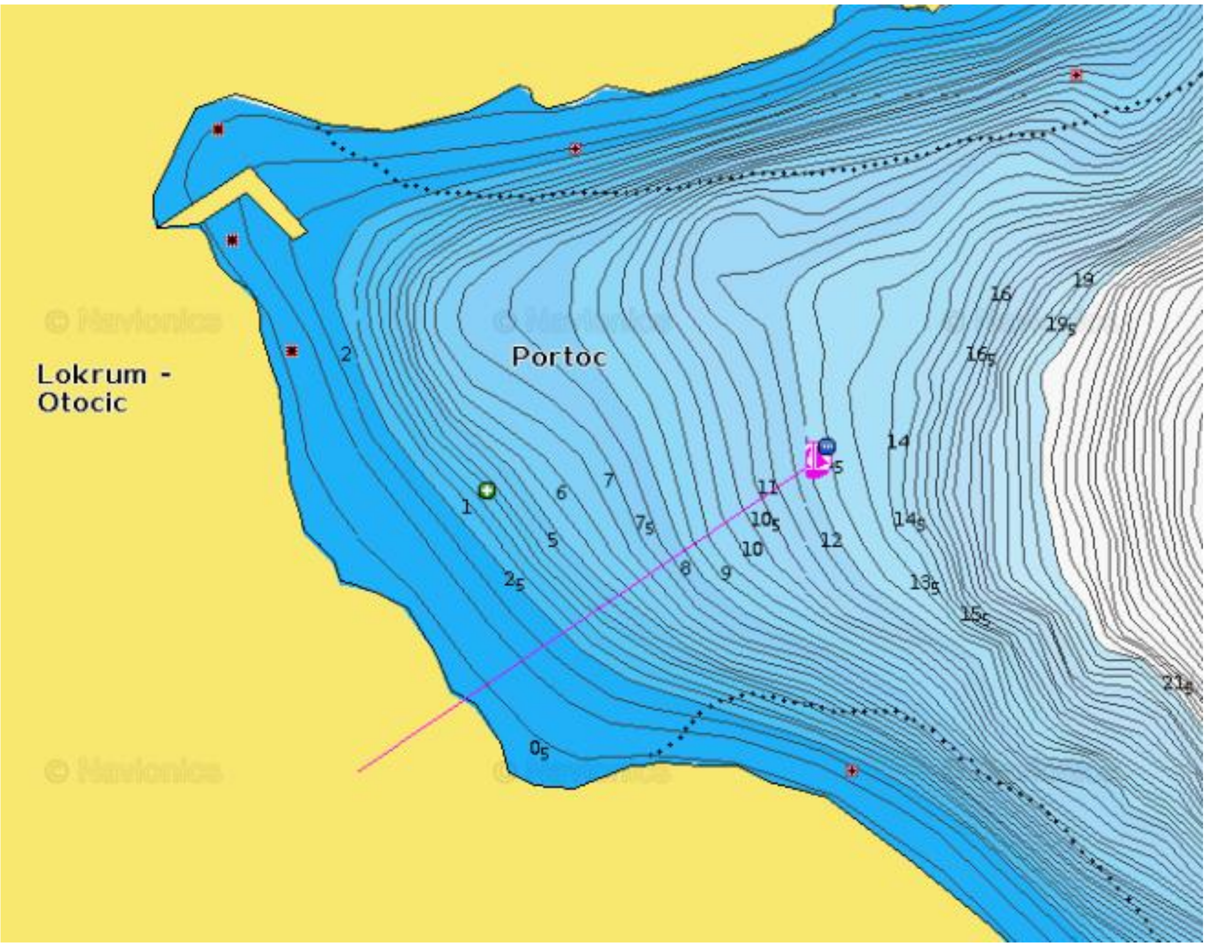


Figure 3. Depth profile of Portoč bay on the island of Lokrum (source: Navionics SonarChart™)

For Mali Ston Bay demo site, depth varies from 1 m shallow waters to 12 m depth which can be seen in Figure 4.

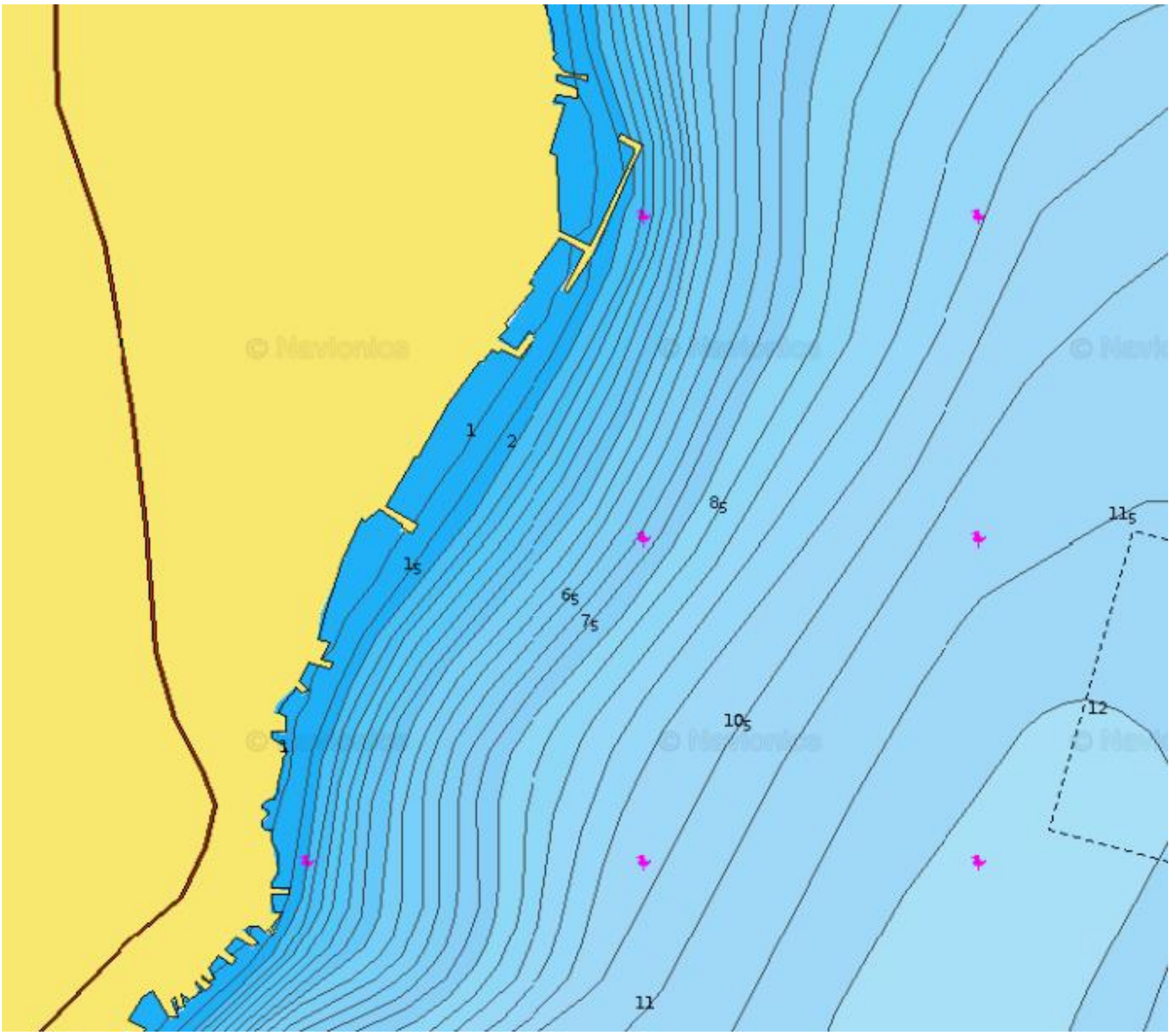


Figure 4. Depth profile of the test site in Bistrina cove in Mali Ston bay (source: Navionics SonarChart™)

2.4 Seabed structure

The shore around **Lokrum island** is a rocky limestone that changes from larger to smaller sized rocks with increasing depth and shifts to *Posidonia oceanica* seagrass beds at 5-10 m depth. In places the coastal limestone form submerged or partially submerged sea caves. The rocky coast of **Mali Ston Bay** does not extend as much from the shore as in Lokrum. It is quickly replaced by a moving sediment of sand, silt and/or mud with scarce individual smaller rocks (<0,5 m diameter) protruding from the bottom. In places, the bottom is covered with discarded or naturally occurring bivalve shells.

2.5 Biodiversity

The island of Lokrum is included in the UNESCO World Heritage List as an integral part of the Historic City Centre of Dubrovnik and listed as a cultural property in the Immovable cultural monuments list. It was protected in 1948 as a special forest vegetation reserve and it is one of the three oldest protected areas of nature in Croatia. From 2013, Lokrum has been an integral part of the Natura 2000 ecological network. There are eight protected habitat types of European importance on the island and its marine area which extends approximately 150 m off the coast. Four of these are marine habitats: 1120* Posidonia beds (*Posidonia oceanica*), 1170 Reefs, 1240 Vegetated sea cliffs of the Mediterranean coasts with endemic *Limonium spp.* and 8330 Submerged or partially submerged sea caves. A large number of tourists visiting the island every year and marine litter represent major anthropogenic pressures in this area. Posidonia beds are abundant in this area but also endangered by increasing number of ships anchoring around the island.

Mali Ston Bay is a marine protected area included in Natura 2000 network with the main habitat being type 1160 Large shallow inlets and bays and the remainder habitats type 1170 Reefs, 1120 Posidonia beds, and 1110 Sandbanks. The sea bottom in Mali Ston bay includes a rocky, as well as sandy and muddy bottom with settlements of seagrasses *Posidonia oceanica* and *Cymodocea nodosa*. Transparency is reduced in some areas under the facilities for shellfish farming. Thus, benthic communities formed under the impact of shellfish farms are characterised with reduced vegetation and small rocky areas densely inhabited by sessile invertebrates. Construction elements and farm facilities are densely overgrown with invertebrates and algae, but with low biodiversity of macroscopic species in this area. Similarly, marine litter is often overgrown by fouling organisms.

A total of 17 protected species (5 algae, 2 seagrasses, 3 bivalve mollusks, 2 cnidarians, 4 sponges and 1 species of fish) were recorded in Mali Ston bay, among which endemic brown algae *Fucus virsoides* and the dense settlements of the bivalve *Pinna nobilis* are particularly interesting from a conservation point of view. This endemic alga has disjunctive distribution within the Adriatic and has suffered a drastic reduction of its range during the last ten years. It seems that it has completely disappeared in the northern Adriatic, where it was previously frequent and today is still present in only few locations, including Mali Ston bay. The noble pen shell (*Pinna nobilis*) is widespread in the Bay of Mali Ston where it often creates dense settlements. However, extinction of this species, which has been occurring throughout the Mediterranean since 2016, also affected this area. Noble pen shells are especially common inside the settlements of Posidonia.

2.6 Marine litter occurrence

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. A study conducted in the wider Mediterranean area showed waste density ranging from 0 to 194.6 items/km, of which 95.6% were different types of plastic - polymers with the highest densities recorded in the Adriatic Sea and north-eastern Mediterranean [2]. Floating waste does not accumulate in any of the locations in the long run, however, it eventually accumulates on the seabed and in deep-sea areas such as submarine Mediterranean canyons. The abundance of plastic on the seabed largely depends on the characteristics of the seabed itself, and the range of waste density can be from 0 to as much as 100,000 objects/km The amount of litter per seafloor unit area varies depending on the exposure to currents, prevailing winds and the pressure of nautical tourism [2].

In general, most of the marine litter comes from inland sources (almost 80%), and only a small part is generated at sea. The two selected demo sites in Dubrovnik area are affected by marine litter of both origins to various degrees. **Lokrum island** has marine litter originating mostly from inland sources, such as tourism activities and severe amounts of waste carried by marine currents and waves from neighbouring countries since this area is directly open to south and south-east winds that can generate enormous waves during large storms, usually occurring in autumn. Apart from bringing large amounts of floating marine litter to the shores around Lokrum, which eventually sink or accumulate on the shoreline, they completely hinder navigation and so any marine-oriented activities during these periods become impossible. Although mostly inland in origin, waste in the marine environment around Lokrum, also comprises material from the fishery industry, so called “ghost nets”.

Two EU projects have conducted research in order to have an overview of the marine litter that can be found on the Dalmatia coastline, including the Lokrum site. 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 seabed, different metal objects could be found, along with accumulated plastic, trapped in the rocky coastline and seabed, including protected areas of Posidonia beds along the Croatian coastline. According to research carried out within the framework of project ML-REPAIR [3] marine litter seafloor monitoring has been held in the Lokrum island area. The data was collected in September 2018 by SCUBA divers along a linear transect 25x4 m, four transects at three locations (Mala and Vela Splilja, Pod Manastijerom, Bočina) and five transects in Portoč Bay. In the end, 77 litter items weighing 27 kg were collected. In the terms of item numbers, the dominant category was artificial polymer materials (plastics) (53% of total number) while metal objects dominated in weight (50% of total weight). Metal and glass/ceramic items are likely to be of local input while plastics due to its long-lasting floating capability can be brought with currents, waves, and wind away from the source.

As opposed to Lokrum island, **Mali Ston Bay** is closed off from the open sea by the Pelješac peninsula and is a much calmer basin. However, it is still heavily affected by marine litter, although paradoxically, mainly that originating from sea, i.e. aquaculture and fisheries activities. The culture equipment used in shellfish 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 it is just discarded in the sea due to bad management practices (intentionally or unintentionally) (Figure 5). Since the bay is not generally prone to bad weather conditions, most farmers do not prepare for tidal waves and similar sudden destructive meteorological events that are rare but do occur occasionally. These have been shown to have devastating effects on the industry, destroying and sinking entire farms. Keeping in mind the long history of aquaculture in this area and recent increased use of non-degradable materials, it is not difficult to imagine the amounts of marine litter that clutter the seabed and are an ever-growing issue in this area. Thus, there is a higher frequency of litter around existing farms and locations with high water currents that concentrate layers of waste materials by carrying and snagging them on man-made and/or natural outcroppings. In addition, general locally sourced marine litter originating from land is a common occurrence in the bay, especially around settlements.

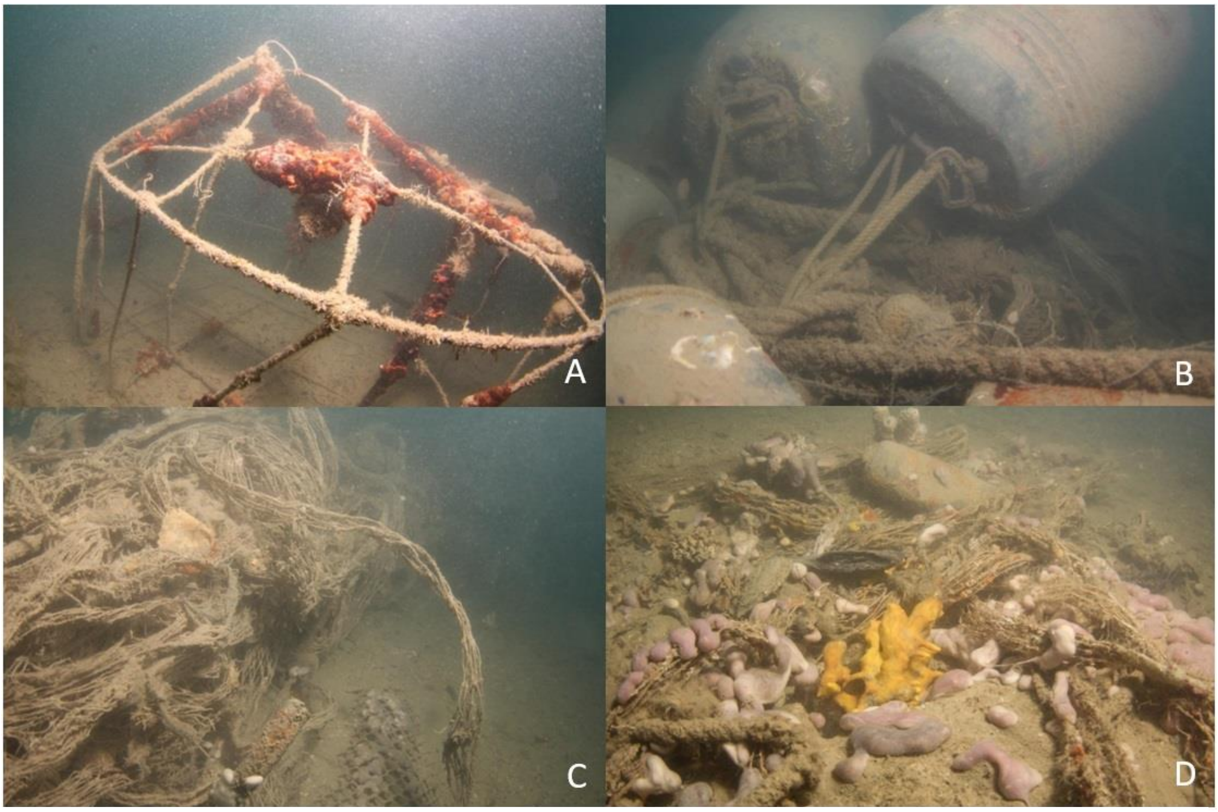


Figure 5. A, B, C, D: Aquaculture and fishing gear at Mali Ston Bay seabed (source: Dubrovnik Neretva County Public Institution for Nature Protection)

2.7 Available infrastructure

The Lokrum site is managed by the Public Institution Lokrum Reserve. Infrastructure available for project activities are the institutional premises with conference rooms. Another building of the Public Institution (Forest-ranger's House) is located near the port area, just at the base of the main pier where the regular boat line docks. The building is around 10 m away from the sea, which means electricity can be brought to the pier and the area around it. The regular boat line from Dubrovnik's Old City port to Lokrum port (Portoč) runs daily every half hour and the ride takes around ten minutes. Lokrum is also connected with several other places in the wider Dubrovnik area, however all these boat lines operate only from April to November. The island is covered by free WIFI. However, site access and the majority of work can be performed aboard the 32 m long research and education boat "Naše more" of the University of Dubrovnik, which is equipped with cranes and winches, a large stern working platform 2-3 laboratory/workshop areas and beds for 19 passengers (beside the crew).

In **Mali Ston Bay**, the University of Dubrovnik has its own laboratories dedicated to aquaculture and marine research. Within this complex, there are several piers and small sheltered docks which are easily accessible from land. The piers are around 0,5 m above sea level. There is a landing ramp and winch used for lowering boats into the sea that is accessible by boat trailers. The whole complex can be accessed from land by car, van or truck right to the water's edge. However, public transport is lacking as the site is quite remote (45-minute drive from Dubrovnik, 15-minute drive from Ston). Employees and visitors mainly arrive by car. Dry closed spaces that can be used as office or workshop space are only a few meters from the sea and can safely house numerous computers and other sensitive technical equipment. The whole building has WIFI coverage and numerous ethernet ports for wired connections and power sockets. It also houses an external washing station used to rinse off diving and similar equipment used in marine research. The central building offers on-site accommodation for visiting researchers 5 double rooms, each with a private bathroom. There is a large communal kitchen area and ample terrace space. It also houses offices and a lecture room for around 50 people that can be used for project meetings and dissemination.

2.8 Legal framework

Legal framework that we need to take into consideration for both demo sites in Dubrovnik Neretva County are:

- Nature Protection Act (NN 80/13, 15/18, 14/19, 127/19)
- Law on Maritime Property and Seaports (NN 158/03, 100/04, 141/06, 38/09, 123/11, 56/16, 98/19)
- Law on Sustainable Waste Management (NN 94/13, 73/17, 14/19, 98/19)
- Marine Strategy Framework Directive (2008)
- Ecological network regulation Natura 2000

More than 60% of Dubrovnik Neretva County area is under Natura 2000 protection with 40 protected natural areas, pursuant to the Nature Protection Act. Both project locations are under protection and represent truly valuable sites for the county, in the histological, sociological, environmental and economic context. The two sites surely increase quality of life in general for the local population. **Lokrum island** is a special nature reserve of forest vegetation and an integral part of the Natura 2000 ecological network, with eight protected habitat types of European importance on the island and its marine area extends approximately 150 m off the coast. It is managed by the Public Institution Lokrum Reserve which is under the local government unit of the City of Dubrovnik administrative jurisdiction. **Mali Ston Bay** was declared a Special Natural Reserve in 1983, it is the biggest known marine reserve and an important part of the Natura 2000 ecological network due to the special properties of its ecosystem. Its administrative scope includes three local government units: Ston, Dubrovačko Primorje and Janjina.

3. General conditions Hamburg Port

3.1 Pilot location

The port of Hamburg is an open tidal port on the Lower Elbe in the Free and Hanseatic City of Hamburg. It is the largest seaport in Germany and the third largest in Europe (as of 2017). It is located about 100 kilometres from the North Sea, and is nevertheless considered a seaport, as it can be approached by seagoing vessels with a draught of up to 15 metres. Hamburg has a long experience in ensuring the water depths required for shipping in the dynamic natural area of the Tide Elbe. The challenge lies in understanding the natural processes and using them sensitively to preserve the port. The port lies in the heart of the city of Hamburg and occupies almost one tenth of the area of the city touching a total of ten districts. These factors provide challenging conditions with a view to detecting, determining the origin and removing waste from the river Elbe in the port area. In addition, there is the high turbidity of the water due to sediments that upstream into the port with every flood, making visual underwater detection of waste almost impossible. The heavy vehicle traffic makes water-side waste collection even more difficult.

HPA has set itself the strategic goal of developing into a plastic-free port. There are different sources and causes when it comes to waste occurrence within the port, ranging from tourists and residents from the adjacent districts to waste that flows downriver from elsewhere and being washed ashore in the port area. Collection at known hotspots is done manually or as a result of targeted requests and is lacking an overall strategy to collect marine litter.

For demonstration services the HPA offers several potential locations to test the SeaClear system under Hamburg conditions (Figure 6). They will be chosen depending on the respective project use case. The natural conditions will be similar in all those locations. The port infrastructure might vary but will be taken care of to match the project’s requirements. Since Hamburg port has been a test area for different R&D- projects in the past and currently still is, two specific areas – Lübecker Ufer (Figure 7) and Fährkanal (Figure 8) - are approved or being developed to be permanent test sites. They are offering perfect infrastructural conditions for the use of waterside and aerial systems. Those as well as additional potential sites for demonstrations are numbered in the map below.

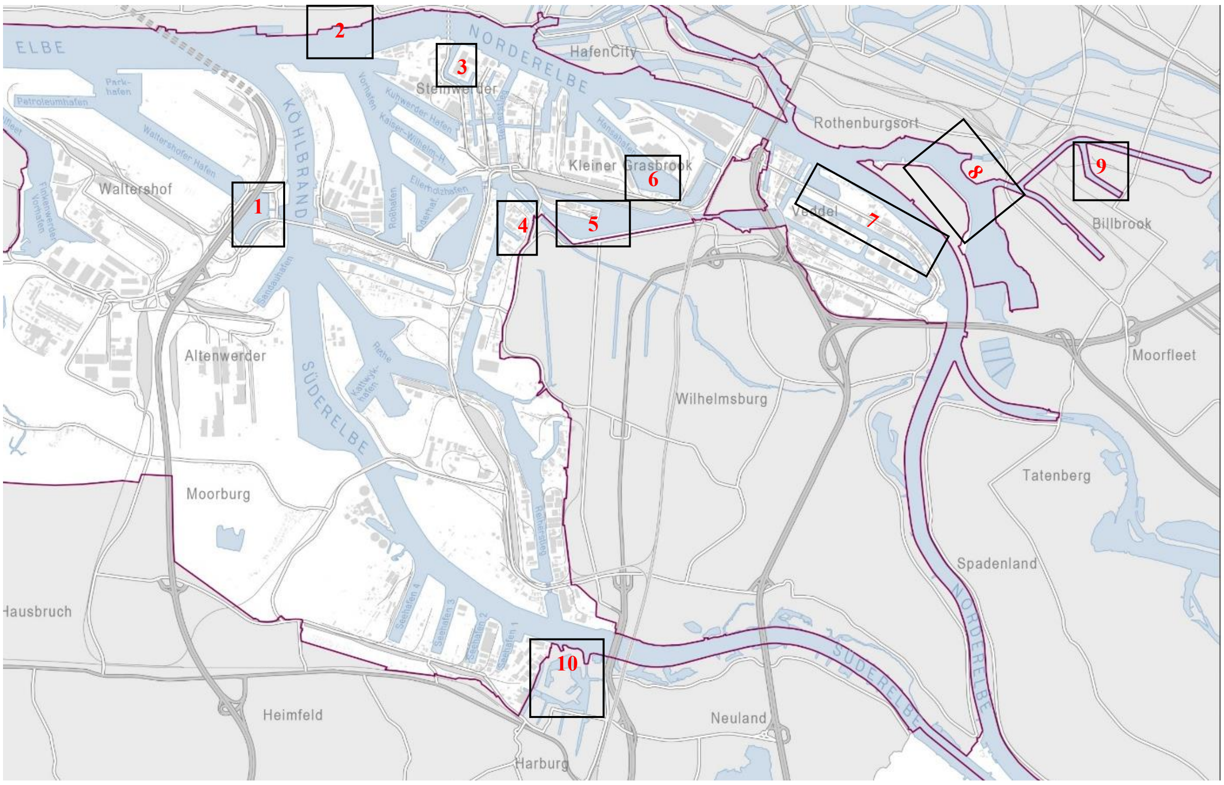


Figure 6. Potential demonstration sites for SeaClear. Number refer to following locations 1: Waltershofer Brücken (53°31'08.6"N 9°58'05.8"E), 2: Edgar Engelhard-Kai / Holzhafen (53°32'37.1"N 9°56'34.3"E), 3: Fährkanal (53°32'21.6"N 9°57'58.8"E), 4: Ernst August Kanal (53°31'28.2"N 9°58'45.2"E), 5: Spreehafen (53°31'19.3"N 9°59'47.9"E), 6: Lübecker Ufer (53°31'46.9"N 9°59'59.5"E), 7: Hovekanal (53°31'15.7"N 10°02'32.5"E), 8: Sperrwerk Billwerder Bucht (53°31'50.2"N 10°01'56.6"E), 9: Billbrook Industriekanal (53°31'29.9"N 10°05'14.0"E) and 10: Harburger Hafen (53°28'10.8"N 9°59'21.2"E)

Autonomous operation is mainly done regarding measurements of the sea ground to estimate necessary dredging and passability of fairways. The overall goal is a more efficient use of e.g. large pilot station ships or survey vessels for more complicated operations, relieving them from standard tasks.

Hamburg port customs is cooperating with an industrial partner for the development of an underwater vehicle to detect forbidden and smuggled goods. Those are expected to be tied to ship hulls and need to be discovered to prevent distribution.

The project RoboVaas (Robotic Vessels as a Service) is covering different use cases and Hamburg serves as demonstration site in fields like ship hull and quay wall inspection as well as anti-grounding and gathering of environmental data. The testing is done at the Lübecker Ufer .

The port premises also serve as a test area in the field of maneuverability of ships and their behavior in currents, and other natural water conditions. Those trials are expected to be implemented in the Ernst-August-Kanal (4.).

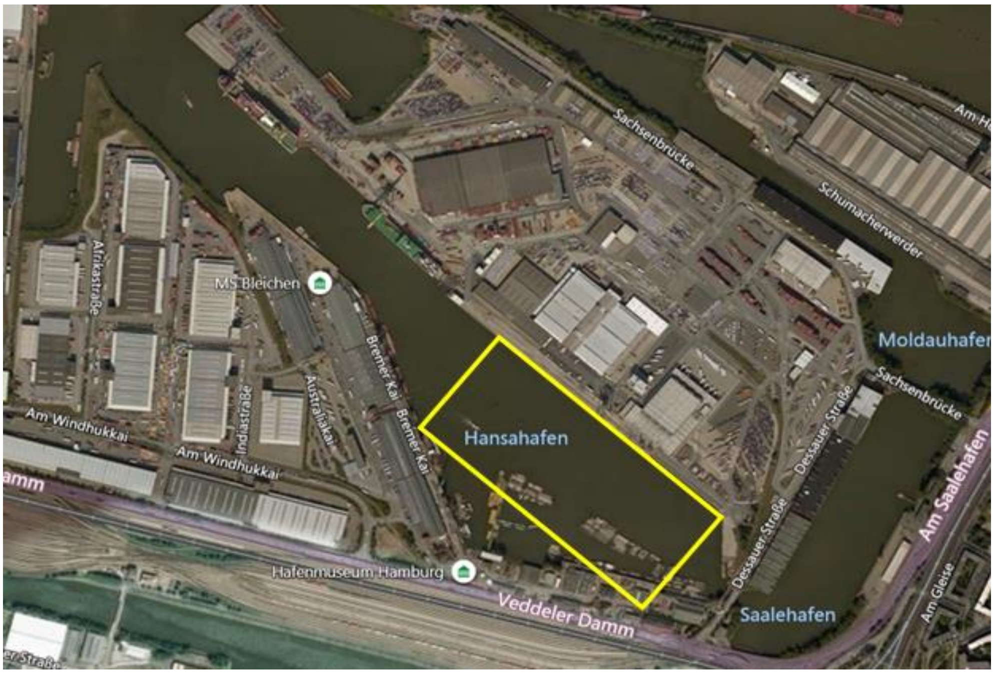


Figure 7. Lübecker Ufer (source: bing maps)

Table 1. Overview on availabilities at Lübecker Ufer

Infrastructure at Lübecker Ufer	
Land space	
in m²	~ 50 m² available - tbd
access infrastructural (road / water)	Both
restricted access (permissions)	Tbd - operational processes have priority - HPA employee needs to ensure compliance with safety precautions (helmet, clothing etc.) - Access from 6: 30 am – 3:00 pm for cars - no crane operation after end of business
parking lot	Available
Crane	Yes

capacity	~ up to 1 t possible - tbd, depending on needs
Quay	Yes
jetty / bridge / slipway	Yes – quay, bridge, slipway
Boat	Available – for rent
Office / workshop	
in m²	~ 20 m² - tbd, depending on needs
storage facilities for technical equipment	Possible, depending on needs-clarification necessary
Electricity	Yes – may need multi-socket and cable drum depending on needs – power for battery charging and laptop use (230 V)
Wifi	Yes - depending on needs: Wifi within HPA premises; LTE / 4G outside

Fährkanal

Figure 8. Water side test area "Fährkanal"

Table 2. General overview on availabilities at Fährkanal

Infrastructure at Fährkanal	
Land space	
in m²	available, tbd - depending on needs
access infrastructural (road / water)	both
restricted access (permissions)	Registration in advance
parking lot	available
Crane	tbd
Capacity	tbd
Quay	yes
pontoon / bridge / slipway	Yes, pontoon
Boat (transfer)	possible
Office / workshop	
in m²	Yes, tbd - depending on needs

storage facilities for technical equipment	Yes, tbd - depending on needs
Electricity	Yes - depending on needs
Wifi	Outside presumably LTE/ 4G

3.2 Climate and weather

The overall climate in the city of Hamburg is considered moderate. Temperatures occasionally fall below 0 degrees in winter times and at the same time rarely exceed 30 degrees in the summer. The weather is considerably stable and shows just rare cases of heavy outbreaks like storms and floods, as shown in Figure 9.

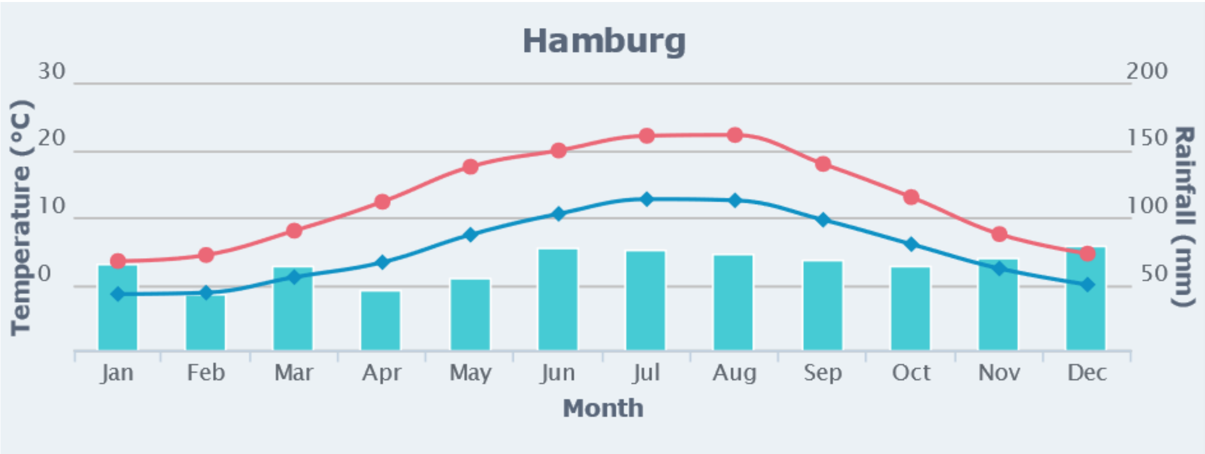


Figure 9. Weather conditions Hamburg (source: World Meteorological Organization)

Floods are most likely in winter times when strong west winds hit the river. Wind coming from the east usually result in low tides. The annual statistic on wind directions and speed show, that wind in Hamburg generally comes from the west with a speed of 8-9 knots, as depicted in Figure 10.

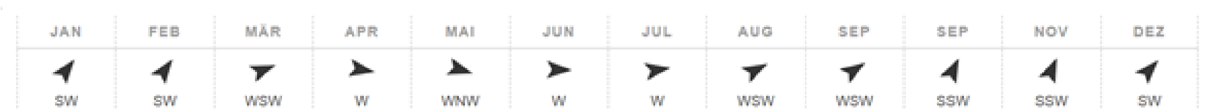


Figure 10: average predominant wind direction in Hamburg (Source: www.windfinder.de)

3.3 Oceanographic parameters

The water in the Elbe river is known to be turbid due to currents, ship movements and tidal flows which tend to carry sediments. In order to ensure navigability within the port, there is ongoing dredging contributing to the limited visibility of 0,5 m and less, as observed in Figure 11. The below picture shows visibility of 0.7 m during ship hull inspection. Less turbid water would allow to see damages to the ship and estimations on necessary maintenance.

Figure 11. Underwater image of the river Elbe (source: Ship_hull_Inspection_2)

Tidal flows carry not only sediments but also saltwater from the North Sea which leads to little salinity. The level within the port is at 0,5 ‰ which can be considered as fresh water. The border between fresh and saltwater is fluent and usually depends on the amount of water coming down the river and overall rainfall.

The oxygen level within the Elbe river depends on the time in the year. The maximum oxygen value is reached in winter at 15 mg/l and respectively the lowest in summer dropping to 2 mg/l.

In terms of temperature the Elbe heats up throughout the year with a possible detected 27 °C being one of the highest values ever measured. The overall range is best described at approximately 0°C in winter gradually warming up. The current temperature in July is measured at 22°C.

General currents will be found all over the river but vary in terms of flow velocity in the different parts of the port and depend on tidal flows as well. The most crucial fact to that is the change of the flow direction due to the tide. During high tide the water comes from the North Sea and comes to a halt when it changes to low tide. The range of the currents vary from 0 m/s to 1,75 m. The strongest flow velocity is detected in the main flow of the river and at the water surface slowing down towards the ground.

The difference between high and low tide ranges at 3,66 m which shows water depths of up to 15 m at peak.

Water movements usually originate from ongoing moderate wind and from large ships, but also the regular ferry transfer. This might cause some waves above 40 cm, as they pass along quickly. When wind and river stream meet from opposite directions, waves may even reach 1-1,5 meters.

Figure 12 and Figure 13 show the water depths as well as potential obstacles (colored) in the designated demonstration areas at Lübecker Ufer and Fährkanal and the surrounding building infrastructure and land space (gray/ white). Colors of the water depth ranging from blue, green to red and pink are indicating ascending slope or respectively shallower waters.

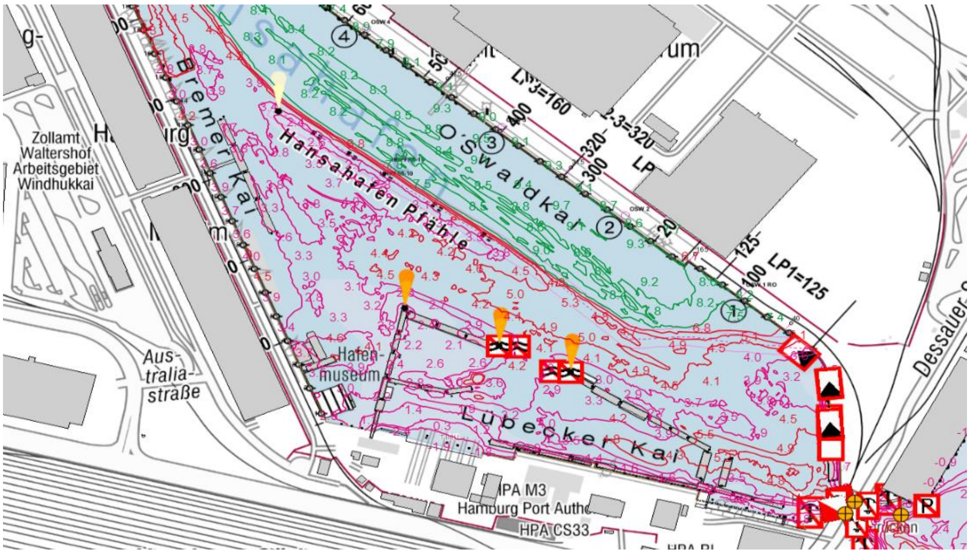


Figure 12. Water depths at Lübecker Ufer

The area at Lübecker Fährkanal is part of the Hansa Hafen, which offers berths for ship (un-)loading. Especially the fenced area named Lübecker Kai will be the focus for the SeaClear project as it offers a slipway to deploy the system. The navigation to alternative demonstration areas like the Spreehafen may commence from here.

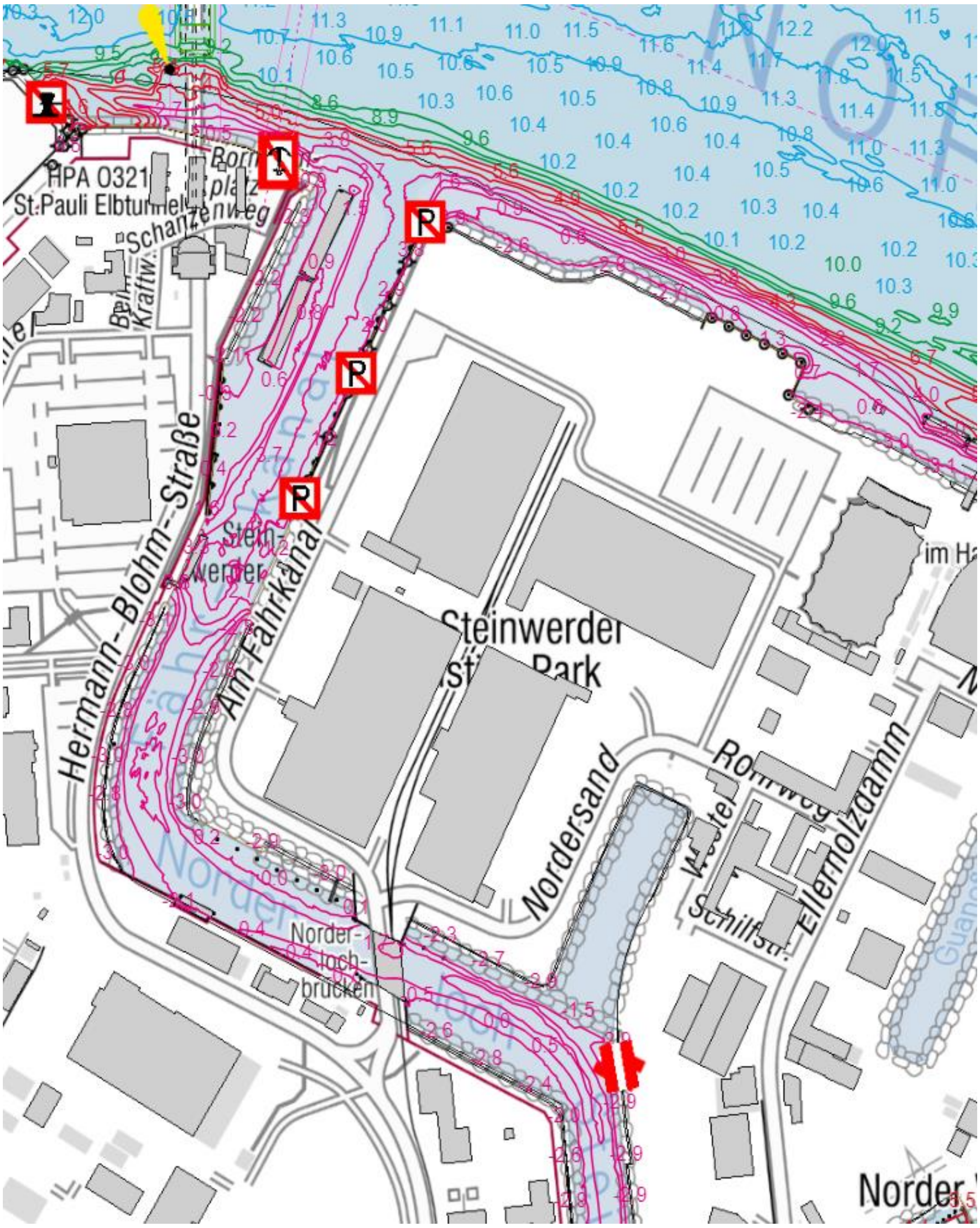


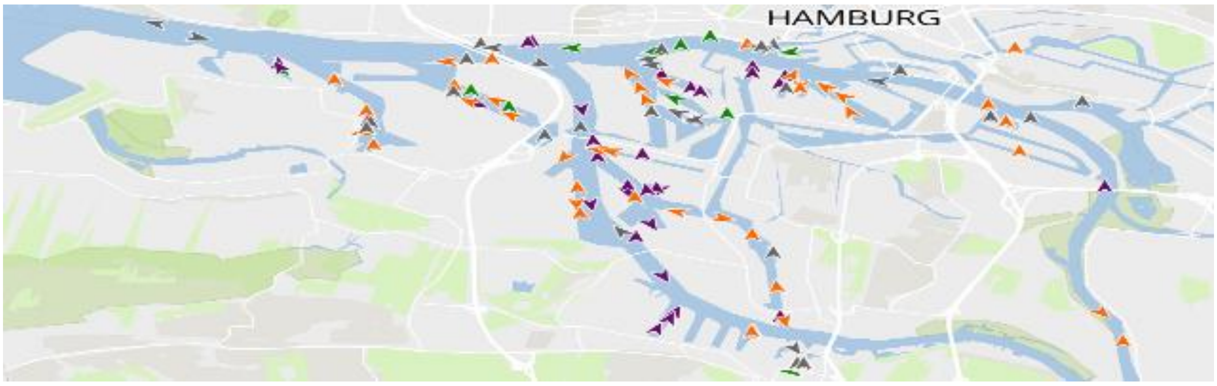
Figure 13. Water depths at Fährkanal

When entering the Fährkanal from the main flow a sudden change of water depths from over 10 meters to less than a meter occurs. This goes along with direct changes of the flow velocity. Right at the entrance to the channel there is a gray area indicating a pontoon which is used for ferry traffic and may also be available to deploy the SeaClear system.

In comparison to Lübecker Ufer, which is characterized by wharves, the shore boundary at the Fährkanal is green space. Fährkanal generally is ready for demonstrations and tests as long as usual port operations are not disturbed. Office space, storage and maybe even a workshop may be available during demonstrations. This needs to be clarified once the SeaClear Consortium agreed on a date and time for demonstrations. HPA needs to know about the requirements from the technical partners in advance to arrange the needed settings. Consultation with the local managers and operators of the land and waterside infrastructure is necessary as the area is not used for research and development solely.

Water traffic

The port shows a very diversified number of traffic participants ranging from public transport, private boats, working vehicles, pilot boats, cruise ships, cargo and passenger vehicles (see Figure 14) which are all monitored by the harbor master. Most important are the at least 8.000 large, heavy cargo ships that are entering and leaving the port every year.



Type of ship: Cargo Passenger Tanker Other

Figure 14. ship movements at Hamburg Port, 01.07.2020 at 2 pm (source: Hafen Hamburg)

Part of the daily traffic results from the public transport system in Hamburg which includes 26 ferries, as the city itself is to some degree divided by the Elbe river. Numerous commuters rely on the regular connections to the respective other side of the river and timetables show a constant traffic as the ferries especially during daytime arrive and depart at several stations within the port area (see Figure 15). The fleet covers seven lines and 30 stops every 10 - 20 minutes especially during daytime. Since the port has a history of over 830 years it is a tourist attraction to visitors and there is a wide range of round tours within the harbour boundaries offered by different companies. They usually operate all year with peak seasons in the summertime, during public holidays and weekends when ferries leave every 30 to 60 minutes.

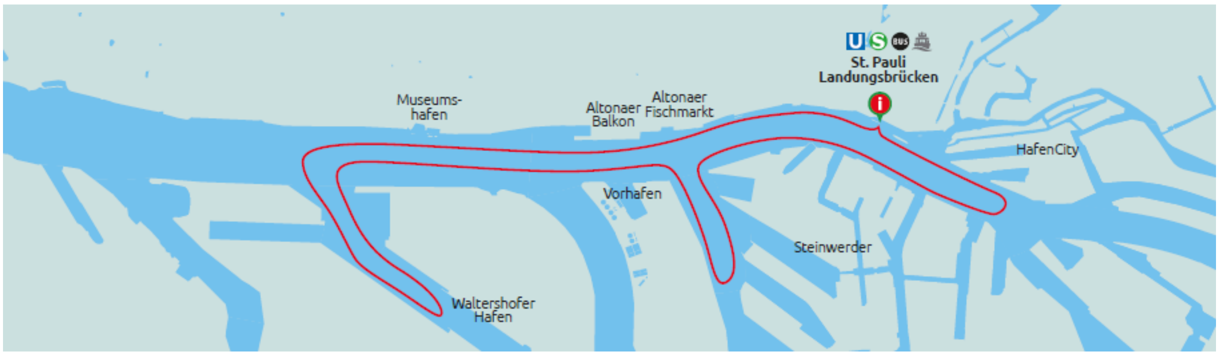


Figure 15. touristic ferry routes - Source: HADAG

In total 25.000 ship movements annually need to be coordinated within the port. However, the heavy traffic will not affect the SeaClear demonstrations as those will be executed in less frequented and traffic calmed zones of the port.

3.4 Seabed structure

The port area is under constant dredging processes, to ensure heavy ship traffic. Depending on tidal flows, wind direction and overall water level the depth of the fairway is passable and needs regular dredging. High tide currents carry sediments form the North Sea and are usually stronger than the low tidal flows, which cannot cope in taking back sediments to the North Sea estuary. The ground is then a heterogenous area with sandy seamounts and respective valleys. The more frequently dredged parts usually show a sludge and sandy structure with occasional occurrence of larger stones.

3.5 Biodiversity

Up until the 1980 the water quality in the Elbe was heavily impacted by industrial wastewater which resulted in the extinction of many species. Sewage treatment and wastewater plants allowed for the recovery of the Elbe and the return of many species. Studies on mussels, snails, worms and crustaceans in the Elbe especially in the port showed an increasing development over time due improved water quality in the last few decades.

According to total number of 49[4] species of fish are counted in the port area of the Elbe River, of which twelve are considered endangered. Because of the special water conditions regarding the salt and

4 https://www.hamburg.de/contentblob/4457730/8b659b697a9587b7871664757c180087/data/download-fischgutachten-2015.pdf

freshwater zone there are eleven diadromous migratory fish species that are able to live in both eco systems. 40% of the counted types are Aland (leuciscus idus), bream, European eel, flounder (platichthys flesus), river perch, white bream (blicca bjoerkna), clawfish (gymnocephalus cernua), roach, smelt (osmerus eperlanus) and pikeperch (sander lucioperca).

Besides the fishes, different mammals like otters, beavers, muskrat and nutria are spotted within the city´s waters. Especially beavers are nowadays considered an established species. Beavers and muskrats are mainly seen in the southern parts of the port that are less effected by the tidal flows as well as the Dove-& Goseelbe or the Holzhafen. In rare cases seals find their way from the Elbe estuary to the most western beginnings of the port. Harbor porpoise are more regularly spotted while following the smelts upriver.

3.6 Marine litter occurrence

Litter occurrence in Hamburg shows a very different picture compared to Dubrovnik, where a clear overview on findings, quantities and types of marine litter is available. For different reasons waste will be found in Hamburg waters as well, but the amount and occurrence itself is rather small in relation to the overall port area of 7,200 km². From the SeaClear perspective, Hamburg does not have a waste problem, but contamination does exist. It ranges from large objects such as vehicles, tyres, machine parts, ammunition or large pieces of wood to 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 impurities 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 by dredging or suction processes. The latter is a constantly occurring process in the port of Hamburg. It serves to ensure sufficient water depth for shipping traffic throughout the port area. Hydrographic soundings have also yielded corresponding findings. Waste examples can be seen in Figure 16 and Figure 17.

Figure 16. Aerial image of waste occurrence at low tide (source: HPA)

Figure 17. Waste examples at low tide (source: HPA)

During recent surveys, only very little contamination, especially at the water surface, was found, which is generally very positive for the Hamburg site. However, and this is shown by experience and discussions with relevant HPA departments, this is also due to the COVID-19 lockdown situation. The generally much lower frequency of use of the water and bank areas by private individuals at present also results in low levels of water pollution. The situation is similar for events not taking place in the port vicinity. This also indicates a significant decrease in water-side contamination. There are also few storms currently recorded which, in the context of floods and tides, would bring further pollution into the port area via the Elbe.

Figure 18. A/B: Waste examples at low tide (source: HPA)

Within the scope of the project there will be further explorations, which, taking into account the above-mentioned circumstances, will provide further information when conditions change. As already described, the visual conditions in the river Elbe are very poor due to the sediments. All attempts to detect objects by visual methods have not led to the desired results so far.

A proof of litter under the water surface can be found in the following pictures (Figure 19 and Figure 20). The HPA is not yet able to distinguish between floating materials and materials lying on the bottom of the Elbe. Apart from relatively clear classifications of heavy objects made of steel, it is not possible to determine the type and quantity of floating materials. At low tide, it has been proven that at least an initial indication can be given of the quantities and types of litter at individual points in the port.

In addition, there are various forms of large scrap-like parts which are taken up from the bottom of the Elbe in the course of excavation work or suction processes. In addition to the identification, HPA is interested in procedures, which enable a simple and efficient extraction of such parts from the bottom of the Elbe.

Figure 19. Scrap salvage within the scope of dredging (source HPA)

The port has certain standards when dealing with dredged goods. Sediments that are recycled into the water at the Elbe grounds, or in a designated area in the North Sea will be filtered and cleaned to an extend that complies with the material which is found in the respective dumping grounds. Otherwise, the dischard would not be allowed as it may impact the environment. Larger items like machine parts, metals and plastics are properly disposed. The same procedure applies for litter found on landside premises.

The port does have some data on materials that have been found in general, but does not yet systematically keep track of quantities and quality of retrieved litter. Therefore, it will be of great interest to gather data on and under the water surface, the water column and seabed.

Figure 20.Waste from the bottom of the Elbe (source HPA)

3.7 Available infrastructure

For the overall demonstrations both locations in Hamburg – Fährkanal and Lübecker Ufer- are accessible by car and offering parking lots. Access needs to be clarified in advance and demonstration needs to be authorized within HPA bodies. Workshops and storage may be available as well as office space and meeting rooms equipped with internet and power connections. Trials may be accompanied by an HPA fleet boat and depending on the respective needs. The overall water access is possible by either quay or piers. Designated areas for Unmanned Aerial Vehicle operation will be provided and operation itself clarified by HPA.

3.8 Legal framework

One of the HPA's main interests in the SeaClear project is to achieve results in the field of carrier integration and the control of autonomous systems in complex infrastructures such as in the port of Hamburg. The HPA is convinced that autonomous platform systems will be able to take over various automated routines in the entire port area in the future in a more cost-efficient and targeted manner compared to existing solutions, e.g. using ships.

In the field of system control, the approach of a central control center is also of great interest to the HPA. Especially the combination of different systems (ROV, ASV & UAV) centralized in one application promises great potential from the user's point of view.

In addition to the technical approach of the overall solution, the legal issues and security-related topics are also of great interest. Thus, it will be a great challenge to introduce a new mode of transport into the complex and high-frequency port infrastructure. Topics such as automated collision avoidance or the required approval procedures are of particular interest to the HPA.

There have been previous learnings, when operating unmanned vehicles within the port area, which might also apply for the SeaClear System and include the following obligations. Operation generally is limited to a specific area within the port as well as a predefined time frame. The system operator needs to show a risk management plan.

Waterside regulations

The HPA hydrography department is already using a waterborne drone for measuring activities. Until now the system needs approval by the harbour master every time it is deployed into the water and is accompanied by a bigger ship which allows deployment and recovery. There are certain standards established which will contribute to the use of SeaClear. Especially when deploying the system in the water, it needs the following features and necessary approvals.

- Visibility above the water surface of up to 500 m is mandatory, operation is only allowed in daylight.
- The system needs to be equipped with a working ship horn.
- The system needs to be equipped with an AIS-system and navigation lights according to Seeschifffahrtstraßen-Ordnung (German Traffic Regulations for Navigable Maritime Waterways)
- The underwater drones should include a transponder.
- The system operator is required to hold a boat license and radio operator license.
- The system operator is required to prove insurance for the surface vehicle.
- The operation requires maritime police permit (Schifffahrtspolizeiliche Genehmigung).
- During operation there should be no interference or hindrance of general port activities.

Aerial regulations

When using air drones, it must be considered that the port of Hamburg is mostly located in the controlled airspace of two airports. The city operates a public airport in the north of the city center. It is considered one of the busiest airports in Germany in commercial flights. The Airport Finkenwerder in the southwest of the city is part of Airbus Operations GmbH. It is located on the company premises and only used for Airbus' purposes e.g. material transportation and test flights. As both flight zones are crossing the port, special conditions need to be considered. In general, drones in this area should not go higher than 50 m above the ground or water.

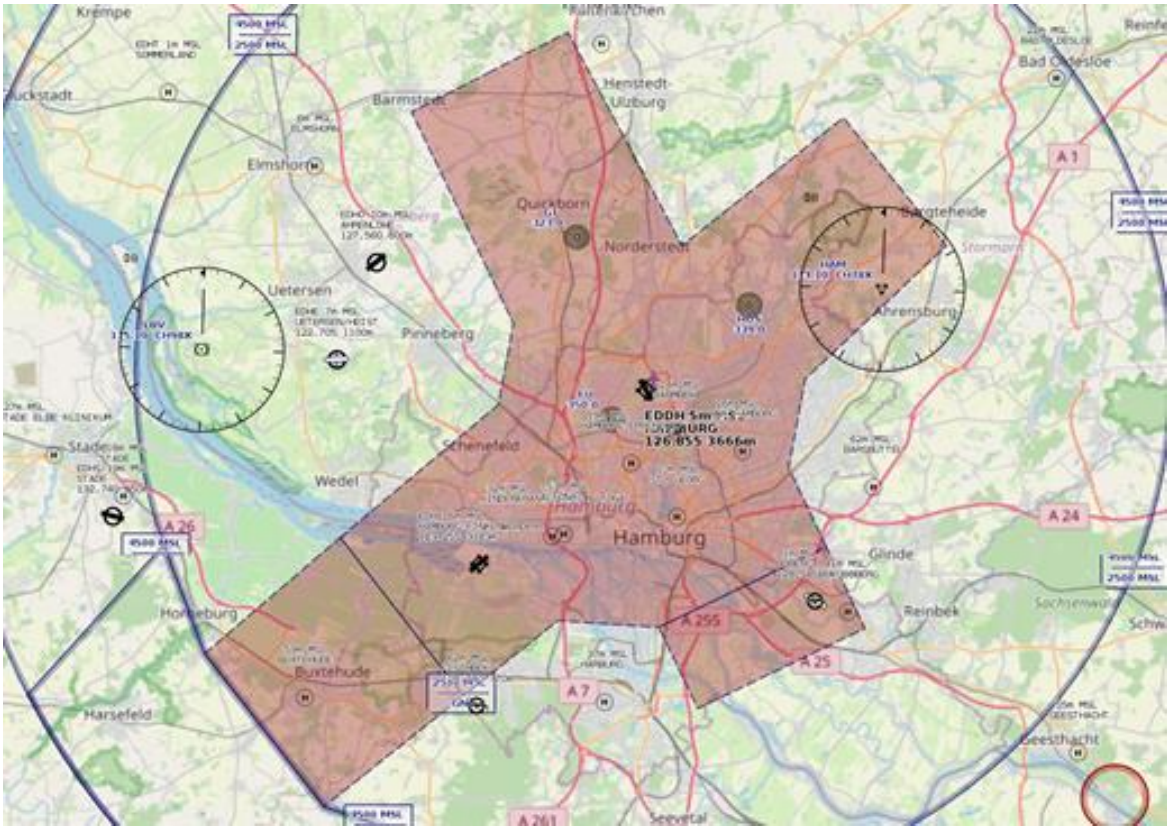


Figure 21. Map of controlled airspace Hamburg

In order to establish visibility in the control centers of the port and the air traffic control tower the following precautions need to be taken.

- Weather conditions need to ensure a visibility of at least 5 km, and clouds no lower than 1.500 ft.

- drones must carry a transponder
- The system needs to be equipped with appropriate position lights in accordance with the applicable regulations (Standardized European Rules of Air-SERA).

System operator needs to present a license and insurance.

4. Pilot Locations Comparison

4.1 Demo sites comparison table

Table 3: Overview on location parameters in Dubrovnik Neretva County and Hamburg

		LOKRUM ISLAND	MALI STON BAY	HAMBURG PORT	
Pilot location type		*protected island-special nature reserve of forest vegetation, touristic site*	*protected bay-marine special nature reserve, mariculture site*	*open tidal port, largest seaport in Germany and the third largest in Europe*	
Demo site	name	***Portoč bay***	***Bistrina bay***	***Lübecker Ufer***	***Fährkanal***
	GPS coordinates	*42°37'32.7"N, 18°07'23.4"E*	*42°52'16.2"N, 17°42'04.3"E*	*53°31'36.7"N, 10°00'11.7"E*	*53°32'19.8"N, 09°57'56.9"E*
	size	*approx. 30.367,67 m²*	*approx. 1.308.741,00 m²*	*approx. 42.000 m²*	*approx. 35.000 m²*
	sea depth	*01 - 19 m*	*00 - 12 m*	*0,2 - 12,7 m*	*0-6,1 m*
Climate and weather		*mild Mediterranean climate*	*mild Mediterranean climate*	*continental climate*	*continental climate*
Oceanographic parameters [4]	sea temperature	*12 - 29 ° C*	*12 - 29 ° C*	*0 - 27 ° C*	*0 - 27 ° C*
	salinity	*32 - 38 ‰*	*32 - 38 ‰*	*0,5 ‰*	*0,5 ‰*

	oxygen	*6,11 mg/l - 7,11 mg/l*	*6,11 mg/l - 7,11 mg/l*	*2 - 15 mg/l*	*2 - 15 mg/l*
	pH	*pH = 8*	*pH = 8*	*pH= 7.7*	*pH=7.7*
	currents	*approx. 0.5 – 2 knots*	*approx. 0.5 – 4 knots*	***high tide:** currents direction from North Sea to Hamburg up to 1,25 - 1,75 m/s (2,4 - 3,4 knots)* ***low tide:** currents direction from Hamburg to North Sea up to 1,25 – 1,5 m/s (2,4 – 2,9 knots)*	
	waves	*Portoč demo site is a small bay facing the mainland and has relatively low waves (exact data unavailable)*	*Bistrina bay is a bay protected from the extremely high waves by the Pelješac peninsula, with relatively low waves (exact data unavailable)*	*up to 1,5 m*	*up to 1,5 m*
	transparency	*< 25 m*	*< 15 m*	*< 0,5 m*	*< 0,5 m*
	turbidity	*low*	*medium*	*high: 25 bis 50 FNU (max. 100 FNU)*	*high: 25 bis 50 FNU (max. 100 FNU)*
Seabed structure		*rocky limestone, submerged or partially submerged sea caves and Posidonia beds*	*rocky coast to moving sediment of sand, silt and/or mud*	*heterogenous area with sandy seamounts*	*heterogenous area with sandy seamounts*
Biodiversity		*high biodiversity level*	*high biodiversity level*	*moderate biodiversity level*	*moderate biodiversity level*
Tourism		*highly developed, mostly nautical tourism, approx. 175000 visitors per year*	*moderately developed, connected to maricutlure activities, approx. 40000 visitors per year*	-	-

Marine litter	origin	*approx. 80% inland sources (tourism, neighbouring countries)*	*approx. 80% sea origin (mariculture and fisheries activities)*	*approx. 80% inland sources (tidal flows, currents coming down river)*	*approx. 80% inland sources (tidal flows, currents coming down river)*
	type	*mostly plastic waste*	*mostly specific waste fractions from mariculture production*	*plastic bags, cans, bottles, wood, bulky waste on ground (machine parts, bikes, fishing nets, tires), ammunition*	*plastic bags, cans, bottles, wood, bulky waste on ground (machine parts, bikes, fishing nets, tires), ammunition*
	occurrence	*high contamination in the period from September to December (high waves and currents period)*	*continuously throughout the year, with high peaks from September to December when high waves create damage on the installations*	*low contamination on water surface, lacking knowledge on water column, occasional occurrence on ground*	*low contamination on water surface, lacking knowledge on water column, occasional occurrence on ground*
Available infrastructure		*infrastructure on site, UNIDU ship*	*infrastructure on site, UNIDU laboratories, UNIDU ship*	*infrastructure on site, ship*	*infrastructure on site, ship*

Legal framework		*Nature Protection Act (NN 80/13, 15/18, 14/19, 127/19)* *• Law on Maritime Property and Seaports (NN 158/03, 100/04, 141/06, 38/09, 123/11, 56/16, 98/19)* *• Law on Sustainable Waste Management (NN 94/13, 73/17, 14/19, 98/19)* *• Marine Strategy Framework Directive (2008)* *• Ecological network regulation Natura 2000*	*• Nature Protection Act (NN 80/13, 15/18, 14/19, 127/19)* *• Law on Maritime Property and Seaports (NN 158/03, 100/04, 141/06, 38/09, 123/11, 56/16, 98/19)* *• Law on Sustainable Waste Management (NN 94/13, 73/17, 14/19, 98/19)* *• Marine Strategy Framework Directive (2008)* *• Ecological network regulation Natura 2000*	*• German Traffic Regulations for Navigable Maritime Waterways (SeeSchStrO)* *• Standardised European Rules of Air (SERA)* *• Maritime Police Permit (Schifffahrtspolizeiliche Genehmigung)*	*• German Traffic Regulations for Navigable Maritime Waterways (SeeSchStrO)* *• Standardised European Rules of Air (SERA)* *• Maritime Police Permit (Schifffahrtspolizeiliche Genehmigung)*

5. Use Case Ideas

5.1 Dubrovnik Neretva County

Dubrovnik Neretva County is one of the most impacted area when speaking about marine litter problematics. Because of its geographic location, in some periods of the year, large amounts of waste from seas are brought to Dubrovnik Neretva beaches and circulated by sea currents to the seabed. Continuous use of autonomous robots for underwater waste collection would reduce the negative impacts of marine litter and in long term, offer the best economic solution for collection of litter from the seabed and water column, while preventing the enormous risk and danger for divers during underwater collection interventions at various depths. The system should be verified for different types of conditions with various types of marine litter. Through the project, the SeaClear system will be demonstrated on two different pilot sites:

– tourism impacted site
– maricultural site – shellfish farming spot

Both locations are under nature protection legislation, so the system should specifically take into consideration biodiversity and wildlife preservation, specially of underwater seagrass species *Posidonia oceanica* that is endemic to the Mediterranean Sea and forms large underwater meadows that are an extremely important part of the ecosystem. Most of the seabed litter gets caught up in these *Posidonia* beds, so this task will be challenging for the system to work autonomously. In the Lokrum area, rocky bottoms with submerged or partially submerged sea caves where litter can be also caught up will be challenging. For Dubrovnik Neretva County needs, the SeaClear system should be verified for different waste fractions, from plastic bottles and similar items from tourism impacted site of Lokrum island, to Mali Ston Bay as mariculture site where large and bulky constructions from shellfish farms can be found. Also, the debris that can be found on the seafloor is usually covered in biofouling, so the identification of the item and recognition in relation to living organisms, will be a challenging task.

5.2 Hamburg Port

Derived from the above findings in Hamburg the SeaClear System could apply for the following Use Cases:

5.2.1 Waste collection on the water surface

Introduction

In its strategic vision Hamburg Port aims to be plastic free and has taken measures to achieve this goal. The SeaClear System can contribute to those efforts by examining the current status of litter occurrence in the port and collecting the detected parts. Most likely litter will run downstream the Elbe river or is carried in by tidal flows and incoming currents.

The port is currently lacking a database on the overall waste situation in Hamburg. To get a clearer view on potential hotspots HPA is examining different parts by boat. Surveys in March and April 2020 have shown that contamination at the water surface is rather low. There are some reasons contributing to that, like the overall flow velocity of the river taking litter with it and the COVID-19 related lock down period, which basically stopped all touristic movements and port-specific events.

Even though, there is no data base on litter findings, the port has been called to action previously by visitors and port personnel, when waste in the water had been detected. Lifting was done manually in the respective spots. For the future HPA expects litter occurrence like that and requires a system for detecting and collecting those items.

Use Case goal

Whenever litter is detected within the port premises, SeaClear will be called to action. This may apply if visitors or port employees spot waste on the water surface or especially after port-related events that may lead to contamination. The main idea is to keep the port clean and contribute to the overall strategy to be a plastic free port and conservation of the close by nature preserve areas. Besides the economic importance the port also is a touristic attraction and needs current maintenance for visitors. The overall vision is the development of a system that fulfils the waste collection service in regions that show similar conditions as Hamburg: little visibility, currents and shipping traffic.

Preconditions

Regardless of the definite location where the system will be deployed to start fulfilling its tasks, the environmental framework conditions remain: turbid water, currents, small waves as well as wind of 9 knots with gusts of up to 18 knots coming most likely from a western direction and will challenge detection, mapping and even collecting of waste as it might be moving.

Waste allocations of e.g. bottles, cups, wrappers, cigarette butts, wooden parts and plastic bags are expected in close vicinity to the shore and quay walls. In that case, the SeaClear systems will be operating in a range of 10 m to quay or building walls and needs to avoid collision with the given surroundings. Depending on the exact location there will be boat traffic causing small waves and potentially stronger currents due to landing and departing. This will ask for stability measures of the surface vehicle, and fastening of the aerial drone, when taking of, landing, and especially while resting on the surface vehicle. The overall weather conditions need to be appropriate for the system to work within its capabilities. The system design itself needs to present durability and resistance to water and corrosion.

Technically, the system needs to receive an initial order through the web interface to start the process. All batteries need enough energy to fulfil the respective task and return home. The collection basket needs to be empty before taking off. The communication processes between the different devices need to work as well as the data imaging, map refining and classification of the litter to be collected.

Work flow

A user – either a visitor to the port or an employee at HPA, detects litter on the water surface and reports findings at the SeaClear web interface by defining the area that should be subject to further analysis. Shared information will include the specific area where and when the litter was spotted including information on size and amount. Any relevant information will be given upon requesting the service. The request is submitted to the data server, from where it will be processed by the technical staff with the help of the ASV towing ROVs and/or an UAV for completing the task. The robots are sent to the area of interest and perform the clean-up service using standard/non-destructive/legislation compliant procedures. An operator ensures the suitability of SeaClear to solve the reported case to avoid misuse or damage to the system.

Once the destination is reached, the USV will first survey the work area with a multibeam bathymetry sonar to produce a 3D map of the seabed for grounding avoidance before deploying the observation UUV and the UAV. The USV will then be in "follow-up mode" controlled by the observation UUV navigation.

The UAV will survey the area in front of the USV. UAV video will be transmitted to the main processing unit on the USV for creating the aerial density map with object detection/classification if images allow (depending on ambient light, surface water conditions, water turbidity, etc.). During that time the observation UUV carries out the underwater survey, reefing the map and detecting debris.

The data is transmitted to the USV for further processing which allows classification of the litter based on trained algorithms as well as updating the map on the location of the litter. Based on this information the collection UUV is sent to collect the litter classified and mapped earlier. The collected items are stored in a basket tethered to the USV.

The whole process is monitored through a shore station to allow human interference if needed. When all litter is collected the supervising UAV returns to the USV platform for battery charging and the UUVs are recovered accordingly. The system returns to its initial position for recovery or the next mission.

Post conditions

The area where the system has been active should be cleaned of any litter. Ideally a report will be refined outlining the mission and findings to enable data collection on amount and type of waste, and even flag those items that couldn't be collected and need other treatment. The system status regarding to battery life and collection basket capacity should enable estimations on possible following missions of litter collection.

Possibilities (other use cases, scaling up)

To extend the overall operation time, increase loading capacity and reduce operation costs the scale up should consider alternative drive technology of either a hybrid drive system, 100% solar or hydrogen.

Future developments should also include a bigger waste storage and a possibly connected sorting system of different types of debris. Ideally, it enables material sorting and further processing directly on board or after dumping on shore.

Considering, that larger amounts of debris are brought to sea and rivers from tributaries, the collection process should concentrate on those areas before the litter even reaches open water - namely rivers.

5.2.2 Debris detection & classification at seabed and ground for targeted salvage

Introduction

Currents in the Elbe do not necessarily bring in litter, but effectively do carry a lot of sediments with them, which require for constant dredging in high frequented canals of the Elbe to allow heavy ship arrivals. The sediments are filtered and cleaned of waste and potential contamination before they are dumped again in the North Sea. Depending on the sand carrying currents, the sediment accumulation and the importance in daily port operations some areas are monitored more closely and will in some cases be examined every two weeks. Areas that are not of high maintenance will at least be checked once a year and are subject to lacking knowledge on waste at the seabed that was brought down river or has been discarded illegally. As seen in Figure 22, there is some common knowledge on quantities, qualities and types of litter appearing during the sediment cleaning process. Since these areas (marked in yellow) are regularly examined and maintained, they are considered rather clean.

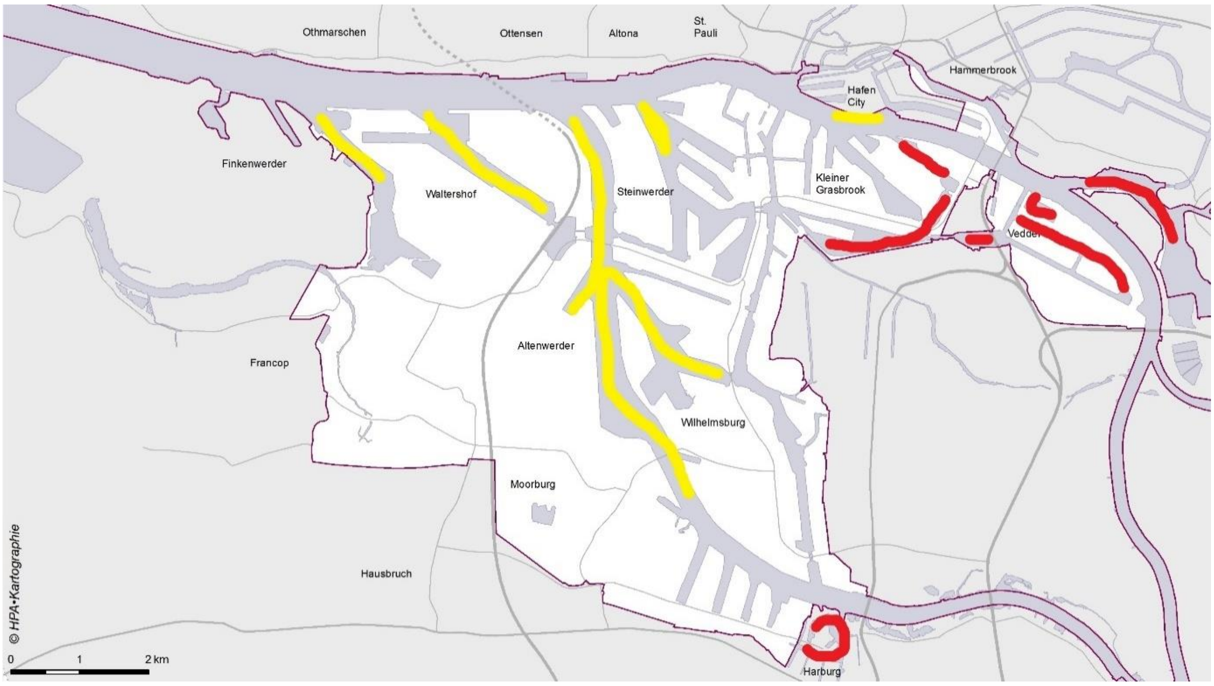


Figure 22. Map on sedimentation intensity in Hamburg port

When looking at the further eastern and southern parts of the port, sedimentation decreases to an extent, that fairways show sufficient depth for passing ships. Those areas (marked red in the map) are examined at least once a year as a general maintenance effort. As a result, there is little to no data on litter and waste. Previous findings on the seabed revealed especially bigger items like tires, metal parts, canisters, bikes, shopping carts, and even cars. Contamination in regard to world war 2 ammunition, and especially the removal of unexploded ordnance is part of regular procedures. In order to maintain those areas and to take appropriate lifting measures, building up knowledge on the seabed is necessary.

The current procedures can be described as follows: Before the dredging is initiated, the port takes measures to evaluate the water depths and the seabed structure. In areas where dredging is common, the hydrographic instruments indicate the nature of the seabed in terms of density, material and soil composition. This allows for determination, if the ground is soft enough and therefore passable for ships, or if it will likely damage the hull, propeller or keel and needs sediment removal.

Detection of debris in cases of deepening the fairway to a new maximum, large ships with echo sound technology are involved to ensure that all harmful obstacles for suction pipes like e.g. explosives and steel beams are removed before the actual construction work begins.

Use Case Goal

In order to avoid unexpected damages on ships and dredging tools, decomposition of alienated materials within the marine eco system, and to estimate tailored tool use for lifting, detection, mapping and classification of debris at seabed and beneath is a desired SeaClear feature. As a result, specific mission planning regarding suitable collection tools and vehicles contributes to cost reductions for HPA. Besides the detection of in ground obstacles, SeaClear is also asked to identify and collect potential litter at seabed, that fit the systems gripping/ suction capacity and size of basket.

Preconditions

Regardless of the definite location where the system will be deployed to start fulfilling its tasks, the environmental framework conditions remain: turbid water, currents of up to 5 m/s, smaller waves as well as wind of 9 knots with gusts of up to 18 knots coming most likely from a western direction. The system will be deployed in an area with potential boat traffic and tidal flows. The latter being of special interest, as low tide may expose the seabed to air and limits the time for the system to operate. Algae, seaweed and smaller stones are expected at seabed especially when dredging is not commonly done.

The area to be examined will most likely have “natural” boundaries in the quay walls for the USV and UUV and potentially cranes installed on shore for the UAV. Depending on the commercial use of the area there might be ships moored at quay as a potential obstacle.

Workflow

The SeaClear service for ground examination is requested by the HPA authorities via a web interface. The initial order contains information on the location within the port boundaries, specifies a date and a scheduled time slot for operation considering the overall weather conditions. After submission of the order, the SeaClear system takes off to the designated area or it is deployed on site.

Once the destination is reached, the USV will first survey the work area with a multibeam bathymetry sonar to produce a 3D map of the seabed, before deploying the observation UUV and the UAV. The USV will then be in “follow-up mode” controlled by the observation UUV navigation.

The UAV will survey the area in front of the USV. During that time the observation UUV carries out the underwater survey, reefing the map and detecting debris at seabed and the ground with multibeam echosounder.

The data is transmitted to the USV for further processing, which allows classification of the litter based on trained algorithms as well as updating the map on the location of the litter. Based on this information the collection UUV is sent to collect the litter classified and mapped earlier. The collected items are stored in a basket tethered to the USV.

Once the designated area is cleaned of the non-organic liftable objects, the map is again updated showing just the non-collectable items at the seabed and in the ground for further collection. Ideally a report is created containing information on the debris that has been collected, and what is left for further treatment with larger, specified ships. This also offers insights on the seabed conditions and enables long-term data collection.

The whole process is monitored through a shore station to allow human interference if needed. After mission completion the UAV returns to the USV platform for battery charging and the UUVs are recovered accordingly. The system returns to its initial position awaiting the next order.

Once the collection of the detected debris is successfully completed, the map needs to be updated to the most recent state. This again should be a task for SeaClear.

Post-Conditions

After task completion there will be a clear picture of the seabed and the items that need to be removed. A report with the images from underwater is created with information about the quantities and type of litter collected as well as the expected items inside the seabed.

Possibilities

For further detection measures the system could potentially be equipped with magnetic sensors as additional feature for data collection on the ground. Especially in offshore wind park installations, SeaClear could potentially contribute to ground explorations for land connection with cable, allow estimations on how to clear the seabed of obstacles like stones or explosives and, thus, might relieve the work of divers, who are currently doing this task.

To broaden the service of the observation UUV a device to take soil samples for studies and monitoring of the environmental status of waterways and seabed might be helpful. This could be used to determine the soil contamination with e.g. micro plastics and the water quality in rivers, lakes and open water.

A port environment detection device may also be used to examine incoming ships for damages and general inspection while unloading takes place or to assist yacht leasing companies and owners for maintenance purposes. It could also be extended to infrastructural observation on buildings, quay walls, bridges, pontoons and floating docks as well as offshore wind turbines.

When it comes to marine aquaculture and commercial breeding SeaClear could be a remote monitoring application sending data on the overall health of the breed and functionality of the equipment to allow for further actions if needed.

5.3 Possibilities

The project mainly concentrates on the tasks of litter detection, classification, mapping and collection, the respective data processing and the necessary communication in between the system components. Bringing the process to an autonomous level will be a unique development.

Related to the described use cases, potential further developments have been briefly outlined.

Up until now autonomous vehicles within the HPA are always accompanied by a larger ship and remotely monitored to allow human interference. The overall development should aim for high level autonomy (TRL 6-7) and integration in ongoing port operations and traffic. This involves public transportation. Hamburg city is to some kind divided by the Elbe river making the port the heart of the city. Naturally there is lots of ferry traffic going on to connect the two sides of the river for commuters. The boats run on a busy and regular schedule and predefined routes, which makes their movements predictable when supervising the overall port traffic. Commercial ship traffic is based on berth availability, (un-)loading times and tidal flows. Maintenance works on the seabed and respective landside infrastructure is planned accordingly. The only unpredictable variable on the water are privately owned boats. Their behaviour is subject to the German Traffic Regulations for Navigable Maritime Waterways (Seeschifffahrtsstraßen-Ordnung), which gives priority to commercial ship traffic. In conclusion the overall traffic situation in the port is very complex but at the same time offers boundary conditions that allow for careful autonomous operation planning.

6. Summary

Oceans are negatively affected by human activities that harm marine life, undermine coastal communities and impact human health, with marine litter being one of the most significant issues facing oceans worldwide. In this document, available data on origin, occurrence, amounts and distribution of marine litter in the selected pilot areas are presented. So far, collection efforts have focused mainly on surface debris, and seabed waste management efforts are usually individual local diving activities. There is no solution that uses autonomous robots to collect underwater waste and first such autonomous underwater and surface vehicles will be developed through the SeaClear project. The present use case definition document gives an overview of the different demo sites, from two demo sites in Hamburg port – 3rd biggest port in Europe, with demanding conditions of extremely high turbidity, to small and protected nature island in Dubrovnik – Lokrum Island, with extremely high water transparency, representing the famous touristic area, to mariculture oriented site with shellfish farms – Bistrina in Mali Ston Bay. Considering the oceanographic parameters, demo sites depth varies from 0 to almost 13 m, sea temperature from the lowest 4 to the highest 29º C; seabed structure varies from rocky bottoms and protected *Posidonia* beds, to muddy seabed and sand seamounts. Approximately 80% of all marine litter in the sites originates from inland, from different human activities, such as tourism, while in demo site Bistrina, Mali Ston Bay, there are marine litter originating in approximately 80% from the sea, with specific waste fractions from shellfish farms. Demo sites cover the protected nature areas with extremely high biodiversity and species protected by different laws, to low biodiversity sites. All demo site locations are coastal areas chosen in order to have an overview of wide range of conditions in which SeaClear system will have to autonomously operate, and to ensure the minimum infrastructure needed for demonstration and verification phase (infrastructure on land, boat/ship, WIFI, etc.).

7. Literature

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