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

SeaClear2.0

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D9.2
Demonstration in Marseille

WP9 – *Demonstrations*

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

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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
- **WP**: Work Package
- **UAV:** Unmanned Aerial Vehicle
- **ROV:** Remotely Operated underwater Vehicle
- **USV:** Unmanned Surface Vehicle
- **LARS** : Launch And Recovery System
- **LVDT**: Linear Variable Differential Transformer
- **USBL** : Ultra Short BaseLine

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1. Executive Summary

This report presents the activities and results of the SeaClear2.0 system demonstrations conducted in Marseille from 8–19 September 2025. The goal of these trials was to validate the integrated multi-robot system in an operational port environment and to evaluate the performance of the main components developed within WP3, WP4, and WP5.

Two test sites, both located in front of Subsea Tech's facilities, were used to carry out installation, calibration, preliminary tests, and final public demonstrations. The schedule included system setup, rehearsal, two full demonstration days, and a consortium meeting.

During the trials, the SeaCAT USV performed bathymetric mapping of the area, enabling Mini-Tortuga to execute automated lawn-mower search patterns and detect seafloor litter using both sonar and camera-based neural networks. The SeaHawk UAV contributed aerial observations, surface-litter detection, and extended tethered operations for improved situational awareness.

The smart grapple developed by TUM successfully retrieved a variety of objects—including a tire, car seat, fencing, and larger fragments—demonstrating compliant grasping of items up to 250 kg, as validated in laboratory tests. Collection operations were completed through the autonomous docking of SeaDragon, which received the retrieved debris and transported it back to shore. All partners conducted additional experiments to evaluate robustness, system integration, and control accuracy.

Overall, the Marseille demonstrations confirmed the operational capabilities of the SeaClear2.0 system and provided valuable datasets and insights for further refinement ahead of future pilot deployments.

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2. Introduction

SeaClear 2.0 builds upon the achievements of the H2020-funded SeaClear project, in which several of the current partners developed the first autonomous robotic system for seafloor litter collection.

In the original system, an unmanned surface vehicle (USV) called *SeaCAT* acted as the central hub for a multi-robot setup composed of:

- an unmanned aerial vehicle (UAV) that detected litter from above an observation ROV (Mini-Tortuga) that located litter underwater
- a collection ROV (Tortuga) equipped with a gripper-and-suction tool to retrieve debris and deposit it into a basket deployed from the USV.

As the first project of its kind, SeaClear 1.0 focused primarily on technological development, including hardware, perception, and autonomy algorithms. However, it was limited to seafloor debris of moderate size (up to tens of centimeters) and shallow depths (tens of meters). It could not handle floating litter or larger submerged objects, such as fishing gear, bicycles, e-scooters, tires, or other heavy marine debris.

SeaClear 2.0 addresses these limitations by scaling up and extending the original concept. The upgraded system is designed to collect larger and heavier debris using an enhanced *SeaCAT* equipped with a smart grapple, supported by a dedicated USV Tender for debris storage and transport to shore. In addition, SeaClear 2.0 introduces surface-cleaning capabilities through a fleet of highly maneuverable surface robots that operate autonomously or in coordination with SeaCAT.

The sensor suite and autonomous intelligence of SeaClear 2.0 have also been upgraded. Advanced AI algorithms enable multi-robot coordination, enhanced debris detection across surface and underwater environments, and adaptive path planning in complex or cluttered conditions. The UAV continues to provide aerial situational awareness, now fully integrated with surface and underwater sensors to produce comprehensive 3D mapping of litter distribution, optimizing collection routes and efficiency.

Finally, SeaClear 2.0 is designed to work synergistically with SeaClear 1.0, creating a multi-layered approach to marine debris removal. SeaClear 1.0 focuses on detecting and collecting smaller seafloor litter, while SeaClear 2.0 handles larger and surface debris, ensuring that a broad range of marine litter—from small fragments to bulky objects—can be autonomously detected, retrieved, and safely removed. This integration demonstrates a comprehensive, practical solution for autonomous marine litter management that is scalable, efficient, and environmentally impactful.

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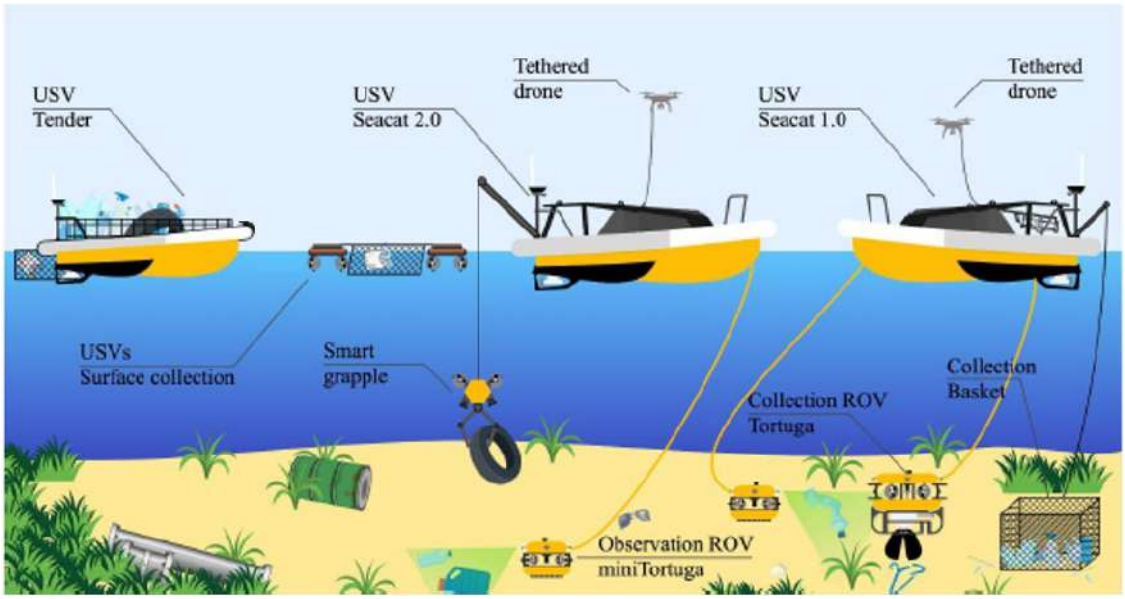


Figure 1: Concept of SeaClear 2.0 robotic system (left/middle) and SeaClear 1.0 (right)

2.1 Demo Sites

Both test sites were located directly in front of the Subsea Tech facilities, providing convenient access for both personnel and equipment, which was essential for the setup, monitoring, and immediate troubleshooting during the tests.

Both SeaClear1 and SeaClear2 systems were tested at the two sites, as initially planned.

The first site, situated on the right-hand side when facing the facility, was designated for installation and preliminary tests. Located next to Marseilles harbor facilities, it was qualified as an industrial harbor site. This site offered a controlled and predictable environment, which was ideal for verifying that all equipment was functioning correctly before proceeding to more complex demonstrations. The controlled conditions allowed the team to methodically test the system's components, including deployment mechanisms, sensor calibration, and communication links, without external disturbances. It also allowed for safe handling of the equipment, minimizing the risk of damage during trials. This site effectively served as a shakedown area, ensuring that all subsystems were operational and that any minor adjustments could be made efficiently before moving to the touristic site.

The second site, located on the left, was slightly farther from the Subsea Tech facilities and was next to Corbières Marina, qualifying then as touristic site. This site provided greater water depth, more open space, and the presence of natural debris, creating conditions closer to those the system would encounter in real-world deployments. The increased distance from the operator introduced additional communication and control challenges, allowing the team to assess the system's robustness in less controlled environments. This site was used for the demonstration at the tourist location, showcasing

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the system to external visitors while also providing a platform to evaluate its performance under practical constraints.



Figure 2 : Sites for demo in front of Subsea Tech facilities

Together, the two sites provided a complementary testing strategy: the first site focused on system verification, calibration, and initial validation, while the second site emphasized performance demonstration, operational feasibility, and scenario-based evaluation. This combination allowed the project team to rigorously assess the system's readiness, reliability, and suitability for real-world applications, while also offering stakeholders and visitors a clear understanding of its capabilities and potential use cases.

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2.2 Schedule

The schedule spanned a total of 9 days, carefully organized to balance technical preparation, system integration, and demonstration activities.

The first 5 days were dedicated to preliminary tests and final system integration, ensuring that all equipment was correctly installed, calibrated, and fully operational. During this period, the teams verified subsystems functionality, conducted troubleshooting as needed, and progressively refined the setup to guarantee reliability for the demonstrations.

The following 2 days were devoted to full system demonstrations, one day at each demo site. These demonstrations aimed to showcase the system under both controlled and realistic operational conditions, allowing partners and external stakeholders to observe performance, validate operational procedures, and evaluate the system's adaptability in different environments.

The final day of the schedule was reserved for the consortium meeting, during which all project partners convened to discuss the overall outcomes of the tests and demonstrations. This meeting provided an opportunity to share insights, identify lessons learned, assess the system's readiness, and discuss potential improvements or next steps for future deployments.

Date (2025)	**Activities**
Sept 8–12 (Mon–Fri)	Installation & preliminary tests
Sept 15 (Mon)	Final rehearsal
Sept 16 (Tue)	Workshop, lunch & demo at test site – Subsea Tech
Sept 17 (Wed)	Demo at tourist site & social evening – Subsea Tech
Sept 18 (Thu)	Consortium meeting & dinner

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2.3 Robotic Agents Roles

- **SeaCAT (SST)**: The autonomous surface vehicle served as the hub platform, providing power and computational support for the other robots. It conducted initial bathymetric scans to create detailed seafloor maps and coordinate the deployment of the ROVs and smart grapple.



Figure 3 :Seacat vessel

- **Mini-Tortuga (SST/UTC)**: This remotely operated underwater vehicle mapped underwater debris using camera and sonar data, assisting the SeaCAT in locating litter for retrieval.



Figure 4 : Mini-Tortuga ROV

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- **Smart robotic grapple (TUM)**: Guided by pre-identified debris locations, the grapple autonomously grasps and lifts heavy items, successfully collecting objects such as tires and placing them on the tender platform.

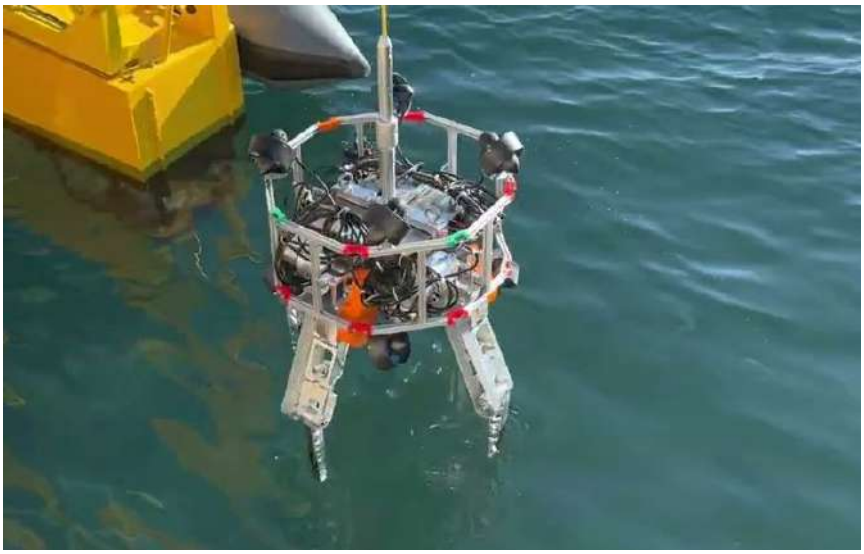


Figure 5:Smart grapple

- **SeaDragon (CML)**: Acting as a mobile tender, the SeaDragon automatically docks to SeaCAT to collect recovered litter and transport it autonomously to shore.



Figure 6 : SeaDragon USV

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- **SeaHawk (UNIDU)**: Provided aerial observation, detected surface litter, and relayed real-time mapping data to coordinate collection activities.



Figure 7: SeaHawk Drone

- **SeaBees (UNIDU)**: These unmanned surface vehicles removed floating debris using nets, operating autonomously based on the UAV's detection and mapping data.



Figure 8:SeaBees

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3. Opérations

3.1 Demonstrations scenario

First, the SeaCat uses the multibeam sonar to create a 3D map of the sea floor and then the Mini-Tortuga is lowered into the water from the SeaCat to scan the bottom for potential litter. The litter is labelled on the previously created map of the area and is made available for the smart grapple.

Based on the refined map, the smart grapple maneuvers to the locations where the objects are identified, collects them with the grapple and load them on the SeaDragon (USV tender). Objects that cannot be collected remain labelled on the map and can be recovered by alternative means, e.g. by divers, once the mission has been completed. The SeaHawk supports the localization of the individual system components and helps to identify litter on the water surface.



Figure 9: Overview of the quay-side installation

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3.1.1 Identification

During the demonstrations, SeaCAT conducted a systematic acoustic scan of the operational area using its bottom-looking imaging sonar. The objective was to acquire a high-resolution map of the local seabed and identify any structures, debris, or irregularities.

The sonar continuously emitted acoustic pulses and recorded the return echoes from the seabed and any protruding objects. These returns were processed in real time to generate a polar-format image representing seafloor geometry and reflectivity. Variations in intensity allowed the system to highlight natural features (sand ripples, slopes, hard patches) as well as potential litter.

The resulting map (shown in the attached image) displays:

- **Seabed texture**, derived from the strength of returned echoes.
- **Contours and objects**, revealed by differences in reflection and acoustic shadowing.
- **Coverage uniformity**, indicating stable navigation and consistent sonar orientation.
- **Identified anomalies**, such as hard targets or debris, highlighted by strong reflections and distinct shadows.

This dataset provides a reliable representation of the surveyed area and serves as a baseline for environmental assessment, operational planning, or future comparison with subsequent scans. The stable platform, controlled trajectory, and continuous sonar acquisition ensured good-quality mapping throughout the dive.

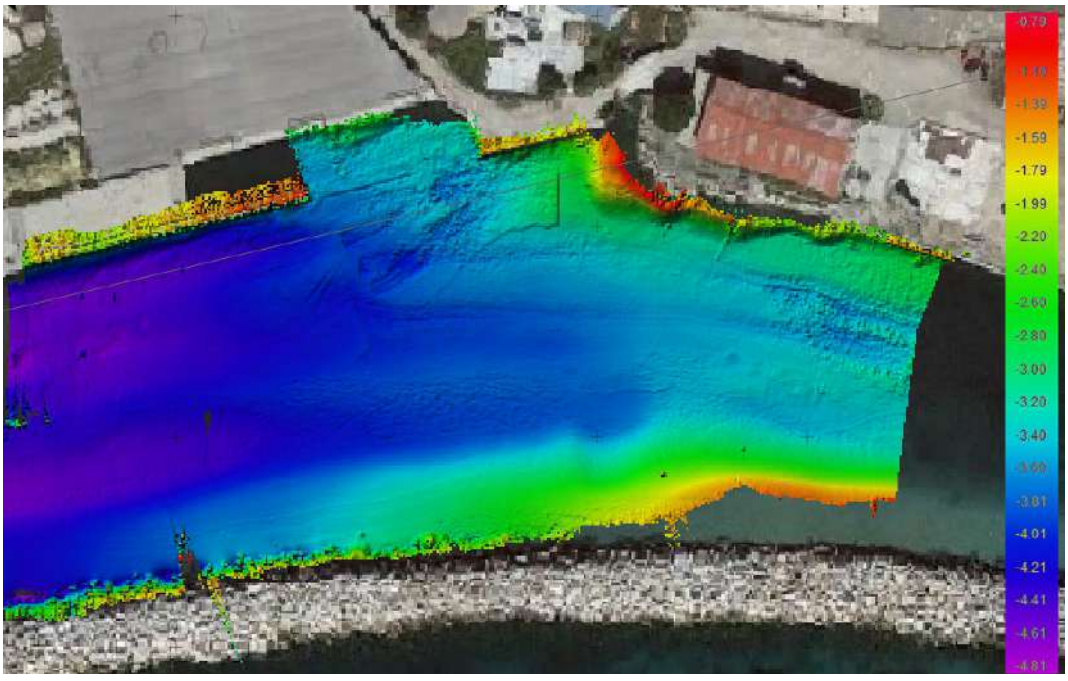


Figure 10: Site demo bathymetry

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SeaHawk – UAV

The SeaHawk has two modes of operation:

- **Free-flying mode** in which the UAV uses its main advantage of covering a wide area for the purpose of litter detection and mapping. The UAV tracked a predefined lawn-mower pattern autonomously. The onboard sensors were the high resolution RGB camera, multispectral and a thermal camera. For surface litter detection we used the multispectral camera specifically adjusted in hardware and with custom software enabling near real-time detection.

- **Tethered mode** in which the UAV is connected to the SeaCat through a cable providing power and communication link thus allowing the UAV to be longer airborne which supports higher level of situational awareness. The coordinated control between the UAV and the winch for the tethered performed successfully allowing the UAV to take-off, track a reference trajectory and land all the while the cable was at a constant slack and tension.

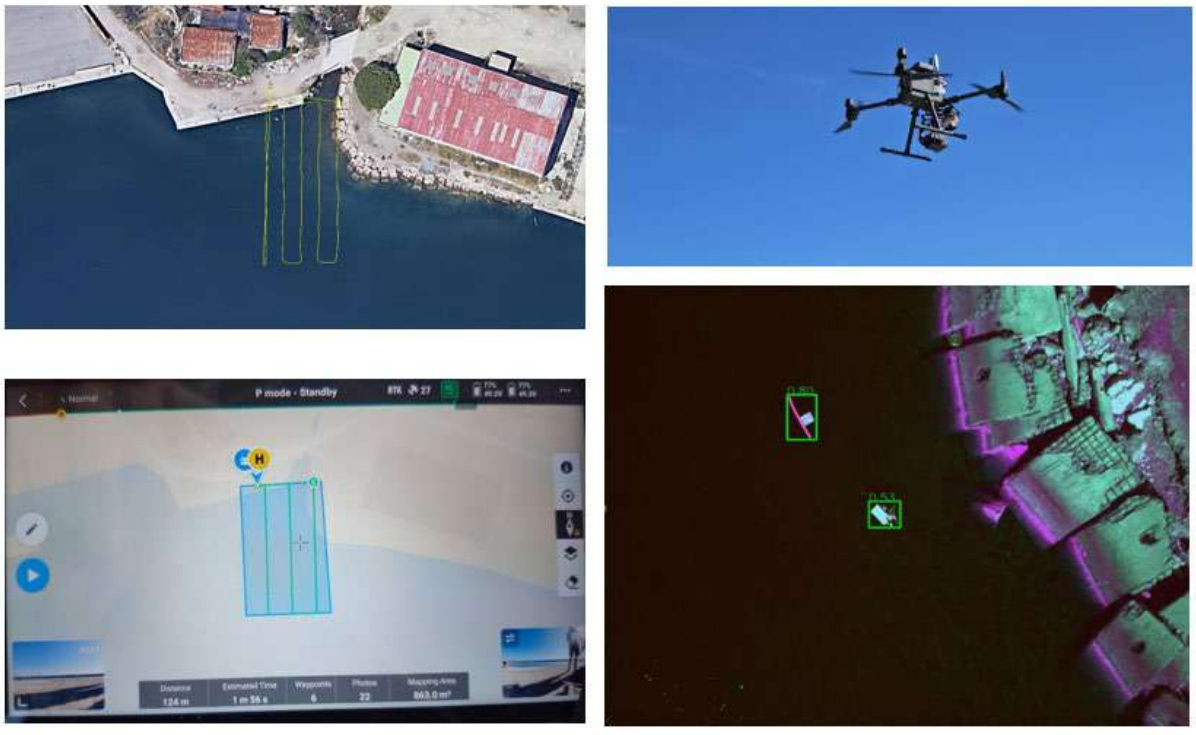


Figure 11: UNIDU Free-flying mode of the SeaHawk. Surface litter detection using mutlispectral camera

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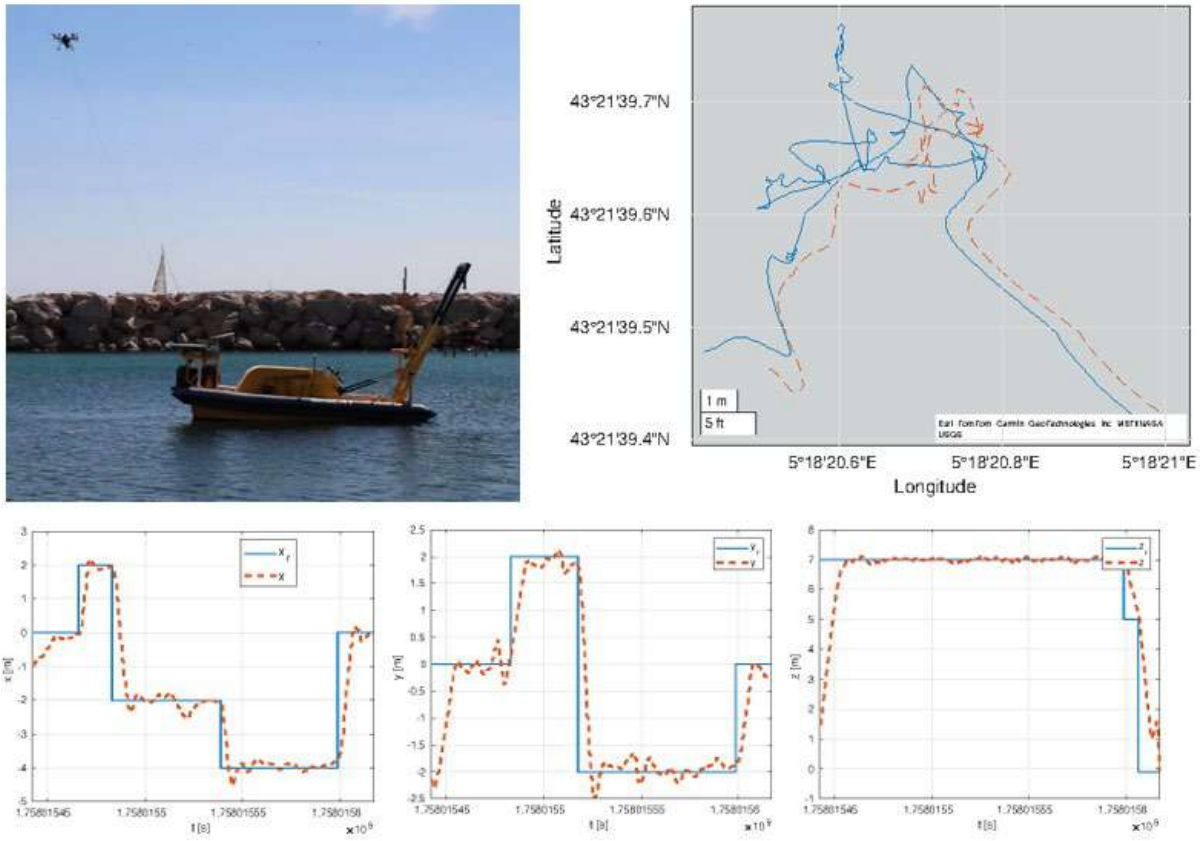


Figure 12: UNIDU Thered mode oh the SeaHawk. Coordinated control of the UAV and the cable winch for autonomous UAV take-off. landing and path following

Mini Tortuga - ROV

The ROV executed a **lawn-mower navigation pattern** to ensure complete and uniform coverage of the survey area. This pattern provided systematic track lines with constant spacing, allowing the sensors to capture overlapping swaths and produce a continuous representation of the seabed.

The ROV's global position was maintained using a **USBL acoustic positioning system**, which delivered absolute coordinates throughout the dive. These USBL fixes were fused with the vehicle's internal navigation data (IMU, depth, and heading) to maintain stable positioning and ensure accurate geo-referencing of all collected measurements.

For environmental assessment, the ROV relied on a **dual-sensor approach** combining:

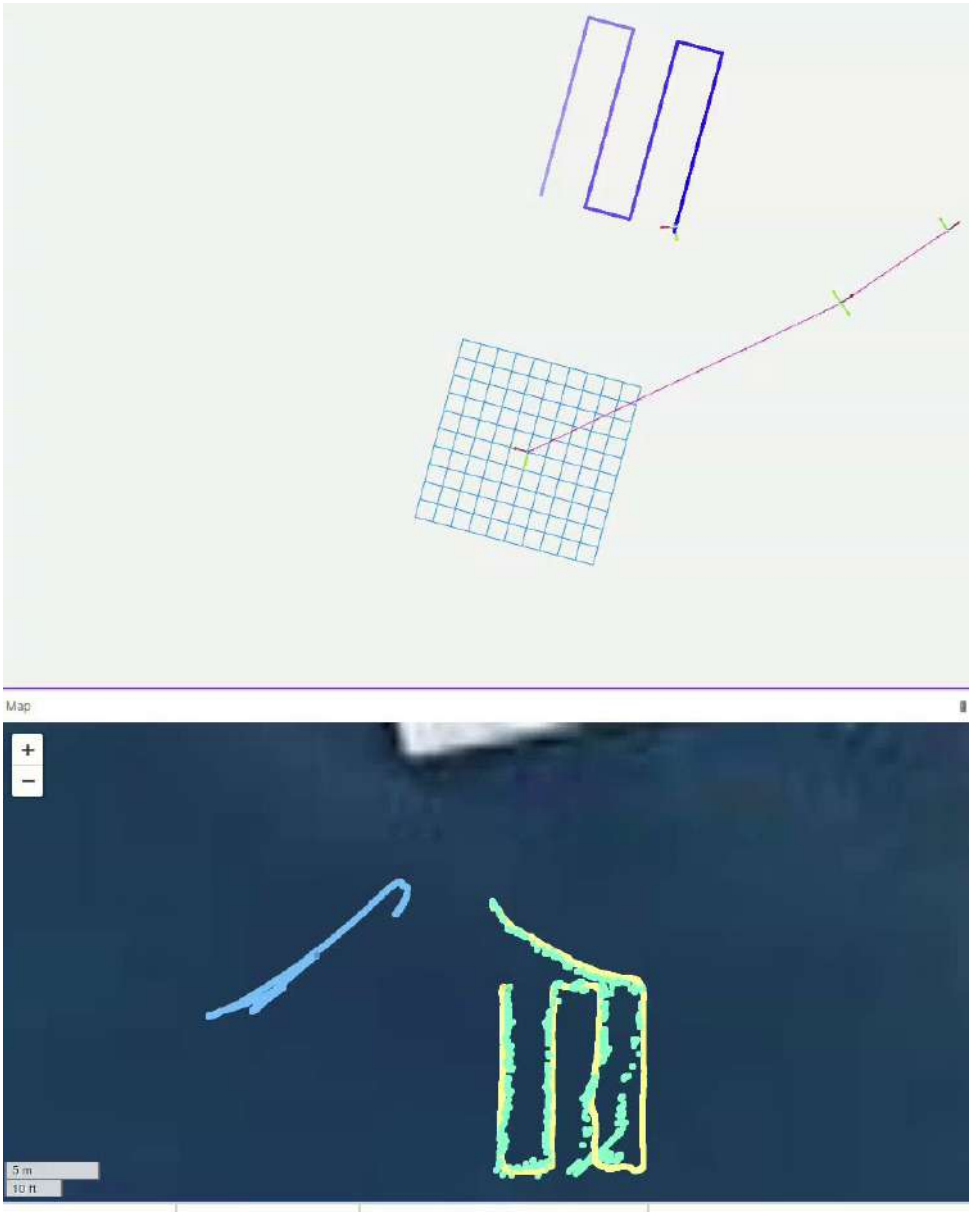
- a **forward-looking imaging sonar** for low-visibility detection, object outlining, and acoustic shadow analysis,
- a **standard onboard camera** for visual confirmation and classification in clear-water segments.

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Both sensors fed an **automatic litter-detection algorithm**, which analyzed sonar frames for strong reflections and shadows, and processed camera images for shape and contour cues. Detected targets were clustered, filtered, and geo-tagged using the USBL-derived position of the ROV. This allowed the system to produce a consistent **litter-mapping layer** across the full survey area, directly linked to the seabed-mapping imagery.

Overall, the combination of stable coverage, accurate underwater positioning, and automatic dual-sensor detection produced a reliable and detailed map of potential debris and seabed features.



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Figure 13: Lawn-monwer navigation pattern and detection form Mini-Tortuga

3.1.2 Grabbing

Once the automatic litter-detection process identified a target, the SeaCat transitioned from survey mode to recovery support. The system first navigated to the **position** of the detected item. Upon arrival, the vehicle switched to **keep-position mode**, holding its heading and location with thruster stabilization to maintain a stable working platform.

With the USV stationary, the **grapple system** was lowered toward the seabed. The operator then used the onboard **camera feed** to refine the final approach. This visual guidance enabled precise alignment with the object, accounting for local currents and small positional errors.

During recovery, the grapple closes around the litter, and the control system **modulates finger actuation** to maintain a target pressure. This ensures the object is firmly secured without causing damage or slipping. The closed-loop feedback from the sensors allows the system to adapt in real time to irregular or fragile debris.

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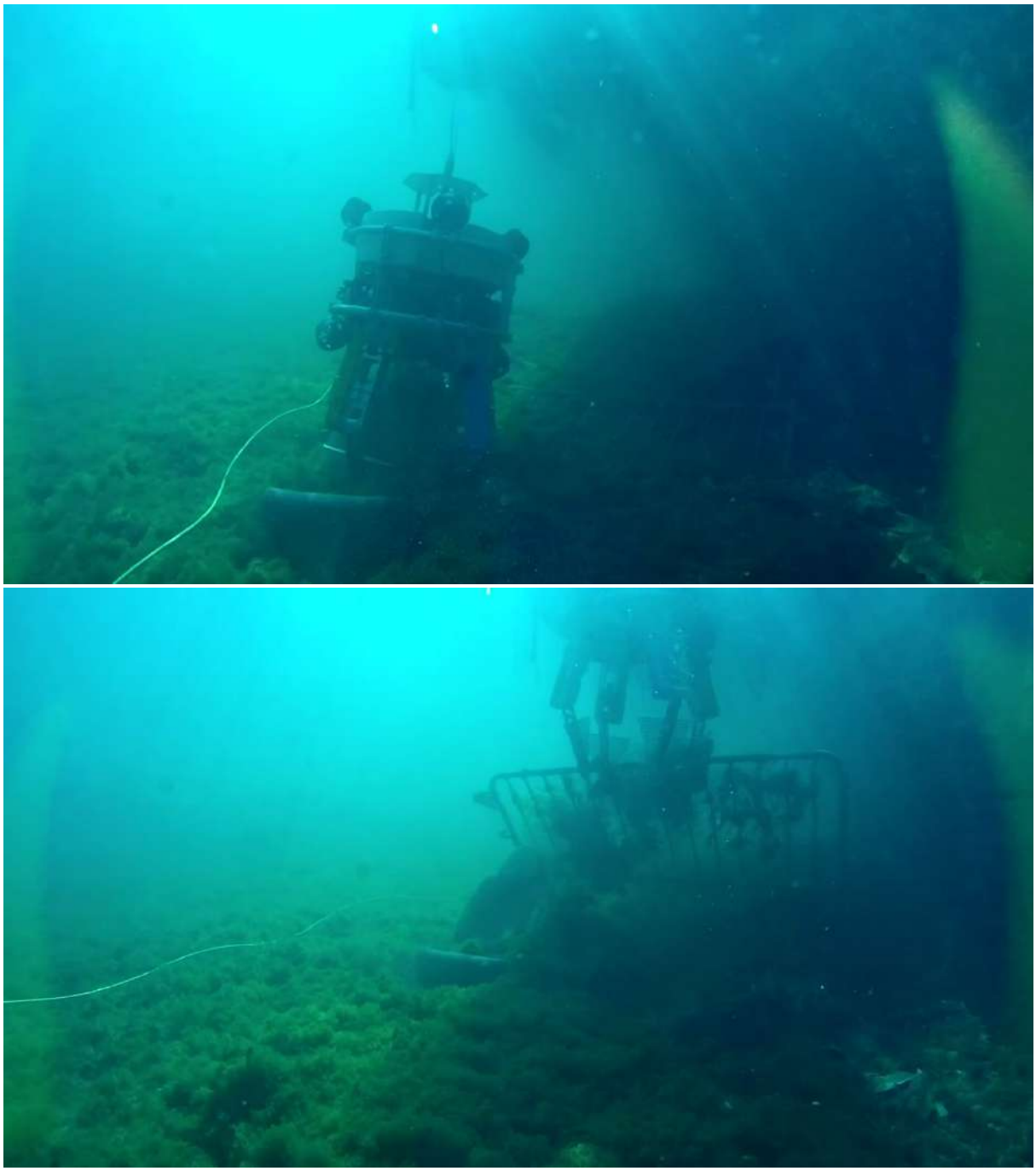


Figure 14: Grapple in the process of retrieving debris (car seat and fence)

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3.1.3 Docking & Collection

The SeaDragon vehicle performed the recovery phase by autonomously docking to the rear of the SeaCat. The docking procedure relied on a combined **camera and radar guidance system** that continuously tracked the alignment markers located on the SeaCat's docking interface. Using these visual and radar cues, SeaDragon refined its relative position and adjusted its heading until it achieved a fully constrained approach corridor.



Figure 15: SeaDragon USV dock to Seacat USV

After confirming correct docking position, the grapple released the debris directly into the **SeaDragon recovery basket** mounted at the stern of the vehicle. This sequence ensured predictable object transfer without operator intervention, even in reduced visibility.

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Figure 16:Seadragon USV loaded with trash

After the litter was unloaded, SeaDragon disengaged from the SeaCat and initiated its **return-to-shore routine**. The vehicle navigated back to the launch area where it was recovered and unloaded.

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3.2 ««Work achieved / evolution »»

3.2.1 Fraunhofer

The scope of the experiments conducted by Fraunhofer was completing the docking and undocking procedure on SeaCat USV with the shuttle tender SeaDragon USV completely autonomous. The SeaDragon USV is a twin-azimuth propelled catamaran, equipped with a litter bay, onto which up to **350kg** of marine litter can be deposited. As in-depth described in D3.3 and depicted in Figure 2, the SeaDragon USV has three main operational states: *path following, docking and station keeping*. While waiting for the detected marine litter element to be picked up and for the deposition phase to be commenced, the SeaDragon USV will be keep its neutral position (*station keeping*).

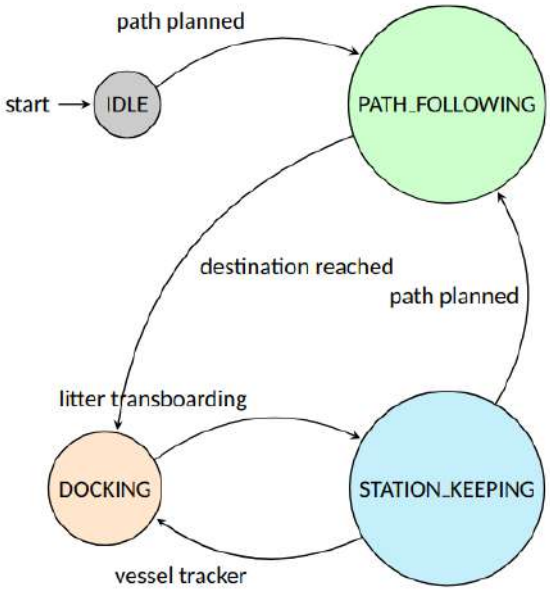


Figure 17. SeaDragon USV operating states

Once the deposition phase begins, the SeaDragon USV will generate a path from its current position to the stern of the SeaCat USV. The exact docking position is relative to the GNSS position of the SeaCat USV, with the offsets being manually determined experimentally. The path is designed to avoid any charted obstacles or land. For this, nautical sea charts are used as a base for constructing the navigable area. In the sea trials and in the demonstrations conducted in Marseille, the chosen areas have been mostly clear of obstacles, while only the quay walls, waterfront and wharfs edging the operational area being of importance. As shown in Figure 3, the path to follow is straightforward, but in order to avoid drifts or undesirable headings, intermediary poses have been introduced between the vessel and its destination.

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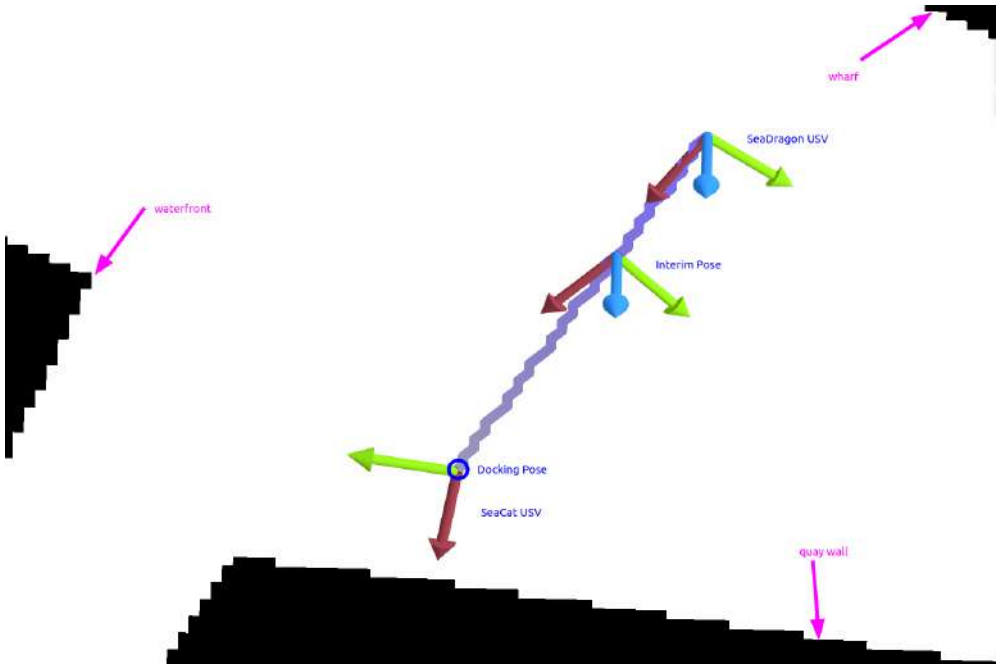


Figure 18. SeaDragon in Path Following state, navigating towards intermediary pose, avoiding charted obstacles

After crossing a radius of acceptance of 30m, SeaDragon USV's autopilot will transition into the *docking* state, in which a 180° rotational offset from the docking pose is implied (see Figure 4). In this phase, the lateral drifts and yaw errors are more heavily penalized, which imply a heavier use of the azimuths in comparison to the previous operational state. This in turns slows down the displacement on the surge axis.

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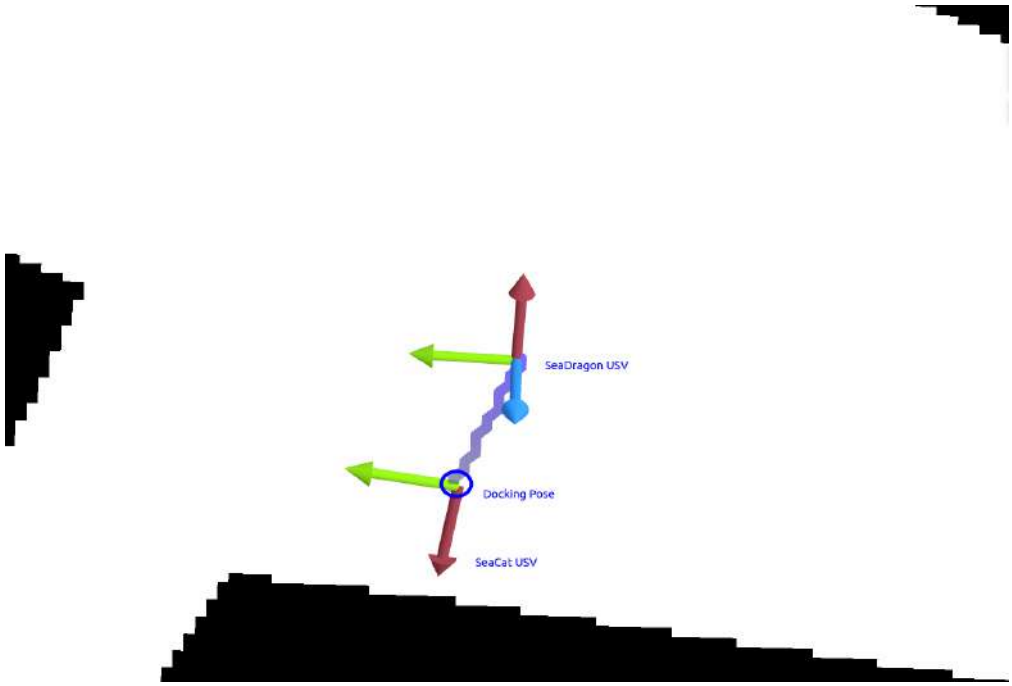


Figure 19. SeaDragon USV in docking state, automatically sailing towards its docking pose

Once docked, the SeaDragon USV continues to lightly push against the SeaCat USV's two contact points, as depicted in Figure 5, following the assumption that the SeaCat USV's considerably larger bollard pull can easily counter the displacement generated by the former. A rotation around the yaw axis cannot be ruled out, however, its effects are negligible.



Figure 20. SeaDragon USV docked onto SeaCat USV, station keeping state, lightly pushing against the contact points (blue rectangle)

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Once the deposition phase has ended, the SeaDragon USV can sail back to shore for discharging the load, or go back to its neutral position for waiting for the next cycle to begin, as seen in Figure 6. In both cases, a home position is predetermined at the beginning of the sea operations.



Figure 21. SeaDragon USV carrying a load of marine litter consisting in a car seat, a car tyre and some plastic bottles. All elements have been collected and deposited autonomously during the sea operations

The sea operations and demonstration in Marseille have been used to test the complete docking and undocking procedure of the shuttle tender USV in a relevant test environment. The sites had low currents, due to being protected by a wharf, but rather mild winds, ranging from **7-18 kts**. Wind have been measured via the onboard sensory system. Both USVs have been RTK-enabled GNSS positions throughout the sea operations and communicated via a shore computer, which was connected to both FastDDS servers (one one SeaCat USV, the other on SeaDragon USV). The tests have showcased that the small **20-30cm** tolerance sideways from the desired pose is not enough for having 100% success rate. The current success rate lies short **<50%**. The following sources of errors have been identified:

- Incomplete hydrodynamic model of the SeaDragon USV
- Insufficiently optimized control allocation law of the low-level controller
- Insufficiently accurate docking pose definition

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For the first two sources of errors, the mitigation strategy will consist in enhancing the control law and identifying the hydrodynamic parameters needed for a more consistent maneuvering. For the later, a LiDAR-based pose estimator will be added for augmenting the desired pose definition.

Furthermore, for the sea operations, a human operator has been assigned for overseeing the autonomous procedure and deciding whether the docking or undocking procedure can start. In SeaClear2's vision, the number of human operators should be reduced for keeping the operational costs lower, hence in the next scheduled sea operations, the role of the human operator for the shuttle tender USV will be merged with one of the other human operators of the other vehicles.

3.2.2 TUM

This section presents the experimental validation of the Smart Grapple system through both controlled laboratory tests and field demonstrations. Laboratory experiments systematically evaluated the grapple's load-bearing capacity by progressively grasping objects up to 251 kg, recording joint positions and torques at each weight increment to verify that the system meets the 250 kg design requirement. Field results from the Marseille demonstration in September 2025 provide real-world validation, documenting successful retrieval of various marine litter objects including a car seat, tire, fences, and an attempted grasp of a shipwreck fragment, with detailed analysis of sensor outputs during representative grasping maneuvers.

Laboratory tests

To validate that the grapple can securely grasp objects up to 250 kg, a series of experiments was con-ducted in which weights were progressively added to a test container until the total load exceeded 250 kg. For each trial, the grapple was lifted up with the container vertically, replicating the operational conditions encountered during underwater litter retrieval. The stability of the grasp was evaluated by verifying whether the object remained securely held throughout the lifting motion. All tested weights were successfully grasped, and the results are summarized in Table 4. These experiments demonstrate that the system is capable of reliably handling objects ranging up to 250 kg, as shown in Fig.22.

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Figure 22: The smart grapple lifting a box of 250 kg under controlled conditions.

Weight [kg]	Joint Position [rad]	Joint Torque [Nm]
20	(2.72, -1.71, 2.47, -2.28, 2.77, -1.79, 2.47, -2.14)	(5.82, 2.70, 2.88, 18.53, 2.15, 0.73, 7.35, 5.27)
40	(2.77, -1.79, 2.32, -2.16, 2.77, -1.79, 2.57, -2.04)	(3.14, 5.81, 5.97, 2.68, 3.96, 5.39, 3.76, 3.73)
60	(2.77, -1.79, 2.32, -2.16, 2.77, -1.79, 2.57, -2.04)	(3.07, 5.81, 6.00, 2.65, 4.00, 5.39, 3.76, 3.73)
80	(2.77, -1.79, 2.32, -2.16, 2.77, -1.79, 2.57, -2.04)	(3.06, 5.81, 6.02, 3.63, 4.02, 5.87, 3.31, 4.60)
100	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(14.18, 27.89, 3.27, 14.61, 2.88, 23.92, 2.62, 15.93)
120	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(13.69, 27.71, 3.27, 14.66, 2.49, 23.23, 2.41, 16.02)
140	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(12.91, 27.57, 3.01, 14.68, 2.31, 22.99, 2.24, 16.05)
160	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(12.94, 27.58, 2.96, 14.95, 3.17, 23.22, 2.88, 16.13)
180	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(12.44, 27.49, 3.38, 15.17, 2.96, 23.03, 3.02, 16.43)
194	(2.81, -2.29, 2.78, -1.89, 2.41, -2.57, 2.77, -1.95)	(3.74, 22.13, 4.31, 13.85, 2.97, 13.54, 6.94, 16.32)
200	(2.72, -1.81, 2.47, -2.28, 2.77, -1.89, 2.47, -2.24)	(12.71, 27.52, 4.40, 15.48, 3.31, 23.06, 2.98, 16.44)
220	(2.70, -2.23, 2.87, -1.88, 2.56, -2.53, 2.83, -1.91)	(6.07, 17.19, 4.49, 9.34, 6.73, 10.77, 7.28, 16.56)
251	(2.55, -1.54, 2.76, -1.61, 2.47, -1.50, 2.76, -1.62)	(11.43, 6.90, 12.74, 11.34, 12.59, 8.90, 16.12, 12.71)

Table 4: Joint position and torque values for different object weights.

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Field Results in Marseille 2025

Grasping of a car seat and a tire on the media day:

In the following, we analyze selected sensor outputs from the Marseille demo in September 2025. We focus on a representative grasping maneuver of a car seat to verify that the grasping algorithms and hardware components behave as expected. The grasped object is shown in Figure 23. At the time of grasping, which occurs shortly after $t \approx 800$ s in the recorded ROS bag, the shoulder joints move from their open to their closed configuration (Figure 33a), and the elbow joints follow the same pattern (Figure 33b). As soon as the smart grapple closes, the joint torques at all degrees of freedom increase noticeably, again shortly after 800 s, as illustrated in Figure 34.

Object	Weight (USV Force Sensor Reading)	Dry Weight (Only Object)
Chair (1)	—	24 kg
Tire	—	6 kg
Car Seat	185 kg (all together)	45 kg
Fences (×2)	156 kg (everything / force sensor)	14 kg
Ship wreck	185 kg	—

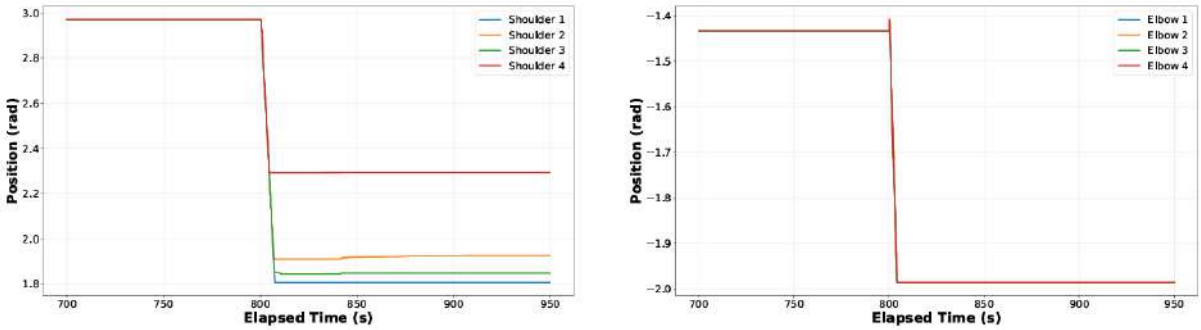
Table 5: Objects grasped in Marseille with corresponding weights. Dry weight is measured separately outside of the water, if available. The USV sensor reading includes the weight of the smart grapple and additional components.



Figure 23 :Grasping of a car seat during the media demo day in Marseille, September 2025. (a) Grapple View (b) Control Center View

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(a) Shoulder joint positions [rad]. (b) Elbow joint positions [rad].

Figure 24: Closing motion of the USG to grasp the car seat. The joint positions can be related to the reference frame introduced in Figure 21. The USG begins to grasp around t ≈ 800 s.

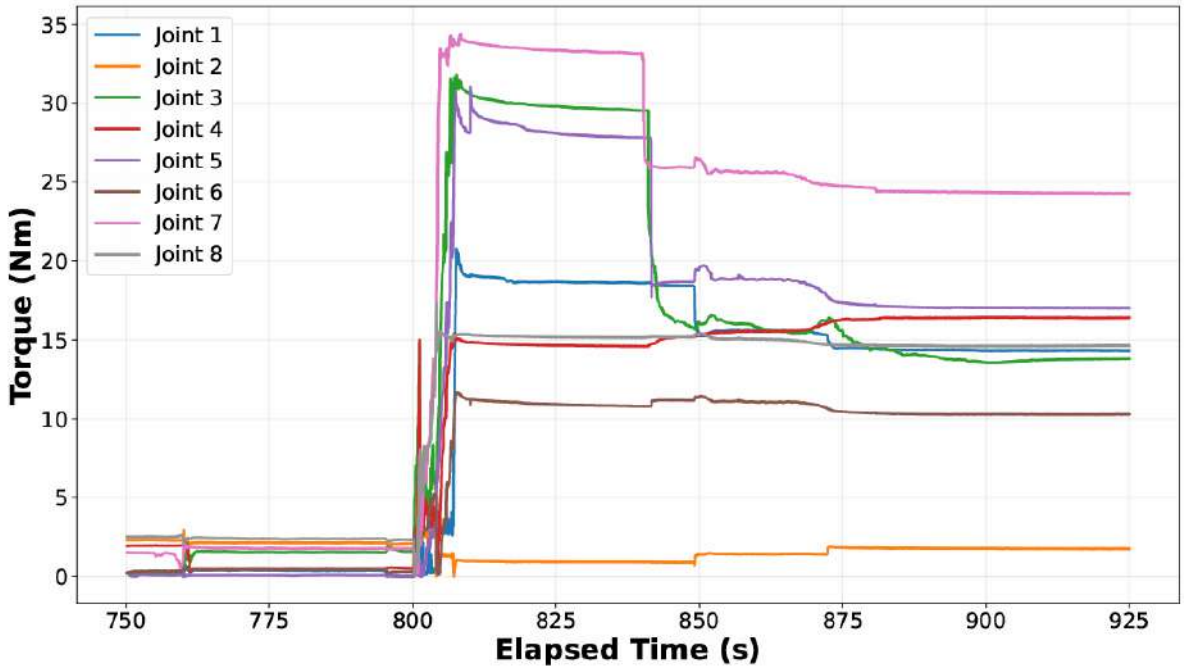


Figure 25: Joint torque profiles during the grasping manoeuvrer, showing a clear increase shortly after t ≈ 800 s once there is contact with the car seat.

Besides grasping smaller objects, such as the car seat (and, in separate trials, a tire), an attempt to grasp a larger piece of shipwreck was also conducted successfully, as seen in Figure 35, although the contact area was too large to recover it completely from the water.

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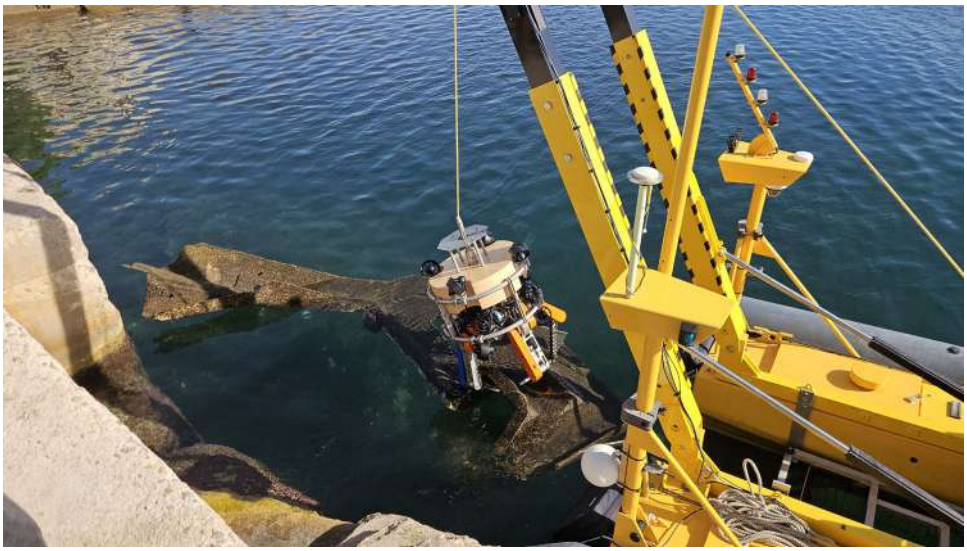


Figure 26: Attempted grasp of a shipwreck fragment during the media demo day.

3.2.3 UTC

The technical objectives for UTC in this demonstration (beyond of course explaining and showcasing the working system to stakeholders) have been twofold:

- Completion and validation of the Mini Tortuga ROS2 software pipeline for (a) pose estimation and automated control for the implementation of the litter search patterns, (b) litter mapping; together with (c) the integration of the neural-network litter detection models. We also aimed to perform (d) an initial validation of a finite state machine for higher-level automation of the Mini Tortuga.

- Collection of datasets for verification of progress towards achieving project KPIs.

On the first axis, (a)-(d) have been almost fully realized, with one comment: automated detection from sonar images has not been fully integrated yet, being planned instead for the Cyprus pilot (it should not be difficult since it is very similar to the integration of camera-based detection). To illustrate point (a), Figure UTC.1 shows automated control along a lawnmower pattern. To illustrate points (b) and (c), Figure UTC.2 gives an example of an object detected by the neural network and the map with several voxels labeled as litter.

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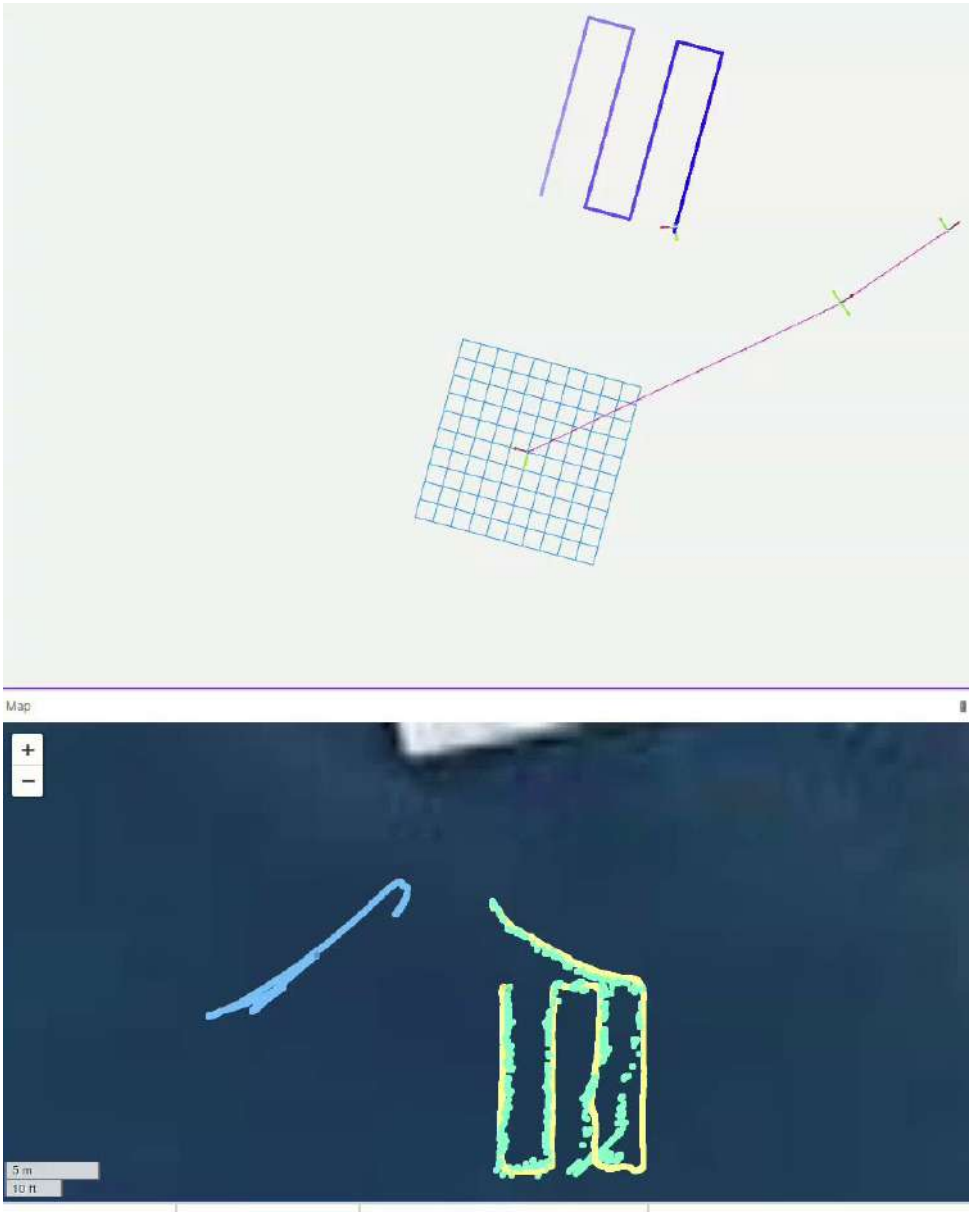


Figure 27: UTC.1 Automated control (with pose estimation in the loop) along a lawnmower pattern. The top graph illustrates the desired lawnmower, together with the current Mini Tortuga pose on the bottom-right of the trajectory. The bottom graph shows the actual trajectory recorded, yellow from the fused pose estimate, green short baseline localization readings. Other less relevant objects, like the SeaCat, are shown in the images. Note the two graphs are rotated with respect to each other.

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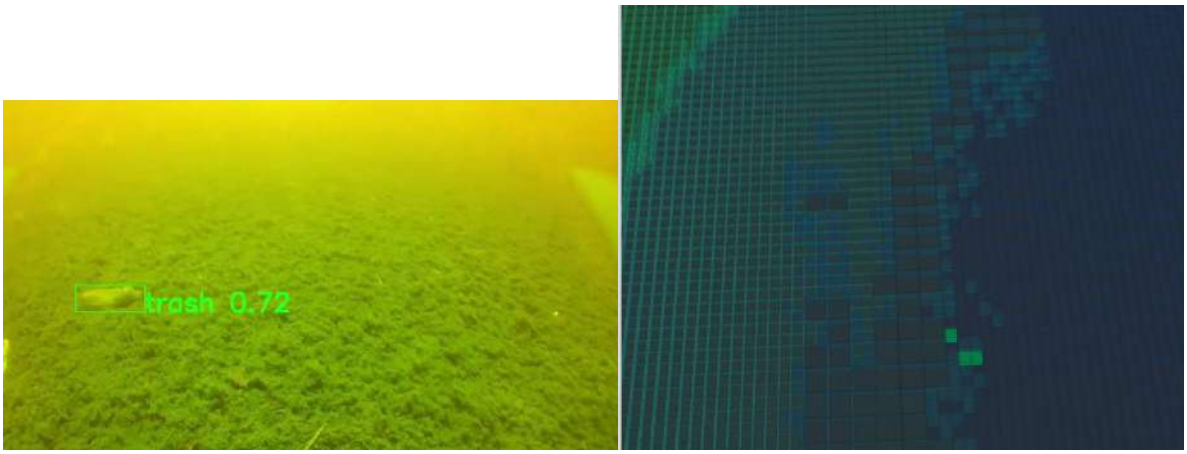


Figure 28: UTC.2. Left: A camera image with litter detected by the deep neural network (the yellow tint is a just rendering artifact, not seen by the network). Right: voxel grid map of the seafloor, with voxels labelled as litter shown in a lighter color.

Differently from the results reviewed in Deliverables 4.2 (on pose estimation) and 5.1 (on control), regarding item (d) we now included higher-level mapping automation via a finite state machine that handles deploying the Mini Tortuga, trajectory execution with tether length management, and vehicle recovery at the end.

This finite state machine is illustrated in Figure UTC.3. Among these items, automated tether management has been tested in field experiments, while deployment and recovery remain to be tested in the final-year demonstrations.

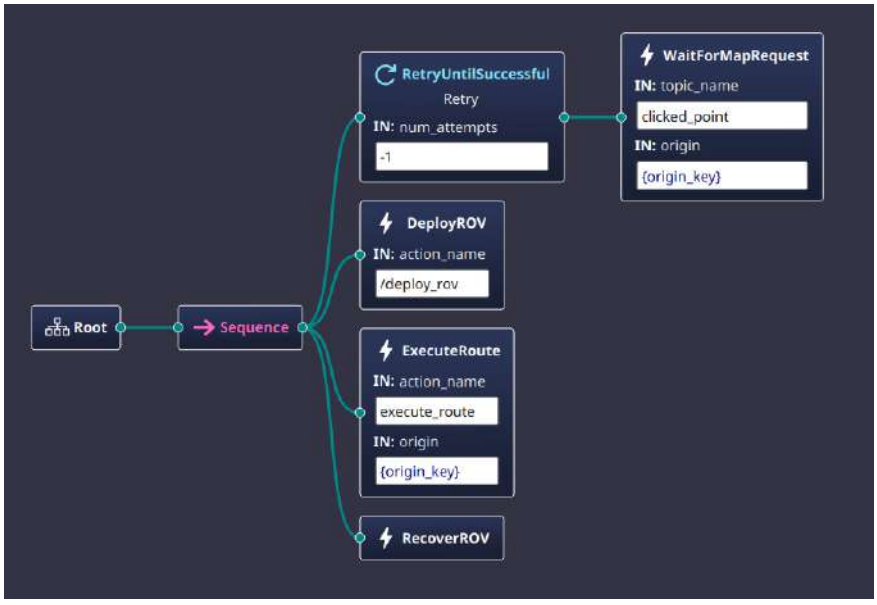


Figure 29: UTC.3. Diagram of the finite state machine used for the Mini Tortuga.

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Datasets have been collected to verify control performance and litter mapping accuracy. Furthermore, adaptive remapping trajectories have been run, aiming to refine initially marked litter. A few notable datasets are described in the table below.

Rosbag name	Pipeline elements validated	Other comments
rosbag2_2025_09_17-11_26_35	Pose estimation; automatic control for lawnmower following	A first mapping experiment with manual litter marking
rosbag2_2025_09_17-13_45_54	Litter detection; pose estimation; litter mapping	A second mapping experiment with neural-network litter detection
rosbag2_2025_09_17-14_49_30	Litter detection; litter mapping and remapping	Remapping experiment 1
rosbag2_2025_09_17-14_56_25	Litter mapping and remapping	Remapping experiment 2

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4. Press and Medias

To complement the technical and operational results, the SeaClear 2.0 project also achieved strong public visibility and outreach, demonstrating wide interest in its environmental and technological goals. Media coverage played an important role in raising awareness about marine pollution and in showcasing how autonomous robotic systems can contribute to cleaner and more sustainable seas.

During the Marseille demonstrations, several national and regional outlets featured reports on the project, emphasizing the innovative use of autonomous surface, aerial, and underwater drones for waste detection and collection.

Coverage included articles from Made in Marseille, Le Marin, and CNEWS, as well as a feature on France Inter and RTL2 radio. These publications highlighted the project's technological innovation, environmental impact, and European collaboration, particularly through the successful public demonstrations at L'Estaque, Marseille.

Together, these media appearances significantly strengthened the project's visibility, connecting the scientific objectives with the general public and policymakers, and underlining the potential of European research and innovation to deliver practical, high-impact environmental solutions.

References:

- Made in Marseille – "Des drones marins récupèrent des déchets en toute autonomie à l'Estaque"
- Neozone - "Le robot de plongée autonome SEACLEAR s'attaque aux déchets des fonds marins marseillais "
- Le Marin – "Le Français Subsea Tech développe pour l'UE un système dronisé de ramassage de déchets marins"
- CNEWS – "SeaClear : qu'est-ce que ce drone maritime nettoyant les fonds marins présenté à Marseille ?"
- France Inter – "SeaClear : ces robots qui détectent et collectent les déchets"

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5. Conclusion

The Marseille demonstration marked a significant milestone for the SeaClear2.0 project, validating the integration and performance of the full multi-robot system in a realistic port environment. Across nine days of preparation, testing, and public showcasing, the consortium successfully demonstrated autonomous detection, mapping, collection, and transport of marine litter using coordinated UAVs, USVs, ROVs, and the smart grapple.

All core components—including seabed mapping, aerial litter detection, underwater localization, autonomous grasping of heavy debris, and USV-to-USV docking—were tested under operational conditions and delivered consistent, measurable results. The trials confirmed the system's capability to retrieve a wide range of debris types, from small objects to heavy items exceeding 200 kg, while highlighting key areas for further refinement, such as improved docking accuracy and extended automation of the Mini-Tortuga workflow.

Beyond technical validation, the demonstration strengthened public and stakeholder engagement. Extensive media coverage helped raise awareness of the environmental impact of marine litter and showcased SeaClear2.0 as a leading European initiative for autonomous marine cleanup.

Overall, the Marseille trials demonstrated the system's maturity, robustness, and potential for real-world deployment. The results provide a solid foundation for the next phase of development and upcoming pilot operations, bringing SeaClear2.0 closer to delivering a scalable, effective, and fully autonomous solution for marine litter remediation.

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