Deliverable No. 2.1

Pilot surveys and use case scenarios definition

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Executive Summary

The goal of Deliverable 2.1 of the NERITES project is to provide a comprehensive description of the pilot cases and define the use cases for implementing the NERITES project's developed autonomous platform for the remote monitoring and chemical mapping of Underwater Cultural Heritage (UCH) sites. This description is primarily carried out by the end users (underwater archaeologists in the phase of implementation of the project) in collaboration with the technological partners. The responsible partner for this deliverable is ATLANTIS, with the participation of 10 other project partners.

The autonomous platform includes an Autonomous Underwater Vehicle (AUV) and a smart Buoy with a docking station. Its mission is to monitor, survey, and scan UCH sites. This involves detecting and identifying signs of degradation caused by physical, chemical, anthropogenic, or biological/natural factors, evaluating the surrounding underwater environment for pollutants, and initiating intervention through alarming actions when necessary. Key performance indicators, evaluation criteria, and methods of measurements also are being described in detail.

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1 Introduction

Task 2.1 of the NERITES project aims to establish a comprehensive evaluation framework to rigorously assess the performance, capabilities, and user experience of the NERITES autonomous platform and its supporting technologies in various use case scenarios. This framework, along with the definition of the use cases, is being developed in collaboration with end users and technological partners. The primary objective is to provide a standardized and robust environment in which the technologies to be researched and developed will be tested and evaluated in the pilot sites. It also provides the main guidelines from the end users partners to the technology partners for their research goals. This Task is being implemented under the responsibility of Atlantis with contributions from the following partners: LZH, ESI, RSE, GT, CNR, UNICAL, IHU, ALPES, KORSEAI, and MIC.

To achieve this objective, the use cases definitions will encompass a broad spectrum of Key Performance Indicators, including different types of evaluation metrics and user experience factors. Diverse data collection methods, such as sensor measurements, mission logs, user surveys, interviews, and observations, will be employed to gather quantitative and qualitative data from various sources. This data will then be analyzed and compared using appropriate statistical and thematic techniques to extract meaningful insights throughout the duration of the project. Clear and measurable metrics are being defined for each performance indicator to quantify the system's performance and capabilities, while user experience assessment will incorporate methods to evaluate ease of use, usability, and overall user satisfaction, among others. To establish a comprehensive evaluation framework for the NERITES project, both technological and end user partners will play crucial roles.

End user partners such as MCI, UNICAL, and KORSEAI are contributing by providing their perspectives from a “market demand” side. This includes defining desired performance metrics and capability indicators, identifying limitations to avoid unnecessary risks, and considering user experience factors, safety parameters, and demands concerning efficiency and effectiveness of operations, among others. They also identify relevant parameters for measuring system performance (e.g. depth reached, accuracy, sensor range), translate technical specifications into measurable criteria, and collaborate with the technology partners on developing protocols for sensor data collection and mission logging. Furthermore, the end user partners will provide insights into user needs and expectations for the autonomous underwater cultural heritage monitoring system, identify usability considerations relevant to the target audiences (archaeologists, cultural heritage professionals, marine biologists etc.), and collaborate on developing user surveys and interview questions to assess user satisfaction, while maintaining highly safety standards. In addition, they will facilitate user recruitment and participation in surveys, interviews, and observation sessions, while providing logistical support for conducting user-based evaluations at the pilot sites. End users partners will also offer practical considerations for real-world application by sharing their knowledge of operational environments and potential deployment use case scenarios for the NERITES system. They can identify end users standards or best practices to incorporate into the evaluation framework and provide feedback on the overall practicality and user-friendliness of the system from an end users perspective, while assisting in the implementation of the pilot tests at the pilot sites in Baiae, Italy, and Fournoi islands, Greece.

On the other hand, technological partners such as LZH, ESI, RSE, UULM, CERTH, GT, CNR, IHU, and ALPES will leverage their expertise to define the performance metrics and capability indicators within the limits of their technological solutions. This involves identifying relevant parameters for measuring system performance (e.g. depth reached, accuracy, sensor range), translating performance requirements into technical specifications and measurable criteria, and collaborating with the end users partners on developing protocols for different solutions from the perspective of a “technology push” approach. Additionally, they will lead the development of data analysis techniques for quantitative visual data, including data processing, correlation analysis (in collaboration with the end user partners), statistical analysis, methods tailored to performance metrics, and data visualization techniques for effectively mapping and presenting the different measurement results.

Even though the main user group for the pilots in the NERITES project comprises underwater archaeologists working in underwater cultural heritage protection and valorization, other user groups may also be able to explore the project's results in the future. These groups include Civil Security and Protection Agencies, the Coast Guard, Port and Coastal Authorities, Insurance Agencies, Relief and Environmental Disaster Support and Recovery Service Providers, the Shipping Industry, the end users, Oil & Gas end users, salvage operators, universities, educational organizations, SMEs, NGOs, and others.

Performance considerations will be a central focus of the evaluation, assessing factors such as maximum depth reached (up to 100m as a technical requirement, but up to 55m for the pilots), longest mission duration achievable, sampling frequency, sensor accuracy, data completeness, system reliability, data processing efficiency, user interface usability, and maintainability. The framework will also accommodate diverse mission environments, varying mission objectives, operational constraints, and user requirements to ensure a comprehensive and realistic evaluation described in the following use case scenarios. By addressing these requirements, considerations, and parameters, the comprehensive evaluation framework will serve as an invaluable tool for assessing the effectiveness, efficiency, and suitability of NERITES technology for a wide range of applications.

2 Short Description of the Pilot Sites

2.1 Fournoi

Fournoi is one of the two locations where the pilot tests of the NERITES advanced technological systems will be conducted. Fournoi lies in the eastern part of the Aegean Sea, very close to the Turkish coast, between the larger islands of Ikaria and Samos. It is a complex of 20 islands and islets. In the past, its indented coastline provided safe anchorage during strong winds—a frequent occurrence in this area, where either strong southern winds or the Etesian north winds (locally known as meltemi) prevail. This highlights the significance of Fournoi within the navigational landscape: the island complex lies along a major east-west crossing route, as well as the primary north-south route that connected the Aegean to the Levant.

An underwater survey conducted from 2015 till 2018, in Fournoi archipelago resulted in the discovery of 58 wrecks along almost 60% of the surveyed coastline. These 58 shipwrecks represent 23% of the known shipwrecks in Greek waters and constitute the Mediterranean's largest known concentration of ships lost while underway. The chronological distribution of the shipwrecks in the archipelago is quite broad, demonstrating Fournoi's significance in the navigational landscape across the centuries, from antiquity to the present day.

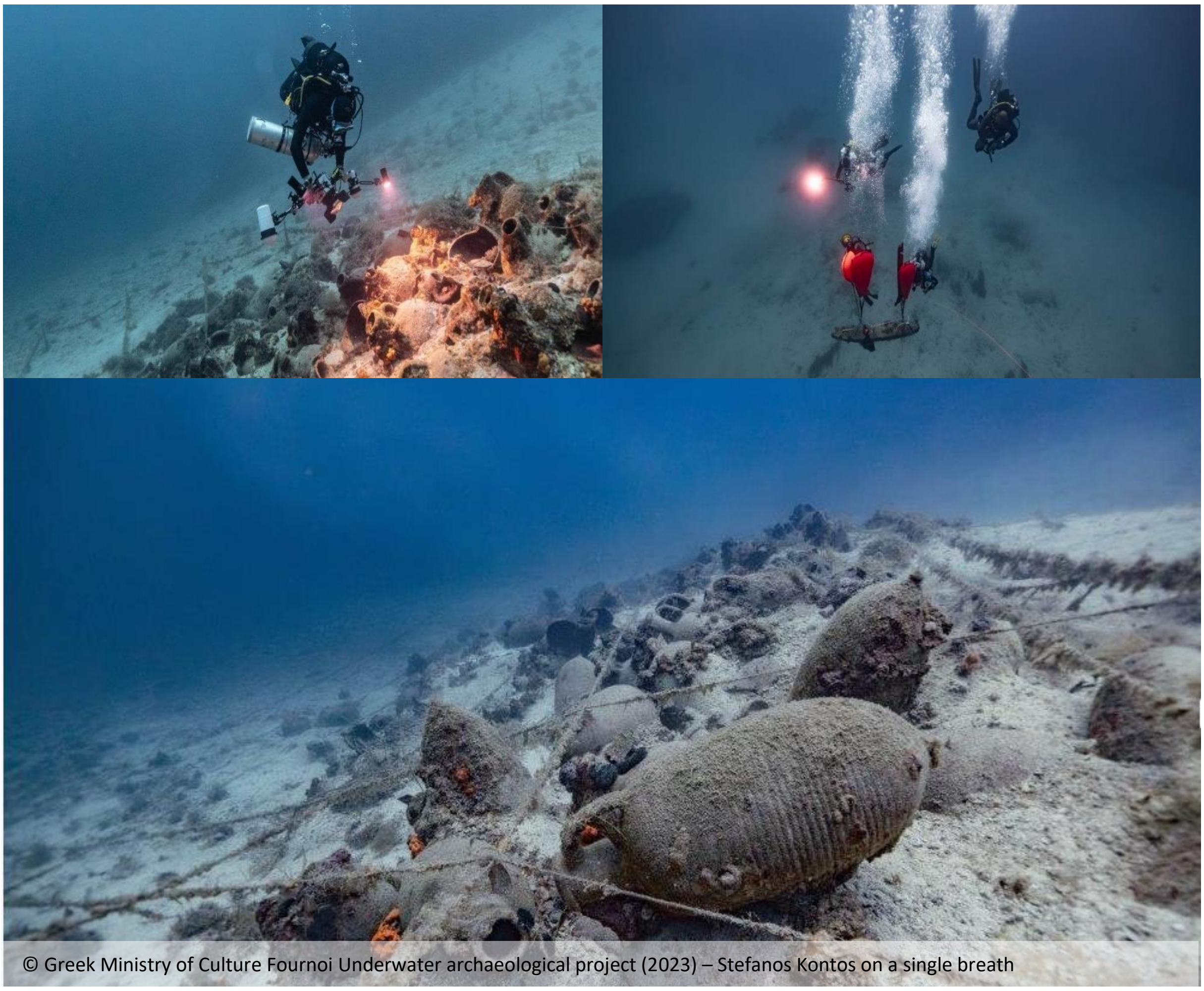

Fig. 1: Photos from the Underwater Archaeological Expedition of Fournoi Island

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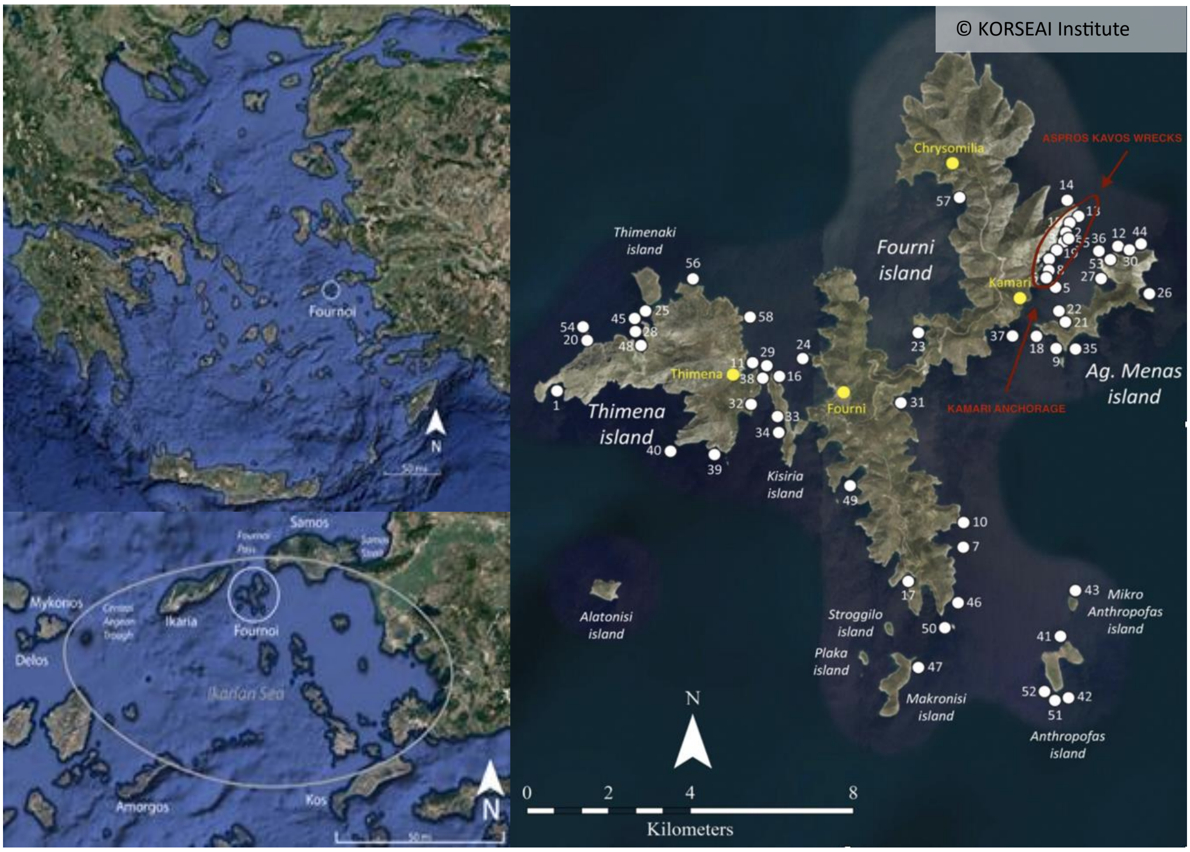

Fig. 2: Maps indicating the exact location of Fournoi Archipelagos and Map of the shipwrecks located around Fournoi island with the pilot sites markes (Aspors Kavos)

ASPROS KAVOS

Since 2020, research has focused on the region of Aspros Cavos -translated as "White Cape"- where the concentration of shipwrecks is particularly high, with six shipwrecks discovered. The strong prevailing winds in this area likely contribute to the high concentration of shipwrecks. The pilot testing of the NERITES monitoring scheme could be conducted in the Aspros Cavos area. The advantage of choosing this location is the availability of several wrecks, providing a wide selection of small case scenarios, with the main materials being clay and possibly some lead. Additionally, Aspros Cavos is the area where Korseai has concentrated efforts during the last three expeditions, making it better studied and allowing end users to provide more informed feedback after the missions.

On the other hand, the disadvantages include the rocky and sloped seabed, the potentially strong winds, and the two-mile distance from the expedition's base. As mentioned, the seabed at Aspros Cavos has a significant incline. To stabilize the anchoring of the docking platform, it is necessary to reach a depth of nearly 55 meters.

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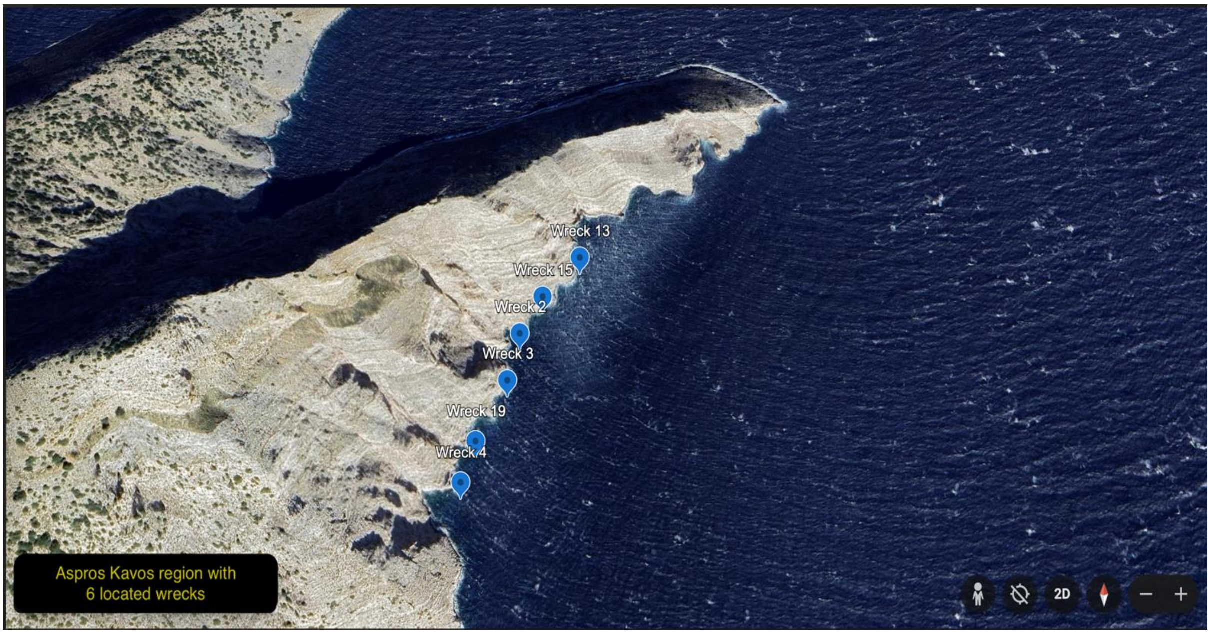

Fig. 3:The location of the six shipwrecks found in Aspros Kavos area (Korseai Institute)

Fig. 4: Divers measuring an anchor at Kamari anchorage (Korseai Institute)

At the Aspros Kavos pilot site, the NERITES AUV mission can span a 10-day trial period. During the first 5 or 6 days, the equipment should be transported, prepared, set up, and deployed in the water for tethered trials (ROV mode). This can be followed by 1 or 2 days of AUV trials. On the first half of the first day, an in-situ imaging survey (photogrammetry - 3D models) can be conducted to determine which wreck will be selected, based on where the AUV operates most effectively. In the second half of the day, samples from the water column (using QCL sensor) and sediment samples (using LIBS sensor) can be collected. On the second day, a more precise mission can be conducted, focusing on small case scenarios and examining materials such as clay amphoras or metallic anchors to assess their chemical and environmental degradation.

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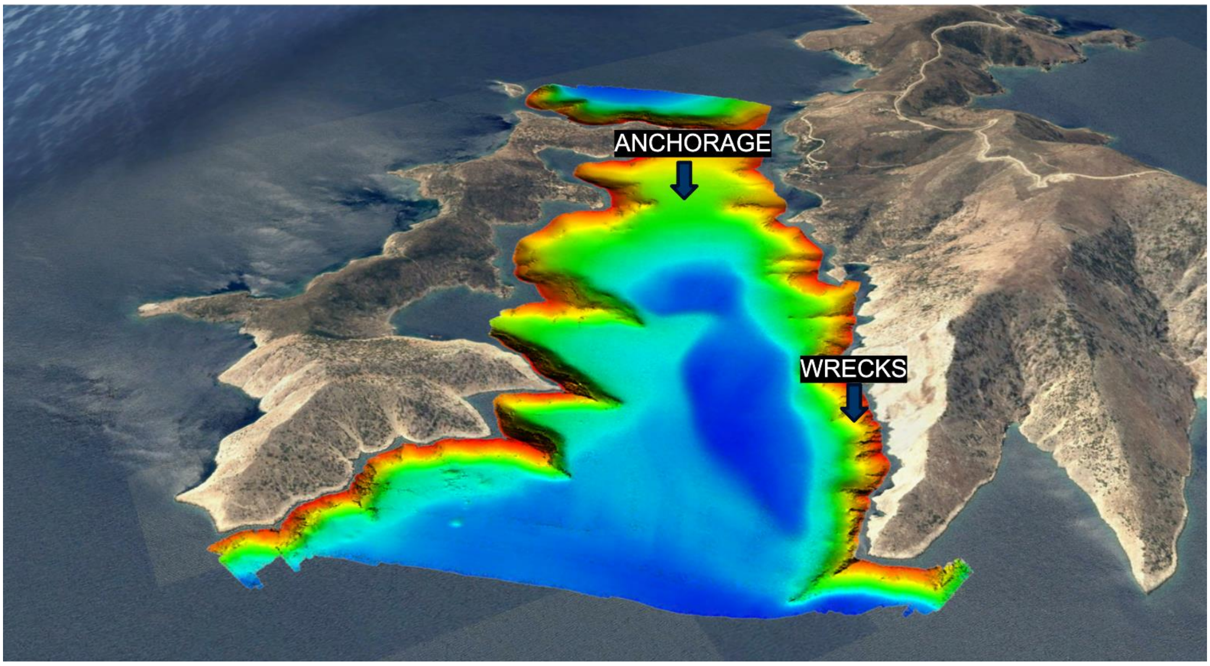

Fig. 5: Bathymetry of the wider area of Aspros Kavos (Korseai Institute)

Tab. 1: Weather Conditions for the Fournoi Pilot Site

ID	Pilot	Month	Usual Prevailing Wind Conditions (direction & force)	Average Water Temperatures	Height of Waves	Water visibility	Rainfall	Water currents
1	Aspros Kavos	09/2026	North – North – East, 4-7 Beaufort. Attention: Possibly South winds up to 11 Beaufort	17-21 °C	Calm in general, occasionally up to 4 m	20 m	Average of 16 mm for 1,8 days	Almost none

2.2 Baiae (Underwater Archaeological Park)

The Underwater archaeological park of Baiae is located off the north-western coasts of the bay of Puteoli (Naples), in the littoral zone between the southern limit of the port of Baiae and the dock of Lido Augusto. This site is part of the coastal region known as Campi Flegrei, which has been characterized in ancient times by periodic volcanic and hydrothermal activity, and it has been subjected to bradyseism, namely gradual changes in the levels of the coast with respect to the sea level.

Fig. 6: Photo of Mosaic from the Underwater Archaeological Park at Baiae

Ancient Baiae was a bathing resort for the Roman aristocracy between the 1st century BC and the 4th AD. As a result of bradyseism, it began to sink into the water around the 3rd century AD. The ancient city, which is now almost completely submerged was famous for its luxurious seaside villas, public offices, baths, shops and coastal installations. Baiae was the theatre of the first underwater explorations in a

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submerged structure by N. Lamboglia, just after the pioneering campaigns of Albenga, and quickly became a site of excellence for the experimentation of new excavation strategies, documentation, protection, enhancement, and mainly, in situ restoration of the underwater cultural heritage (Stefanile, 2014)].

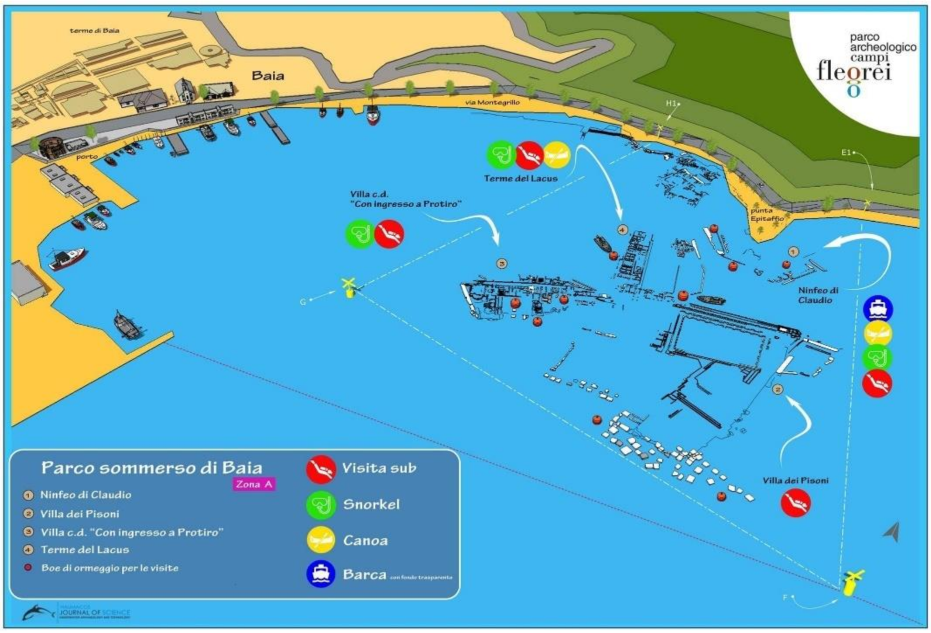

Fig. 7: Map of the archaeological area of the Underwater Park of Baiae (Copyright Underwater Archaeological Park of Campi Flerei, Ministry of Culture)

The Underwater archaeological park of Baiae, covering an area of about 176.6 hectares, not only safeguards the archaeological remains of the Roman city and the infrastructure of the Roman harbor, Portus Iulius, but also represents an underwater area of great environmental value. The environmental significance of this area is tied to its unique volcanic and geo-deformational history. As is well known, this coastal region has been subject to the phenomenon of bradyseism since antiquity, which can be either positive or negative. Currently, the remains from the Roman Era are submerged at depths ranging between 1 and 14-15 meters below the current sea level (Davidde Petriaggi et al., 2019).

In recent years, the Soprintendenza Archeologica di Napoli served as the Managing Authority of the MPA-UP, but this role has recently transitioned to the Parco Archeologico dei Campi Flegrei as the new Managing Authority. Today, the MPA-UP of Baiae features has least five sites open to the public, accessible to both divers and non-divers. These underwater sites include: 1) the Villa of the Pisoni, 2) the "Villa with Protyr entrance" – "Villa with vestibule", 3) the "Nymphaeum of Punta dell'Epitaffio" 4) "Portus Iulius"; and 5) the "Secca fumosa".

Within the Underwater Archaeological Park of Baiae, the pilot site selected is the Villa dei Pisoni, whose viridarium, surrounded by a portico marked by niches and half-columns, is now one of the most popular destinations for divers. The villa, named after the Calpurnii Pisones—who were involved in a conspiracy against Nero and were related to the owners of the magnificent Villa dei Papiri in Herculaneum—spans a large area near the lacus Baianus. This ancient port basin, now entirely submerged, was once surrounded by piers and arches, villae maritimae, and palaces (Di Fraia et al., 1988; Lombardo, 1993; Scognamiglio, 1997; Davidde Petriaggi et al., 2020).

Because of its unique materials and the high volume of tourists, the villa represents a study site that requires ongoing monitoring. The villa preserves the remains of colonnades and corridors made of bricks and mortars from the porticoes that once surrounded the large garden (viridarium), as well as a

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fountain and a large thermal pool. Additionally, there are fishponds, pilae, the Via Herculanea, and rooms with distinctive mosaic floors made from calcareous and marble tiles.

Fig. 8: The Villa dei Pisoni (Copyright Central Institute for Restoration, Ministry of Culture)

Tab. 2: Weather Conditions for the Fournoi Pilot Site

ID	Pilot	Month	Usual Prevailing Wind Conditions (direction & force)	Average Water Temperatures	Height of Waves	Water visibility	Rainfall	Water currents
1	Villa of Pisoni	07/2026	West, 1-2 Beaufort	26-28 °C	Calm in general, occasionally up to 2 m	10 - 15 m	Average of 0 – 1 mm/day	Almost none

3 Performance Requirements

3.1 Technologies to be developed

In this section, we outline the key technologies that will be developed and utilized within the NERITES project. These technologies are crucial for achieving the project's objectives, encompassing a range of advanced tools and systems designed to enhance the monitoring and analysis of underwater cultural heritage sites. In Tab. 9 each technology is detailed in terms of its function, contribution to the project, and the partner responsible for its development or provision. In detail:

- **Technology**: This column lists the different technologies that are used in the NERITES system. These technologies work together to allow NERITES to function and achieve its research goals.
- **Description**: This column provides a brief explanation of each technology. It explains what the technology does and how it contributes to the overall functionality of NERITES.
- **Responsible Partner**: This column identifies the partner organization that is responsible for developing or providing each technology. The NERITES project likely involves collaboration between multiple partners, each with expertise in a specific area. This column clarifies which partner is accountable for each technology.

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Tab. 3: NERITES Technologies

ID	Technologies	Description	Responsible Partner
3.1	Autonomy Platform with hovering capabilities and its control station	Enable NERITES system to operate autonomously by planning routes, avoiding obstacles, and collecting data without human intervention.	GT, ESI, RSE
3.2	Docking Station/Charging Buoy with renewable energy sources	Provides a secure location for NERITES system to be deployed, charged, and communicate with.	GT, ESI, RSE
3.3	LIBS	Laser-Induced Breakdown Spectroscopic (LIBS). A technique used for elemental analysis to detect the presence of heavy metals.	LZH
3.4	QCL	The Quantum Cascade Laser (QCL). Detects chemical compounds at UCH sites.	ALPES
3.5	Advanced Image Processing with AI algorithms	Analyzes images and videos captured by a camera to extract information and assess the degradation process.	CERTH, IHU
3.6	Multi-temporal (4D) Analysis of Photogrammetric 3D Models	Develops multi-temporal (4D) analysis of photogrammetric 3D models to assess the structural integrity of UCH sites.	CERTH, IHU

The end user partners, in agreement with the technological partners, concluded that the use of ultrasonic sensors does not contribute any more information to the physical degradation of the UCH and decided to use Advanced Image Processing techniques based on AI models and to introduce also in the project the multi-temporal (4D) Analysis of Photogrammetric 3D Models for assessing the structural integrity of UCH with better results.

3.2 Key Results (KRs), Key Performance Requirements (KPIs) and Evaluation Approach

The primary Performance Requirement set by the end users artners calls for a transportable autonomous platform capable of cost-effective, systematic, and remote surveying of Underwater Cultural Heritage (UCH) assets (such as artifacts, mosaics, walls, etc.). The platform should utilize low-cost digital sensing and accurate devices and techniques, while also being able to detect pollutants in the water or/and the artifacts/buildings using non-destructive methods.

In the project proposal, a triangularly combined torpedo-shaped AUV platform was described, designed to accommodate all necessary electrical and computational power, as well as all the required sensors for the proposed measurements. However, underwater archaeologists have expressed concerns that a larger autonomous platform would reduce underwater maneuverability near artifacts and make field deployment less practical. Therefore, the shape of the autonomous platform will be determined based on the technological partners' response to the set requirements and the research solutions developed. It is likely that a two-part torpedo-shaped AUV will be chosen.

Given these considerations, new and appropriate assessment protocols must be developed for utilizing the autonomous remote sensing platform. These protocols aim to reduce both operational expenses (OPEX) and capital expenses (CAPEX), increase in situ assessment accuracy, decrease human risks, and reduce the time required for onshore analysis, compared to conventional systematic assessment protocols used in common practice.

In Tab. 4 below, the Key Results and the Key Performance Indicators set by the end users in collaboration with the technology partners – from the proposal preparation phase to the present – are described. Additionally, the type of evaluation criterion has been categorized into three types: Desired Performance Achieved (DPA) as a yes or no, Quantitative Target Reached (QTR-number) and/or

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Quantified Qualitative Evaluation Result (QQER). For QQER, a target score of 4 or greater on a 1-7 scale in questionnaires is considered a successful outcome, while 7 indicates total satisfaction and 1 indicates no satisfaction. In addition, the 10 KPIs which are correlated with the Expected Outcomes have been included in a separate Tab. 5.

The following table presents specific Key Results (KRs) and Key Performance Indicators (KPIs) to measure success.

Tab. 4: Key Results (KRs) and Key Performance Indicators (KPIs)

KR / KPI Description		Source of KR / KPI	Type of Evaluation Criterion
Technical Objective 1:	Development of LIBS underwater sensor for in situ real time measurement of metals		
KR1.1:	Development of LIBS system (WP4, T4.1)	GA(*)	DPA
KR1.2:	Test of LIBS system in LZH water tank (WP4, T4.1)	GA	DPA
KR1.3:	Integration to AUV (WP5, T5.2 & T5.4)	GA	DPA
KPI1.1:	LIBS system for 100 m water depth developed	GA	DPA
KPI1.1.1:	LIBS system tested successfully for 100m depth	NEW	DPA, QTR
KPI1.2:	Compact and lightweight LIBS system integrable on AUV	GA	DPA
KPI1.3:	Use of a green 532 nm double pulse laser with approx. 40 mJ pulse energy for LIBS	GA	DPA, QTR
KPI1.4:	Long working distance up to 300 mm from the artifacts for the LIBS	gA	QTR
KPI1.4.1:	Short working distance from 100mm from the artifacts for the LIBS	NEW	QTR
KPI1.5:	Flexible beam deflection for generating line scans with approx. 50-100 mmnts for the LIBS	GA	QTR
Technical Objective 2:	Development of underwater QCL sensor for in situ real time measurement of carbon and nutrients		
KR2.1:	Smart QCL sensor for the detection of pollutants around artefacts developed in WP5, integrated and validated in WP4, T4.2	GA	DPA
KPI2.1:	phosphates, nitrates, dissolved CO2 and VOCs at ppm (parts per millions) concentration levels or below; 1 order of magnitude better detection capabilities compared to other spectroscopic methods (Limit of Detection improvement).	GA	QQER
KPI2.1.1:	QCL system developed, tested and integrated successfully on the platform with a working depth of 100m**.**	NEW	DPA, QTR, QQER
KPI2.1.2:	The QCL system must be able to successfully detect and map the presence of pollutants in the column of water and near the submerged artifacts such as phosphates, nitrates, dissolved CO2 and VOCs.		QQER

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KR / KPI Description		Source of KR / KPI	Type of Evaluation Criterion
Technical Objective 3:	Autonomous remote sensing platforms (ARSP) for UCH artifacts and monuments surveying		
KR3.1:	Autonomous Online Mission Planning (AutoMP) for Resource-Efficient UCH Remote Surveying (T3.4)	GA	DPA
KR3.2:	Dynamic heuristic function's elements prioritization for effective AutoMP in UCH applications (T3.3, T3.4)	GA	DPA
KR3.3:	NERITES Predefined Sensing Paths and Protocols for UCH Surveying (T4.4)	GA	DPA
KR3.4:	AUV and docking station, T3.2	GA	QPA
KR3.5:	Buoy and control station onshore, T3.1, T3.3	GA	DPA
KPI3.1:	Online autonomous mission planning response time, generated navigation mission's time and energy efficiency	GA	QQER
KPI3.2:	Offline sensing and sampling mission measurements quality, risks and robustness efficiency for NERITES platform	GA	QQER
KPI3.3:	Triangular AUV hovering stability and safe-landing ability	GA	QQER
KPI3.4:	Triangular AUV spatial ability to integrate differently shaped sensing tubes and chambers	GA	DPA, QQER
KPI3.4.1:	The autonomous platform must pose no risk to swimmers, snorkelers, scuba divers, boats, submerged artifacts and the environment (such as the Posidonia Oceanica)	NEW	DPA, QQER
KPI3.4.2:	The autonomous platform must be able always to avoid collision with the sea floor and the submerged artifacts	NEW	DPA
KPI3.4.3:	The autonomous platform must be able to approach and collect data at the proximity of the submerged artifacts up to 100mm from them. In case of collision with them, this must be done with minimal force	NEW	DPA, QTR
KPI3.4.4:	The autonomous platform must be tested successfully at a depth of 55m during the pilot demonstrations.	NEW	DPA, QTR
KPI3.5:	Docking station parking procedure for data and power transmission to the AUV	GA	DPA
KPI3.6:	Docking station low-energy processing capacity for hosting pretrained inferencing AIs	GA	DPA, QQER
KPI3.7:	Mechanical tethering mechanism loading bounds for safely launching and retrieving the submerged docking station, when incorporating the AUV	GA	DPA, QQER
KPI3.8:	Renewable energy harvesting (peak) capacity of the buoy	GA	DPA, QQER
KPI3.9:	Total NERITES platform weight for easier launching and retrieving from the surface vessel	GA	QQER
KPI3.9.1:	Maximum single Mission Duration (at least 3 days) to be reached. At least 1 hour continuous mission duration.	NEW	DPA, QTR
KPI3.9.2:	Satisfaction of the navigation performance of the AUV inside the underwater archaeological area and documentation of the relevant movement.	NEW	QTR, QQER

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KR / KPI Description		Source of KR / KPI	Type of Evaluation Criterion
KPI3.9.3:	Easiness and speed of the initial set-up of the AUV	NEW	DPA
KPI3.9.4:	Evaluates the friendliness of usage of the system by the industrial partners, including mission planning, speed and format of data collection and retrieval using the boy, mapping capabilities of presenting the gathered data, alarming capabilities, easiness of maintenance, reliability of the system et al. Benchmarking against other similar if any vehicles in the market and typical underwater procedures performed by divers will be very useful. Every one of the above qualities will be evaluated independently.	NEW	QTR, QQER
KPI3.9.5:	The system and the AUV must confirm with all the EU and National Regulations concerning its operation	NEW	DPA
KPI3.9.6:	The system must be able to demonstrate its multi-use capabilities and satisfy more than one groups of audiences and end user partners	NEW	DPA, QQER
KPI3.9.7:	Successful connection between the buoy and docking station for seamless energy and data transmission	NEW	DPA
KPI3.9.8:	The buoy must be able to be safely moored without compromising artifacts safety as well as creating any environmental hazards.	NEW	DPA, QQER
KPI3.9.9:	Efficient communication between the Buoy and RMCC for reliable data exchange	NEW	QQER
KPI3.9.10:	RMCC's capability to visually represent data from the AUV and send mission information to the AUV, both through the Buoy	NEW	DPA, QQER
KPI3.9.11:	Avoidance of use of plastics as far as possible	NEW	DPA, QQER
KPI3.9.12:	Successful completion of Use Case 1 in Baia. Italy. Evaluation of the effectiveness and the efficiency of the mission implementation	NEW	DPA, QTR, QQER
KPI3.9.13:	Successful completion of Use Case 2 in Baia, Italy. Evaluation of the effectiveness and the efficiency of the mission implementation	NEW	DPA, QTR, QQER
KPI3.9.14:	Successful completion of Use Case 3 in Fournoi island, Greece. Evaluation of the effectiveness and the efficiency of the mission implementation	NEW	DPA, QTR, QQER
KPI3.9.15	Successful completion of Use Case 4 in Fournoi island, Greece. Evaluation of the effectiveness and the efficiency of the mission implementation.	NEW	DPA, QTR, QQER
Technical Objective 4:	Image identification and classification of underwater geomorphology, chemical, physical, and biological parameters		
KR4.1:	To achieve a perimetral digital footprint with high resolution, T4.3.	GA	DPA
KR4.2:	Achieve correlations as indicators between advanced image processing and organic material T4.3, T5.5.	GA	DPA
KR4.3:	Characterize biological colonization on the surface of the monuments/artifacts. T4.3	GA	DPA
KR4.4:	Provide info to be complemented with other methods (i.e. ultrasonic) to validate the structural integrity, T4.3.	GA	DPA

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KR / KPI Description		Source of KR / KPI	Type of Evaluation Criterion
KR4.5:	Identify the alarming conditions T4.5.	GA	DPA
KPI4.1:	Achieve semi-quantitative indications of organic material and biological colonization (correlation and alignment with the next objective and KPIs).	GA	DPA
Technical Objective 5:	Data-Driven UCH Deterioration Assessment and Preservation Advisor		
KR5.1:	Data-Driven UCH Deterioration Assessment and Preservation Advisor (T4.5)	GA	DPA
KR5.2:	Corresponding preservation recommendations matrix based on different defect levels (T4.5)	GA	DPA
KPI5.1:	Estimation accuracy of mechanical defects and conditions severity and remaining useful life	GA	DPA, QQER
KPI5.1.1:	The image processing system to be developed must be able to achieve a sufficient perimetral digital footprint with high resolution.	NEW	DPA, QQER
KPI5.1.2:	The image processing system must also be able to identify the relevant alarming conditions when necessary	NEW	DPA
KPI5.2:	Estimation accuracy of bio-corrosion (colonists) defects and conditions severity and remaining useful life	GA	DPA, QQER
KPI5.3:	Estimation accuracy of metal-corrosion defects and conditions severity and remaining useful life	GA	DPA, QQER
KPI5.3.1:	Development of a useful Data-Driven UCH Deterioration Assessment and Preservation Advisor Digital Toolbox with estimation accuracy of mechanical defects and conditions severity and remaining useful life of the submerged artifacts, including metal ones and buildings.	NEW	DPA, QQER
KPI5.4:	Granularity of different defect levels and corresponding recommendations matrix	GA	DPA, QQER
Market Objective 6:	Techno economic study of the proposed solutions		
KR6.1:	Develop marketable products, technologies and services for the UW sector, T5.1.	GA	DPA
KPI6.1:	NERITES exploitation plan including a techno - economic analysis	GA	DPA
Societal Objective 7:	Social and Cultural inclusion of proposed solutions		
KR7.1:	Communicate, raise awareness, support active participation and increase the sense of belonging for the citizens' society and the general public, T6.1	GA	DPA
KPI7.1:	Communicating the project's goals and results to > 10000 citizens before project end.	GA	QTR

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Tab. 5: Correlation of Expected Outcomes (EO) with KRs and KPIs

KRs	Validated	WP	KPIs	Source of KR / KPI	Type of Evaluaion Criteria	Type / target group
EO.1: New and innovative remote methods to monitor the state of degradation of original materials of cultural heritage monuments, buildings and artefacts						
KR1.1-3 KR2.1 KR3 KR5 KR6.1 KR7.1	Pilots for the technical part and feedback from the market actors for the economic part.	3, 4, 5 and 6	**KPI O1.1:** The development of 3 remote sensing methods (LIBS, QCL, advanced image processing with better accuracy compared to the present SotA (i.e. information for metal release over time, pollution, characterization of organic surface material and biological colonization) for in-situ UW measurements.	GA	DPA	Scientific, KPI O1.1, O1.2 & O1.3/B2, B3 &C1 Societal, KPI O1.4/all Economical KPI O1.5/ A1, A2, A3, B1, B2 & B3.
			KPI O1.2: Development and operational capacity for ASRP to support remote sensing.	GA	DPA	
			KPI O1.3: Evaluation of structural integrity of >10 buildings, monuments or artifacts using digital vision) (the original KPI O1.3 has been altered)	GA/NEW	DPA	
			KPI O1.4: Raising awareness for the state of UCH monuments/artifacts to >10000 citizens (project end).	GA	QTR	
			KPI O1.5: Bringing closer to market >4 innovative products regarding remote measurements (upgraded LIBS and QCL, ASRP, NERITES solution as a product).	GA	DPA	
EO.2: Innovative on-site monitoring methods of pollutants and the status of previous interventions in cultural heritage buildings, monuments and artefacts in order to select the optimal green and effective conservation strategies and material.						
KR1 KR2 KR4 KR6.1 KR7.1	Laboratory and field results (pilots), number of web visitors and feedback from the citizens,	3, 4, 5 and 6	**KPI O.2.1:** On-site monitoring of 4 inorganic and > 15 organic pollutants (heavy metals such as Pb, Zn, Cu, and Fe), pesticides, HCs etc). For certain organic compounds improvement of LoD by one order of magnitude (using QCL).	GA	DPA	Scientific, KPI O2.1 & O2.2/ Societal KPIO2.3/all Economical, KO2.4/B1, B2&B3
			KPI O2.2: Evaluation and monitoring for 4UW buildings/monuments to assess and evaluate the effectiveness of the previous interventions.	GA	DPA	
			KPI O.2.3: Citizens' pressure to local/regional authorities for zero-waste and circular economy policies (qualitative KPI).	GA	DPA, QQER	
			KPI O2.4: Support for accessible UCH sites backed up with a toolbox describing a step-by-step procedure to allow the sustainable exploitation (as part of D5.1 and D6.2). Funding raise >5M € by 2028 to support monitoring, preservation and greener implementation strategy to support UCH. Scientific, KPI O2.1 & O2.2/ Societal KPIO2.3/all Economical, KO2.4/B1, B2&B3 Associated with document Ref. Ares(2023)7154417 - 20/10/2023 Call: CL2-2023-HERITAGE-01-01— Advanced technologies for remote monitoring of heritage monuments and artefacts [101132575] [NERITES] – Part B Page 23	GA	DPA	
			KPI O2.5: Support 2 related organizations for the decision making of greener and cost-effective strategies for UW conservation tasks and methodologies (qualitative).	GA	DPA	

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The evaluation approach should ensure that data collection methods are standardized, consistent, and aligned with the evaluation criteria. It is essential to analyze the quantitative and quantified qualitative data using statistical methods to calculate means, standard deviations, and other relevant metrics. The analytical techniques employed must be capable of identifying recurring patterns, themes, and insights. The goal is to provide a comprehensive understanding of the system's performance and user experience. The methods used for data gathering are summarized in Tab. 6 Data Collection Methods below.

Tab. 6: Data Collection Methods

ID	Method	Description
1.1	Sensor measurements	Direct recording of sensor readings during missions of different types of data and measurement units including time, data size and energy consumption and storage.
1.2	Mission logs	Recording of system status, deployment time, mission duration, achievements in the implementation of the use case scenarios in the pilots and sampling frequency.
1.3	User surveys	Questionnaires to assess user experience with deployment, operation, data processing, overall system usability et al. Mainly quantitative quality indicators are going to be used.
1.4	User interviews	In-depth interviews to gather detailed feedback from users. Interviews provide qualitative data in the form of user narratives, explanations, and suggestions for improvement. Again, mainly quantitative quality indicators are going to be used.
1.5	Obervation	Direct observation of system operation to identify maintainability, reliability, potential risks and other issues. There are two different options: a) Human observation: This can provide qualitative data on factors such as ease of deployment, system behavior in different environments, and potential safety hazards. b) Camera/technology, recording observation: Video or sensor recordings can capture qualitative data on system operations and potential issues for later analysis.

The evaluation approach will assess the system's performance against the established evaluation criteria, KPIs, and metrics. It will also compare the system's performance to existing technologies, established measurement methods in the field or lab, and/or reference data. The aim is to identify areas of strength and weakness based on the evaluation results. The findings should be presented to stakeholders in a clear, concise, and visually appealing manner. Additionally, the evaluation outcomes must be communicated through all available channels of the project.

4 Definition and description of small, large scale and use cases scenarios

In the NERITES project, various scenarios are defined to evaluate the performance and capabilities of the autonomous platform during the pilot tests. These scenarios range from small, single-mission operations to more complex, large-scale missions, and fully developed use cases that replicate typical underwater archaeological research projects. Below are the definitions and descriptions of each type of scenario:

- **Small Case Scenario**: A small case scenario involves a single mission of the AUV platform focused on the measurement of a single artifact.

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- **Large Case Scenario**: A large case scenario includes either a single mission involving multiple measurements or artifacts, at least two different missions in a single day, or missions extending over two or more days.
- **Use Case Scenario**: A use case scenario represents a typical mission of the autonomous platform within an underwater archaeological research project. The NERITES project will implement four use case scenarios at the pilot sites during the project's pilot period—two in the Fournoi islands in Greece and two in Baiae in Italy.

Tab. 7 below provides a description of the different measurements, which can be combined to create small and large scale, or use case scenario.

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Tab. 7: Measurements in Small, Large and Use Case Scenarios.

ID	Measured Material/Area	Degradation detected	Parameters detected and technology used			Measurements	Method of Validation	Pilot sites
2.1	Stone and ceramic (mosaic tesserae, mortars, marble slabs, bricks, amphoras)	Chemical/ environmental degradation	Presence of heavy metals	Cu, Pb, Zn, Ni	LIBS	1 or 2 samples chosen at the beginning of the survey	In-lab analysis will be conducted on samples using ICP-AES DMA technology	Baia and Fournoi island
2.2	Sediment	Chemical/ environmental degradation	Presence of heavy metals	Cu, Pb, Zn, Ni	LIBS	10 samples were chosen at the beginning of the survey	in-lab analysis will be conducted on selected sediment samples collected from the seafloor using ICP-AES DMA technology	Baia and Fournoi island
2.3	Sediment	Physical and chemical properties of the boundary conditions	pH at the sea-sediment interface	pH*	pH sensor probe over samples	Dimensional Accuracy: ±0.1	Use of Sensor probe over samples	Baia and Fournoi island
2.4	Water column	Chemical/ environmental degradation	Concentration of chemical compounds	VOCs-Volatile Organic Compound	QCL	Presence	In-lab analysis will be conducted on samples using GC-MS technology	Baia and Fournoi island
2.5	Stone and ceramic (mosaic tesserae, mortars, marble slabs, bricks, amphoras)	Biological degradation	Percentage of biological colonization (covering)	Perforated areas (e.g. holes, bioerosion traces), encrusted/covered areas (patinas, algal felts)	Photogrammetry, 3D models, and automatic image analysis	% on a reference area (the size of the sample areas depends on camera resolution and FOV)	Monitoring the percentage coverage at defined time intervals for the identification of biodeteriogens using Macroscopic observations /Optical and electron microscopy	Baia and Fournoi island
2.6	Stone and ceramic (fragments of mosaic floor, walls, masonries, amphoras)	Degradation forms (besides biological)	Identification of degradation forms (besides biological)	Fractures, collapses, detachments, removals, losses	4D Analyses	Critically reference areas identified within the UCH site	Comparison at defined intervals over time of photogrammetry and 3D models compared to the results obtained using Classification according to the standardized methods	Baia and Fournoi island

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ID	Measured Material/Area	Degradation detected	Parameters detected and technology used			Measurements	Method of Validation	Pilot sites
2.7	Water column	Physical and chemical properties of the boundary conditions	Water column profiles	pH*	CTD Vertical casts	±0.1	Vertical casts on selected points using CTD sensors	Baia and Fournoi island
2.8	Water column	Physical and chemical properties of the boundary conditions	Water column profiles	T*	CTD Vertical casts	0.1°C	Vertical casts on selected points CTD of sensors	Baia and Fournoi island
2.9	Water column	Physical and chemical properties of the boundary conditions	Water column profiles	Dissolved O2*	CTD Vertical casts	Ppm	Vertical casts on selected points using CTD sensors	Baia and Fournoi island
2.10	Water column	Chemical/ environmental degradation	Concentration of chemical compounds	Phosphate, Nitrate	QCL	presence	Determination of nitrate and phosphate ions by laboratory analysis using IC Chromatography	Baia and Fournoi island
2.11	Water column	Chemical/ environmental degradation	Concentration of chemical compounds	Dissolved O2*	CTD Vertical casts	presence	In-lab analysis will be conducted on samples	Baia and Fournoi island
2.12	Archaeological metals	Metal alloy	presence of elements in the alloy	Different metals	LIBS	presence	In-lab analysis will be conducted on samples	Baia and Fournoi island

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4.1 Pilot Site #1- "Underwater Archaeological Park of Baiae", Italy

Tab. 8: General Description of Data Collection Conditions in Baiae

<table>
<tr><th colspan="3">Baiae - Underwater Archaeological Park, Italy</th></tr>
<tr><td>1</td><td>Scope of the Institution</td><td>The Underwater Archaeological Park of Baiae was established to protect and preserve the submerged remains of the ancient Roman city of Baiae, which was a prominent resort for the Roman elite. Due to volcanic activity and subsequent subsidence, much of Baiae sank into the sea, creating a unique underwater site. The park aims to safeguard the ruins, which include luxurious villas, mosaics, statues, and thermal baths, while also making them accessible for study and responsible tourism, such as guided diving tours and glass-bottom boat excursions.
Over the last years, the Soprintendenza Archeologica di Napoli was the Managing Authority of the MPA-UP, however recently this role moved to the Parco Archeologico dei Campi Flegrei as the new Managing Authority.</td></tr>
<tr><td>2</td><td>Short description of the Pilot Site</td><td>The Underwater Archaeological Park of Baiae is located off the north-western coast of the Bay of Puteoli (Naples), in the littoral zone between the southern limit of the port of Baiae and the dock of Lido Augusto. This site is part of the coastal region known as Campi Flegrei. Ancient Baiae was a bathing resort for the Roman aristocracy between the 1st century BC and the 4th century AD. Due to bradyseism, the city began to sink into the water around the 3rd century AD. The ancient city, now almost completely submerged, was famous for its luxurious seaside villas, public offices, baths, shops, and coastal installations. The Underwater Archaeological Park of Baiae covers an area of about 176.6 hectares. It not only safeguards the archaeological remains of the Roman city and the infrastructure of the Roman harbor named Portus Iulius, but it also represents an underwater area of great environmental value. The environmental aspects of this area are related to its unique volcanic and geo-deformational history. Since antiquity, this coastal region has been subject to the phenomenon of bradyseism, which can be positive or negative. In its present state, the remains of the Roman era are submerged at depths ranging from 1 to 14-15 meters below the current sea level. Today, the Marine Protected Area (MPA) of Baiae has at least five sites open to the public, accessible to both divers and non-divers. These underwater sites are:
the Villa of the Pisoni,
the "Villa with Protyro Entrance" – "Villa with Vestibule,"
the "Nymphaeum of Punta dell'Epitaffio,"
"Portus Iulius," and
the "Secca Fumosa.</td></tr>
<tr><td>3</td><td>Topology of the Pilot Site</td><td>The seabed of the Underwater Archaeological Park of Baiae is characterized by its unique composition and geological features. Primarily composed of volcanic material from the Campi Flegrei area, the seabed includes pyroclastic deposits, volcanic ash, and tuff. Overlying these volcanic layers are fine sediments such as sand and silt, accumulated over centuries through natural processes and human activities. The area is rich in archaeological debris, including fragments of ancient Roman structures like bricks, tiles, and pottery, which have settled on the seafloor. Marine life, including algae and seagrasses, colonizes the submerged ruins, creating a biodiverse habitat. Additionally, the seabed features fumaroles and thermal springs, where volcanic gases and hot water emerge, influencing the local sediment and marine ecosystem. These unique conditions contribute to the complex and dynamic nature of the Baiae seabed, making it an area of significant archaeological and environmental interest.</td></tr>
<tr><td>4</td><td>Details of operational environment</td><td>Access to the underwater park typically begins by boat, departing from local ports such as the port of Baiae and the dock of Lido Augusto, located along the north-western coast of the Bay of Puteoli. The bay experiences mild to moderate currents, influenced mainly by tidal flows and local wind patterns, which generally remain gentle, contributing to the preservation of the underwater archaeological sites.
Key underwater cultural heritage (UCH) sites within the park are marked with buoys to ensure safe and organized access. Depending on the specific UCH site, the distance from the coast ranges from approximately 100 to 200 meters.</td></tr>
<tr><td>5</td><td>Demonstration objectives</td><td>The objectives of this Use Case scenario would be the assessment of the performance, capabilities, and user experience of the NERITES autonomous platform with its supporting technologies, during a demonstration of a non-intrusive monitoring activity of the state of degradation of the UCH site. In details:
Obj 1. Monitoring the physical and biological degradation of mosaic and wall structures using high-resolution imaging technologies (photogrammetry, automatic image analysis, and 4D analysis) to assess structural integrity and detect early signs of deterioration.
Obj 2. Assess the anthropogenic impact by conducting environmental surveys and data analysis to quantify the impact of factors such as chemical and environmental pollution and sedimentation on artifact stability, based on data provided by QCL and LIBS.</td></tr>
</table>

Baiae - Underwater Archaeological Park, Italy		
6	Planned activities	The plan involves several key activities to test the AUV within a specified area of 2000 square meters and a maximum depth of 6 meters. The docking station will be placed 100 to 200 meters from the nearest artifact and tested for stability and secure mooring solutions to ensure it remains undisturbed. The sea-surface buoy's ability to supply continuous energy and maintain communications will also be assessed, including the potential need for supplementary power sources. Establishing non-intrusive routes for power lines from land to the docking station will be crucial to avoid interference with the cultural heritage site. The primary objective of the demonstration activities is to ensure the AUV and its sensors operate effectively and safely without coming into direct contact with artifacts, thus preventing any potential damage. Trials will be conducted to verify that the AUV can maneuver near artifacts without touching them. To assess the consistency of sensor measurements (LIBS, QCL, High-resolution camera), the AUV's ability to maintain a constant distance from artifacts will be tested. The accuracy of the AUV's positioning system will be evaluated using highly sensitive sensors. Finally, the AUV's control capabilities will be tested to ensure it can maintain stable hovering, perform safe landings, and navigate accurately using optical-based guidance from the docking station as a reference point.
7	Activities duration	The validation activities of the project at the pilot sites are scheduled to last 7 days, with underwater activities between 4 to 6 days in total. Approximate date: Summer 2026.
8	Use-patterns to be demonstrated	Testing all parts of the system in two different missions: 1. Monitoring physical and biological degradation of Mosaic and Wall Structures 2. Assessment of Anthropogenic Impact on the MPA-UP of Baiae
9	Professionals and stakeholder to be involved	Stakeholders to be involved: managing authority of MPA-UP of Baiae, conservators, UCH sites technical directors, archaeologists.
10	Data to be collected for validation	• Sensor measurements • Mission logs • User surveys • User interviews • Observation This will lead to a validation process, which will involve the KPIs provided in Tab. 4

Tab. 9: Use case #1

Use Case #1 **Baiae – Villa of the Pisoni**		Monitoring physical and biological degradation of Mosaic and Wall Structures: - Preliminary optical 3D mapping of the villa. - Preliminary cleaning of selected areas in the wall structures and mosaics. - Assess the biological degradation of wall structures and mosaics using automatic image analysis. - Assess the physical degradation of wall structures using 4D Analyses on 3D models.
1.	Brief Description	The Primary Actor's goal is to assess the performance of the AUV during a mission that involves analyzing the biological and physical degradation of wall structures and mosaics within the UCH site of Villa of the Pisoni. The assessment must be conducted in safety conditions for the UCH site and according to the given timetable. The goal also includes collecting the expected data, processing it, and storing it using the mission planner.
2.	Primary Actors	Underwater archaeologist, survey specialist, Engineers.
3.	Additional/ Supporting Actors	Supply vessel crew and assistants; Supply vessel terminal operator; Remote terminal operator; Others.
4.1.	General Preconditions	Favorable weather and sea conditions; Favorable environment conditions (the presence of other boats or divers in the same area can affect the session); Convenient logistic organization according to the timetable and, if need be, to the sea tides; Proper calculation of the amount of data to be collected during the mission session;

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		Ensure all systems, including navigation, communication, and propulsion, are fully operational before deployment.
4.2.	Specific Preconditions	The primary Actor must be well-trained and briefed on their role, mission objectives, and safety procedures to ensure effective operation. The AUV must be in optimal condition, with all systems checked thoroughly and the battery fully charged to 100% capacity. The AUV's navigation system must be calibrated accurately to maintain precise underwater positioning throughout the mission. The AUV's HD camera and communication systems, including those at the docking station, must be fully operational to ensure seamless data transmission and monitoring. Backup systems and redundancy measures must be in place for critical components such as navigation, communication, and power supply to minimize mission disruption in case of failures.
5.	Basic Flow / Main success scenario: Data survey mission	Logistics: 1. Equipment and Personnel Transportation: Arrange transportation of AUV equipment and personnel to the testing site ensuring all necessary items are securely transported and accounted for. 2. Boat and Equipment Preparation: Ensure all boats and necessary equipment (such as AUV deployment systems, buoys, DGPS) are prepared and in optimal working condition prior to departure. 3. Site Accessibility and Safety Check: Conduct a thorough check of the survey area to ensure clear access to points of interest, taking special care to identify and avoid fishing nets or other obstructions. 4. Departure and Anchorage Planning: Depart from the designated port (e.g., Baiae port) and anchor at the predetermined starting point of the survey site, ensuring all safety protocols are followed during navigation. 5. Equipment Setup for Monitoring Test Dives: Set up monitoring equipment to oversee and record AUV test dives, ensuring all monitoring systems (e.g., cameras, communication devices) are operational. 6. Georeferencing and Point of Interest Confirmation: Prepare equipment to confirm the location of points of interest, such as releasing buoys at specific survey points. Use the boat's DGPS to georeferenced these locations accurately for data analysis Details of the NERITES system check are as follows: On the surface supply vessel: A.1: The Primary and/or supporting Actors perform the technological devices checks; A.2: The supporting Actors perform the Primary Actor's safety parameters checks; A.3: The Primary and/or supporting Actors perform the communication signal check; A.4: The Primary Actor starts the AUV mission, and the mission planner checks mission execution. In underwater environment: B.1: AUV Navigation to First Waypoint: The AUV initiates the mission and navigates towards the first waypoint to commence the 3D photogrammetry mission. B.2: Initiation of Photographic and Photogrammetric Campaign: The AUV begins capturing photographs and executing the photogrammetry mission as planned. B.3: Communication with Topside Unit: AUV maintains communication by sending and receiving messages to and from the Topside Unit to monitor and adjust the mission as needed. B.4: Control of AUV Actions: The Primary Actor sends commands to control actions of the AUV to facilitate optimal operation during the mission. B.5: Mission Stop Command: The Primary Actor issues a STOP command to halt the AUV's mission activities.

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		B.6: Termination of Data Logging: The AUV stops logging data including HD photos, sensor data, and position logs as the mission concludes. B.7: AUV Emergence from Water: The AUV surfaces or completes its underwater activities as required and come back to the docking station. B.8: Mission Data Upload: Mission data and logs (HD photos, sensor data, position logs) are uploaded for analysis and review.
6. **6.1.** **6.1.**	Exception Flows Exception 1 Exception 2	A failure causes the crash of the mission planner A failure causes a miscommunication between the various components of the system
7. **7.1.**	Alternate Flows / Extensions of the main scenario Alternative to exception 1	The software restores the session recovering the data collected until the system failure
7.2.	Alternative to exception 2	The software restores the communication between the various components of the system
8. **8.1.**	Post Conditions Success End Condition	The planned data have been successfully collected during the expected timeframe. The collected data have been successfully stored in a safe server; The conditions of the AUV are good; The safety conditions during data collection are good; The conditions of the NERITES system are good.
8.2.	Failure End Condition	a. The AUV cannot collect the expected data during the planned session. The session must be rescheduled. b. The AUV collected the planned data during the first mission and saved them on a safe server, but no further missions are possible due to system failure. The session must be rescheduled.
9. **9.1.**	Special Requirements Performance	a. Battery Capability for Multiple Missions: The AUV must be equipped with exchangeable or rechargeable batteries capable of supporting multiple mission sessions, each lasting up to 1 hour, within the same operational day for intense testing. b. Data Storage and Transfer: The AUV must have the capability to immediately transfer collected data from its onboard storage to a computer on the surface vessel after each mission. This ensures data integrity and accessibility even in locations where Internet access for cloud-based transfers may be limited or unavailable. c. Immediate Data Backup: The AUV must incorporate mechanisms for immediate backup of collected underwater data to ensure redundancy and prevent data loss. This backup process should be initiated as soon as the AUV is retrieved back onto the surface vessel. d. Compliance with Operational Accessibility Requirements: Ensure that the mission manager design and operation adhere to relevant accessibility standards, such as those outlined in the European Accessibility Act, wherever feasible. This includes considerations for ease of use, safety, and accessibility of controls and data interfaces.
9.3.	Usability / Accessibility	Compliance with the European Accessibility Act requirements [where possible].

Tab. 10: Use Case #2

Use Case #2 **Baiae – Villa of the Pisoni**		Monitoring the anthropogenic impact on the site: - Assess the concentration of Phosphate and Nitrate in the water column using QCL measurements. - Assess the Concentration of VOCs-Volatile Organic Compound in the water column using QCL measurements. - Assess the presence of heavy metal in the sediment, wall structures, and mosaics using LIBS measurements.
1.	Brief Description	The Primary Actor aims to evaluate the performance of the AUV during a mission tasked with monitoring the anthropogenic impact at the Villa of the Pisoni UCH site. This assessment must be conducted under safe conditions for the UCH site and in adherence to the provided timetable. The goal also encompasses collecting the specified data, processing it, and storing it using the mission planner.
2.	Primary Actors	Conservationists, Archaeologists, AUV Operators, Environmental Managers.

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3.	Additional/ Supporting Actors	Supply vessel crew and assistants; Supply vessel terminal operator; Remote terminal operator; Mission Planners; Others.
4.1.	General Preconditions	Favorable weather and sea conditions; Favorable environment conditions (the presence of other boats or divers in the same area can affect the session); Convenient logistic organization according to the timetable and, if need be, to the sea tides; Proper calculation of the amount of data to be collected during the mission session; Ensure all systems, including navigation, communication, and propulsion, are fully operational before deployment.
4.2.	Specific Preconditions	The primary Actor must be well-trained and briefed on their role, mission objectives, and safety procedures to ensure effective operation. The AUV must be in optimal condition, with all systems checked thoroughly and the battery fully charged to 100% capacity. The AUV's navigation system must be calibrated accurately to maintain precise underwater positioning throughout the mission. The AUV, LIBS, QCL, and communication systems, including those at the docking station, must be fully operational to ensure seamless data transmission and monitoring. Backup systems and redundancy measures must be in place for critical components such as navigation, communication, and power supply to minimize mission disruption in case of failures.
5.	Basic Flow / Main success scenario: Data survey mission	Logistics: 1. Equipment and Personnel Transportation: Arrange transportation of AUV equipment and personnel to the testing site ensuring all necessary items are securely transported and accounted for. 2. Boat and Equipment Preparation: Ensure all boats and necessary equipment (such as AUV deployment systems, buoys, DGPS) are prepared and in optimal working condition prior to departure. 3. Site Accessibility and Safety Check: Conduct a thorough check of the survey area to ensure clear access to points of interest, taking special care to identify and avoid fishing nets or other obstructions. 4. Departure and Anchorage Planning: Depart from the designated port (e.g., Baiae port) and anchor at the predetermined starting point of the survey site, ensuring all safety protocols are followed during navigation. 5. Equipment Setup for Monitoring Test Dives: Set up monitoring equipment to oversee and record AUV test dives, ensuring all monitoring systems (e.g., LIBS, QCL, communication devices) are operational. 6. Georeferencing and Point of Interest Confirmation: Prepare equipment to confirm the location of points of interest, such as releasing buoys at specific survey points. Use the boat's DGPS to georeferenced these locations accurately for data analysis Details of the NERITES system check are as follows: On the surface supply vessel: A.1: The Primary and/or supporting Actors perform the technological devices checks; A.2: The supporting Actors perform the Primary Actor's safety parameters checks; A.3: The Primary and/or supporting Actors perform the communication signal check; A.4: The Primary Actor starts the AUV mission and the mission planner checks mission execution. In underwater environment:

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		B.1: AUV Navigation to First Sampling Point: The AUV initiates the mission and navigates towards the first sampling point to commence LIBS and QCL measurements B.2: Initiation of Measurement Campaign: the AUV begins capturing data and executes the measurement mission as planned, scanning the water column and sediment with QCL, and the sediment, walls, and mosaics with LIBS at each sampling point. B.3: Communication with Topside Unit: AUV maintains communication by sending and receiving messages to and from the Topside Unit to monitor and adjust the mission as needed. B.4: Control of AUV Actions: The Primary Actor sends commands to control actions of the AUV to facilitate optimal operation during the mission. B.5: Mission Stop Command: The Primary Actor issues a STOP command to halt the AUV's mission activities. B.6: Termination of Data Logging: The AUV stops logging data including QCL and LIBS data, auxiliary sensor data, and position logs as the mission concludes. B.7: AUV Emergence from Water: The AUV surfaces or completes its underwater activities as required and comes back to the docking station. B.8: Mission Data Upload: Mission data and logs (QCL and LIBS measurements, auxiliary sensor data, position logs) are uploaded for analysis and review.
6.	Exception Flows	
6.1.	Exception 1	A failure causes the crash of the mission planner
6.1.	Exception 2	A failure causes a miscommunication between the various components of the system
6.1	Exception 3	A failure causes intermittent operation of the LIBS sensor
6.1	Exception 4	A failure causes data loss from the QCL sensor due to storage device malfunction.
7.	Alternate Flows / Extensions of the main scenario	
7.1.	Alternative to exception 1	The software restores the session recovering the data collected until the system failure
7.2.	Alternative to exception 2	The software restores the communication between the various components of the system
7.2.	Alternative to exception 3	The system checks to detect and alert operators to sensor anomalies.
7.2.	Alternative to exception 4	The software conduct integrity checks on stored data and implement automated recovery procedures in case of corruption.
8.	Post Conditions	
8.1.	Success End Condition	The planned data have been successfully collected during the expected timeframe. The collected data have been successfully stored in a safe server; The conditions of the AUV are good; The safety conditions during data collection are good; The conditions of the NERITES system are good.
8.2.	Failure End Condition	a. The AUV cannot collect the expected data during the planned session. The session must be rescheduled. b. The AUV collected the planned data during the first mission and saved them on a safe server, but no further missions are possible due to system failure. The session must be rescheduled.
9.	Special Requirements	
9.1.	Performance	a. Battery Capability for Multiple Missions: The AUV must be equipped with exchangeable or rechargeable batteries capable of supporting multiple mission sessions, each lasting up to 1 hour, within the same operational day for intense testing. b. Data Storage and Transfer: The AUV must have the capability to immediately transfer collected data from its onboard storage to a computer on the surface vessel after each mission. This ensures data integrity and accessibility even in locations where Internet access for cloud-based transfers may be limited or unavailable. c. Immediate Data Backup: The AUV must incorporate mechanisms for immediate backup of collected underwater data to ensure redundancy and prevent data loss. This backup process should be initiated as soon as the AUV is retrieved back onto the surface vessel.

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		d. Compliance with Operational Accessibility Requirements: Ensure that the mission manager design and operation adhere to relevant accessibility standards, such as those outlined in the European Accessibility Act, wherever feasible. This includes considerations for ease of use, safety, and accessibility of controls and data interfaces.
9.3.	Usability / Accessibility	Compliance with the European Accessibility Act requirements [where possible].

4.2 Pilot Site #2 – Fournoi island, Greece

Tab. 11: General Description of Data Collection Conditions in Fournoi

Fournoi Island, Greece		
1	Scope of the Institution	Korseai is an institute of historical and archaeological research that consists of maritime archaeologists, commercial divers, conservators, engineers, photographers, topographers, etc. The main area of its action is the island of Fournoi, where since 2015 underwater archeological research is underway. The first four years of this research have resulted in the discovery of 58 wrecks around the island of Fournoi and its surrounding islets. Since 2020 the underwater archaeological excavation of a Byzantine wreck has been conducted. The institute has participated in the DiveSafe EU project and has always been collaborating with the Ephorate of Underwater Antiquities of the Greek Ministry of Culture, for the promotion of the UCH of the Fournoi Archipelago and the maritime archaeology of the Aegean and East Mediterranean Sea in general.
2	Short description of the Pilot Site	Fournoi is one of the two places where the pilot tests of the Nerites advanced technological systems will be implemented. Fournoi, lies on the eastern part of the Aegean Sea, very close to the Turkish coast between the bigger islands of Ikaria and Samos. It is a complex of 20 islands and islets. Its lacy coastline would provide in the past a safe anchorage when strong winds occurred - and this would often happen, considering that, in this area either strong southern winds, or the Etesian north winds (or meltemi as known with its local name) prevail. We can therefore realise the significance of Fournoi within the navigational landscape: the complex of the islands lies along a major east-west crossing route, as well as the primary north-south route that connected the Aegean to the Levant. An underwater survey conducted from 2015 till 2018, in Fournoi archipelago, resulted in the location of 58 wrecks at almost 60% of the total coastline surveyed. These 58 shipwrecks represent the 23% of the known shipwrecks in Greek waters and the Mediterranean's largest known concentration of ships lost, while underway.
3	Topology of the Pilot Site	Aspros Kavos. Geologically, the rocks of the island are either shale, usually in the lower parts of the hills, or limestone in the higher parts. The coasts are steep, typical of the Aegean landscape, full of bays and coves. The sea area is characterised by shallow depths and relatively gentle slopes. The seabed is rocky and sloped. During the months of July and August the island is subject to strong winds (meltemia).
4	Details of operational environment	Aspros Kavos. Access to the shipwrecks is possible only by boat, departing from a small dock at the small settlement of Kamari, located along the north-eastern coast of the Fournoi island. The area experiences strong winds and currents on the surface, especially during summer, but mild to moderate currents underwater. There is no stable or organised access to the sites (no buoys, no docks), as they are still under research and investigation. The shipwrecks site of Aspros Kavos can only be reached by boat and operations must be conducted onboard.
5	Demonstration objectives	The aim of this Use Case scenario is to evaluate how well the NERITES autonomous platform and its associated technologies perform, including their capabilities and user experience, during a simulated non-intrusive monitoring activity focused on assessing the degradation state of the UCH site. The objectives of this Use Case scenario would be the assessment of the performance, capabilities, and user experience of the NERITES autonomous platform with its supporting technologies during a simulation of a non-intrusive monitoring activity of the state of degradation of the UCH site. In details: Obj 1: The use of high-resolution imaging technologies like photogrammetry, automatic image analysis, and 4D analysis to monitor the physical and biological degradation of wrecks. This approach will enable the evaluation of structural integrity and the early identification of deterioration. Monitoring the physical and biological degradation of wrecks using high-resolution imaging technologies (photogrammetry, automatic image analysis, and 4D analysis) to assess structural integrity and detect early signs of deterioration. Obj 2: Evaluate the human impact on artefact stability by conducting environmental surveys and analysing data to measure the effects of factors like chemical pollution,

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Fournoi Island, Greece		
		environmental pollution, and sedimentation, using information provided by QCL and LIBS.
6	Planned activities	The plan involves several key activities to test the AUV within the area either of a wreck (Aspros Kavos) or some specified metal objects around it anchors (Aspros Kavos)Kamari) at a maximum depth of 55 metres. The docking station will be positioned 100 to 200 metres from the nearest artefact, where it will be tested for stability and secure mooring to ensure it remains undisturbed. The performance of the sea-surface buoy in providing continuous energy and maintaining communications will also be evaluated, along with the potential need for additional power sources. It will be essential to establish non-intrusive routes for power lines from land to the docking station to avoid disrupting the cultural heritage site. The docking station will be placed 100 to 200 meters from the nearest artifact and tested for stability and secure mooring solutions to ensure it remains undisturbed. The sea-surface buoy's ability to supply continuous energy and maintain communications will also be assessed, including the potential need for supplementary power sources. Establishing non-intrusive routes for power lines from land to the docking station will be crucial to avoid interference with the cultural heritage site. The main goal of the demonstration activities is to confirm that the AUV and its sensors function effectively and safely without making direct contact with artefacts, thereby preventing any potential damage. The capacity of the manoeuvrability of the AUV will be tested by trials in order to avoid direct contact with the artefacts. The consistency of sensor measurements (LIBS, QCL, high-resolution camera) will be verified through the AUV's ability to maintain a constant distance from artefacts. The accuracy of the AUV's positioning system will also be assessed using highly sensitive sensors. Lastly, before operating the AUV must be tested for its capabilities to hover steadily, perform safe landings, and navigate precisely, using optical-based guidance from the docking station as a reference point.
7	Activities duration	The validation activities of the project at the pilot site are scheduled to last 10 days, with underwater activities between 4 to 6 days in total. Approximate date: September 2026
8	Use-patterns to be demonstrated	Testing all parts of the system in two different missions: 1. Monitoring physical and biological degradation of either wrecks (amphoras) or metal objectsanchors 2. Evaluate the human impact on artefacts stabilityAssessment of Anthropogenic Impact on the wider area of Aspros Kavos in Fournoi
9	Professionals and stakeholder to be involved	Stakeholders to be involved: Korseai mission members, conservators, archaeologists.
10	Data to be collected for validation	• Sensor measurements • Mission logs • User surveys • User interviews • Observation This will lead to a validation process, which will involve the KPIs provided in Tab. 4

Tab. 12: Use case #3 - Wreck

Use Case #3 **Fournoi – Wreck nr 15 (Alternatively Wrecks Nr 13 or 4)**		Monitoring physical and biological degradation of wrecks: - Preliminary cleaning of selected amphoras – if necessary. - Measure Assess the biological degradation of amphoras using automatic image analysis. - Measure Assess the physical degradation of the wreck using 4D Analysis on 3D models.
1.	Brief Description	The Primary Actor's objective is to evaluate the AUV's performance during a simulated mission focused on analysing the biological and physical degradation of amphoras within Wreck 15. This evaluation must be carried out under safe conditions for the UCH site and in accordance with the specified timetable. The goal also involves collecting the required data, processing it, and storing it using the mission planner.The Primary Actor's goal is to assess the performance of the AUV during a mission simulation that involves analyzing the biological and physical degradation of amphoras within the Wreck 15. The assessment must be conducted in safety conditions for the UCH site and according to the given timetable. The goal also includes collecting the expected data, processing it, and storing it using the mission planner.

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2.	Primary Actors	Underwater archaeologists, conservators, Korseai expedition members, survey specialists, engineers.
3.	Additional/ Supporting Actors	Supply vessel crew and assistants; Supply vessel terminal operator; Remote terminal operator; Locals, divers, others.
4.1.	General Preconditions	Favorable weather and sea conditions; Favorable environment conditions (the strong winds often prevailing in the area can affect or abort the session); Convenient logistic organization according to the timetable and, if need be, to the sea and wind conditions; Proper calculation of the amount of data to be collected during the mission session; Verify that all systems, including navigation, communication, and propulsion, are fully functional before deployment.Ensure all systems, including navigation, communication, and propulsion, are fully operational before deployment.
4.2.	Specific Preconditions	The primary Actor must be well-trained and briefed on their role, mission objectives, and safety procedures to ensure effective operation. The AUV must be in optimal condition, with all systems checked thoroughly and the battery fully charged to 100% capacity. The AUV's navigation system must be calibrated accurately to maintain precise underwater positioning throughout the mission. The AUV's HD camera and communication systems, including those at the docking station, must be fully operational to ensure seamless data transmission and monitoring. Backup systems and redundancy measures must be in place for critical components such as navigation, communication, and power supply to minimize mission disruption in case of failures.
5.	Basic Flow / Main success scenario: Data survey mission	Logistics: 1. Equipment and Personnel Transportation: Arrange transportation of AUV equipment and personnel to the testing site ensuring all necessary items are securely transported and accounted for. 2. Boat and Equipment Preparation: Ensure all boats and necessary equipment (such as AUV deployment systems, buoys, DGPS) are prepared and in optimal working condition prior to departure. 3. Site Accessibility and Safety Check: Conduct a thorough check of the survey area to ensure clear access to points of interest, taking special care to identify and avoid fishing nets or other obstructions. 4. Departure and Anchorage Planning: Depart from the designated port (e.g., Aspros Kavos) and anchor at the predetermined starting point of the survey site, ensuring all safety protocols are followed during navigation. 5. Equipment Setup for Monitoring Test Dives/missions: Set up monitoring equipment to oversee and record AUV test dives, ensuring all monitoring systems (e.g., cameras, communication devices) are operational. 6. Georeferencing and Point of Interest Confirmation: Prepare equipment to confirm the location of points of interest, such as releasing buoys at specific survey points. Use the boat's GPS to georeferenced these locations accurately for data analysis Details of the NERITES system check are as follows: On the surface supply vessel: A.1: The Primary and/or supporting Actors perform the technological devices checks; A.2: The supporting Actors perform the Primary Actor's safety parameters checks; A.3: The Primary and/or supporting Actors perform the communication signal check; A.4: The Primary Actor starts the AUV mission and the mission planner checks mission execution. In underwater environment:

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		B.1: AUV Navigation to First Waypoint: The AUV initiates the mission and navigates towards the first waypoint to commence the 3D photogrammetry mission. B.2: Initiation of Photographic and Photogrammetric Campaign: The AUV begins capturing photographs and executing the photogrammetry mission as planned. B.3: Communication with Topside Unit: AUV maintains communication by sending and receiving messages to and from the buoy to monitor and adjust the mission as needed. B.4: Control of AUV Actions: The Primary Actor sends commands to control actions of the AUV to facilitate optimal operation during the mission. B.5: Mission Stop Command: The Primary Actor issues a STOP command to halt the AUV's mission activities. B.6: Termination of Data Logging: The AUV stops logging data including HD photos, sensor data, and position logs as the mission concludes. B.7: AUV Emergence from Water: The AUV surfaces or completes its underwater activities as required and comes back to the docking station. B.8: Mission Data Upload: Mission data and logs (HD photos, sensor data, and position logs) are uploaded for analysis and review.
6.	Exception Flows	
6.1.	Exception 1	A failure causes the crash of the mission planner
6.1.	Exception 2	A failure causes a miscommunication between the various components of the system
7.	Alternate Flows / Extensions of the main scenario	
7.1.	Alternative to exception 1	The software restores the session recovering the data collected until the system failure
7.2.	Alternative to exception 2	The software restores the communication between the various components of the system
8.	Post Conditions	
8.1.	Success End Condition	The planned data have been successfully collected during the expected timeframe. The collected data have been successfully stored in a safe server; The conditions of the AUV are good; The safety conditions during data collection are good; The conditions of the NERITES system are good.
8.2.	Failure End Condition	a. The AUV cannot collect the expected data during the planned session. The session must be rescheduled. b. The AUV collected the planned data during the first mission and saved them on a safe server, but no further missions are possible due to system failure. The session must be rescheduled.
9.	Special Requirements	
9.1.	Performance	a. Battery Capability for Multiple Missions: The AUV must be equipped with exchangeable or rechargeable batteries capable of supporting multiple mission sessions, each lasting up to 1 hour, within the same operational day for intense testing. b. Data Storage and Transfer: The AUV must have the capability to immediately transfer collected data from its onboard storage to a computer on the surface vessel after each mission. This ensures data integrity and accessibility even in locations where Internet access for cloud-based transfers may be limited or unavailable. c. Immediate Data Backup: The AUV must incorporate mechanisms for immediate backup of collected underwater data to ensure redundancy and prevent data loss. This backup process should be initiated as soon as the AUV is retrieved back onto the surface vessel. d. Compliance with Operational Accessibility Requirements: Ensure that the mission manager design and operation adhere to relevant accessibility standards, such as those outlined in the European Accessibility Act, wherever feasible. This includes considerations for ease of use, safety, and accessibility of controls and data interfaces.
9.3.	Usability / Accessibility	Compliance with the European Accessibility Act requirements [where possible].

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Tab. 13: Use case #4 - Fournoi

Use Case #4 **Fournoi – Wreck 15**		Monitoring the anthropogenic impact on the site: - Measure the Concentration of VOCs (Volatile Organic Compounds) in the water column using QCL measurements. - Measure the presence of heavy metal in the sediment, ceramics, and metal objects (anchors) using LIBS measurements. - Measure the exposed areas with active corrosion on metal objects (mainly iron or lead) using LIBS.
1.	Brief Description	The Primary Actor's objective is to evaluate the AUV's performance during a simulated mission focused on the measurement of the human impact on artefact stability within Wreck 15. This evaluation must be carried out under safe conditions for the UCH site and in accordance with the specified timetable. The goal also involves collecting the required data, processing it, and storing it using the mission planner.
2.	Primary Actors	Conservationists, Archaeologists, AUV Operators, Environmental Managers.
3.	Additional/ Supporting Actors	Supply vessel crew and assistants; Supply vessel terminal operator; Remote terminal operator; Mission Planners; Others.
4.1.	General Preconditions	Favourable weather and sea conditions; Favourable environment conditions (the strong winds often prevailing in the area can affect or abort the session); Convenient logistic organisation according to the timetable and, if need be, to the sea and wind conditions; Proper calculation of the amount of data to be collected during the mission session; Verify that all systems, including navigation, communication, and propulsion, are fully functional before deployment.
4.2.	Specific Preconditions	The primary Actor must be well-trained and briefed on their role, mission objectives, and safety procedures to ensure effective operation. The AUV must be in optimal condition, with all systems checked thoroughly and the battery fully charged to 100% capacity. The AUV's navigation system must be calibrated accurately to maintain precise underwater positioning throughout the mission. The AUV, LIBS, QCL, and communication systems, including those at the docking station, must be fully operational to ensure seamless data transmission and monitoring. Backup systems and redundancy measures must be in place for critical components such as navigation, communication, and power supply to minimize mission disruption in case of failures.
5.	Basic Flow / Main success scenario: Data survey mission	Logistics: 1. Equipment and Personnel Transportation: Arrange transportation of AUV equipment and personnel to the testing site ensuring all necessary items are securely transported and accounted for. 2. Boat and Equipment Preparation: Ensure all boats and necessary equipment (such as AUV deployment systems, buoys, DGPS) are prepared and in optimal working condition prior to departure. 3. Site Accessibility and Safety Check: Conduct a thorough check of the survey area to ensure clear access to points of interest, taking special care to identify and avoid fishing nets or other obstructions. 4. Departure and Anchorage Planning: Depart from Aspros Kavos and anchor at the predetermined starting point of the survey site, ensuring all safety protocols are followed during navigation. 5. Equipment Setup for Monitoring Test Dives: Set up monitoring equipment to oversee and record AUV test dives, ensuring all monitoring systems (e.g., LIBS, QCL, communication devices) are operational. 6. Georeferencing and Point of Interest Confirmation: Prepare equipment to confirm the location of points of interest, such as releasing buoys at specific survey points. Use the boat's DGPS to georeferenced these locations accurately for data analysis

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		Details of the NERITES system check are as follows: On the surface supply vessel: A.1: The Primary and/or supporting Actors perform the technological devices checks; A.2: The supporting Actors perform the Primary Actor's safety parameters checks; A.3: The Primary and/or supporting Actors perform the communication signal check; A.4: The Primary Actor starts the AUV mission and the mission planner checks mission execution. In underwater environment: B.1: AUV Navigation to First Sampling Point: The AUV initiates the mission and navigates towards the first sampling point to commence LIBS and QCL measurements B.2: Initiation of Measurement Campaign: the AUV begins capturing data and executes the measurement mission as planned, scanning the water column with QCL, and the sediment, ceramics, and metals with LIBS at each sampling point. B.3: Communication with buoy AUV maintains communication by sending and receiving messages to and from the Topside Unit to monitor and adjust the mission as needed. B.4: Control of AUV Actions: The Primary Actor sends commands to control actions of the AUV to facilitate optimal operation during the mission. B.5: Mission Stop Command: The Primary Actor issues a STOP command to halt the AUV's mission activities. B.6: Termination of Data Logging: The AUV stops logging data including QCL and LIBS data, auxiliary sensor data, and position logs as the mission concludes. B.7: AUV Emergence from Water: The AUV surfaces or completes its underwater activities as required and come back to the docking station. B.8: Mission Data Upload: Mission data and logs (QCL and LIBS measurements, auxiliary sensor data, position logs) are uploaded for analysis and review.
6.	Exception Flows	
6.1.	Exception 1	A failure causes the crash of the mission planner
6.1.	Exception 2	A failure causes a miscommunication between the various components of the system
6.1	Exception 3	A failure causes intermittent operation of the LIBS sensor
6.1	Exception 4	A failure causes data loss from the QCL sensor due to storage device malfunction.
7.	Alternate Flows / Extensions of the main scenario	
7.1.	Alternative to exception 1	The software restores the session recovering the data collected until the system failure
7.2.	Alternative to exception 2	The software restores the communication between the various components of the system
7.2.	Alternative to exception 3	The system checks to detect and alert operators to sensor anomalies.
7.2.	Alternative to exception 4	The software conduct integrity checks on stored data and implement automated recovery procedures in case of corruption.
8.	Post Conditions	
8.1.	Success End Condition	The planned data have been successfully collected during the expected timeframe. The collected data have been successfully stored in a safe server; The conditions of the AUV are good; The safety conditions during data collection are good; The conditions of the NERITES system are good.
8.2.	Failure End Condition	a. The AUV cannot collect the expected data during the planned session. The session must be rescheduled. b. The AUV collected the planned data during the first mission and saved them on a safe server, but no further missions are possible due to system failure. The session must be rescheduled.

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9.	Special Requirements	
9.1.	Performance	a. Battery Capability for Multiple Missions: The AUV must be equipped with exchangeable or rechargeable batteries capable of supporting multiple mission sessions, each lasting up to 1 hour, within the same operational day for intense testing. b. Data Storage and Transfer: The AUV must have the capability to immediately transfer collected data from its onboard storage to a computer on the surface vessel after each mission. This ensures data integrity and accessibility even in locations where Internet access for cloud-based transfers may be limited or unavailable. c. Immediate Data Backup: The AUV must incorporate mechanisms for immediate backup of collected underwater data to ensure redundancy and prevent data loss. This backup process should be initiated as soon as the AUV is retrieved back onto the surface vessel. d. Compliance with Operational Accessibility Requirements: Ensure that the mission manager design and operation adhere to relevant accessibility standards, such as those outlined in the European Accessibility Act, wherever feasible. This includes considerations for ease of use, safety, and accessibility of controls and data interfaces.
9.3.	Usability / Accessibility	Compliance with the European Accessibility Act requirements [where possible].

5 State of the Art Methodologies for Validating NERITES Sensing Technologies

This section outlines the state-of-the-art methodologies used to validate NERITES sensing technologies. For each type of measurement in the small, large, and use case scenarios described in Tab. 7, traditional and alternative methods of measurement and monitoring will be used to assess the performance of the NERITES system.

ID 4.1: The heavy metal content in mineralized samples is determined using atomic emission spectroscopy with an inductively coupled plasma source (ICP-AES). This technique is based on the measurement of radiation emitted by the sample following the excitation of atoms and their subsequent return to the ground state. Applied methods: Cu, Pb, Zn, Ni in ceramic: EPA 3052 (Microwave assisted acid digestion of siliceous and organically based matrices); EPA 6010C (Inductively Coupled Plasma-Atomic Emission Spectrometry; ICP-AES); EPA 7473 (Direct Mercury Analyzer, DMA, Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometer)

ID 4.2: Cu, Pb, Zn, Ni in sediment: See 4.1. Applied methods: EPA 3052 (Microwave assisted acid digestion of siliceous and organically based matrices); EPA 6010C (Inductively Coupled Plasma-Atomic Emission Spectrometry; ICP-AES); EPA 7473 (DMA, Mercury in solids and solutions by thermal decomposition, amalgamation, and atomic absorption spectrophotometer)

ID 4.3: Ph in sediment: Elemental Analyzer (EA), which is used to determine the elemental composition of a sample. Applied methods: "Metodologie Analitiche di Riferimento (ICRAM, 2001).

ID 4.4: VOCs in seawater: Gas Chromatography-Gas Spectrometry. Applied methods: EPA 5021 (Volatile organic compounds in various sample matrices using equilibrium headspace analysis); EPA 8260b (Volatile organic compounds by Gas chromatography/mass spectrometry; GC-MS)

ID 4.5: The monitoring of biological colonization on archaeological artefacts in the marine environment is a fundamental phase in the field of conservation and restoration works because underwater sites are particularly subjected to recolonization phenomena after restoration or dredging interventions. The methodology commonly used to monitor biological degradation consists of the in situ graphical and photographical mapping of the biological covering of UCH

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sites using the SAMAS BIO Analytical Data Card (I and II level), which is linked to the archeological SAMAS Data Card. These instruments have been developed by the Central Institute for Restoration to provide a cognitive picture of the general state of the underwater archaeological structures and of the seriousness of the biological deterioration in progress. Monitoring operations require periodic inspections to detect changes in an underwater site's condition. Preliminary studies have illustrated the use of 3D imaging techniques to study bioerosion phenomena of Underwater Cultural Heritage, but the field of biological monitoring with the abovementioned techniques has not yet been investigated in detail. 3D imaging techniques can be easily performed on selected volumes that have to be controlled and can, therefore provide useful information on the growth rate of the organisms, their distribution on the surface, and the related influence of environmental factors such as the hydrodynamism (on different exposures, at different heights, on different lithotypes, etc.). The 3D images associated with the photographic documentation permit to reach a greater level of detail leading to an identification of the main groups of colonizers. The advantages of this method are above all the possibility of observing the archaeological structure in its entirety and simultaneously assessing the biological covering and any damage suffered by the artefact/structure in relation to its exposure in a specific microhabitat. The rapidity and multiplicity of the results obtained with the 3D imaging techniques make this method very useful both in periodic monitoring procedures and in planning maintenance and restoration works. The aim of this methodology is to produce an accurate three-dimensional model of the archaeological structure or site. The evaluation of the percentage of coverage is carried out by visual inspection and image analysis, the identification of degradation patterns is carried out by observing samples under optical and electron microscope, to identify the biodeteriogenes and their extension within the materials.

ID4.6: The methodology commonly used to monitor structural degradation phenomena on underwater heritage sites is the in situ graphical and photographical mapping of the physical degradation phenomena using the archaeological SAMAS Data Card developed into two different sheets to differentiate the structures/sites to be mapped. One model has been devised for surveying foundations and structures in elevation (mainly vertical surfaces),), and another for recording floors, decorative and/or simple wall plasters, and other architectonic components (mainly horizontal surfaces). All the data cards are printed on polyester to be filled underwater. The data from the SAMAS Data Cards is then transferred to the SAMAS Archive Data Card, which contains further entries regarding bibliographical references, information on earlier restoration or excavation projects, and an open field entitled observations, where the compiler can insert other significant points of interest. The data recording model for these cards is based on that of the Risk Map of Cultural Heritage, now collecting all the information on the Italian Underwater Cultural Heritage (http://www.cartadelrischio.beniculturali.it/webgis/).

Marine Geophysics can be applied for monitoring the physical degradation of underwater archaeological sites. MBES systems can provide high-resolution bathymetric data, allowing researchers to create detailed maps of the seafloor. Changes in bathymetry over time can indicate erosion or sedimentation around archaeological sites.

The 4D Analyses will allow the monitoring of physical damages (fractures, collapses, cracks, detachments, etc) over time by comparing different 3D models at defined intervals. This activity will be performed on reference areas of 1x1 m to focus on structures or artefacts that present peculiar characteristics due to precarious conditions that need to be considered. Experts in the conservation of stone materials conduct the identification of degradation forms through

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inspections of surfaces. They apply glossaries based on ICOMOS-ISCS and UNI 11182 standards to accurately classify and identify these forms. The assessment is repeated at different time intervals.

ID4.7: CTD (Conductivity, Temperature, and Depth) profiler: provides profiles of physical and chemical parameters of the water column at a fixed point through vertical casts. The CTD is deployed from a vessel using a winch, lowering it from the sea surface to the seabed at a specific point and time. During measurements, the CTD records seawater temperature and other variables in its internal memory. Water samples may be collected at specific depths using Niskin bottles.

ID4.8: See ID 4.7

ID4.9: See ID 4.7

ID4.10: A sample of seawater is collected from the pilot site, then the determination of the anions and the cations is carried out in laboratory by ion chromatography analysis, for this purpose an IC chromatograph is used.

ID 4.11: The measurements of the dissolved CO2 in water column typically relies on a combination of traditional techniques and emerging technologies. Here are some state-of-the-art methods:

In-Situ Sensors: Deploying in-situ sensors equipped with optical or electrochemical sensors can provide real-time measurements of dissolved CO2 levels. These sensors can be integrated into autonomous underwater vehicles (AUVs) or buoys for continuous monitoring.

Underwater Spectroscopy: Spectroscopic techniques, such as UV-Vis or fluorescence spectroscopy, can be used to indirectly measure dissolved CO2 concentrations by analyzing the spectral properties of water samples.

Chemical Sensors: Advanced chemical sensors based on selective membranes or molecular recognition elements can be deployed to directly measure dissolved CO2 concentrations with high sensitivity and specificity.

Carbonate Chemistry Models: Sophisticated carbonate chemistry models, such as those based on the CO2SYS package, can be used to calculate dissolved CO2 concentrations from measured parameters like pH, alkalinity, and temperature.

Microfluidic Devices: Miniaturized microfluidic devices can be used for in-situ measurements of dissolved CO2 concentrations, offering high sensitivity and rapid analysis capabilities.

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