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NERITES replication and assessment protocols' innovations

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Executive Summary

As part of its mission to preserve Underwater Cultural Heritage (UCH), the NERITES project has developed a novel framework for the remote monitoring of degradation processes. This document, Deliverable D6.4a, is the first of two deliverables produced under Task 6.4 and focuses on the definition of **preliminary utilization guidelines** and a **preservation assessment protocol** for the remote monitoring of degradation phenomena affecting UCH sites.

Building upon the conceptual framework established in Deliverable 2.3 - *Framework for the systematic degradation assessment of UCH* [1], this report translates theoretical constructs into a structured, archetype-based monitoring logic. It proposes workflows for site classification, sensor-based data acquisition, and index-driven degradation assessment. These components form the foundation of an adaptable, condition-specific monitoring system aimed at supporting decision-making in conservation planning.

Given that the NERITES technologies are still under development, the guidelines and protocols presented in this document are considered **pre-operational**. They are intended to inform the planning and preparation of upcoming testing activities in WP5 and to support stakeholder engagement actions in WP6. While not yet validated through in situ deployments, these preliminary instruments offer a coherent framework for simulation exercises, mission planning, and participatory design processes involving relevant stakeholders.

In addition, the deliverable explores potential pathways for regulatory alignment, interoperability with existing EU policy frameworks, and mechanisms for long-term institutional adoption of the NERITES methodology. Particular attention is given to alignment with UNESCO and EU conservation agendas.

A subsequent document, Deliverable D6.4b (due in Month 36), will consolidate technical refinements, feedback from pilot activities, and empirical evidence from field trials. This forthcoming deliverable will present a **tested operational version** of the **guidelines and preservation assessment protocol**, informed by real-world application and multidisciplinary collaboration.

1 Introduction

This deliverable presents the preliminary version of the **NERITES Utilization Guidelines** and the **UCH Preservation Assessment Protocol**, developed within Task 6.4. Its primary objective is to define a coherent monitoring logic and outline implementation pathways for the future deployment of the NERITES system in real-world UCH contexts.

The guidelines build upon the **degradation assessment framework** introduced in Deliverable 2.3, which proposed a **three-pillar architecture** linking UCH site classification, sensor-based observation, and adaptive monitoring missions. This conceptual structure is here operationalized into actionable workflows, including site analysis protocols, degradation indices, and archetype-driven monitoring strategies.

Given the current stage of the project and the technological readiness level of the system, the deliverable does not describe a validated operational solution. Rather, it provides a **simulation-ready** and **design-complete reference model**. This model defines the expected relationships between degradation processes, sensing modalities, mission profiles, and data interpretation mechanisms—serving as a blueprint for subsequent implementation, testing, and refinement.

In addition, the deliverable introduces the first version of the **Preservation Assessment Protocol**, developed to evaluate both the conservation condition of monitored UCH sites and the performance of the NERITES monitoring system itself. The protocol includes a preliminary set of key performance indicators (KPIs) and evaluation criteria, which will be tested and refined during the upcoming pilot deployments.

The document is structured to follow the logical progression from conceptual framing to field implementation and policy integration:

Section 2 presents the monitoring guidelines, covering degradation processes, the NERITES framework, implementation protocols, and associated risk assessment tools;

Section 3 outlines the Preservation Assessment Protocol and its technical components;

Section 4 addresses policy integration, regulatory alignment, and stakeholder engagement strategies.

This deliverable provides the foundation for the empirical and stakeholder-oriented activities that will follow, supporting the full operationalization of the NERITES methodology by the end of the project lifecycle.

This deliverable provides the foundation for the empirical activities and stakeholder-facing work that will follow, ultimately enabling the full operationalization of the NERITES methodology by the end of the project.

2 Development of Monitoring Guidelines for UCH Degradation Assessment

This section outlines the monitoring logic and procedural architecture supporting the deployment of NERITES technologies for the assessment of UCH degradation. It builds upon the conceptual model developed in Deliverable 2.3, translating its principles into a structured, actionable implementation framework.

The NERITES monitoring strategy is built on three interconnected components: (a) **analytical site classification** and **archetype assignment**, (b) **activation of tailored monitoring protocols** based on **degradation profiles**, and (c) **structured interpretation of results** through **risk assessment** and **adaptive feedback**.

These components are integrated into a five-step operational workflow, presented in Section 2.1, which guides the sequence from site diagnosis to mission configuration and evaluation. The goal is to ensure that monitoring is both technically rigorous and conservation-relevant, enabling consistent data acquisition, interpretation, and decision-making across a wide variety of UCH scenarios.

2.1 NERITES Monitoring Workflow: Logic and Structure

The NERITES monitoring approach is structured around a five-step operational workflow that enables systematic, site-specific assessment of UCH degradation. This workflow, introduced in D2.3 (Section 5), serves as the operational backbone for all monitoring activities carried out under Task 6.4. It is designed to ensure that monitoring strategies are both technically rigorous and responsive to the diverse material, environmental, and conservation contexts found across UCH sites. It enables the activation of tailored, archetype-driven monitoring missions that align with degradation risks and site-specific constraints.

The five steps of the NERITES operational workflow are (Figure 1):

Step 1 – Site Classification

Integration of archaeological, environmental, and material data from non-invasive surveys and archival sources to establish the initial diagnostic profile of the site.

Step 2 – Archetype Assignment

Analytical assignment of the site to a predefined archetype, based on quantifiable environmental conditions, material composition, and expected degradation patterns. Archetypes serve as the reference point for selecting monitoring strategies.

Step 3 - Monitoring Protocol Activation

Based on the assigned archetype, an appropriate monitoring protocol is configured. This includes sensor payload selection, mission frequency, spatial and temporal resolution, and data acquisition workflows.

Step 4 - Sensor Deployment and Data Collection

Execution of monitoring missions using NERITES-enabled platforms. Sensors collect multimodal data—chemical, physical, visual—according to the activated protocol, ensuring consistency and comparability across missions.

Step 5 - Risk Evaluation and Decision-Making

Collected data are analyzed to generate condition indices and risk scores. These are evaluated against predefined thresholds to determine whether the monitoring strategy should continue, be adapted, or trigger a reclassification of the site.

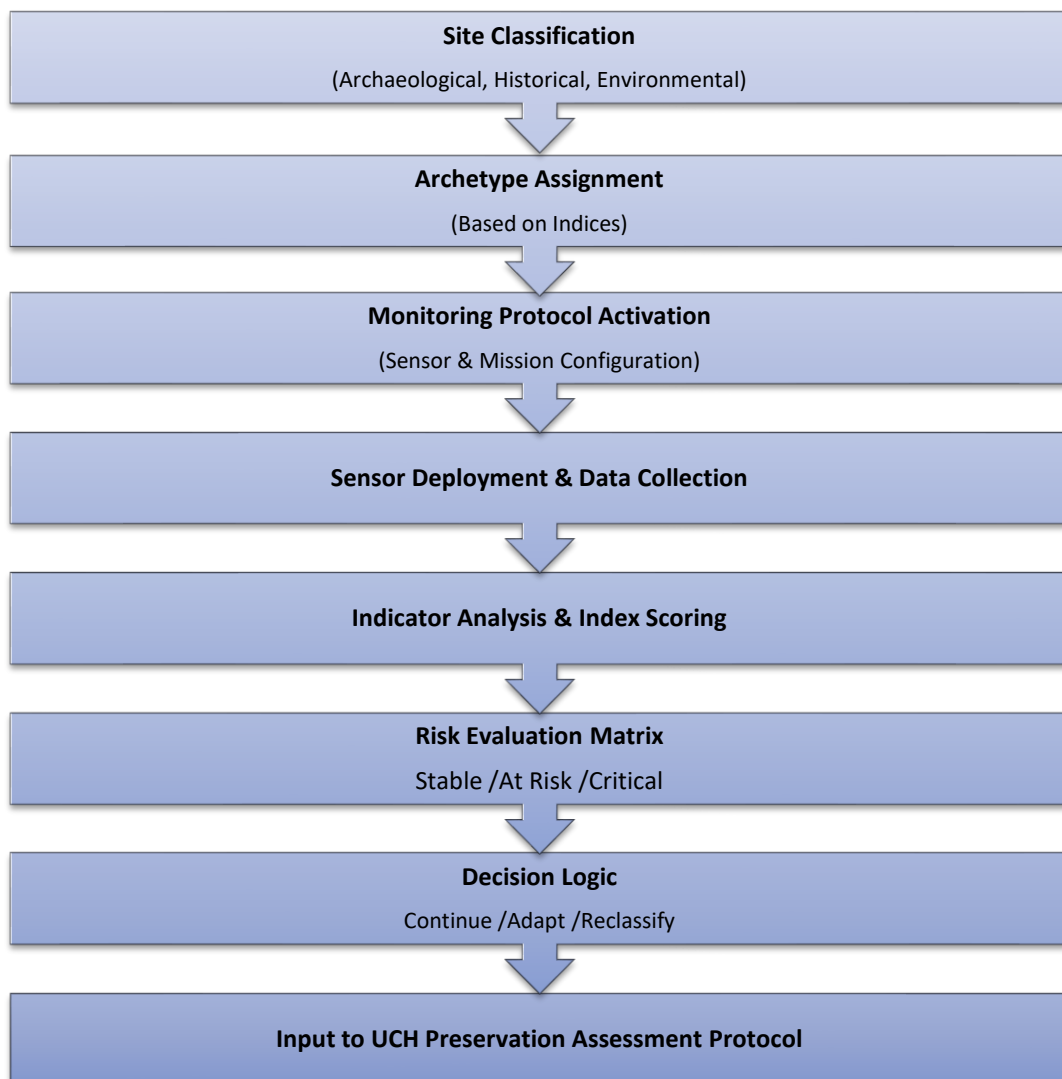


Figure 1. NERITES Monitoring and Decision Logic

This operational workflow is supported by the conceptual structure of the NERITES framework, detailed in Section 2.3, which introduces **three foundational pillars**:

- **Pillar 1 - Site classification and archetype assignment.** Provides the logic for understanding the site's material and environmental profile and assigning it to one of the defined UCH archetypes.
- **Pillar 2 - Sensing technologies for degradation monitoring.** Defines the sensor modalities and data types required to observe and quantify site-specific degradation processes.
- **Pillar 3 - Adaptive mission planning strategies.** Guides the iterative configuration of monitoring missions based on real-time data and risk feedback.

Each phase of the five-step workflow is directly supported by one or more of these pillars, ensuring consistency between theoretical models, technological implementation, and conservation objectives. In this way, the NERITES workflow operationalizes the D2.3 framework and enables systematic monitoring tailored to the complexity and variability of UCH environments.

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The following sections examine each phase in detail—beginning with the degradation processes that determine what is monitored (Section 2.2), followed by the NERITES conceptual framework that supports classification and planning (Section 2.3), the operational procedures for implementation in the field (Section 2.4), and the tools for interpreting results and supporting adaptive decision-making (Section 2.5).

2.2 Understanding Degradation Processes in UCH

A critical first step in any degradation monitoring strategy is to understand the processes that threaten UCH integrity. Section 2.2 provides a synthesis of these degradation mechanisms, offering the contextual basis for the site assessments and indicator selection procedures that follow in later stages of the workflow. As reported in Deliverable D2.3, UCH sites—including shipwrecks, submerged settlements, and ancient artifacts—are subject to a variety of degradation processes that threaten their long-term preservation. These processes can be broadly categorized into **physical**, **chemical**, and **biological factors**, which often act simultaneously and synergistically. A comprehensive understanding of these mechanisms is essential for the development of effective conservation and monitoring strategies.

Physical Degradation Processes

Physical degradation arises from mechanical forces that directly damage or alter UCH structures. Key contributors include:

- **Hydrodynamic Forces.** Water currents, waves, and tides exert continuous stress on underwater structures, leading to displacement, erosion, and breakage of artifacts. High-energy environments, such as coastal zones, pose greater risks due to stronger wave action.
- **Sediment Movement.** Burial and re-exposure of artifacts due to shifting sediments can accelerate deterioration. While sediment coverage can offer protection by reducing oxygen exposure, sudden uncovering can make UCH vulnerable to further degradation.
- **Abrasion and Scouring.** Sediment particles transported by currents can erode surfaces, wearing down fragile materials like wood, ceramics, and metals over time.
- **Human Activities.** Unauthorized diving, looting, and construction projects (e.g., offshore drilling, pipeline installation) contribute significantly to physical damage, sometimes leading to irreversible destruction.
- **Seismic and Geological Events.** Earthquakes, underwater landslides, and tsunamis can displace or fragment UCH sites, making conservation efforts more complex.

Chemical Degradation Processes

Chemical reactions between submerged materials and the surrounding environment lead to corrosion, dissolution, and structural weakening. The most common chemical degradation processes include:

- **Metal Corrosion.** Shipwrecks and metallic artifacts are particularly vulnerable to oxidation and electrochemical reactions. In seawater, iron-based materials undergo rapid corrosion, forming iron oxides and hydroxides (e.g., rust). The presence of sulfate-reducing bacteria can accelerate the process, leading to the formation of iron sulfides, which can cause long-term instability.
- **Acidification and pH Changes.** Increased CO₂ levels in seawater contribute to ocean acidification, which dissolves calcium carbonate-based materials like corals, shells, and limestone artifacts. This process weakens structural integrity and accelerates the loss of historical features.

- **Salt Crystallization.** The deposition of salt crystals within porous materials, such as wood and ceramics, can cause expansion and fracturing, particularly when artifacts are exposed to varying salinity conditions.
- **Oxidation and Redox Reactions.** Organic and inorganic materials react differently depending on oxygen availability. In anoxic (low-oxygen) environments, organic matter like wood may be better preserved, while in oxygen-rich conditions, oxidation accelerates decomposition.

Biological Degradation Processes

Biological activity plays a significant role in the deterioration of UCH, particularly in marine environments rich in micro and macro organisms. Key biological threats include:

- **Biofouling and Encrustation.** Marine organisms, including barnacles, algae, and mollusks, colonize UCH surfaces, forming thick encrustations that obscure details and alter surface properties. Over time, biofouling can contribute to structural weakening.
- **Endolithic colonization.** the process by which organisms penetrate and inhabit the interior of solid substrates, poses a significant threat to UCH sites. Among the most destructive endolithic organisms are sponges, mollusks, and some species of cyanobacteria, which bore into materials such as carbonatic (marble, limestone, travertine, etc.), biogenic carbonatic materials (corals, shells, etc.) and sometimes even metal, leading to structural weakening and long-term degradation.
 - **Sponges**, particularly species from the Clionidae family, create extensive networks of tunnels within calcareous materials, progressively breaking them down through chemical dissolution and mechanical excavation.
 - **Mollusks**, such as *Lithophaga lithophaga*, *Rocellaria dubia* burrow into calcareous materials, accelerating decomposition and reducing stability.
 - **Cyanobacteria**, known for their ability to colonize porous surfaces, infiltrate microscopic cracks and excrete acidic compounds that dissolve carbonates, exacerbating erosion. These organisms thrive in marine environments where nutrient levels, temperature, and light conditions support bioerosion.

As endolithic activity progresses, cultural artifacts become more fragile and susceptible to fragmentation, highlighting the importance of implementing targeted monitoring and conservation strategies to mitigate biological degradation in submerged archaeological sites.

- **Wood-Boring Organisms.** Shipwrecks and other wooden artifacts are highly vulnerable to destruction by wood-boring species such as *Teredo navalis* (shipworms) and *Limnoria* spp. (gribble). These organisms create extensive tunnels in submerged wood, leading to rapid structural collapse.
- **Microbial Degradation.** Bacteria and fungi contribute to the breakdown of organic materials through enzymatic action. Sulfate-reducing bacteria, for example, accelerate metal corrosion, while certain fungi decompose cellulose in waterlogged wood.
- **Predation and Grazing.** Herbivorous marine organisms, such as certain fish and sea urchins, can feed on biofilm layers covering UCH surfaces, indirectly influencing degradation dynamics.

2.3 The NERITES Framework for Degradation Assessment of UCH Sites

Having outlined the degradation phenomena that NERITES is designed to monitor, this section introduces the **NERITES framework for degradation assessment**, as defined in D2.3. This framework

defines **the logic** that links **site characterization** with **sensor deployment, mission planning, and adaptive risk evaluation** — and directly supports steps 2 to 5 of the monitoring workflow introduced in Section 2.1. The framework is conceived to support scalable and interoperable assessment strategies across a range of UCH contexts. It introduces a **three-pillar approach** that systematically connects **degradation drivers, site-specific features, and technology selection** to support informed, archetype-driven monitoring of UCH sites. In particular, the framework serves a dual purpose:

- To enable **analytical site classification** based on **quantifiable environmental and material indicators**;
- To guide the activation of **context-specific monitoring protocols** aligned with the **site's degradation profile and conservation needs**.

The **first pillar** concerns the **classification of UCH sites** through a **structured, multi-phase process** that progresses from data collection to analytical categorization. It begins with the historical, archaeological, environmental, and material characterization of the site, which provides the empirical basis for analysis. Based on this characterization, a set of quantitative indicators is derived to support the systematic classification of the site's conservation status and degradation profile. This analytical process culminates in the assignment of the site to a specific archetype, a predefined typological category representing sites with similar material compositions, exposure conditions, and degradation dynamics. Archetype assignment is a prerequisite for determining monitoring priorities, selecting appropriate technologies, and tailoring conservation responses.

The **second pillar** defines **the sensor technologies integrated into the NERITES system for in-situ degradation monitoring**. These include advanced environmental and chemical sensors, such as **LIBS** (Laser-Induced Breakdown Spectroscopy), **QCL** (Quantum Cascade Laser-based systems), as well as **AI-enhanced imaging tools**. These sensors are deployed via an autonomous underwater vehicle (AUV), and are designed to operate in different marine environments and at varying levels of granularity. The technological configuration is determined by the site's assigned archetype and degradation profile. Each sensing modality is associated with specific indices defined in D2.3 (Section 5.1), allowing for the detection of physical, chemical, and biological deterioration phenomena. This ensures that data acquisition is directly aligned with conservation-relevant variables and degradation risks.

The **third pillar** is concerned with the definition of **an adaptive mission strategy**. Rather than applying a **fixed monitoring scheme**, the framework introduces the concept of a **modular and scenario-specific mission suite**. This suite combines the outputs of the classification process and sensor capabilities to define the most appropriate monitoring logic for each context. This adaptive approach ensures operational flexibility and facilitates the alignment of monitoring efforts with conservation priorities, logistical constraints, and environmental variability.

2.4 Operational Guidelines for Monitoring Implementation

This section describes how the **NERITES degradation assessment framework** is operationalized in the field. It translates the conceptual structure described in Section 2.3 into a repeatable process for configuring and deploying monitoring activities in accordance with site-specific degradation profiles.

The implementation approach is based on an **archetype-driven logic**. Each UCH site, once classified through a predefined set of indicators, is assigned to a specific archetype as described in D2.3. The archetype determines the monitoring strategy: **which sensors to use, what to measure, how often to deploy missions, and how to evaluate the results**.

While this section presents the structured methodology for site classification, indicator tracking, and monitoring decision flows, it is important to emphasize that the described protocols are **pre-operational** and will be tested in demonstration settings during the final phase of the project.

2.4.1 Archetype-Based Monitoring Logic

The process begins with the **analytical classification of the site**, in which a standardized set of degradation indicators is measured using validated in-situ techniques. These indicators include **environmental parameters, physical conditions, biological indicators, and material condition metrics**.

Each indicator is converted into a **quantitative index** (as defined in D2.3, Section 5), collectively capturing the degradation dynamics of the site (see Table 1). **Composites indices** aggregate multiple **simple indicators** to provide a high-level overview of site conditions, while simple indices correspond to specific measured variables.

Table 1. Overview of Indices used for Site Classification and Archetype Assignment as defined in Section 5 of D2.3

Composite indices	Simple indices	
Environmental Index (EI)	BQI	Biological Quality Index
	WQI	Water Quality Index
	TRIX	Trophic Index
	PLI	Pollution Load Index
Chemical-physical degradation index (CPI)	TEDI	Total Extent of Damage Index
	PDI	Progressive Damage Index
	SDI	Seriousness of Damage index
Chemical-biological degradation index (CBI)	BDI	Biological Degradation Index
	BRI	Biodeterioration Risk Index
	BCSI	Bio-Chemical Stability Index

These indices reflect the site's vulnerability to specific degradation mechanisms and serve as the basis for **archetype assignment**. Each **archetype** is a conceptual model grouping sites with similar material compositions, environmental exposure, and degradation behavior. Assignment to an archetype is not merely descriptive—it determines the **monitoring strategy** to be applied. In particular, UCH sites are classified into five main archetypes: **Pristine, Stable, Vulnerable, Critical, and Collapsing** (refer to table 2). Sub-archetypes (e.g., Type 2-B, Type 3-C) highlight specific situations where biological, physical and environmental factors dominate the degradation process (table 2 – see D2.3, Section 5.2 for computational details).

Table 2. Archetype Assignment of UCH sites as defined in Section 5 of D2.3

Archetype	Environmental Index (EI)	Chemical-Physical Index (CPI)	Chemical-Biological Index (CBI)	Description
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Type 1 Pristine Condition	0.9 – 1.0	0.9 – 1.0	0.9 – 1.0	Sites with minimal stress across all indices; stable, balanced, and pristine with no significant risks.
Type 2 Stable Condition	0.7 – 0.9	0.7 – 0.9	0.7 – 0.9	Sites with minor stress across all indices.
Type 2-A Biologically active but stable	0.7 – 0.9	0.7 – 0.9	0.5 – 0.7	Sites with notable biological activity but structural and environmental conditions remain stable
Type 2-B Physically active but stable	0.7 – 0.9	0.5 – 0.7	0.7 – 0.9	Sites with notable structural stress, while biological and environmental conditions remain stable.
Type 2-C Environmentally active but stable	0.5 – 0.7	0.7 – 0.9	0.7 – 0.9	Sites with notable environmental stress but stable biological activity and structural conditions.
Type 3 Vulnerable Condition	0.5 – 0.7	0.5 – 0.7	0.5 – 0.7	Sites experiencing moderate stress across all indices.
Type 3-A Biologically Vulnerable	0.5 – 0.7	0.5 – 0.7	0.3 – 0.5	Sites dominated by biological degradation.
Type 3-B Physically Vulnerable	0.5 – 0.7	0.3 – 0.5	0.5 – 0.7	Sites where structural degradation is the primary issue.
Type 3-C Environmentally Vulnerable	0.3 – 0.5	0.5 – 0.7	0.5 – 0.7	Sites where environmental stress is the primary degradation driver.
Type 4 Critical Condition	0.3 – 0.5	0.3 – 0.5	0.3 – 0.5	Sites in critical condition, experiencing severe degradation across all indices
Type 4-A Biologically Critical	0.3 – 0.5	0.3 – 0.5	0.0 – 0.3	Sites with critical biological degradation destabilizing material integrity, compounded by secondary structural and environmental impacts.
Type 4-B Physically Critical	0.3 – 0.5	0.0 – 0.3	0.3 – 0.5	Sites experiencing severe structural degradation as the dominant issue, with biological and environmental stress as secondary concerns.
Type 4-C Environmentally Critical	0.0 – 0.3	0.3 – 0.5	0.3 – 0.5	Sites where extreme environmental stress destabilizes the site
Type 5 Collapsing Condition	0.0 – 0.3	0.0 – 0.3	0.0 – 0.3	Sites in extreme degradation states across all indices, at imminent risk of total collapse or material loss.

2.4.2 Indicator-Driven Protocol Activation

Once an archetype is assigned, a corresponding monitoring protocol is activated. This protocol includes:

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1. The **key indicators** to be **tracked over time**;
2. The **sensor configurations** and **measurement techniques** required for **in-situ observation**;
3. The **frequency** and **resolution** of **monitoring activities**;
4. The **baseline thresholds** and **acceptable variability ranges** for each indicator.

These protocols are predefined and not configured manually per mission, ensuring coherence with the classification logic and enabling repeatable and scalable deployment. The same logic is applied to data interpretation, using archetype-specific thresholds to evaluate deviations from the expected degradation profile.

Table 3 presents an example of an operational monitoring protocol for an Archetype 1 site (pristine condition), as defined in the NERITES framework and derived from D2.3. The protocol outlines the specific monitoring tasks, recommended sensing strategies, observation frequency, relevant degradation indices, and associated threshold values that may trigger adaptive responses or further investigation. The proposed **monitoring frequency** is to be interpreted as a **minimum recommended interval**, subject to refinement based on site-specific conditions and conservation priorities. Similarly, the **warning threshold** values included in the protocol are **empirically defined based on preliminary analysis**; however, their robustness and applicability will require validation through future pilot studies and field deployments.

Table 3. Example of monitoring protocol for an UCH site in Pristine condition (Archetype 1)

Tasks	Actions	Frequency	Indices	Warning threshold
Environmental Monitoring	Assess water quality using QCL sensors and VOCs.	Seasonal (four times per year)	Environmental Index (EI)	> 20% increase in pollutants;
	Use an auxiliary multiparametric probe to measure pH, temperature, dissolved oxygen, and salinity.	Seasonal (four times per year)		> 10% decrease in Dissolved Oxygen compared to baseline.
Structural Integrity Monitoring	Conduct high-resolution photogrammetry of critical areas.	Biannual	Chemical-physical degradation index (CPI)	> 10% variation in geometry, crack formation, or surface instability vs. baseline.
	Apply AI-based comparison of multi-temporal 3D models to detect structural anomalies.	Biannual		
Biological Monitoring and	Deployment of LIBS sensor to assess sediment heavy metals and chemical pollutants.	Annual	Chemical-biological	> 15% increase in biofilm coverage or
	Complement LIBS with sediment sampling and lab analysis to map pollutant distributions.	Annual		

Pollutant Detection	Monitor biofouling and colonization using AI-assisted photogrammetry.	Biannual (aligned with imaging)	degradation index (CBI)	abnormal colonization.
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2.4.3 Adaptive Monitoring and Reclassification Logic

The **NERITES monitoring strategy** is inherently **iterative** and **adaptive**. Once a site has been assigned to a specific archetype and its monitoring protocol activated, data acquisition proceeds over time according to the prescribed frequency and resolution. The aim is not merely to collect observations, but to continuously assess whether the site's current condition aligns with the expected behavior associated with its archetype classification.

If the **monitored values** begin to **deviate significantly from the reference parameters** defined in the original protocol, this may indicate the onset of active degradation processes or a shift in the site's environmental context — such as altered sedimentation, pollution inflows, biological colonization, or structural destabilization. In such cases, the system must trigger an adaptive response, which may include:

1. Increased monitoring frequency or resolution;
2. Substitution or augmentation of sensor packages;
3. Re-evaluation of the site's archetype classification based on updated degradation indices;
4. Activation of mitigation or conservation actions.

Sensor deployment and **data interpretation** are therefore governed by a **feedback-based decision logic**, rather than manually defined mission cycles. This ensures that monitoring activities remain coherent with the initial classification while also capable of responding to dynamic environmental or material changes. The thresholds and indices defined in D2.3 provide the quantitative criteria used to detect deviation from archetype norms.

This logic guarantees:

1. Comparability across sites, as protocols are archetype-bound;
2. Repeatability of observation, through standardized frequency and indicator sets;
3. Scalability, by decoupling mission planning from individual operator decisions;
4. Responsiveness, through automated reclassification triggers and threshold-based alerts.

The evaluation cycle aligns with the broader degradation assessment framework introduced in Section 5.4 of D2.3, in which multi-temporal datasets are fused to produce an updated condition assessment. If necessary, this leads to the re-assignment of the site to a new archetype, which in turn activates a revised monitoring protocol.

The following diagram (Figure 2) illustrates the full feedback loop between classification, monitoring, evaluation, and reclassification:

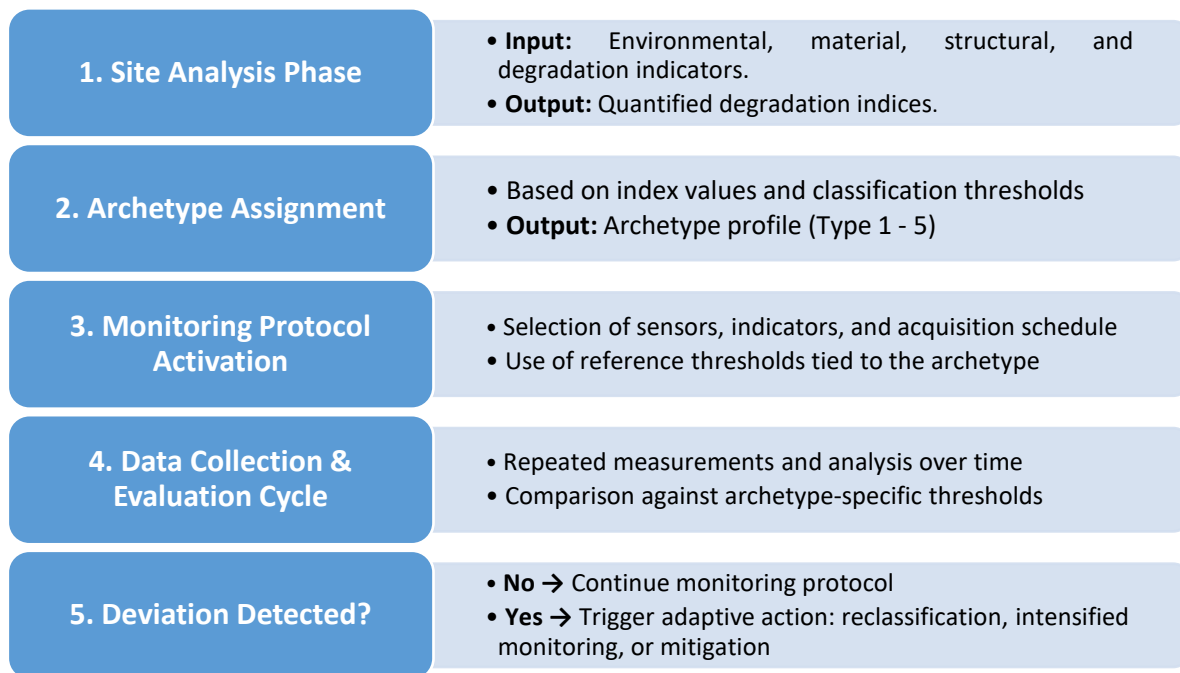


Figure 2. Archetype-Driven Monitoring Workflow in NERITES

2.4.4 Sensor Deployment and Data Acquisition Strategy

The effective implementation of the NERITES monitoring protocols relies on the proper configuration, deployment, and management of a modular sensor suite integrated on a single operational platform: the NERITES Autonomous Underwater Vehicle (AUV). This AUV serves as the technological backbone for all in-situ data acquisition activities and supports the full range of degradation indicators defined in the project's assessment framework.

1. Sensor Suite and Indicator Mapping

As described in D2.3, the NERITES AUV is designed to accommodate a heterogeneous array of sensors, each mapped to specific degradation indices.

- **LIBS (Laser-Induced Breakdown Spectroscopy).** Detects heavy metal presence and elemental signatures in sediments and material surfaces.
- **QCL (Quantum Cascade Laser).** Measures dissolved contaminants such as nitrates, phosphates, in water column.
- **Multiparametric probe.** Provides real-time data on pH, redox potential, temperature, salinity, and dissolved oxygen — core variables for general site characterization.
Note. This sensor may be installed on board the AUV or alternatively deployed as a fixed installation near the site, depending on operational requirements and site accessibility.
- **High-resolution photogrammetry and AI-enhanced imaging system:** Supports 3D reconstruction, surface and shape comparison, and detection of biological colonization patterns.

Sensor selection and configuration are driven directly by the archetype classification and the degradation indicators prioritized within each site's monitoring protocol.

2. Mission Configuration and Execution

All monitoring operations are executed via autonomous AUV missions. As detailed in D2.3, the AUV is programmed to follow a predefined sensing trajectory aligned with the spatial layout and degradation

profile of the site. These missions can include grid-based surveys, linear transects, or localized hovering over critical features.

Before deployment, the mission parameters are configured in the mission planning module:

- **Navigation path** (based on bathymetry and site targets),
- **Sensor activation schedule** (timing, frequency, and resolution),
- **Depth layers and sampling intervals** (as needed for vertical gradients),
- **Environmental constraints**, such as visibility or current thresholds.

The AUV is also equipped with internal navigation (e.g., DVL, inertial unit) and positioning tools to ensure precise geolocation and orientation of sensor data.

3. Data Acquisition and Pre-Processing Workflow

During operation, the AUV autonomously collects synchronized data streams from all onboard sensors. Upon mission completion, raw datasets are retrieved and processed through a standardized workflow:

- **Noise filtering** and drift correction for each sensor channel;
- **Timestamp alignment** across sensor modalities;
- **Geo-referencing** of visual and chemical data using integrated navigation logs;
- **Metadata enrichment** using mission profiles, environmental context, and sensor configuration parameters.

This workflow ensures that the data are not only reliable for single-mission assessments but also consistent across repeated deployments, allowing for multi-temporal monitoring and degradation trend analysis.

4. Interoperability and Data Harmonization

All sensor data are formatted and structured to comply with a common metadata schema and harmonization logic. This allows seamless integration of datasets across sites and missions and supports long-term preservation assessment.

Each dataset is tagged with:

- Site and mission identifiers;
- Archetype classification at the time of monitoring;
- Sensor settings and calibration information;
- Environmental conditions during deployment.

This interoperability framework ensures comparability and reusability of data across the entire NERITES system and supports future aggregation into centralized repositories or dashboards.

5. Operational Considerations and Quality Assurance

While the NERITES monitoring system is designed for autonomy and repeatability, site-specific conditions may require minor adjustments to planned missions (e.g., reduced coverage due to turbidity). In such cases, fallback logic is applied, ensuring that critical indicators are prioritized and the minimum dataset required for degradation assessment is collected.

To support robustness, each mission includes:

- Built-in redundancy in sensor readings (e.g., overlapping scans);
- Pre- and post-mission calibration checks;

- Logging of anomalies or technical issues for data validation.

This single-platform strategy simplifies the logistics of deployment while maintaining a high degree of methodological rigor and technical flexibility, making it suitable for the varied environmental and material conditions encountered at UCH sites.

2.5 Risk Assessment and Decision-Making Tools

The final phase of the NERITES monitoring workflow consists of a structured interpretation process aimed at translating raw sensor outputs and index calculations into risk-informed, actionable conservation decisions. This risk assessment phase is fully integrated within the monitoring protocol logic and reflects the project's emphasis on **site-specific**, **index-based**, and **archetype-driven** evaluation.

Within the NERITES framework, risk is not assessed in absolute or generic terms but **contextualized** through the degradation profiles associated with each UCH archetype. Each monitoring protocol specifies the key degradation indices relevant to the archetype, along with corresponding thresholds that define the expected variability under normal conditions. The three main indices—**Environmental Index (EI)**, **Chemical-Physical Index (CPI)**, and **Chemical-Biological Index (CBI)**—are derived from multi-sensor observations and used to diagnose the condition of the monitored site.

Importantly, while the risk assessment structure is fully defined in this deliverable, it is intended as a **pre-operational decision-support tool**. Its full validation requires multi-seasonal monitoring campaigns and sustained data acquisition, which fall outside the scope and timeline of this project. Within the duration of NERITES, only a subset of its logic will be tested using controlled field demonstrations and simulation-based performance analyses.

The decision logic described in this section is designed to be **semi-automated** and compatible with the autonomy components of the NERITES system (e.g., mission planning, sensor activation, adaptive monitoring frequency). However, in the current phase of the project, these features will be demonstrated in pilot scenarios and reviewed using **expert-in-the-loop interpretations**.

In the final project phase, results from field testing and pilot missions will be used to refine the thresholds, enhance scoring accuracy, and better define the interface between risk levels and actionable recommendations. These updates will be consolidated in Deliverable 6.4b, providing a robust foundation for future deployment and institutional adoption.

2.5.1 Index Interpretation and Risk Zones

The degradation indices are normalized on a 0 to 1 scale, where **higher values indicate lower degradation** and **values approaching 0 correspond to critical degradation conditions**. The risk model divides this scale into five classes for each index, based on scientific literature, empirical reference data, and expert-defined thresholds. These classes provide a diagnostic overview of the current state of the site and guide the urgency of response (Tables 4, 5 and 6).

Table 4. Chemical-Physical Index (CPI) Risk Classification

CPI Range	Condition Tier	Interpretation	Recommended Action
0.90 – 1.00	Minimal Stress	Structural integrity is excellent; no visible physical degradation.	Continue standard monitoring

0.70 – 0.90	Minor Degradation	Early-stage fractures or erosion detected.	Monitor for trend evolution; retain current frequency.
0.50 – 0.70	Moderate Degradation	Observable material loss; risk of structural destabilization.	Intensify monitoring; assess need for mitigation.
0.30 – 0.50	Severe Degradation	Advanced structural weakening; high risk of collapse	Trigger stabilization measures and engineering review
0.00 – 0.30	Critical/Collapsing	Catastrophic degradation or active collapse.	Initiate immediate intervention and site protection.

Table 5. Environmental Index (EI) Risk Classification

EI Range	Condition Tier	Interpretation	Recommended Action
0.90 – 1.00	Optimal Conditions	Environmental variables are stable; low-stress habitat.	Continue standard seasonal monitoring.
0.70 – 0.90	Low Environmental Stress	Minor fluctuations in chemical-physical parameters; no significant threats.	Monitor for evolving changes; validate indicator drift.
0.50 – 0.70	Moderate Stress	Environment is deviating from baseline; increased chemical or physical stress.	Raise monitoring frequency; evaluate pollutant sources.
0.30 – 0.50	High Stress	Unfavorable environmental parameters (e.g., acidification, low oxygen).	Deploy mitigation and protective measures.
0.00 – 0.30	Critical Instability	Environmental collapse conditions; immediate danger to UCH materials.	Immediate conservation alert; consider emergency plans.

Table 6. Chemical-Biological Index (CBI) Risk Classification

CBI Range	Condition Tier	Interpretation	Recommended Action
0.90 – 1.00	Minimal Biological Impact	Clean surfaces; no colonization or encrustation detected.	Retain biannual survey cycle
0.70 – 0.90	Early Colonization	Biofilm present; low to moderate biological activity.	Increase visual documentation; no action needed.
0.50 – 0.70	Moderate Colonization	Colonization visible (e.g., algae, sponges); structural impact possible.	Monitor and consider localized cleaning.

0.30 – 0.50	Extensive Colonization	Heavy encrustation or boring fauna; measurable loss of material.	Biological removal and protective measures required.
0.00 – 0.30	Biological Criticality	Active degradation by bio-organisms; functional collapse likely.	Emergency response and full site reassessment.

2.5.2 Multi-Index Integration and Decision Matrix

Each index provides a distinct perspective on site degradation. Risk assessment is based on their **combined interpretation**, along with temporal trends and context factors (e.g., exposure, material, prior stress history). To synthesize the multi-index readings into a single operational outcome, NERITES employs a decision matrix combining **condition severity** and **response urgency** (table 7).

Table 7. Decision Matrix for risk assessment

Condition Severity	Response Urgency	Risk Level	Recommended Action
Low	Low	Stable	Continue standard protocol
Moderate	High	Emerging Risk	Raise monitoring frequency; validate thresholds
High	Low	Latent Risk	Plan intervention; initiate technical review
High	High	Critical	Activate conservation alert; reclassify site

The **condition severity** is assessed by comparing each index against its defined zones. **Urgency** is based on:

- 1. Rate of change between monitoring cycles;**
- 2. Site importance and vulnerability;**
- 3. Accessibility for intervention.**

2.5.3 Action Triggers and Protocol Adjustment

Based on risk classification, the system triggers operational responses. These may include:

- **Continue Monitoring.** All indices within stable range or showing non-critical deviation.
- **Increase Monitoring Frequency.** Trend indicates deterioration, though current state is not yet critical.
- **Trigger Conservation Assessment.** Indices indicate structural, chemical, or biological thresholds have been exceeded.
- **Reclassify Site.** Sustained deviation incompatible with current archetype; protocol must be updated.

These decisions feed directly into the adaptive monitoring cycle described in Section 2.4.3.

2.5.4 Toward Automation and Decision Support Systems

The NERITES risk logic has been designed to be integrated into the AUV mission control system and the centralized monitoring platform. By embedding threshold definitions, temporal scoring, and archetype rules, the system is capable of:

- Automatically detecting index anomalies;
- Generating alerts for conservation staff;
- Recommending protocol adjustments based on trend evolution;
- Supporting transparent reporting for heritage managers and policymakers.

This progression toward **semi-automated decision support** ensures that the NERITES framework remains operationally efficient, scientifically sound, and adaptable to long-term site management needs.

3 Preliminary UCH Preservation Assessment Protocol

3.1 Scope and Concept

The **Preliminary UCH Preservation Assessment Protocol** defined in this section represents the first version of a standardized method for evaluating the effectiveness of the NERITES technological solutions in preserving UCH assets. It will be **partially demonstrated** during the project lifetime and **finalized in Deliverable 6.4b**. While the monitoring guidelines presented in Section 2 focus on detecting, quantifying, and interpreting degradation phenomena, this protocol introduces a complementary layer: a structured **assessment of preservation outcomes**.

The protocol is intended to provide a **consistent** and **repeatable methodology** that goes beyond degradation monitoring, offering a means to assess whether the application of NERITES tools and workflows contributes to the **mitigation, stabilization, or slowing** of degradation processes at UCH sites. In this respect, it serves both as a **validation framework** for the system itself and as a **decision-support tool** for cultural heritage managers and policymakers.

This first iteration of the protocol is conceptual and methodological in nature. It is designed to:

- **Frame the assessment logic** to be applied at the end of each monitoring cycle;
- **Define core indicators** related to preservation performance and monitoring system efficacy;
- **Support cross-site comparisons** using a standardized scoring methodology;
- **Enable adaptive updates** to mission planning and site classification based on outcome trends.

By focusing on **preservation-oriented assessment**, the protocol complements the **detection-oriented logic** of the risk model described in Section 2.5. Together, these components form a feedback-driven system in which observed site conditions inform not only conservation risk but also the performance and impact of the monitoring process itself.

The preservation protocol also aims to ensure **scalability and interoperability** across different UCH archetypes, site typologies, and stakeholder contexts. It has been structured to operate within the archetype-based monitoring framework defined in D2.3 and aligns with the three-pillar logic of classification, sensing, and adaptive mission planning.

In this preliminary version, the protocol is based on simulated scenarios and methodological synthesis derived from the NERITES framework. In the next phases of the project, it will be **field-tested, validated, and refined** through WP5 implementation activities and user feedback. The final version will be released in **Deliverable 6.4b**, incorporating empirical performance data, expert reviews, and updates for regulatory and policy alignment.

3.2 Indicators and Evaluation Metrics

The NERITES Preservation Assessment Protocol relies on a structured set of indicators to evaluate the impact of monitoring activities on the long-term conservation of UCH sites. These indicators fall into two main categories:

1. **Preservation Condition Indicators**, which reflect the current conservation status of the site;
2. **Monitoring Performance Indicators**, which evaluate the effectiveness of the NERITES system in enabling timely, precise, and meaningful conservation decisions.

Each indicator is derived from the sensor-based measurements and degradation indices discussed in Section 2, and interpreted through an archetype-specific logic. This dual-level assessment allows both **the state of preservation** and the **efficacy of the monitoring protocol** to be systematically evaluated.

3.2.1 Preservation Condition Indicators

Preservation condition indicators are used to assess whether the monitored site is maintaining its structural, chemical, and biological stability over time. These indicators are primarily based on the **three degradation indices**:

- **Environmental Index (EI)**
- **Chemical-Physical Index (CPI)**
- **Chemical-Biological Index (CBI)**

Each index is interpreted using the zone classification tables provided in Section 2.5, enabling the classification of the site into one of five preservation tiers: **pristine**, **stable**, **vulnerable**, **critical**, or **collapsing**. The core idea is to track the **stability or change** of each index across monitoring cycles and determine whether conservation efforts are effectively maintaining the site within the expected archetype behavior.

Additional preservation condition indicators may include:

- **Index delta (Δ)**. Change in index values between monitoring cycles (e.g., $\Delta\text{CPI} = \text{CPI}_t - \text{CPI}_{t-1}$);
- **Multi-index convergence**. Degree to which all indices move in the same degradation direction;
- **Preservation trajectory**. Site's long-term trend toward stabilization or decline.

These indicators help answer the question:

“Is the site being preserved as expected under the assigned monitoring protocol?”

3.2.2 Monitoring Performance Indicators

In addition to evaluating the site condition, the protocol introduces performance indicators to assess how well the NERITES system itself is operating as a preservation support tool. These include:

1. **Detection Responsiveness (DR)**. Time elapsed between the onset of degradation (as inferred from index thresholds) and the system's first alert or response.
2. **Reclassification Accuracy (RA)**. Degree to which changes in site condition correctly trigger archetype reassignment, minimizing false negatives and false positives.
3. **Sensor Effectiveness (SE)**. Percentage of planned data points successfully acquired and usable for index calculation.
4. **Protocol Consistency (PC)**. Degree to which monitoring actions match predefined protocol steps for the given archetype.
5. **Trend Recognition Fidelity (TRF)**. Ability of the system to detect early warning signals based on small, persistent shifts in indices.

Each of these metrics is calculated per mission and then aggregated across multiple cycles to evaluate overall system reliability and performance. Poor performance on any of these indicators may suggest the need to revise the mission logic, reconfigure sensors, or improve data interpretation tools.

However, due to the inherently slow and long-term nature of many UCH degradation processes, the accurate calculation and validation of these performance indicators—particularly those related to responsiveness and trend detection—require multi-annual data acquisition campaigns that extend beyond the timeframe of the NERITES project. As such, the current implementation provides a conceptual foundation and early-stage validation strategy that will need to be further developed and monitored in subsequent operational cycles.

3.3 Preliminary Protocol Application Logic

The implementation of the Preliminary Preservation Assessment Protocol is designed to follow the operational logic established in the NERITES monitoring framework. It serves as a structured overlay to the degradation monitoring workflow, focusing on how the outcomes of each monitoring cycle can be interpreted to support preservation-oriented decision-making.

Rather than functioning as a standalone process, the protocol is **tightly integrated** with the archetype-based classification and indicator logic described in Section 2. The logic of application is cyclical and modular, enabling it to adapt to different site types, sensor availability, and mission contexts.

Step-by-Step Application Logic

1. Initial Site Classification and Baseline Setting

Upon the first deployment, the site is classified according to the NERITES archetype logic (based on physical, environmental, and material indices). A baseline dataset is acquired using the full suite of available sensors (e.g., LIBS, QCL, multiparametric probe, photogrammetry), establishing reference values for all degradation indicators.

2. Monitoring Cycle Execution

A monitoring protocol specific to the site's archetype is activated. Each sensor records targeted parameters at defined temporal intervals (e.g., seasonal for QCL, annual for LIBS). Data are pre-processed, harmonized, and analyzed to update the three core indices: EI, CPI, and CBI.

3. Condition Assessment

The computed indices are compared to the reference values and degradation thresholds defined for that archetype (see Section 2.5). Deviations are assessed in terms of:

- Magnitude of change (Δ Index);
- Deviation from stable range;
- Persistence across cycles.

If all indices remain within expected variability, the site is considered stable, and the protocol is reaffirmed.

4. Preservation Impact Interpretation

In addition to evaluating degradation, the protocol interprets whether current monitoring efforts are contributing to the **stabilization** or **slowing** of degradation. This is assessed through:

- Reduction in index volatility;
- Improved early detection responsiveness;
- Successful validation of threshold logic (no false positives/negatives);
- Consistency with predicted degradation patterns for the archetype.

5. Adaptation or Escalation

If one or more indicators cross predefined thresholds (e.g., drop in CPI, rise in pollutant levels), or if the monitoring performance indicators flag a deviation, the following may be triggered:

- **Increased monitoring frequency;**
- **Sensor recalibration** or reconfiguration;
- **Re-assignment of site archetype;**

- **Initiation of conservation assessment** (e.g., external expert review, field intervention).

6. Documentation and Feedback Loop

At the end of each monitoring cycle, the following outputs are compiled:

- Updated index values and condition status;
- Interpretation of preservation trends;
- Monitoring performance indicators;
- Any deviation flags and protocol adjustment actions.

These records are stored in a standardized log to support multi-year tracking.

During the pilot deployments in Baiae and Fournoi, this logic will be used to simulate full protocol application. Although limited in time, these testbeds will allow partial execution of the above steps, especially:

- Initial classification and baseline acquisition;
- Data harmonization and index calculation;
- Preservation trend analysis over short cycles.

Findings from these pilots will guide the refinement of protocol logic, the validation of threshold assumptions, and the final design of the feedback and documentation mechanism in the full version of the protocol.

3.4 Limitations and Next-Phase Refinements

The current version of the NERITES Preservation Assessment Protocol provides an operational framework for evaluating degradation at UCH sites using structured indicators and archetype-driven logic. While the structure is conceptually mature and aligned with the goals of Task 6.4, several technical limitations exist due to the developmental status of the sensing system and the constrained duration for multi-temporal field testing. These limitations impact both the **protocol's assessment robustness** and its **operational readiness**.

3.4.1 Identified Technical Limitations

1. Incomplete Data Acquisition Cycles

Degradation processes in UCH sites evolve over long timescales (months to years), but NERITES will only begin technology deployment around Month 24. This results in:

- Lack of multi-temporal index series (ΔEI , ΔCPI , ΔCBI) to support trend-based classification logic.
- Absence of ground-truthing loops for sensor performance benchmarking (e.g., LIBS and QCL vs. lab validation).
- Reduced confidence in early detection or rate-of-change interpretations.

2. Non-Calibrated Index Thresholds

Thresholds for degradation severity—used in Section 2.5 for classification into stable/degraded/critical zones—are currently based on expert assumptions and legacy literature. For example:

- CPI warning levels have not yet been validated across multiple UCH substrates.
- CBI biofouling coverage thresholds are not calibrated against regional biodiversity baselines.
- EI values from QCL and LIBS lack in-situ chemical validation from pilot sites.

Without statistical validation across N sites and N missions, these values remain **indicative** and should not yet inform policy decisions or automated mission logic.

3. System Integration Gaps

Several critical components of the NERITES monitoring logic are not yet fully integrated:

- Automated reclassification logic (based on deviation from reference archetype behavior) is not implemented in the mission software stack;
- KPI-based performance logging (e.g., DR, SE, PC) is not embedded in the AUV firmware or mission interface;
- Multi-sensor data harmonization tools (time-aligned photogrammetry, LIBS, QCL) are not operationalized in a shared backend.

This results in a partially manual application of the protocol, with limited support for real-time or semi-automated assessment workflows.

4. Lack of Coverage for All Archetypes

The current protocol is tested in two pilot sites (Baiae and Fournoi), which, although diverse, do not encompass:

- Deepwater (>100 m) wrecks with strong abiotic corrosion dynamics;
- Shallow cave environments or highly dynamic sedimentary sites;
- Sites with complex hybrid materials (e.g., mixed wood-metal composites).

As a result, the protocol logic (sensor selection, frequency tuning, evaluation thresholds) may not generalize to all use-case categories defined in D2.3.

3.4.2 Planned Refinements for Deliverable 6.4b

In D6.4b, the protocol will be refined and finalized through the following actions:

1. Empirical Calibration of Index Thresholds

- Collection of controlled datasets from WP5 field missions (QCL, LIBS, 3D imaging) will be used to fit threshold models for site conditions.
- Threshold deviations will be statistically benchmarked against mission metadata (e.g., environmental conditions, material type, deployment depth).

2. KPI Operationalization and Logging

- System performance metrics (DR, RA, SE, PC, TRF) will be formally embedded into the mission execution environment.
- KPI logs will be collected via middleware running onboard the AUV or the surface control station, enabling cycle-level performance reports.

3. Enhanced Pilot-Based Validation

- Protocol steps will be tested across multiple missions per site.
- Mission reports will include deviations, delays, sensor dropout events, and feedback from field operators to evaluate robustness and usability.

4. Optional Aggregated Output Layer (if feasible)

- A simplified scoring or condition-rating tool may be introduced for field use.

- This may include color-coded status labels (e.g., GREEN–YELLOW–RED) for rapid on-site interpretation by cultural heritage managers or marine archaeologists.

4 Policy and Standardization Considerations

The implementation of the NERITES monitoring framework and Preservation Assessment Protocol is accompanied by a clear strategy for institutional alignment and long-term sustainability. While the system is primarily technical in nature, its effectiveness ultimately depends on its ability to operate within — and contribute to — existing policy, regulatory, and heritage management frameworks at the European and international levels.

This section outlines the policy landscape relevant to UCH preservation and situates the NERITES approach within current regulatory structures. It identifies opportunities for alignment with the 2001 UNESCO Convention, EU environmental and cultural heritage directives, and national heritage governance frameworks. It also explores how the technical outputs of the project — including the degradation indices, monitoring protocols, and risk assessment models — can be potentially translated into tools and recommendations that support policy-making, standardization, and institutional uptake.

In addition, this section defines a roadmap for structured stakeholder engagement, with the objective of ensuring that the NERITES results are not only scientifically robust but also actionable and visible within the operational domain of cultural heritage authorities, funding bodies, and regulatory institutions.

4.1 Regulatory Landscape and Alignment Opportunities

The long-term success of the NERITES system depends not only on its technical performance but also on its compatibility with existing legal and governance frameworks for UCH. As part of Task 6.4, this section assesses the current regulatory landscape in Europe and internationally, identifying areas where the NERITES approach can provide added value, and highlighting opportunities for alignment with policy and standardization mechanisms.

UNESCO Regulations and Guidelines

The **2001 UNESCO Convention on the Protection of the Underwater Cultural Heritage** remains the principal international legal framework governing UCH. It outlines four foundational principles:

- **Preservation in situ** as the preferred approach;
- **Prohibition of commercial exploitation** of UCH;
- **International cooperation** in heritage protection;
- **Application of scientific and non-destructive methodologies** in all interventions.

While the Convention provides a robust legal basis for UCH preservation, it suffers from **non-uniform adoption across EU member states**. Several countries, including the UK and some Scandinavian states, have not ratified the Convention, citing conflicts with existing maritime law. This results in **inconsistent implementation** and leaves some UCH sites legally vulnerable.

To support operationalization, UNESCO has published **technical** and **ethical guidelines**, emphasizing responsible site management, community engagement, and the use of non-invasive technologies — a principle strongly reflected in the NERITES system design.

EU Directives and Legal Frameworks

While the EU does not yet have a directive specifically dedicated to UCH, multiple existing legal instruments contribute to its protection:

- **Directive 2014/89/EU** (Maritime Spatial Planning). Encourages sustainable use of maritime spaces, including heritage protection.

- **Directive 2011/92/EU**, amended by **2014/52/EU** (Environmental Impact Assessment). Requires cultural heritage impacts to be assessed for underwater and coastal development projects
- **Council of Europe's Valletta Convention (1992)**. Provides a transnational legal framework for the protection of archaeological heritage, including submerged sites.
- **EU Blue Growth Strategy**. While focused on economic development (e.g., aquaculture, offshore wind), it recognizes the need to preserve UCH as part of Europe's maritime identity.

Despite the presence of these instruments, variations in national implementation, lack of enforcement mechanisms, and conflicts with commercial activities (e.g., offshore energy, dredging) reduce their effectiveness in practice.

Future Directions

European and UNESCO regulations provide a **solid framework for the protection of UCH**, yet persistent challenges in enforcement and cross-border coordination limit their effectiveness. Addressing these gaps requires stronger international collaboration, sustained investment in scientific research, and greater engagement of policymakers and the public in preservation efforts.

Among the **key priorities** are the **EU-wide ratification** of the **2001 UNESCO Convention**, stronger enforcement against **looting** and **illicit trade**, and the development of **climate-resilient conservation strategies**. Integrating UCH into broader maritime governance policies is equally essential to ensure that heritage protection aligns with sustainability and spatial planning objectives.

The **NERITES project** directly contributes to these goals by **bridging technological innovation** with **heritage policy needs**. Its non-invasive monitoring system is fully aligned with the principles of in situ preservation and scientific best practices promoted by UNESCO. Through structured, archetype-based protocols, NERITES transforms general conservation principles into repeatable and operational procedures that support evidence-based site management.

In the European context, **NERITES offers practical tools** to support the implementation of **existing directives**. Its capacity to generate spatially explicit degradation indices and risk models can inform heritage-sensitive decision-making under the **Maritime Spatial Planning Directive (2014/89/EU)** and complement **Environmental Impact Assessments (2011/92/EU)**. The framework's modularity and scalability make it suitable for integration into national heritage systems, promoting consistency in monitoring across diverse marine environments.

Furthermore, the **system's sensitivity to environmental parameters and biological activity** positions it as a valuable tool for anticipating the impacts of **climate change and human activity** on submerged cultural assets. In this way, **NERITES supports** the ambitions of the **EU Blue Growth Strategy**, contributing to a balanced approach between marine development and heritage preservation.

4.2 Guidelines for Policy Integration

The impact of the NERITES system will ultimately depend not only on its technical innovation but also on its ability to interface effectively with policy mechanisms, regulatory mandates, and institutional workflows governing UCH. To ensure that the outputs of the system contribute to long-term heritage protection strategies, this section defines a **roadmap** for the integration of **NERITES methodologies** into existing and emerging **policy environments** at both the European and international levels.

A central objective of Task 6.4 is to ensure that the monitoring results, risk models, and degradation indicators generated by NERITES are not isolated technical products, but are operationally relevant and translatable into formats that support governance, conservation planning, and resource allocation. This requires alignment with legal standards, metadata conventions, and decision-making frameworks currently in use across national and EU agencies.

To facilitate this integration, the **project envisions three complementary pathways: strategic policy communication, adherence to interoperability standards, and iterative stakeholder engagement.**

1. Policy Briefs and Strategic Recommendations

NERITES will generate targeted policy briefs that distill the system's scientific contributions and operational relevance into actionable insights for policymakers. These briefs will serve as concise, high-level instruments aimed at institutions such as the European Commission (DG RTD, DG MARE, DG CULTURE), national ministries of culture and environment, and intergovernmental organizations like UNESCO and ICOMOS.

Each document will:

- Summarize the monitoring logic, degradation indicators, and preservation assessment methodologies developed within the project;
- Articulate the policy relevance of early degradation detection for preventive conservation;
- Recommend specific governance measures — such as integrating degradation monitoring into national heritage registries or mandating remote sensing baselines for vulnerable sites.

2. Standardization and Interoperability Protocols

To maximize the potential for institutional uptake and technical integration, NERITES will assess the feasibility of aligning its outputs with widely recognized data and documentation standards. The structuring of sensor data, degradation indices, and condition reports will be evaluated for compatibility with **interoperability frameworks such as CIDOC CRM** (for cultural heritage documentation and knowledge modeling), **ISO 19115, INSPIRE-compliant metadata schemas** (for geospatial datasets), and **SensorML / OGC SWE standards** (for real-time environmental sensor data).

This assessment will inform the extent to which NERITES data products can be formatted for **future integration** with **EU-level platforms** such as **EMODnet, Copernicus Marine Service, and national Spatial Data Infrastructures (SDIs)**. By exploring these compatibility pathways, the project aims to support the aggregation and cross-site comparison of UCH condition data at regional and continental scales, while laying the groundwork for integration into marine spatial planning, environmental impact assessment, and long-term heritage monitoring programs.

3. Institutional Co-Design and Uptake Strategy

A defining aspect of the NERITES approach is its iterative interaction with heritage practitioners and institutional stakeholders. Throughout the project, user engagement will be pursued through:

- Technical demonstrations of the monitoring platform at pilot sites;
- Scenario-based workshops with cultural heritage authorities and archaeological agencies;
- Collaborative development of monitoring templates and evaluation dashboards tailored to user needs.

This co-design approach ensures that the Preservation Assessment Protocol is grounded in real-world workflows and that users contribute directly to shaping both the format and content of outputs.

Feedback from these engagements will be used to adapt terminology, revise protocol complexity, and align evaluation logic with institutional reporting practices.

The culmination of these efforts in the final phase of the project will include:

- The delivery of the finalized NERITES Preservation Assessment Protocol (Deliverable 6.4b);
- A compendium of tested policy use cases and implementation guidelines;
- Strategic positioning of the project outcomes within the EU heritage innovation agenda and national digital heritage strategies.

4.3 Stakeholder Engagement Strategy

The successful integration of NERITES technologies and methodologies into policy and operational practice requires structured engagement with key stakeholders throughout the project lifecycle. This engagement ensures that the outputs of the project are not only scientifically and technically robust but also meet the practical needs and institutional constraints of those responsible for the preservation, regulation, and governance of UCH.

The stakeholder engagement strategy within Task 6.4 is built on three objectives: **(1) identify and map relevant institutional actors and networks; (2) create structured opportunities for dialogue, co-design, and validation; and (3) facilitate long-term uptake through the demonstration of operational relevance and added value.**

4.3.1 Key Institutional Actors

NERITES targets a diverse set of stakeholders spanning different levels of governance and expertise. These include:

1. European Commission Directorates-General:

- **DG RTD.** Oversees Horizon Europe and research policy. A key actor for evaluating the innovation outcomes and policy recommendations from NERITES.
- **DG MARE.** Responsible for marine spatial planning and the Blue Economy. Relevant for integrating UCH monitoring into broader marine governance frameworks.
- **DG CULTURE** (within DG EAC). Focuses on cultural heritage policies, including support for the implementation of the UNESCO 2001 Convention. A primary interlocutor for cultural heritage alignment.

2. UNESCO and ICOMOS. International reference institutions for cultural heritage conservation and policy development. Their engagement is crucial for ensuring the international relevance and ethical alignment of the NERITES preservation protocol.

3. National and Regional Authorities. Ministries of Culture, Environment, and Maritime Affairs across EU member states are responsible for implementing heritage monitoring and regulatory compliance. These actors will be engaged through national roundtables and feedback sessions.

4. Heritage Protection Agencies and Archaeological Services. Including national superintendencies, underwater archaeology units, and UCH management authorities that are involved in real-world deployment, validation, and long-term stewardship.

5. Scientific and Conservation NGOs. Organizations such as the Nautical Archaeology Society and the European Institute for Underwater Archaeology, which serve as multipliers for good practices and public engagement.

4.3.2 Engagement Formats

To effectively reach these stakeholders, NERITES partners will adopt a multi-format engagement strategy, to be implemented during and beyond the project's duration. Planned activities will include:

- **Scenario-Based Workshops.** Hands-on sessions with end users, held at pilot sites, to test and refine the monitoring protocol and decision-support tools. These workshops will demonstrate real-world applicability and solicit expert feedback.
- **Policy Roundtables and Strategic Dialogues.** These events will convene policymakers, researchers, and heritage professionals to exchange perspectives and co-develop recommendations for institutional integration.
- **Technical Demonstrations.** Field trials of the AUV-based monitoring platform and remote sensing workflows will be shared with regulators and practitioners to illustrate the system's capabilities and ease of use.
- **Inter-Project and Cross-Sectoral Collaboration.** Coordination with other EU-funded projects and international initiatives will support knowledge transfer, tool reuse, and mutual validation.
- **Digital Communication and Dissemination.** Stakeholder engagement will be reinforced through online channels, including webinars, technical briefs, white papers, and interactive tools made available via the project's website and EU dissemination platforms.

These engagement formats are designed not only to inform but to involve stakeholders in the co-development and validation of NERITES methodologies, ensuring their long-term usability and policy relevance.

5 Conclusion

This deliverable presents the preliminary version of the NERITES Utilization Guidelines and the UCH Preservation Assessment Protocol, developed in accordance with the objectives of Task 6.4. It translates the theoretical framework introduced in Deliverable D2.3 into an operational structure for degradation monitoring, site classification, and preservation evaluation, establishing the foundation for the full deployment of the NERITES system in real-world UCH contexts.

The document has outlined the rationale and implementation logic for monitoring activities that are archetype-driven, indicator-based, and designed to support long-term, repeatable observation of degradation phenomena. A preliminary assessment protocol has been introduced to evaluate whether the use of NERITES technologies contributes to the stabilization or improvement of site conditions, with a dual focus on conservation impact and technical monitoring performance.

Additionally, this deliverable situates the NERITES methodology within the broader regulatory and policy landscape, identifying pathways for standardization, stakeholder engagement, and institutional uptake. Strategies have been proposed to ensure that the guidelines and assessment protocol are not only scientifically robust but also actionable and aligned with current EU and UNESCO policy frameworks.

As this is an interim document, several limitations have been acknowledged — primarily the need for field validation, user feedback, and empirical calibration. The roadmap presented in Chapter 4 describes how these limitations will be progressively addressed in the second phase of the project through WP5 deployments, iterative testing, and stakeholder engagement. Deliverable 6.4b will consolidate the insights gained from these activities into a technically grounded and field-informed version of the preservation assessment protocol. While this will not yet represent full integration into institutional or regulatory frameworks, it will enable a first critical evaluation of the protocol's strengths and limitations, with the aim of supporting future alignment with operational practices and policy instruments.

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