PLANAPP Centro de Planeamento e de Avaliação de Políticas Públicas
Em parceria com: fct Fundação para a Ciência e a Tecnologia
PRR Plano de Recuperação e Resiliência | REPÚBLICA PORTUGUESA | Financiado pela União Europeia NextGenerationEU

POLICY BRIEF 2026

SCIENCE4POLICY
CONCURSO DE ESTUDOS DE CIÊNCIA PARA AS POLÍTICAS PÚBLICAS

Freshwater/saltwater: archaeological heritage at risk, in a changing climate

Diniz, Mariana; Freitas, Mª.Conceição; Carvalho, Daniel, Almeida, Rui; Capelo, Jorge; Carvalho, Rosário; Carvalho, Palmira; Costa, Ana; Freitas, Joana; Garcia, César; Neves, César; Viegas, Catarina

Centro de Arqueologia da Faculdade de Letras da Universidade de Lisboa - UNIARQ

Executive Summary

In the face of the environmental risks that Archaeological Heritage is encountering, exacerbated within the context of climate change and extreme weather events, the Freshwater/Saltwater project has selected two case studies: the site of Vila Nova de São Pedro (VNSP) (Azambuja), occupied throughout the 3rd millennium BC, and the site of Loulé Velho (LV) (Loulé), occupied during the Roman period, whose architectural structures are respectively exposed to the impacts of invasive native vegetation and rainwater, and to the aggravated phenomena of coastal erosion. The fieldwork, carried out by a multidisciplinary team, concludes that the limestone walls of VNSP are severely threatened by shrub-type vegetation and that, despite the air quality – demonstrated by the variety of lichens on site – the degradation of the structures by the effect of rainfall is visible. At LV, the rapid advance of seawater threatens the structures that still remain at the site, which are at risk of total disappearance.

Recommendations

- Periodic monitoring of the sites, with control (physical and chemical) of vegetation;
- Conservation/restoration actions on the stone architectural structures at risk of erosion;
- Monitoring of the evolution of the coastline at Loulé Velho;
- Protection actions for the ruins of Loulé Velho.

Target Audience of the policy brief

Ministries, namely Culture – PC, IP, Economy and Territorial Cohesion, Education, Science and Innovation – Secretariat of State for Science and Innovation; Coordinating Commissions for Regional Development (CCDR Lisbon and Tagus Valley; CCDR Algarve), Azambuja City Council and Loulé City Council and their respective Parish Councils.

© PLANAPP-S4P-PB/8047/2025/ENG

Introduction and Problem Framework

The aim of this project is to monitor, at archaeological sites, the impact of ongoing climate change, in particular that caused by the effects of rainwater and seawater, obtaining multidisciplinary information that will make it possible to anticipate future scenarios and risks, contributing to the definition of the best policies for minimising impacts on heritage. FRESHWATER/SALTWATER – HERITAGE AND CLIMATE RISK, under the responsibility of Mariana Diniz and Maria Conceição Freitas of the University of Lisbon, has selected two

case studies: the site of Vila Nova de São Pedro (VNSP) (Azambuja), occupied throughout the 3rd millennium BC, and the site of Loulé Velho (LV) (Loulé), occupied during the Roman period, whose architectural structures are exposed to the impacts of invasive native vegetation and rainwater, and to the aggravated phenomena of coastal erosion.

The two selected case studies – the Chalcolithic settlement of Vila Nova de São Pedro (Azambuja), a national monument since 1971, and the Roman site of Loulé Velho (Loulé) – with their different geographical locations, function as privileged observation points and testing laboratories for safeguard protocols for threatened sites. Freshwater, saltwater: archaeological heritage at risk in a changing climate thus presents itself as a multidisciplinary project that combines archaeologists, geologists and biologists, with a shared agenda in the pursuit of scientific knowledge that will make it possible to face the immense challenges that climate change poses to archaeological sites. On the basis of an overall methodology that involves fieldwork, laboratory work and archival research, a diagnosis is constructed of the immediate risks and those that, as a consequence of climate change, hang over the sites in the short and medium term, namely acid rain, uncontrolled growth of invasive vegetation and the advance of seawater, and preventive measures are proposed in a best-practice dossier to be made available to the Administration.

The fieldwork, carried out by a multidisciplinary team, concludes that the limestone walls of VNSP are severely threatened by shrub-type vegetation and that, despite the air quality – demonstrated by the variety of lichens on site – the degradation of the structures by the effect of rainfall is visible, although the quality of the rainwater collected in the karst system on which the site is situated is acceptable. At LV, the rapid advance of seawater, caused by the imbalance of the coastal strip introduced by the construction of the groynes, threatens the integrity of the site, which is at risk of total disappearance.

Analysis / Key Findings

Within the framework of the project, the following actions were carried out with the aim of producing a risk diagnosis at the sites through:

- archival work, with an inventory of written and iconographic documentation (maps, photographs), recording changes in the coastline at LV and transformations of the landscape at VNSP.

- collection and analysis of the chemical composition of rainwater and the water table underlying the VNSP site; initial identification of the types of lichens present; inventory and characterisation of the plant species present; selection of areas for geoarchaeological coring to reconstruct environmental evolution and anthropogenic impact on the territory.

- the construction of algorithms and exploratory data analyses for the archaeological sites of VNSP for endemic vegetation and LV for changes in the coastline.

The main results of this project are:

1. Analysis and recognition of the evolution of vegetation at VNSP and mitigation of its growth.

At Vila Nova de São Pedro, a settlement occupied throughout the 3rd millennium BC, situated in a limestone region on a tributary of the right bank of the Lower Tagus, the assessment of the dissolving character of freshwater (precipitation, runoff and groundwater) on the architectural structures built of limestone and mortar was one of the core objectives of the project, through the collection and laboratory analysis of precipitation, runoff and groundwater from the aquifer developed in the karst system on which the site is situated.

At the same time, the characterisation of the dynamics of the surrounding landscape and of the extent, over the Longue Durée, of anthropogenic impact, through deforestation, agricultural activity, and more recent rural abandonment, justifies the carrying out of geoarchaeological test pits and the obtaining of

© PLANAPP-S4P-PB/8047/2025/ENG

long sediment cores in the valley of the Ribeira de Almoster, which runs to the west of the archaeological site and whose analysis made it possible, among other aspects, to assess the weight, among other species, of Quercus coccifera L., commonly known as kermes oaks, in the history of the regional vegetation. Defining the best strategies for controlling this vegetal threat, omnipresent in Mediterranean climates and with a tendency to increase – given the expected rise in temperatures – was also one of the objectives of this project.

Using satellite images and computer vision algorithms constructed for this purpose, it was possible to explore the archaeological site of VNSP viewed from a fixed altitude of 500 m and over the same area of approximately 1 km², during the months of July between 2016 and 2022. By distinguishing between areas with vegetation and those without, and comparing their evolution over this period, it was possible to construct data visualisations that demonstrate the decline in vegetation and its control from the moment when annual archaeological excavation campaigns began to take place, with a reduction of about 17% at the start of the process.

It was also possible to create a forecasting exercise for the expansion of Quercus coccifera L. and its impact on the stone structures of VNSP. Using metrics related to root size, growth rate and the resistance of the limestone structures, it was concluded that within a space of five years, the growth of Quercus coccifera L. roots embedded in the stone structures constitutes a scenario of irreversible damage if not controlled.

Still within the scope of endemic vegetation, a great diversity of lichen species covering the exposed stone blocks was detected. In this specific case, it was found that these serve as a protective layer for the limestone material and should not be cleaned or removed.

The analyses of the cores are still ongoing and their results will provide fundamental data for the reconstruction of Holocene environmental dynamics, given that the depth reached (c. 10–12 m) is highly promising in that respect.

2. Coastal erosion impacts coastal heritage and preventive measures

The site of Loulé Velho, occupied during the Roman period and Late Antiquity, is now located on the cliff of a beach on the south coast of the Algarve and is threatened by the advance of seawater – the saltwater – an advance connected to global warming. In this case, the objectives of the project included the detailed monitoring of changes to the coastline and the growing impact that this has been exerting on the archaeological site, which is at risk of disappearance.

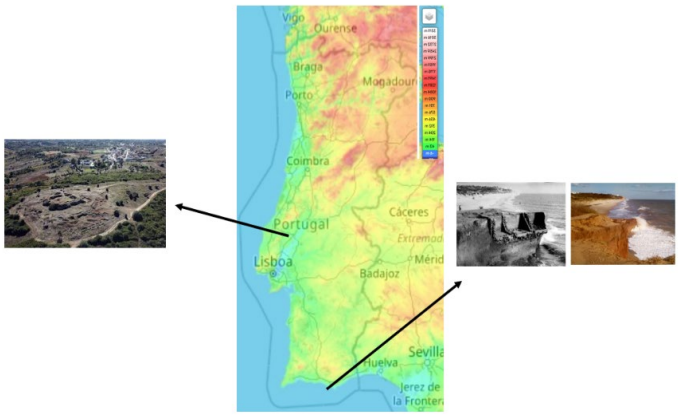
The carrying out of geoarchaeological test pits and the obtaining of sediment cores in the palaeo-estuary, together with the collection from archives of historical information and recent photographic records, documented, through the digital reconstruction of the surrounding area, the rate of coastal erosion and made clear the urgency of proactive measures for the defence of coastal heritage, particularly in an area of enormous vulnerability such as the western limit of the Ria Formosa.

The identification of the coastline through satellite images and historical documentation made it possible to understand the advance of the sea and the retreat of the beach area in an inexorable manner. Although it is possible to reach this conclusion, the causes, metrics and predictive models that might be inferred, used or constructed suffer from a chronic lack of data (as already noted in Santos et al 2017).

To this end, we created a risk model based on available data, with exposure to climatic drivers, physical vulnerabilities and temporal windows. With this, it is possible to understand that only with a multimodal and interdisciplinary model can the protection and mitigation of risks to cultural heritage in coastal zones be achieved.

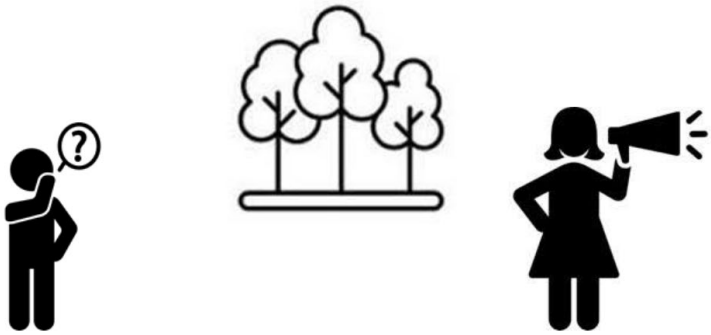
© PLANAPP-S4P-PB/8047/2025/ENG

Figure 1 – Location of VNSP (left) and LV (right).



Source: Project team.

Figure 2 – Phases of the project methodology: from the formulation of research questions, to fieldwork, and the development of recommendations.



Source: Project team.

Policy Options and Recommendations

The recommendations of the Freshwater/Saltwater Project will be presented alongside the conclusions of the analyses carried out, and the following measures are proposed to minimise the impacts of climate change and the adverse effects that these impose on archaeological heritage.

Best Practices at VNSP

1. Vegetation control: Half-yearly control of invasive native vegetation, through site maintenance protocols that include physical and chemical weeding actions, with a view to preserving the structures and controlling the risk of fire by reducing biomass;

2. Monitoring models: For effective control, we recommend that these computer vision methodologies be used for site monitoring, especially when site visits are not possible. This will allow, using open data, a preliminary approach to be created and attention and resources to be allocated to the most affected or uncontrolled areas;

3. Modelling the reduction of dominant native species: it is necessary to document and understand the extent of "invasive" flora and its consequences for archaeological heritage, understanding the particularities of each site. An analysis that explores various types of data and combines them makes it possible to construct simple predictive models and to determine a time frame (e.g., 5 years) within

© PLANAPP-S4P-PB/8047/2025/ENG

which action is required. This will allow the creation of an archaeological heritage management strategy based on data-driven decisions and on-the-ground intervention.

4. Preservation of species benign to archaeological structures: through the identification, monitoring and preservation of plant species that benefit the conservation of the archaeological sites themselves, as is the case with the lichens that serve as a protective barrier at VNSP.

5. Periodic analyses of rainwater quality: The monitoring of rainwater is a fundamental aspect that should be managed with a view to preserving the good quality of the soils and the salubrity of VNSP, both in terms of archaeological work and the cultural enjoyment of the site itself and its surroundings.

Best Practices at LV

1. Monitoring the evolution of the coastline at Loulé Velho: The coastline should be monitored from a multidisciplinary perspective and using various types of complementary data. In this context, it is necessary to articulate archaeology with geology, hydrology, and archival science – in addition to a technological component involving geographic information systems, computer vision and predictive models. This recommendation is fundamental, as it is crucial to generate higher-quality and consistently flowing data so that actions can be carried out within short temporal windows.

2. Coordination with coastal artificial nourishment works: Coastal artificial nourishment must take into account strategic points related to archaeological heritage, namely structures and their surroundings, since these themselves serve as monitoring stations for the quality of coastal conservation measures. Archaeological sites here serve as elements to be protected, but equally as vehicles for broader coastal protection.

3. Periodic conservation and restoration of stone structures: The structures should be subject to specific conservation actions in response to the damage that climatic drivers or physical vulnerabilities may bring, within the appropriate temporal windows.

4. Construction of risk models: The data collected should be used immediately for the construction of risk models, which will guide policies and operationalise the management of the coast and the existing archaeological heritage. These models should possess a local layer but should also be constructed in such a way as to be shareable, reusable and adapted to the complexity of the existing drivers and vulnerabilities.

5. Development of digital twins: The monitoring of this type of site should be ensured through the construction of digital twins, that is, through the capture of data via sensors, in real time or at pre-defined intervals, of what happens to the archaeological site. This digital tool represents an international best practice in the field of archaeological site protection, and its implementation in high-risk areas is therefore crucial.

Conclusion

From the Freshwater/Saltwater – Heritage and Climate Risk project, it is concluded that there is an urgent need for common and concerted policies between the scientific community and policy makers in the safeguarding and preservation of archaeological heritage, which is today at risk in the face of climate change and extreme weather events. Beginning with the inventory and diagnosis of risks that hang over archaeological heritage, identifying sets of measures – to be carried out by different public administration bodies – to guarantee the preservation for the Future of heritage at risk, this type of project can also prioritise threats and propose preventive and/or reactive measures, scheduled in the short, medium and long term, ensuring through their maintenance the enjoyment of heritage for future generations.

© PLANAPP-S4P-PB/8047/2025/ENG

References

Convenção de La Valetta - https://www.coe.int/en/web/culture-and-heritage/vallettaconvention

FIGUEIREDO, A. e MARTINVILLE, S. (2024). Impacto Ambiental e das Mudanças Climáticas na Preservação do Património Arqueológico Costeiro em Zonas de Arriba, (Portugal): Um Estudo Abrangente e Urgente. Quaternary and Environmental Geosciences, 15.

HOLLESEN, J. (2022). Climate change and the loss of archaeological sites and landscapes: a global perspective. Antiquity. 96. 1-14. 10.15184/aqy.2022.113. https://doi.org/10.5281/zenodo.7492858

SANTOS, F.D. LOPES, A.M., MONIZ, G. RAMOS, L., TABORDA, R., 2017. Grupo de Trabalho do Litoral: Gestão da Zona Costeira: O desafio da mudança. Filipe Duarte SANTOS, G. e LOPES, A. (Eds). Lisboa (ISBN: 978-989-99962-1-2).

SHYDLOVSKYI, P., TELIZHENKO, S.; IVAKIN, V. (2022). Archaeological Heritage as a Target during War. The European Archaeologist, 74, 36–43. Unesco - https://www.unesco.org/en

UZUNEL, A. (2023). Earthquakes and Archaeological Heritage Sites: The Case of February 6 Earthquakes Depremler ve Arkeolojik Miras Alanları: 6 Şubat Depremleri Örneği. Uluslararası Tarih Araştırmaları Dergisi. 7. 10.47088/utad.1308570.

VV.AA (2025) - Salvaguarda do Património Arqueológico Costeiro em Risco. Eds. Património Cultural, IP e Riksantikvaren.

© PLANAPP-S4P-PB/8047/2025/ENG

HOW TO CITE THIS DOCUMENT

Diniz, Mariana., Freitas, Mª. Conceição; Carvalho, Daniel, Almeida, Rui; Capelo, Jorge; Carvalho, Rosário; Carvalho, Palmira; Costa, Ana; Freitas, Joana; Garcia, César; Neves, César; Viegas, Catarina (2026). *Freshwater/saltwater: archaeological heritage at risk, in a changing climate*. S4P-25 Policy Brief 8047/2025. PLANAPP – Centro de Planeamento e de Avaliação de Políticas Públicas.

CONTACT

science4policy@planapp.gov.pt

COPYRIGHT

© PLANAPP, 2026

Ciência para as políticas públicas
PLANAPP
Newsletter
PLANAPP
@planapp_
PLANAPP podcasts

This policy brief was developed under the Science4Policy 2026 (S4P-25): Public Policy Science Studies Call, an initiative by the Centre for Planning and Evaluation of Public Polices (PLANAPP) in collaboration with the Foundation for Science and Technology (FCT), financed by Portugal´s Recovery and Resilience Plan. Thematic line S4P-25/23: Climate scenarios and expected impacts on Portugal's cultural heritage (archaeological and architectural).

The content is the sole responsibility of its authors and does not bind or commit PLANAPP nor FCT.