# Water Table Fluctuations and Degradation Risk Assessment at the Waterlogged Site of La Draga (Lake Banyoles, Spain)

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## Abstract

Pile dwelling sites in Mediterranean lakes face increasing threats to their conservation and safeguarding from climate change and its associated impacts. The primary objective of this study is to investigate the influence of climate change and water table fluctuations on the preservation of archaeological layers, with a particular focus on organic layers and wooden remains. Based on a combination of lake water level fluctuation analysis, water table measurements, and stratigraphic data, we managed to gauge the effects of recent water table fluctuations on the preservation of the occupation levels at the Neolithic site of La Draga (Lake Banyoles). By simulating and analysing the relationship between water table levels and their effects on the stratigraphic sequence, we were able to identify areas that are most susceptible to the impact of water table fluctuations and therefore potential post depositional processes. Moreover, statistical analysis of recent hydrological data has shown that there is a direct relationship between lake level and water table at the settlement. This would have been a factor affecting the preservation of both artefacts and deposits since the occupation of La Draga. Thus, the importance of considering hydrological factors when analysing and interpreting lakeside archaeological sites is highlighted.

## Keywords

Wetlands; climate change; wood degradation; 3D modelling; environmental modelling; water level changes

## Introduction

Prehistoric pile dwellings, known for their exceptional preservation of the archaeological record, provide valuable insights into past landscapes and historical processes. Research on pile dwellings has a long history, particularly in Central Europe, which is home to a significant concentration of these sites. Previous studies have explored various aspects related to pile dwellings, including the formation of archaeological contexts, economic practices, landscape transformations, climate influences, and mobility patterns (Haf ner et al. 2022; Menotti 2009; Pétrequin and Bailly 2004; Pétrequin, Magny, and Bailly 2005; Swierczynski et al. 2013). These studies contribute to our understanding of prehistoric societies and shed light on the complex interactions between humans and their environments during ancient times.

However, due to the fragile balance that has enabled the conservation of these sites, archaeological pile dwellings are seriously threatened by natural phenomena and/or anthropogenic actions. Their conservation mostly depends on their past and present environment, i.e. climate, sediments and water quality, human activities, etc. For this reason, the conservation of these sites is endangered by the impact of climate change and anthropogenic pressure, further exacerbated by the sensitive lacustrine environments. Yet, little research has been done regarding the current effects of global change and human activity. Most of the research into the conservation and main risks has been conducted on water logged pile dwellings in Alpine areas and northern Europe, many of which have been designated world heritage by UNESCO, with special focus on the artificial lowering of lake levels, bank erosion in the lakes and desiccation of moorlands (Heumüller 2012; Hostettler and Hafner 2020; Köninger and Schlichtherle 2016). This awareness has resulted in the implementation of specific measures to protect the archaeological layers and prevent their destruction (Brem and Leuzinger 2016; Hafner 2008). Some of these include *in situ* moni toring of the hydrological conditions (Holden et al. 2006). In addition to these, transnational measures have also been taken for better protection and conservation of these very fragile archaeological sites through heritage legislation and coordination between researchers (Corboud and Gowen 2016). At the same time, sea level rise seems to be the other side of the same coin at the Black Sea shores, where many prehistoric sites are likely to be located in areas that are now underwater (Peev et al. 2020).

In contrast, research on lake dwellings in the Mediterranean basin is relatively scarce due to limited evidence of such archaeological sites and the short research history in this area. Consequently, significant knowledge gaps exist regarding Mediterranean lake dwellings, particularly concerning their preservationand vulnerability. Nevertheless, various studies have pointed out the effect of water table fluctuations on archaeological layers during the past in a similar case study in Greece (Karkanas et al. 2011). The results of micromorphological analysis in this case have shed light on the differential preservation of organic material in depositional environments ranging from wet to occasionally wet to dry. Such is also the case at the early Neolithic archaeological site of La Draga located on the shore of Lake Banyoles (NE Spain) (Figure 1), where the present research was carried out. Notable discoveries of Neolithic artefacts and structures have been made at this site, where some of the archaeological layers have remained below the water table since the abandonment of the settlement in prehistoric times. Waterlogged and submerged areas have provided a unique preservation environment, leading to the recovery of various organic materials and structures that offer valuable insights into the Neolithic community's way of life. The primary scope of the analyses presented in this paper is to gauge the effects of water table fluctuations on the archaeological layers at the site. We aim to gain valu able insights into the relationship between water table dynamics and the preservation and formation of the archaeological record, especially wooden remains. Fluctuating water levels have likely caused substantial degradation and loss of organic materials. This would have caused significant impact on the preservation of delicate and perishable materials, such as wood, basketry, and other organic artefacts.

Extreme drought periods have been recorded in the area since systematic measures of rainfall and temperatures were established during the last century (https://www.meteobanyoles.com/). Because of these drought periods, the lake water level has experienced periodic drops. This drop in the lake water level, combined with high evaporation during heatwaves in summer months, has had an impact on the ground water level along the lakeshore, where part of the archaeological site is located. The fluctuations in groundwater level affecting the waterlogged archaeological layers are likely the most significant risk on the site; however, their potential impact is currently unknown. Through this study, our objective is to assess the potential risks posed by global warming to the conservation of the site.

Assessing the consequences of water table fluctuations at La Draga is crucial not only for archaeological research but also for the development of preservation policies and research strategies. By studying the impact of water table fluctuations, researchers can identify areas of high vulnerability and implement appropriate measures to minimise further degradation and loss. Preservation policies can involve measures such as site monitoring, environmental controls, and targeted excavation approaches to ensure the protection and long-term preservation of the archaeological record. In the case of La Draga, ongoing excavations and further research will continue to enhance our understanding of the site's significance and con tribute to a broader knowledge of early Neolithic com munities in the western Mediterranean basin. The main goal of the research conducted within the WoodPLake project is to assess the impact of climate change and extreme climate events on the conservation and protection of pile dwellings in Mediterranean lakes.

## La Draga

La Draga, an open-air settlement located in the north east of the Iberian Peninsula, has provided some of the earliest evidence of farming communities in the region (Figure 1). The site was discovered in 1990 and has been under excavation ever since (Bosch, Chinchilla, and Tarrús 2000; 2006; 2011; Palomo et al. 2014). While a portion of the site is submerged beneath the lake waters (Sector C), most of the settlement is situ ated on dry land (Sectors A and B-D). The original extent of the site covered an area of over 15,000 m$^2$. To date, approximately 1000 m$^2$ of the site have been excavated, including both terrestrial (Sectors A and B) and underwater sectors (C) (Figure 1).

The occupation of La Draga can be divided into two broad chronological phases. The oldest phase is dated between 5300–5200 cal BC, while the more recent phase occurred between 5100 and 4800 cal BC (Andreaki et al. 2022; Piqué et al. 2021). A set of depositional events define a transitional period that was dated in the interval of 5200–5100 cal BC, prob ably explaining the change in construction methods thereafter (Andreaki et al. 2022). It is noteworthy that only the archaeological layers from the oldest phase have remained below the water table since the settlement was abandoned. This distinction in preservation conditions between the two occupational phases is significant for deciphering the site's history and the impact of water table variations (Figure 2).

The geochemistry data and geomorphological description of 13 cores obtained from the excavated Sector B-D have identified significant ground subsidence in the vicinity of the excavated area in that sec tor. This subsidence could be one of the causes of the abandonment of the early settlement and an important factor responsible (Andreaki 2022; Andreaki et al. 2022; Iriarte et al. 2014) for the submersion of the archaeological layers into the water table. How ever, geomorphological analysis of the processes behind the ground subsidence at La Draga is still ongoing.

Figure 1. Location map of the lakeside settlement of La Draga on the shores of Lake Banyoles (Spain) on the left and plan of the excavated sectors on the right.

The fluctuating groundwater levels, influenced by the proximity to the lake, have significantly impacted on the preservation of Neolithic artefacts and deposits at La Draga. The recovery of wooden tools has not been possible in Sector A due to its location further inland at a greater distance from the lake shore and at a higher elevation (Figure 2). Instead, only the ends of the wooden piles were discovered approximately 70 cm below the archaeological level. In contrast, Sector B-D is also situated on dry land, but the lower archaeological layers have remained below the water table, thus enabling better preservation conditions for a wider range of artefacts. Sector C, lies completely underwater, resulting also in the preservation of the organic remains.

The site of La Draga stands out among other sites of similar chronology in the region due to its remarkable preservation of organic matter corresponding to the oldest occupational phase (Palomo et al. 2022). In addition to the piles, planks, and other building elements, La Draga has yielded a significant number of wooden objects. The waterlogged conditions have resulted in the preservation of these organic artefacts, which are otherwise susceptible to decay in dry environments. The recovered wooden tools shed light on the technological advances and subsistence of the early farming communities at La Draga (Bosch, Chinchilla, and Tarrús 2006; Herrero-Otal, Romero-Brugués, and Huerta 2021; Palomo et al. 2013; Piqué et al. 2015; Piqué et al. 2022; Romero-Brugués, Huerta, and Herrero-Otal 2021; Terradas et al. 2017). The presence of piles and beams from Neolithic constructions is another noteworthy feature of these submerged areas. These structural elements offer insights into the architecture and building techniques applied by the past community (López-Bultó 2015; López-Bultó and Piqué Huerta 2018).

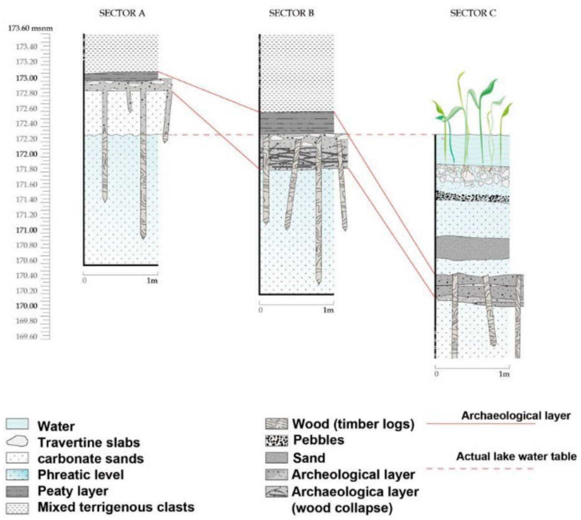


Figure 2. Schematic representation of stratigraphic sequences in each excavated sector showing the relationship between the water table and the archaeological layers at La Draga (Andreaki et al. 2022).

## Lake Banyoles: Context and Current Environmental Data

Lake Banyoles is not only one of the largest lakes in the Iberian Peninsula but also the deepest, with a karstic-tectonic origin. Situated in northeastern Catalonia, it occupies a strategic location between the Mediterranean coast and the Pyrenees, approximately 175 m above sea level. The lake is nestled within a natural depression that originates from a lacustrine basin. Covering an area of 110 hectares, Lake Banyoles is characterised by its diverse features, including the main lake body and a collection of sinkholes, wetlands, and intermittent ponds.

With an average depth of 14 m and a maximum depth of 132 m, the water volume in the lake is significant. The lake consists of six main basins, which were formed through different episodes of collapse.

The influx of water from underground sources located at the bottom of some basins constitutes a significant water supply to Lake Banyoles. These ground water springs contribute approximately 85% of the total water influx to the lake and they are part of an aquifer system that fills the lake. The hydrological dynamics of the aquifer recharge area are influenced by local variability in rainfall. The area experiences intense hydrological fluctuations, which are attributed to changes in rainfall patterns. These fluctuations impact the water availability and overall water balance of Lake Banyoles. During the Middle Ages, extensive channelling projects were carried out with the purpose of draining water and mitigating the recurrent flooding that had a significant impact on the village of Banyoles. This canalisation work played a crucial role in control ling water levels and shaping the lake in its actual state (Bosch, Chinchilla, and Tarrús 2000). The area around the lake is predominantly flat, characterised by gentle slopes that generally remain below 5%. Still, the north ern and western sectors feature higher elevations with slopes exceeding 50%. As a result, during periods of heavy rainfall, the surrounding areas of the lake are prone to flooding. This flood-prone zone includes the archaeological site of La Draga.

The climate in Catalonia, including the surroundings of Lake Banyoles, can be described as Mediterranean. This implies that summers are characterised by hot and dry conditions, while winters tend to be mild. Historical temperature data from the past century indicate a noticeable trend of increasing temperatures. Banyoles receives average annual rainfall of between 850 and 800 mm. Yet, winters in Catalonia and Banyoles in particular, are relatively drier compared to the typical Mediterranean climate, primarily due to the Pyrenees intercepting a significant portion of the Atlantic storms.

The climatic parameters being examined primarily in this study revolve around the water level both of the lake and the terrestrial area, where most part of the archaeological site is situated.

## Materials and Methods

By combining lake water level fluctuation analysis, water table measurements, and stratigraphic data we aimed to assess the influence of recent water table fluctuations on the archaeological layers at La Draga. This multidisciplinary methodology enhances the robustness of our research and allows for a more nuanced understanding of the site's history and formation processes.

### *Analysis of Climatic Data*

Public data were gathered about historical water level fluctuations in the vicinity of La Draga site. This information provides valuable insights into the long-term hydrological patterns of the area and served as a reference for understanding the potential impact on the archaeological layers. Recent water level data from Lake Banyoles, coverning the years 2005–2021, were obtained from the meteorological association Meteo banyoles(https://www.meteobanyoles.com/). Additionally, the city council of Banyoles provided data with a 15-minute frequency from 2007 to 2016. These datasets are especially valuable for areas, where the lake reaches its lowest levels. Such conditions may expose the submerged part of Sector C and/or lead to a decrease in the groundwater level in the terrestrial part of the archaeological site, posing a higher risk of deterioration due to the absence of water in the wood-containing layers.

The data are originally referenced to the so called 'Alsius zero level', originally engraved on a rock in 1887 by the local pharmacist and scholar Pere Alsius in the area known as Banys Vells (Estragués and Estra gués 2007). A total station, an instrument that com bines theodolite with a distance metre to measure horizontal and vertical angles as well as distances, was used to reference the data to above sea level (a.s.l). This way, the Alsius zero level was determined and correspond to 173.963 metres a.s.l.

### *Onsite Measurements of the Lake and Water Table Levels*

Water table dynamics at La Draga were studied through data measurements collected once per month at selected points within the excavation area. This data allowed us to observe and analyse the relationship between water table fluctuations and the stratigraphic layers. The selection of appropriate groundwater sampling points is crucial for studying the potential impact on the deterioration of the wood in the archaeological site. Additionally, the lake level was used to establish a correlation with the groundwater measurements and evaluate risk thresholds. Three sampling points were selected for this study. The first is located on the shore of the lake near the site, while the other two are situated in the terrestrial area of the archaeological site to measure the water table level. More specifically, one is in Sector A, currently under excavation, and the second between sectors A and B/D in an underground deposit built to store the wooden piles after excavation (Figure 3).

The water level at each sampling point was determined by referencing the altitude of their upper part with respect to sea level, which was measured using a total station. This altitude was determined using a total station

(Table 1). Measurements from the refer ence point were taken by tape with a resolution of 1 mm. An uncertainty of 1 cm was considered due to the measurement methodology.

To explore the potential relationship between the lake water level and the water table, the Pearson corre lation coefficient was initially applied. This statistical measure assessed the strength and direction of the lin ear relationship between these datasets. It is essential to note that, for accurate conclusions using the Pear son correlation, having data that follows a normal distribution is preferred. Following the correlation analysis, the Shapiro Wilk test was conducted to assess the normality assumption of the datasets.

Figure 3. Aerial view of La Draga site with water level sampling points marked. Lake level at the footbridge (blue star), water table in the Concrete deposits (black star) and water table at the base of Sector A (red star).

If a significant correlation was found between the lake water and water table levels, a linear model was then employed to represent this relationship. The linear model allowed for the establishment of an equation describing the connection between the variables, aiding to predicting groundwater levels based on lake water levels.

Subsequently, to evaluate the accuracy of this model, the Root Mean Squared Error (RMSE) was used. This metric measures the difference between the values predicted by the model and the observed actual values. RMSE is calculated from the square root of the average of the squared deviations between the predicted valued and the observed value. A low RMSE value indicated that the linear model is able predict groundwater levels with higher precision, whereas a high value suggests a substantial discrepancy between the model's predictions and the observed data.

In summary, the Pearson correlation was used to investigate the association between lake water levels and groundwater levels, followed by a linear model if a significant correlation was established. The precision of this model was further assessed using the RMSE. This process allowed for the analysis and quantification of the relationship between these hydrological variables and the evaluation of the proposed model's reliability in predicting groundwater levels.

Table 1. Elevations above sea level (a.s.l.) of the upper part of the sampling points.

| Sampling Point | Height a.s.l. (m) |
|---|---|
| Footbridge | 174.301 |
| Concrete deposits | 173.669 |
| Base of Sector A | 173.663 |

### *3D Modelling of Water Level Fluctuations and Correlation with Stratigraphic Data*

In addition to the hydrological data, we relied on the existing stratigraphic records of the archaeological layers at La Draga (Andreaki 2022; Palomo et al. 2014). These records provided a detailed description of the sedimentary sequences and the different cultural horizons encountered during the excavations. Water table and lake level rates measured during this research were introduced into the Rockworks programme (Rockware 2020) frequently used in geology. In our case, *Rockworks21* offers a way of visualising water table fluctuations in real time, in addition to cor relating these fluctuations with spatial variables (stratigraphy, identified formation processes, structures, etc.). The overarching goal of this analysis is to assess the potential effects of a dynamic water table on the conservation of the archaeological record, both depos its and artefacts.

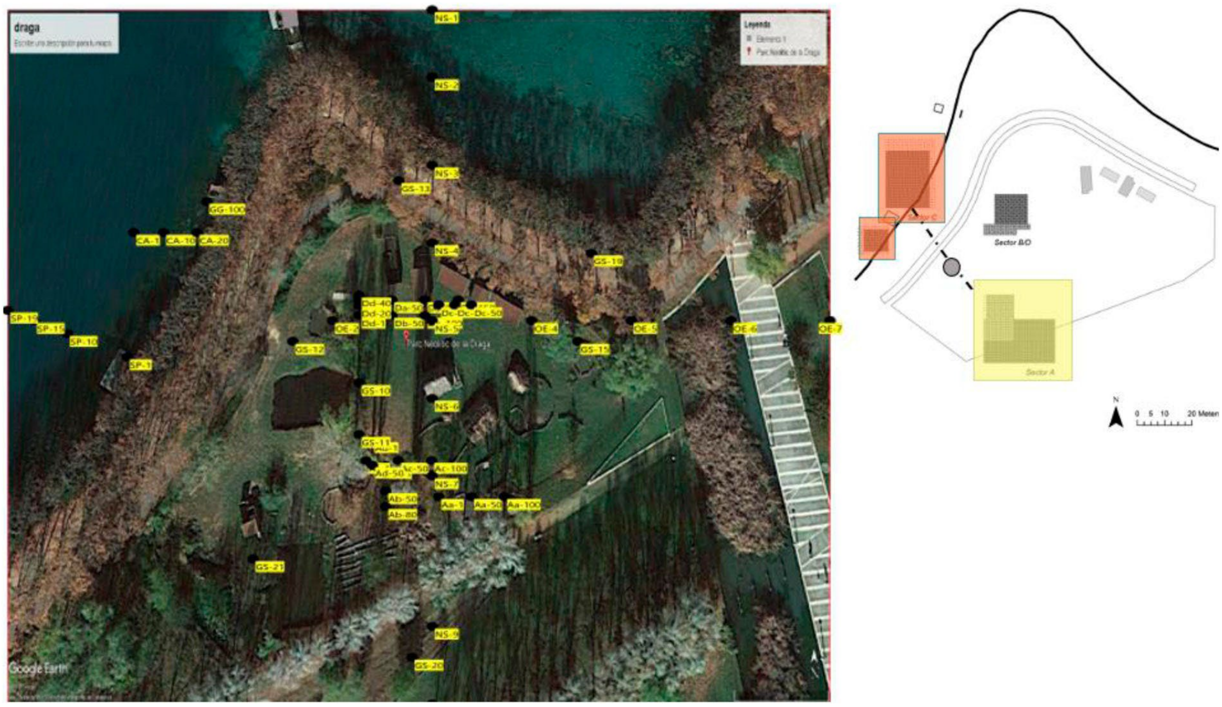


Figure 4. Borehole locations from all excavated sectors at La Draga (left) and general plan of the excavation sectors (right). Bore holes from sectors A (yellow) and C (orange) were used for the present study.

Cartesian coordinates (x, y, z) were used to establish boreholes based on stratigraphic sections including the area under study between Sectors A and C. Boreholes refer to vertical columns created out of the stratigraphic sections, each one with its own sequence. The boreholes available for Sectors A and C were used, whereas bore holes in Sector D were not used in the present study (Figure 4). However, the position of Sector B/D is included in the final model.

All the data were imported in the software, where all data relevant to each borehole such as stratigraphy, T Data, water level data, etc. were inserted and /or modified during the process. Temporal interval Data (T-Data) refer to samples measured over depth intervals and have a specific date/time record. The data used for the present analysis refer to two dates (02/ 05/2022 and 02/08/2022), of which the former rep resents the higher and the latter the lower water table. Apart from the three monitor points used for the present analysis, additional boreholes in the excavated sectors A and C at La Draga were used as well. This would enable the correlation of the water level and time interval data with the stratigraphic sequence in the excavated sectors.

### *Water Level and Time Interval Data*

The elevations (z) retrieved from the monitor points were transformed in Depth to Top and Depth to Base measurements, with top meaning the water table and base the lake marl substrate fixed at 172 metres a.s.l. Water level data were added for all the boreholes from sectors A and C and were directly related to the T-Data by introducing the date of sample. Watertable measurements have not yet been made in Sector B/D, because of the underwater position of the archaeological layers on both 02/05/2022 and 02/08/2022.

The water levels were subsequently modelled using surface modelling (gridding) tools for the date 02/08/ 2022. At the same time, the programme interpolated a grid model for the groundwater elevations on the specified date. In other words, this refers to a T-Data model constrained by a Water Level Surface at the top, and Bedrock Surface at the bottom (Rockware 2020). The algorithm selected was Inverse Distance Weighted – Advanced (IDW). This is a method of interpolation estimating cell values which are influenced by the average of points found in greatest proximity to the centre of the estimated cell. Apart from representing the water level measurements in Sectors A and C, this method was also able to predict the water table in Sector B/D.

## Results

### *Water Table Fluctuations*

Modern time fluctuations in the water level of the lake have been recorded from 2005 to January 2023 (Figure 5). Most of the data have been collected by MeteoBanyoles and the Banyoles city council, while the last part of the time series has been measured by the working research group (UAB-CSIC). In periods where both series coincide, the correlation is good, implying that the evolution is similar. However, there are discrepancies in the values, either due to the difference in temporal periodicity between the two series or errors in the sampling process of one of the systems. The mean value during the monitoring period is 173.940 m a.s.l. with extreme values of 174.533 and 173.733 m a.s.l., which translates into a range of oscillations of 0.8 m.

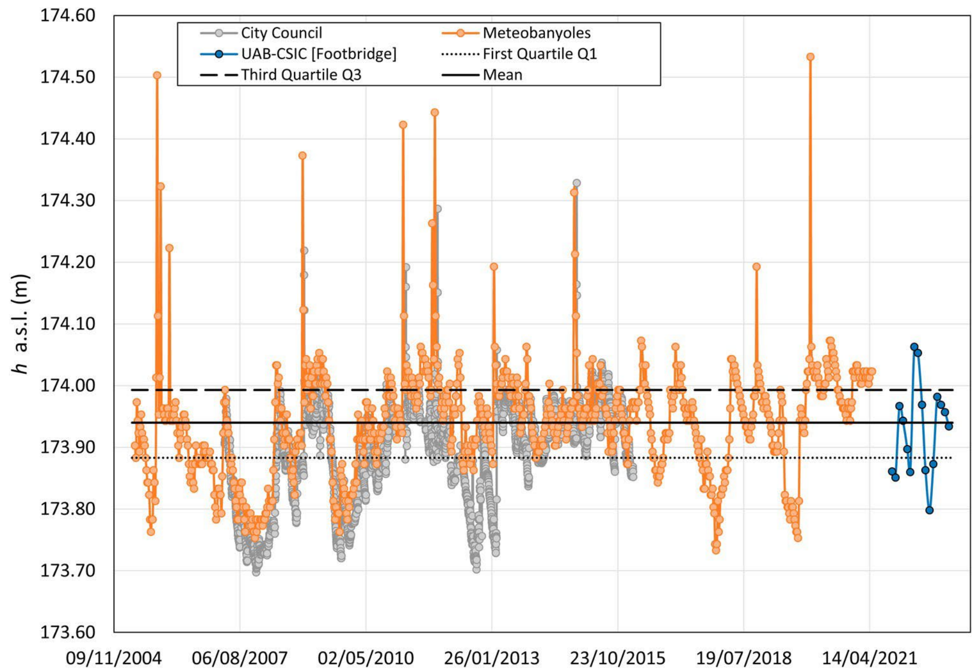


Figure 5. Recent evolution of the water level *h* a.s.l. in Banyoles lake. The first quartile Q1 = 173.883 m, the third quartile Q3 = 173.993 m and the mean value of 173.940 m are indicated.

The periods when the lake level shows extreme values, maximum or minimum, are not correlated with the seasons of the year. They are generally distributed throughout the year. However, higher water levels in the lake exhibit a more transitory behaviour, i.e. they do not persist over time. The lake water returns to average values in less than 1 month. This is not the case of lower levels, which encompass longer time periods as indicated by the values of the first quartile.

For the period between November 2021 and January 2023, there were two additional monitoring points in the terrestrial part of La Draga archaeological site. Figure 6 shows the variation in the level at the mentioned sampling points and the corresponding water level measurement in the lake. These data are the first step to obtain a possible relationship with the water table which is directly related to pile dwellings conservation.

The average water level in the lake during that period was 173.93 m a.s.l., which is very similar to the data recorded average, although it does not cover the entire range of modern time values. On average, the water table level in the deposits is 1.08 metres below, and the corresponding level at the base of Sec tor A is 1.23 metres below. Similarly, the area farthest from the perimeter delimited by the lake always has a lower water table level, as indicated by Figure 6. The statistical analysis of the data suggests that the three series can be reasonably assumed to follow an approximately normal distribution. This conclusion is supported by the results of the Shapiro–Wilk test conducted at a significance level of 0.05. Therefore, it is justifiable to proceed analysing the linear relationship between series using the Pearson correlation coefficient which is more reliable and appropriate when dealing with normally distributed data.

A correlation analysis yielded coefficients of $r =$ +0.85 between the lake level and the base of Sector A, and $r = +0.89$ was obtained for the lake level and the point in the concrete deposits. These results signify a statistically significant correlation, with 95% confidence that the observed relationship between the variables is not simply the result of chance. In addition, it underscores the influential connection between the lake level, the base of sector A and the point in the concrete deposits.

Essentially, as the lake level fluctuates, there's a corresponding change in both the base of sector A and the point in the concrete deposits, confirming their interdependency.

Based on this evidence, a linear model has been proposed to relate the lake level with the corresponding water table level in the archaeological site. These values have been plotted against the lake level and fitted with a linear regression (Figure 7). The functional relationship between the lake level 'x' and the corresponding terrestrial water table level 'y' can be observed in each case. The coefficient of determination ($R^2$) in both cases is above 0.70, indicating that over 70% of the variability in the ground water level can be explained by the linear relationship with the lake level.

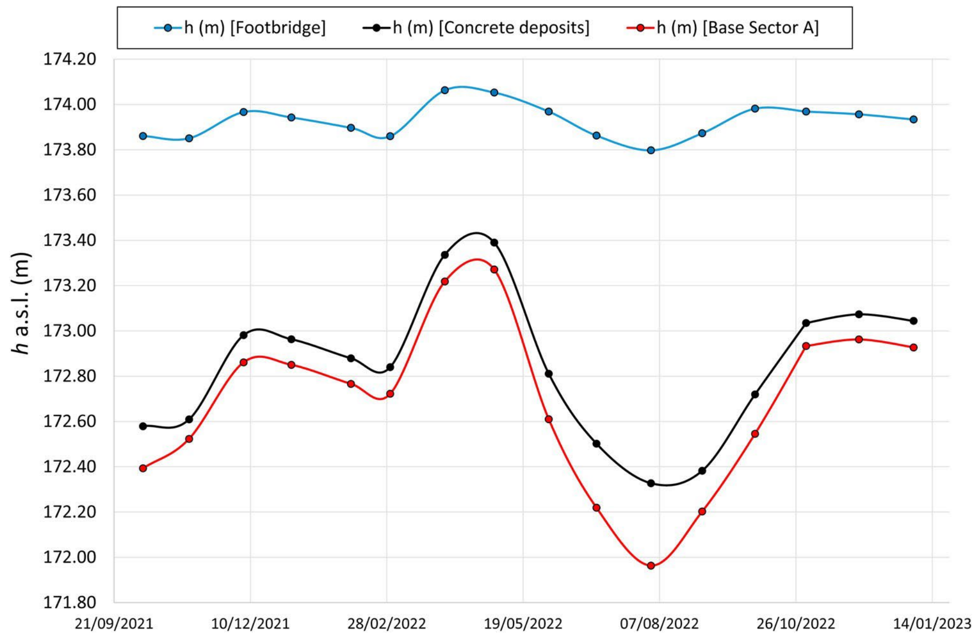


Figure 6. Water level *h* a.s.l. fluctuation in Lake Banyoles and at both sampling points in the terrestrial part of the archaeological site.

The evaluation of model goodness has been con ducted based on the residuals of the linear fit. Residuals are the differences between the observed values and the values predicted by the model. By plot ting the residuals, one aims to identify systematic or non-random patterns in the model errors. The residual plot shows that the potential errors made when using the model to predict real data fall within the approximate range of −0.4 m to +0.4 m. The pat tern of residuals is random and homogeneous, indicat ing a good model fit (Figure 8).

In this study, the accuracy of a model has been assessed by calculating the RMSE (Root Mean Square Error). RMSE is the square root of the average of the squared deviations between the predicted value and the observed value. The RMSE is calculated by taking the square root of the mean of the squared residuals. The obtained RMSE values are 0.19 m for Base of Sector A and 0.15 m for Concrete deposits. These values suggest that the model fits the data well and can make predictions close to the actual values. This implies that the model has reliable forecasting capabilities and can be useful in decision-making or understanding the studied phenomenon.

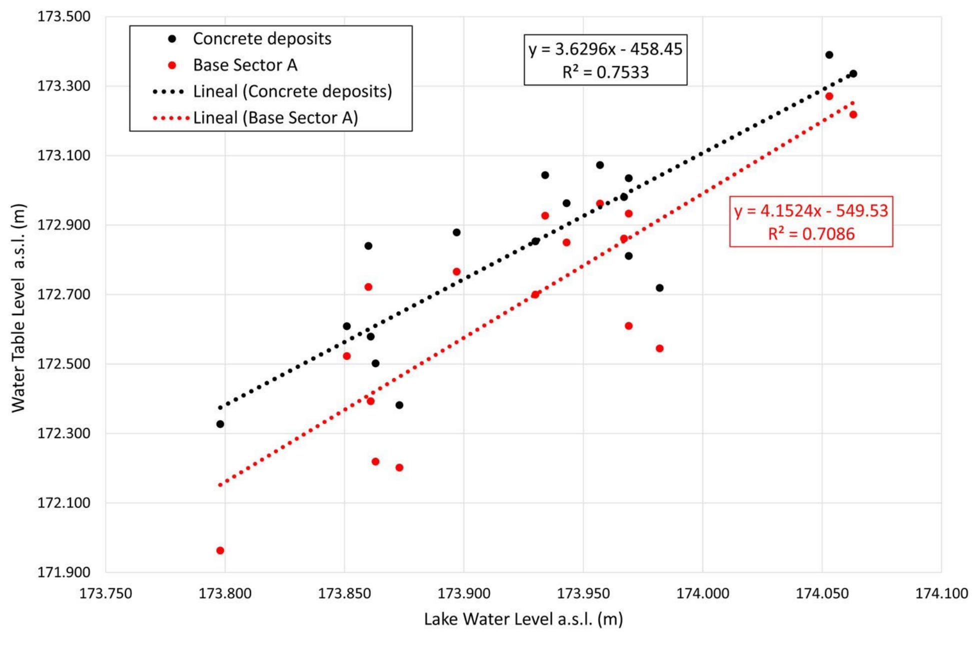

Figure 7. Graphical representation of the water table level in the Concrete deposits (black points) and at the base of Sector A (red points) in relation to the lake level. The performed linear regression and the functional relationship between them are displayed.

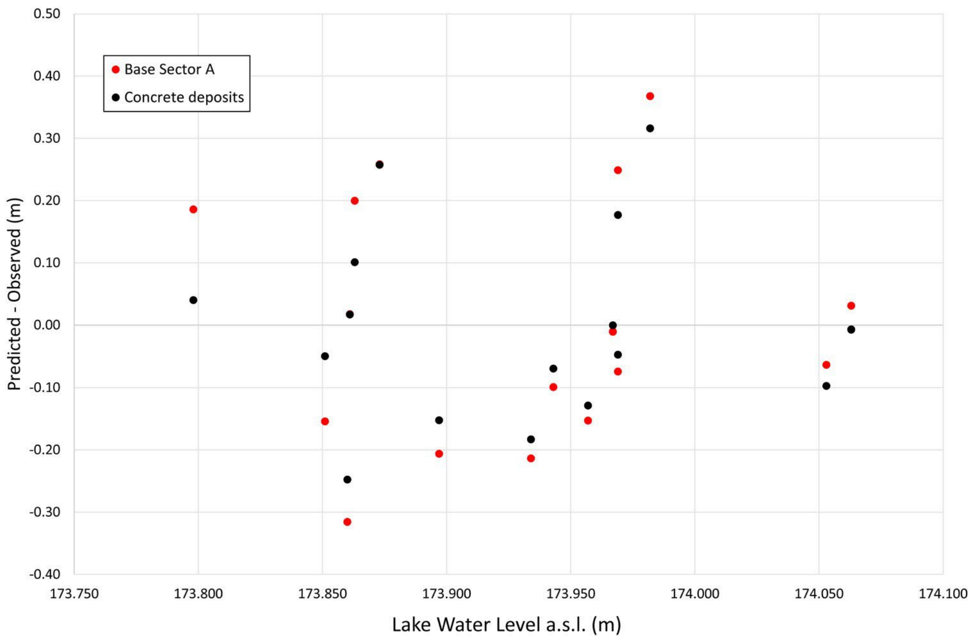


Figure 8. Scatter plot of the residuals, showing the difference between the predicted values observed and values from the linear regression model for both terrestrial sampling points.

The RMSE obtained indicates that the model exhibits acceptable accuracy and can be used as an effective tool for predicting the water table levels from the lake level. However, it is crucial to continue evaluating and validating the model in different scenarios and data sets to gain a more comprehensive understanding of its performance.

As has been explained above, the potential risk of wood deterioration becomes more pronounced when the groundwater level is lower. Since historical data for these levels is not available, they have been esti mated based on the lowest recorded values of the lake level in history. Figure 5 shows that the lowest recorded value is 173.702 m. By applying the linear equation shown in Figure 7 in each case, the water table level in the Concrete deposits would be 172.019 m and at the base of Sector A it would be 171.750 m.

### *The Effect of Water Level Fluctuations on the Excavated Sectors at La Draga*

The lower water table evidenced in 02/08/2022 was modelled and its impact on the archaeological deposits in Sector A is characteristic of fluctuating periods of exposure (Figure 9). More specifically, Sector A, located further inland, is considered one of the most susceptible areas to ground water fluctuations. The vulnerability of Sector A to ground water fluctuations is indicated by the presence of preserved wood only in the lake marl substrate (Figure 10).

Various slices of the fence diagram display the range of effects in the study area restrained to Sector A, located in the southeastern corner of the 3D model (Figure 9). During spring, winter and autumn, the groundwater level rises above the archaeological layers in all sectors, including Sector A (Figures 10 and 11).

Conversely, the lowest measurement of the ground water affects the lake marl substrate, leaving it exposed during the summer, and reaching the lowest level regis tered on 02/08/2022, at 171.96 m a.s.l. in Sector A. This means the complete exposure of the lake marl surface which ranges between 172.2 and 172.5 m a.s.l. and a maximum of 54 cm of water-deprived substrate. These measurements are in accordance with the tops of the preserved wooden piles found stuck in the marl at various elevations between 172.1 and 171.8 m a.s.l. (Figure 10). The consequences of this event trigger either degradation in the exposed parts of the wooden piles found in the lake marl substrate or lead to the complete disappearance of the organic layers in contact with the lake marl surface. In the first case, the degradation of the wood is slowing down due to the humidity contained in the lake marl under an anaerobic environment. Instead, in the second case, the effects of air on the organic layers lead to their loss.

In the concrete deposits between Sectors A and B/D, the lowest water table is recorded at 172.33 m a.s.l. (Figure 9(c)). Given its greater proximity to B/ D in the north (Figure 3), a lower water table has further implications for the deposits in the non-excavated part between Sectors A and B/D. The lake marl surface elevation in Sector B/D is around 172-172.1 m a.s.l. (Figure 11). Thus, taking the elevation of the lake marl surface in Sectors A and B/D as a reference, the difference from the water table would be only around 10 cm in the former, while in the latter the lake marl surface would remain covered.

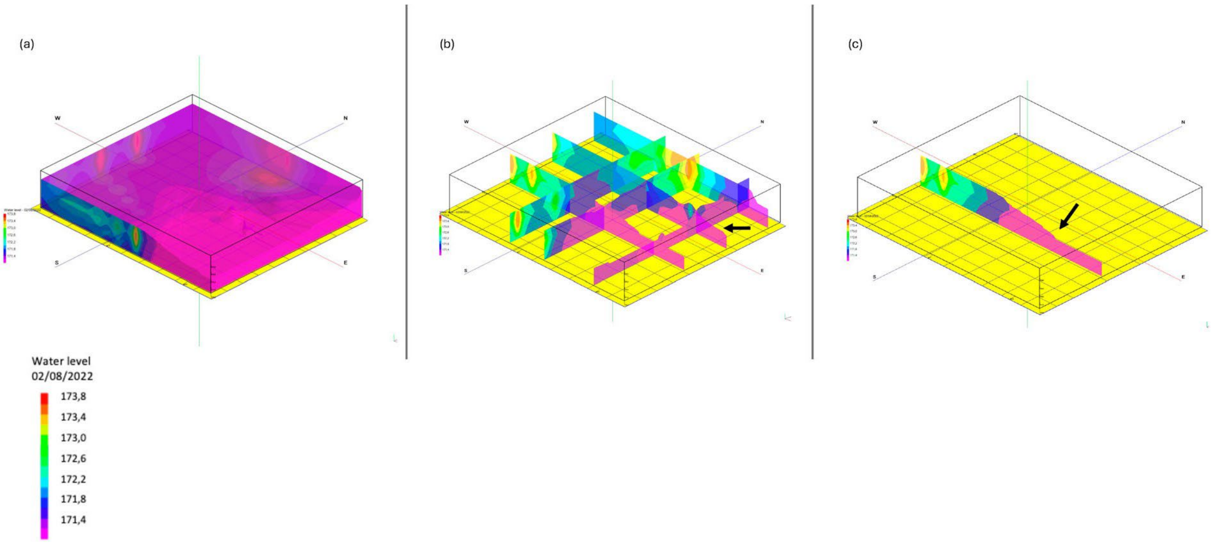


Figure 9. 3D model showing (a) a general display of the water levels on 02/08/2022 all over the studied area, (b) multiple water level vertical slices all over the excavated area highlighting the water table in Sector B/D (black arrow) and (c) 3D fence diagram showing the transition from higher lake level in Sector C (west) through slightly lower water table in the concrete deposits (black arrow) to the lowest water table in Sector A (east, pink) (*Figure by V. Andreaki*) (*RockWorks21, Rockware* 2020).

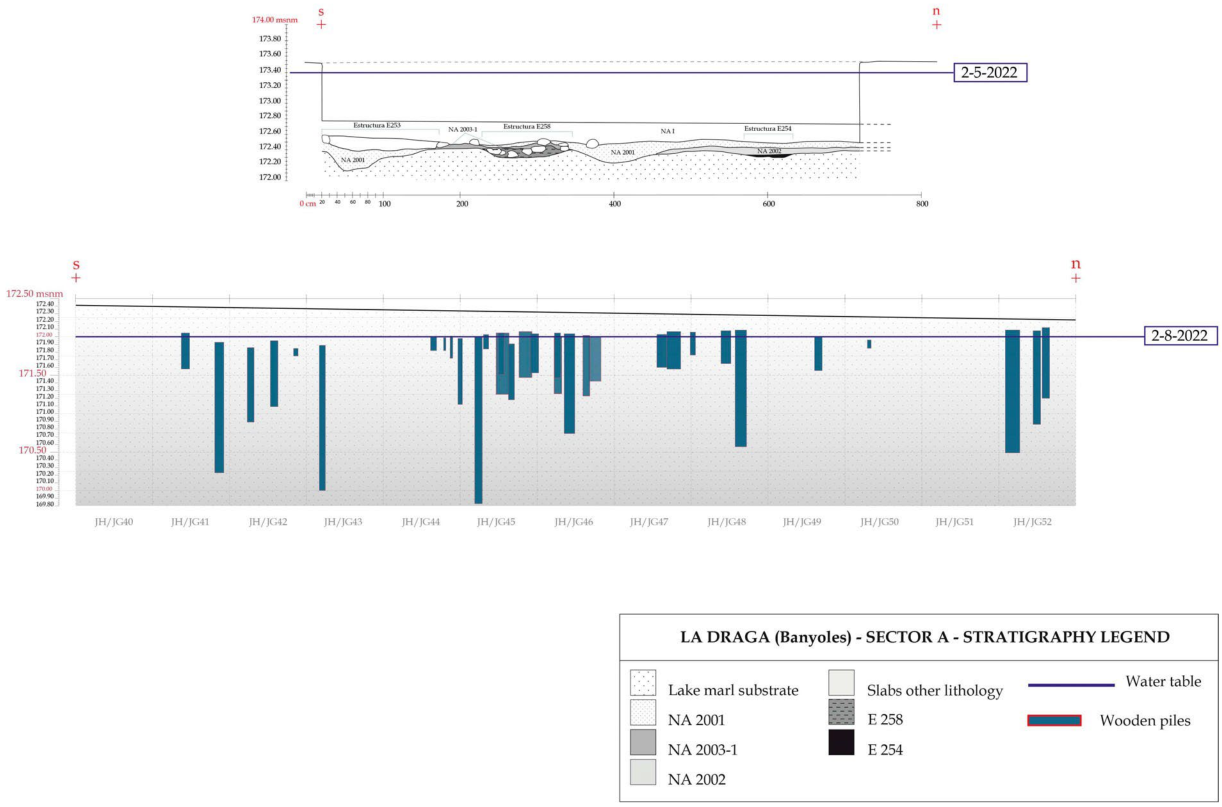


Figure 10. Water table during both dates of measurement in Sector A and its relationship with the vertical wooden piles found in the lake marl substrate.

Even though exact measurements are not available yet, the privileged position of Sector B/D in a lower ground altitude due to subsidence enhances its preservation even under the lowest water table measurement (Figure 11). Until the data from Sector B/D is further analysed, the prediction of the water table through interpolation is only possible at a preliminary level. In the 3D model, a slightly higher water table is shown in Sector B/D for 02/08/2022 (Figure 9(b)) than in the concrete deposits (Figure 9(c)).

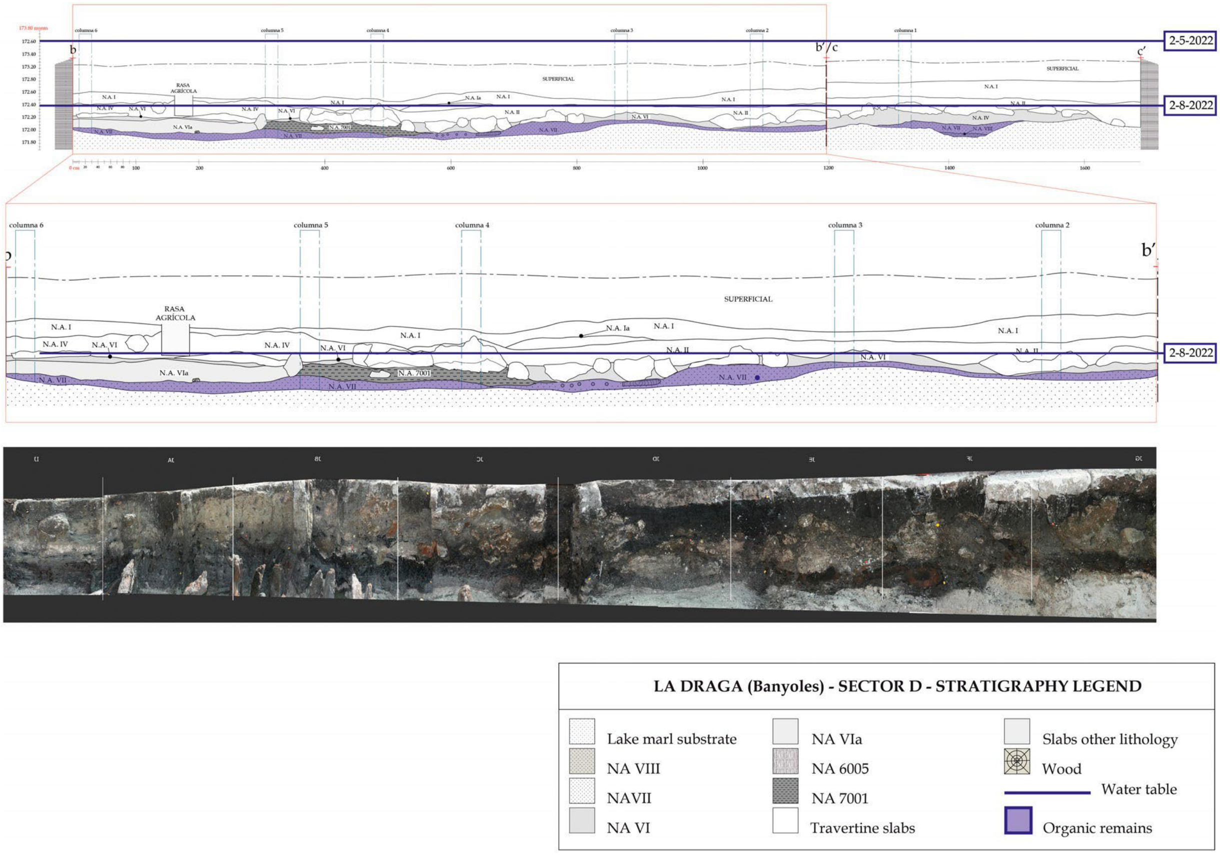


Figure 11. Estimation of possible water table reflected on the stratigraphic sequence from sector B/D on both dates of measurement and the possible effect of the lowest water table on 02/08/2022 on the archaeological layers, especially the ones containing organic remains (purple).

## Discussion

The implications of water table fluctuations at La Draga are far-reaching. The research suggests that changes in the water table over time have influenced the terrestrial sectors of the site. Previous archaeological studies have indeed determined that the conservation of organic matter varies unevenly across different sectors of the site (Antolin 2013; Palomo et al. 2014; Terradas et al. 2015). At the same time, this depends on the elevation of the archaeological layers in each sector (Bosch, Chinchilla, and Tarrús 2000). Furthermore, the examination of wooden artifacts retrieved from all excavated sectors of the site since the beginning of archaeological works highlights significant variations in their preservation. In addition to variables like sector and depth that condition the conservation of wooden objects from La Draga, there are several other factors that influence the state of preservation, including taxon and form (García-Alonso et al. in press). Moreover, sediment context plays an important role as the foundation piles, situated in the lake marl substrate, exhibit superior preservation compared to the horizontal wood embedded in clay sediments. According to the forementioned studies, the preservation of organic material is not consistent throughout the site, and factors such as sector location, sediment layer and elevation of the deposits play a role in its conservation (Figure 2).

The historical actions taken to manage the lake and its surroundings through water canalisation, agricultural drainage, and the creation of a lakeside promenade, have markedly modified the lake's initial boundaries and water levels (Bosch, Chinchilla, and Tarrús 2000). Consequently, the water table level currently remains above all the archaeological layers in all sectors. However, the unequal preservation of organic material suggests that in the past, the lake water level and the water table levels were lower. This lower water table caused the degradation of organic matter in the upper archaeological layers of Sectors B, D and C, and all the layers in Sector A. This indicates that fluctuating water table levels in the past have directly impacted on the preservation and degradation of organic material in different sectors of the site.

The current water table level at La Draga is closely tied to changes in the lake level, which, in turn, is influenced by rainfall in the aquifer recharge area, evaporation and water consumption as the lake pro vides the local population and agriculture needs. Based on the results of the water table measurements conducted in this research, it has been observed that the water table level is lowest at the farthest distance from the lake. This suggests that the water table level is affected by the proximity to the lake and its fluctuations, but also the elevation of the lake marl surface. As a result, the water table level can vary spatially within the site, with the farthest areas from the lake experiencing lower water table levels compared to areas closer to the lake.

The measurements of both the lake level and the water table have revealed a robust correlation between them.

The analysis of historical data series for the lake water level has shown periodic episodes of higher and lower levels, because of the annual variations in the Mediterranean precipitation regime and its periodic oscillations, with the drops in the lake level particularly critical for the conservation of organic layers. Since 2004, there have been at least five occasions when the lake water level dropped by approximately 25 cm. According to our model, this significant decrease in the lake water level corresponds to an estimated drop in the water table level of approximately 1 m.

Several studies have highlighted the impact of the drop of groundwater level on the waterlogged archaeological layers of wells, shipwrecks and pile dwellings (Holden et al. 2006; Van de Noort et al. 2002). Klaas sen et al. (2023) conducted controlled experiments to measure the rate of degradation over time under lab oratory conditions. Their results have showed, in the first phase of water drop, wood is better protected in sandy soil than in peat or clay. The authors propose that a solitary period of low water levels lasting no more than 3–6 months would not cause a lasting adverse impact on buried wood. However, when dry spells recur, their cumulative duration can be considered as significant exposure, sustaining the progression of fungal activity. Similar controlled experimentations have been carried out by other authors showing the relationship between water table fluctuations and wood conservation (Chaumat et al. in press; Elam and Björdal 2023).

In the case of La Draga the drops in the lake water level pose a significant risk to the conservation of organic layers. It has been proved that there is a positive correlation between the lake water level fluctuations and on-site groundwater level at various measured points. This correlation allowed for an assessment of how the drop-in lake level has affected the archaeological layers. The importance of standardised hydrological data to improve prediction of preservation risk from environmental disturbance and the need to carry out to site-specific studies has been remarked by several authors (Holden et al. 2009). Numerous hydrological monitoring programmes con ducted at waterlogged sites in England have under scored the significance of sustained, long-term monitoring of archaeological sites (French 2017). In the case of La Draga, our measurements currently have a low temporal resolution, as they were taken only once a month over the course of one year. Recent data of the lake water level indicates that the higher lake level returns to average values in less than 1 month and in the case of lower levels this return hap pens over longer time. Nevertheless, we don’t have enough data regarding the groundwater level returns. Thus, we cannot currently determine how long the organic layers remained above the groundwater level.

Previous research has underscored the critical role of contextual comprehension in unravelling past and present preservation environments. This is particularly vital as preservation conditions can vary significantly over short distances (French 2017). By simulating and analysing the relationship between water table levels and their effects on the stratigraphic sequence, it has been possible to define the areas that are more susceptible to the impacts of water table fluctuations. The modelling of the fluctuation of the water table has shown that the most susceptible area to exposure is in fact Sector A. Furthermore, micro morphological analysis of sediments in this sector also indicates that alternate periods of exposure have occurred during the past which helps to further explain the deformation processes affecting the artefacts and deposits in this part of the settlement (Andreaki 2022; Andreaki et al. 2022). Although we should bear in mind that even though measurements from Sector B-D are not yet available for the present study, the distance of this sector from the lakeshore is not much greater than Sector A. However, ground subsidence over time surrounding Sector B-D may have led to a better state of preservation of the cultural horizons (Andreaki 2022). The effects of the lowest measured water table in the case of the concrete deposits found between Sectors A and B/D in the north are also worthy of attention. This area is outside the subsidence area including Sector B/D and periods of low water table could lead to exposure of the lake marl surface, and consequently the possible risk of organic layer degradation.

## Conclusions and Perspectives

The present research highlights the importance of considering hydrological factors when analysing and interpreting archaeological sites, particularly in areas where water dynamics play a significant role. Through the study of the hydrological dynamics and its relationship with the stratigraphy at the early Neo lithic site of La Draga, our research has successfully elucidated the impact of water table fluctuations on the archaeological layers. The results obtained indicate that there is a positive connection between the lake level and the groundwater at the various points of measurement in the settlement. This implies a direct link between the processes of formation and deformation within the settlement, interacting with the lake as an active water source. These interactions significantly influence the preservation of organic material in the waterlogged levels.

The relationship between water table levels and the stratigraphic sequence has shown that preservation risks are particularly evident in Sector A, where drops in groundwater levels affect both archaeological layers and wooden piles. In this sector, the decreasing groundwater level poses threats to the preservation of wooden piles, especially the shorter ones. The knowledge gained from this study provides a foundation for future research and enhances our understanding of the site’s formation, post-depositional processes, and the preservation of organic materials. However more high-resolution measures are needed for a better understanding of how the drop of the groundwater level affects the preservation of the organic waterlogged layers in all sectors of the site.

In this sense, two probes have recently been installed in Sectors A and B/D to measure parameters related to oscillations in the water table. The probes (TD-Diver, vanEssen Instruments) consist of a pressure sensor that measures the absolute pressure, the water pressure plus the air pressure pressing on the water surface. The outside air pressure is measured with another probe (TD-Baro, vanEssen Instruments) to convert the underwater pressure readings to water level data. These probes also record the temperature. Continuous recording of these parameters enables greater control over them and monitoring throughout the year. In turn, the installation of these probes in the two sectors will provide more precise data on their respective dynamics in order to establish the risks in each one of them and to be able to develop possible preventive policies in the future.

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## CRediT

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