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VEGETATION HISTORY OF LAKE MARMARA  
(W. TÜRKİYE) AND SURROUNDING AREA DURING  
THE LAST 700 YEARS

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**Abstract**

In this study, a 65 cm long sediment core was obtained for pollen analysis from Lake Marmara situated in the west of Türkiye. The bottom sediment was dated by one AMS radiocarbon date on bulk organic carbon. Thus, the core provides information about the vegetation history of the lake for the last 700 years. Palynological evidence indicates that the vegetation around the lake basin was dominated by *Quercus* (evergreen oaks) and *Pinus*. The presence of *Olea*, *Juglans*, and Poaceae pollen grains reveals that this forest vegetation was interrupted from time to time by human impact. The existence of the non-arboreal *Taraxacum* and *Plantago* in the uppermost zones of the pollen diagram also indicates grazing or deterioration of the vegetation cover in this region from 1568 AD to the present.

**Key words:** Lake Marmara, pollen, *Olea*, *Juglans*, vegetation change

**Introduction.** Many methods are used to reconstruct environmental changes in Quaternary research. One of these methods is pollen analysis, a significant data source in reflecting the climate and vegetation changes that occurred naturally or through human impact. With pollen analyses and pollen diagrams, climate changes in the Holocene, plant composition changes, the emergence of agricultural

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activities, and human impact on the vegetation structure can be identified in detail [1,2].

Pollen analyses include examining pollen obtained from various settings, such as peatlands, lake sediments, river and marine sediments, glaciers, lignites, and hard coal. Lakes, one of the Quaternary period's critical archives for palynological studies, reflect local and global climate changes more precisely due to closed systems. Pollen analysis studies have been carried out in many lakes and wetlands to identify Türkiye's vegetation change and its development. Some of these studies in western Türkiye were carried out at Lake Köyceğiz [3], Lake Gölçük [4], Lake Sögüt [5], Lake Gölhisar [6], Lake Bafa [7] and Lake Belevi [8]. In lakes Bafa, Gölçük, and Gölhisar close to the study area, temporal change and vegetation development have been revealed through pollen analyses. In Lake Marmara, which was chosen as the research area, environmental changes – based on geochemistry – around the lake were examined by BULKAN et al. [9] especially over the last c. 1800 years. However, no research has been conducted by pollen analysis in this area so far. This study aims at revealing the vegetation history around Lake Marmara for the last 700 years through pollen analyses.

**Material and methods. Description of study area.** Lake Marmara is situated in the west of Türkiye, between the Gölarmara and Salihli districts of Manisa province in the Aegean region (Fig. 1). The elevation of the lake is 80 m. The surface area of the lake changes seasonally according to the amount of

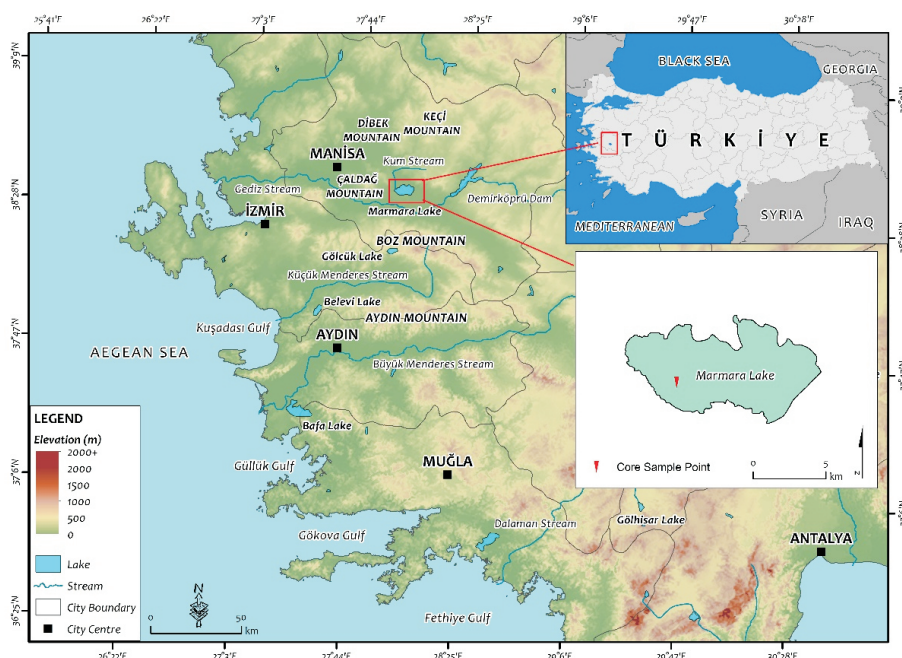


Fig. 1. Map showing location of Lake Marmara

precipitation; it is 40 km<sup>2</sup> on average and its basin area is 1780 km<sup>2</sup>. The lake is located in the lowest part of the tectonic depression between the Salihli and Göl marmara districts, in the flat basin formed by the alluvium carried by the Gördes Stream and the Gediz River [10,11]. The lowland area around the lake is bordered by the Boz Mountain (1135 m) range to the south, Mount Dibek (1100 m) and Mount Keçi (632 m) to the north, and Mount Çaldağ (1034 m) to the west. Metamorphic rocks of the Menderes Massive are present in the northern part of the lake's drainage area. Furthermore, Plio-Quaternary formations are also present at the southern margin of the lake. These units contain fluvial sediments at the bottom and lacustrine carbonates on the top. The Quaternary sediments exhibit mainly fluvial character, but some young palaeo-soils were also observed along the southern coast of the lake [9].

The surrounding area of Lake Marmara is nowadays covered with vast agricultural land irrigated by the lake. Farmland is interrupted by forests and shrubs in the mountainous areas. Marmara Lake basin is an area of 12 000 km<sup>2</sup>, dominated by agricultural lands (Fig. 2). A study covering the period between 1975 and 2011 found that agricultural and residential areas increased while forest areas decreased [12]. According to the Köppen–Geiger climate classification, the most common climate type in Türkiye, C (mild-latitude climate type with mild humid winters), is dominant on the shores of the Aegean region, which includes Lake Marmara. Csa subtype of Köppen–Geiger climate classification is observed

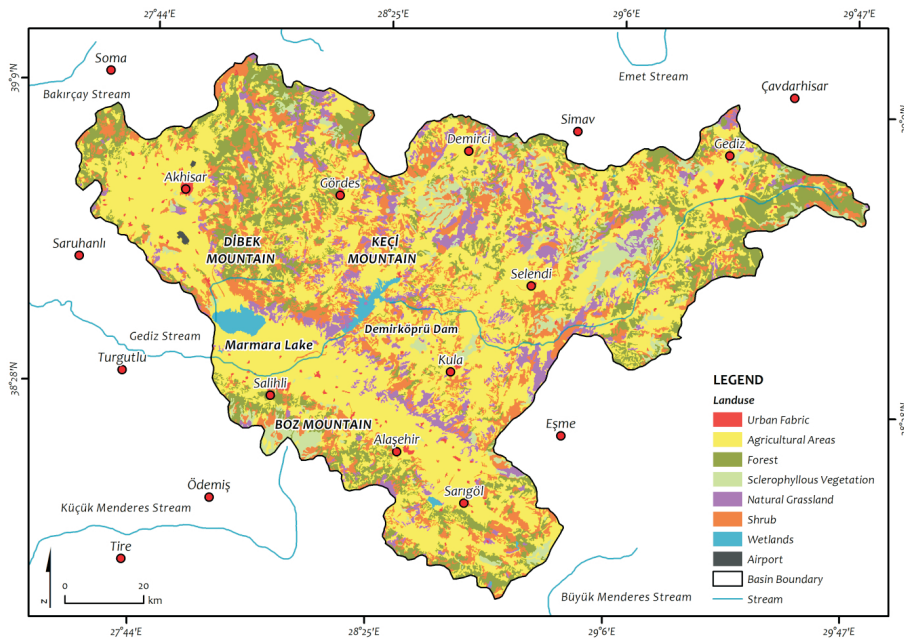


Fig. 2. Land use map of Lake Marmara drainage basin [14]

around Marmara Lake. Csa is a typical Mediterranean climate, with mild winters and very hot summers [13].

The climatic conditions of the region affect the vegetation distribution. There are *Pinus brutia* Ten. forests in the lake basin, away from anthropogenic effects. Maquis and garigue communities, *Quercus coccifera* L., *Cistus creticus* L., *Pistacia terebinthus* L., *Pistacia lentiscus* L., *Arbutus andrachne* L., *Arbutus unedo* L., *Olea europaea* L., *Erica arborea* L., *Phillyrea latifolia* L., *Rubus* sp. and *Sarcopoterium spinosum* (L.) Spach can be found on the southern slopes of Mount Çal and Mount Dibek [12]. Today, Lake Marmara is an important wetland area used for agricultural irrigation, fishing, and recreation.

#### **Collection of core and processing of samples for pollen analysis.**

In the fieldwork, a 65 cm long core, core MD (UTM ZONE 36N X: 584327 Y:4275524), was taken from the deepest part of the lake (water depth is 420 cm) water level for pollen analysis using a KAJAK gravity corer in 22.08.2019. The core was brought to the Palynology Laboratory of the Forest Botany Department in the Faculty of Forestry of Istanbul University-Cerrahpaşa for fossil pollen analysis. The core was sub-sampled for pollen analysis: every 5 centimeters with a volume of 2 cm<sup>3</sup>. Firstly, 10% cold HCl acid and 47% cold HF acid were added to eliminate carbonate and silica content, respectively. We used HCl again to remove the fluor gel formed by the HF reaction. Then, ZnCl<sub>2</sub> (density > 2.0) was used to separate palynomorphs. The remaining sediment was sieved using 200 and 10 µm sieves [15]. The final residue was mounted on a glass slide with one drop of glycerin and fixed by cover glass. Identification and counting of the pollen grains was made using a computer-assisted Leica DM750 light microscope using ×40, ×100 immersion objective and 10× ocular. Pollen atlases were used together with reference pollen preparations in the Palynology Laboratory for identification [15,16]. Pollen grains were identified at the family and genus level and a total of 250 terrestrial pollen grains were counted in each sediment sample. Pollen percentage data were calculated for each taxon and the pollen diagram was drawn with the program TILIA [17]. Pollen diagrams are divided into a series of pollen zones called “Local Pollen Assemblages Zones: LPAZ”, which are characterized by largely similar pollen content at different stratigraphic intervals. A stratigraphically-constrained cluster analysis using a square root transformation was run by CONISS (constrained incremental sum-of-squares cluster analysis). Also, the pollen diversity index has been calculated according to the number of taxa per 100 pollen grains in each sample.

**Radiocarbon dating.** Radiocarbon dating was performed by accelerator mass spectrometry (AMS<sup>14</sup>C) at the Radiocarbon Laboratory in TUBITAK. A sample taken from the bottom of the core was used for AMS radiocarbon analyses of the Total Organic Carbon. The calibrated age was calculated using the Calib 8.2 Radiocarbon Calibration Program [18].

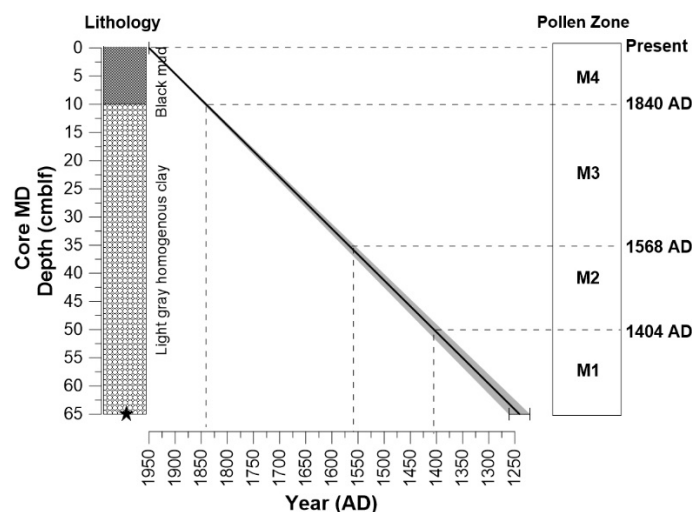


Fig. 3. Age-depth model for core MD based on linear interpolation using calibrated age (star). Grey highlights show error margin

**Results. Lithological description.** Core MD was subdivided into two different lithological zones. The first lithological unit (0–10 cm, Unit I) was a black-coloured mud and the second unit (11–65 cm, Unit II) was distinguished by its light grey homogenous clay (Fig. 3, 4). These lithological units of the core MD exhibited similar litho-stratigraphical characteristics in two cores of a previous study [9].

**Radiocarbon dating results.** The age of the core top was assumed to be the present day (2019). An age-depth model was created by applying linear interpolation (Fig. 3). The uncalibrated age of the sediment sample, at 65 cm depth, was  $813 \pm 24$  yr BP. Calibrated age is  $709 \pm 20$  yr BP. According to the age-depth model, the core MD covers a 700 year-long sedimentary history. If we assume linear sedimentation through the core, the average sedimentation rate is 0.093 cm/yr. BULKAN et al. [9] found sedimentation rate in the core (H3) which is close to our studied core and was calculated as 0.06 cm/yr which is lower than our sedimentation rate of 0.09 cm/yr. Differences in those rates could be caused by the water depth of the core locations or the lithological change of cores.

Plio-Quaternary formations which contain fluvial sediments and lacustrine carbonates are present at the southern margin of the lake. Such regional geology may cause a radiocarbon reservoir effect in lakes. However, there is no reservoir age determination in the previous studies on the lake. For the determination of the reservoir effect detailed analysis and discussion would need to be performed. Thus, here, palynological evidence of the vegetation around the lake basin is presented using calibrated age without reservoir effect estimation.

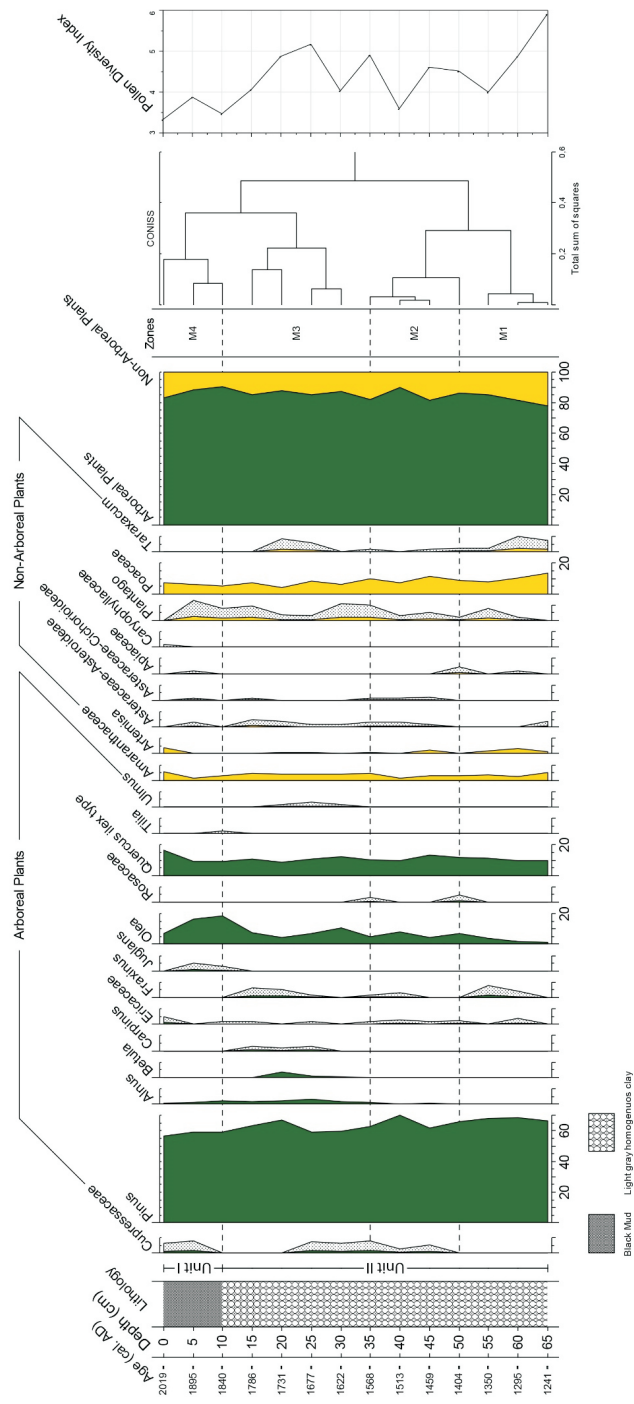


Fig. 4. Percentage pollen diagram of arboreal and non-arboreal taxa in the core MD of Lake Marmara

**Palynological results.** The MD diagram was divided into four Local Pollen Assemblages Zones (LPAZ): M1, M2, M3 and M4, based on the pollen percentage data. Zone M1 of the core includes the depths of 65–50 cm, M2 zone includes 49–35 cm, M3 zone includes 34–10 cm and M4 zone includes 9–0 cm (Fig. 4). Also, the pollen diversity index fluctuated between 3.33 and 5.92 over time. When the pollen percentage diagram was examined, it was observed that the pollen diversity of arboreal taxa was higher than that of herbaceous taxa (non-arboreal). Pollen identification found thirteen taxa belonging to arboreal taxa (AP): thus Cupressaceae, *Pinus*, *Alnus*, *Betula*, *Carpinus*, Ericaceae, *Fraxinus*, *Juglans*, *Olea*, *Quercus ilex* type, *Tilia*, *Ulmus*, and Rosaceae. Nine non-arboreal taxa belong to the NAP group; namely, *Artemisia*, Asteraceae-Asterioideae, Asteraceae-Cichorioideae, Apiaceae, Caryophyllaceae, Amaranthaceae, *Plantago*, Poaceae and *Taraxacum*, were also represented in this diagram (Fig. 4).

When the total pollen percentage values of arboreal and herbaceous taxa are examined, the pollen percentage value of arboreal taxa is over 80% throughout the entire diagram. The types with the highest pollen percentage belonging to arboreal plants were *Pinus*, *Quercus ilex* type, and *Olea*. Regarding the herbaceous taxa (NAP), the highest pollen percentage of non-arboreal taxa belonged to the families of Poaceae and Amaranthaceae (Fig. 4).

In the M1 zone (dated to 1241–1404 AD), the pollen percentage of *Pinus* at the beginning of the pollen diagram was 66.7% and it showed a slight decrease towards the end of this zone. While the pollen percentage of *Quercus ilex* type was 9.6% at the beginning of this zone, it increased to 11.8% at the end of the zone. The pollen percentage of *Olea* started with the value of 1.5% in this zone and increased at the end of the zone. The pollen percentages of *Fraxinus*, Ericaceae, and Rosaceae were below 2% in this zone. The pollen percentage of Poaceae was determined as 13.3%, and it showed a slight decrease towards the end of the zone. The pollen percentage of Amaranthaceae started at 5.2% and decreased towards the end of this zone (3.2%). Pollen percentages of *Artemisia*, Asteraceae-Asterioideae, Asteraceae-Cichorioideae, Apiaceae, *Plantago*, and *Taraxacum* were below 2% (Fig. 4).

In the M2 zone (dated to 1404–1568 AD), the pollen percentages of *Pinus* fluctuated and it decreased at the end of the zone. Although the pollen percentage of *Quercus ilex* type was 11.8% at the beginning of this zone, it dropped to 10.5% at the end. The pollen percentage of *Olea* started at 7.2% and showed a large decrease towards the end of the zone (4.9%). Pollen percentages of Ericaceae, *Fraxinus*, and Rosaceae were also below 4%. *Alnus* and Cupressaceae emerged in this zone for the first time, and pollen percentages remained below 2%. The pollen percentages of Poaceae and Amaranthaceae increased at the end of the zone. Pollen percentages of *Artemisia*, Asteraceae-Asterioideae, Asteraceae-Cichorioideae, Apiaceae, *Plantago* and *Taraxacum* were represented with low values (Fig. 4).

In the M3 zone (dated to 1568–1840 AD), the pollen percentage of *Pinus* increased a little then decreased towards the end of the zone. The pollen percentage of *Quercus* fluctuated in this zone and the pollen percentage decreased slightly at the end. The pollen percentage of *Olea* increased considerably at the end of this zone (18.6%). *Alnus*, Cupressaceae and Ericaceae maintained their presence across the M3 zone. *Betula*, *Carpinus*, *Juglans*, *Tilia* and *Ulmus* emerged in this zone for the first time although pollen percentages remained below 2%. Rosaceae disappeared in this zone. The pollen percentage of Poaceae, Amaranthaceae and *Artemisia* decreased towards the end of the M3 zone. Pollen percentage of *Artemisia*, Asteraceae-Asteroideae, Asteraceae-Cichorioideae, *Plantago* and *Taraxacum* was very low in this zone (Fig. 4).

In the M4 zone (dated to 1840–2019), the pollen percentage of *Pinus* at the beginning of the pollen diagram was 56% and showed a slight decrease towards the end of this zone. The pollen percentage of *Quercus ilex* type increased at the end of this zone and reached its highest value in the pollen diagram with 16.4%. Pollen percentage of *Olea* decreased considerably at the end of the zone. Cupressaceae, *Alnus*, Ericaceae and *Tilia* were also quite low. The pollen percentage of Poaceae, Amaranthaceae and *Artemisia* increased towards the end of the M4 zone. A pollen percentage of Caryophyllaceae pollen was found in this zone for the first time but it was quite low. Asteraceae-Asteroideae, Asteraceae-Cichorioideae, Apiaceae, and *Plantago* maintained their presence in the M4 zone (Fig. 4).

Among the arboreal taxa in Lake Marmara, *Pinus*, *Quercus ilex* type and *Olea* had the highest pollen percentage, respectively. The pollen percentage of *Pinus* slightly decreased in the upper zone of the pollen diagram. That of *Quercus* showed an inverse relationship with the pollen percentage of *Pinus* and the pollen percentage increased towards the present day. The pollen percentage of *Olea*, after a long increasing trend, showed a decreasing trend in recent years.

**Discussion and conclusion.** Palynological evidence indicates that the vegetation around the lake basin is dominated by *Quercus* (evergreen oak) and *Pinus*. As a result of pollen analyses, the presence of *Olea*, *Juglans*, and Poaceae pollen grains in the diagram reveals that this forest vegetation was interrupted from time to time by human impact. When the pollen diagrams of Gölhisar [6], Bafa [7] and Belevi [8] lakes were compared over the last 700 years with the pollen diagram obtained from Lake Marmara, *Pinus* was again identified as the dominant taxon. The second important taxon in the diagram is evergreen oaks. The increasing presence of arboreal taxa *Olea* and *Juglans* characterize arboriculture around Lake Marmara from AD 1786 to the present in our study. Similarly, it has been noted in the uppermost zone of the pollen diagram obtained from Lake Bafa [7] that the increasing pollen values of *Olea* serve as evidence for the cultivation of olives during this period. In the study conducted at Lake Belevi [8], an emphasis was placed on the increase of *Olea* pollen from the year 1574 in the obtained pollen diagram, and it was noted that *Pinus* was the most abundant taxon among all

arboreal taxa.

The presence of Poaceae in the uppermost of the pollen diagram shows that cereal cropping was carried out in this region between 1786 and 1895 AD in our study. The occurrence of *Taraxacum* and *Plantago* in the M3-M4 zones indicates grazing or deterioration in the vegetation cover, and pollen data of these taxa also show human impact. In this study, it was proposed that the species showing human impact were *Taraxacum* and *Plantago*; similarly, [5] and [19] also stated that these species indicated grazing and deterioration in the region.

At the end of the M4 zone since 1895, there was a slight decrease in olive and walnut cultivation, however, pine and oak forests increased in the area in place of abandoned agricultural lands according to the reforestation activities.

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