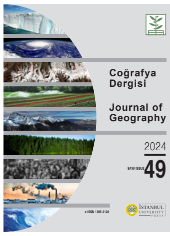

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Vegetation History of Karacabey Longoz Forest and Surrounding Area During the Last 250 Years (Bursa, Türkiye)

Karacabey Longoz Ormanı ve Çevresinin Son 250 Yıllık Vejetasyon Tarihi (Bursa, Türkiye)

Nurgül KARLIOĞLU KILIÇ[1], Rüya YILMAZ DAĞDEVİREN[1], Dilek AYKIR[2], Şakir FURAL[3], Serkan KÜKRER[4], Turhan DOĞAN[5], Yunus Emre MUTLU[6], Nurettin YAKUPOĞLU[7]

[1]Istanbul University-Cerrahpasa, Faculty of Forestry, Department of Forest Botany, Istanbul, Türkiye
[2]Izmir Katip Celebi University, Department of Geography, Izmir, Türkiye
[3]Ahi Evran University, Department of Geography, Kirsehir, Türkiye
[4]Izmir Katip Celebi University, Department of Ship and Ocean Engineering, Izmir, Türkiye
[5]TUBITAK National AMS Laboratory, Marmara Research Center, Kocaeli, Türkiye
[6]Sakarya University, Department of Geography, Sakarya, Türkiye
[7]Istanbul Technical University, Faculty of Mines, Istanbul, Türkiye

ORCID: N.K.K. 0000-0002-6255-6819; R.Y.D. 0000-0003-1209-5257; D.A. 0000-0002-2748-4055; Ş.F. 0000-0002-1603-2424; S.K. 0000-0001-6924-3199; T.D. 0000-0002-1917-8437; Y.E.M. 0000-0003-0421-4535; N.Y. 0000-0003-2837-5771

ABSTRACT
In this study, a 24-cm-long sediment core was taken from Poyraz Lagoon located on the northern side of Karacabey district in Bursa, northwest of Türkiye, using KAJAK gravity core sampling. The bottom sediment was dated using one AMS radiocarbon date on bulk organic carbon. The 13δ corrected radiocarbon age was determined as 238±24 BP. Sediment sub-samples were taken at 4-cm intervals along this core, and pollen slides were prepared using the standard method. A total of 250 terrestrial pollen grains were counted in each sediment sample. The aim of this study was to determine the vegetation history of Karacabey Longoz (Floodplain) Forest and its surrounding area, which have diverse habitat mosaics, over the last 250 years. Palynological evidence indicates that the vegetation around this lagoon basin was dominated by *Fraxinus, Alnus, Carpinus, Quercus* (deciduous oaks), and *Corylus*. The increase in the pollen percentage of *Fraxinus, Alnus*, and *Ulmus*, which are characteristic species of Longoz forests, particularly in the KRC-2 zone, indicates that the presence of these taxa in the area has increased from 1850 AD to the present. Additionally, the increased pollen percentage of anthropogenic indicator species such as *Castanea, Olea*, Chenopodiaceae, and Poaceae in the upper zone of the pollen diagram indicates that the Longoz vegetation in this region has undergone changes due to human impact since 1850 AD.
Keywords: Poyraz Lagoon, Karacabey Longoz Forest, Pollen Analysis

ÖZ
Bu çalışmada, KAJAK karot örnekleyici kullanılarak Türkiye'nin kuzeybatısında yer alan Bursa ilinin kuzeyindeki Karacabey'de bulunan Poyraz Lagününden 24 cm uzunluğunda bir sediman karotu alınmıştır. Karotun en dibinden alınan sediman örneğindeki toplam organik karbona göre AMS radyokarbon tarihlendirilmesi yapılmıştır. Kalibre edilmiş radyokarbon yaşı G.Ö. 238±24 yıl bulunmuştur. Karot boyunca 4 cm aralıklarla sediman örnekleri alınmış ve bu örneklerden standart yöntem kullanılarak polen preparatları hazırlanmıştır. Her örnek seviyesinde toplam 250 adet karasal polen sayılmıştır. Bu çalışmanın amacı: farklı habitat mozaiklerine sahip olan Karacabey Longoz (Subasar) Ormanı ve çevresinin son 250 yıllık vejetasyon tarihini belirlemektir. Palinolojik veriler bu lagünün etrafındaki vejetasyonun baskın türlerini *Fraxinus, Alnus, Carpinus*, yaprak döken meşeler ve *Corylus*'un oluşturduğunu göstermektedir. Longoz ormanlarının karakteristik türlerinden *Fraxinus, Alnus* ve *Ulmus*'un polen yüzdesinin özellikle KRC-2 zonunda artması, 1850 yılından günümüze bu

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Corresponding author/Sorumlu yazar: Nurgül KARLIOĞLU KILIÇ / nurgulk@iuc.edu.tr

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taksonların alandaki varlığının arttığını ifade etmektedir. Ayrıca, polen diyagramının bu üst zonunda antropojenik gösterge türlerinden *Castanea, Olea*, Chenopodiaceae ve Poaceae polen yüzdesinin de artan varlığı, bu bölgedeki longoz vejetasyonunun 1850 yılından günümüze kadar insan etkisiyle değiştiğini de belirtmektedir.
Anahtar kelimeler: Poyraz Lagünü, Karacabey Longoz Ormanı, Polen Analizi

INTRODUCTION

During the Holocene, forest ecosystems underwent significant changes, primarily due to shifts in climatic factors and human impact (Marigrani et al., 2017). The palaeoecological approach has been employed to understand these changes and their causes (Izdebski et al., 2016). One of the most important proxies used in the evaluation of this approach is fossil pollen analysis (Bradley, 2015; Karlıoğlu Kılıç et al., 2018). Pollen analysis, conducted on sediment samples taken from environments such as lakes, wetlands, and marshes, makes it possible to determine the changes in vegetation around these areas during the Holocene. One of the environments where pollen analyses are most effective in identifying changes in past vegetation is the Longoz (Floodplain) Forests (Klimo and Hager, 2001). These forests are defined by the presence of water in the root zone throughout the vegetation period, a condition that significantly affects the growth environment and consequently plant and soil development. In the global literature, many researchers have generally focussed on the biodiversity of Floodplain Forests, which have diverse habitat mosaics (Hughes, 1997; Vukelic and Raus, 2001; Ward et al., 2002). The dominant tree species of Longoz Forests are *Alnus glutinosa, A. incana, Fraxinus excelsior, Populus nigra, Salix alba, S. fragilis, Betula pubescens,* and *Ulmus glabra*. Furthermore, numerous palaeoecological and paleoclimatic studies have been conducted on these specific vegetation ecosystems, providing detailed examinations of the vegetation changes that Longoz Forests have undergone from the past to the present (Bozilova and Beug, 1992; Brayshay and Dinnin, 1999; Filipova-Marinova, 2003; Driese et al., 2005; Jones et al., 2007). Bozilova and Beug (1992) presented the vegetation history of Lake Arkutino, showing no major fluctuations except for Longoz forests, which began to develop around 3000 BP. In the study of Filipova-Marinova (2003), an expansion of *Quercus* and *Corylus* was determined about 9600 yr BP in the paleovalley of the Veleka River on the Strandza Mountains (southern Bulgarian coast). In Türkiye, there are several areas with longoz forests, primarily in the Marmara Region. İğneada Longoz Forests (3155 ha), Hendek Süleymaniye (1650 ha); Adapazarı Dokuma-Döşeme (3000 ha) and Meşeligöl (500 ha); Karasu Turnalı-Acarlar (3000 ha); Bursa-Karacabey (750 ha); İzmit Büyükderbent (250 ha); Sinop Bektaşağa-Aksaz (100 ha); and Hacıosman in Samsun (86 ha) longoz forests constitute the significant floodplain forests in our country (Efe and Alptekin, 1989). The first paleovegetation study within the longoz forests of Türkiye was conducted in the İğneada Longoz Forests (Kırklareli) on the Black Sea coast, and the changing vegetation structure of these forests during the Middle-Late Holocene was extensively examined in a TUBITAK project (Karlıoğlu Kılıç et al., 2023) and as part of a doctoral thesis (Yılmaz Dağdeviren, 2023). The palynological study of Yılmaz Dağdeviren et al. (2024) presents a high-resolution record of vegetation history around Lake Mert, located within the İğneada longoz forests, for the last 6600 years in this region.

Figure 1. The location map of the study area.

The distribution of mixed oak forests began to decline around 1360 BP, coinciding with a significant increase in the presence of *Alnus, Fraxinus*, and *Ulmus.* These trees are characteristic species of floodplain forest and indicate the initiation of the formation of the İğneada Longoz Forests after 1360 BP. Furthermore, there was a substantial decrease in the pollen percentages of *Quercus* and *Fagus* around 420 BP. The increase in the pollen percentages of indicator herbaceous taxa (*Plantago*, Poaceae, and Chenopodiaceae) in the vicinity of Lake Mert serves as evidence of the conversion of forest areas into agricultural and grazing lands during the last 420 years (Yılmaz Dağdeviren et al., 2024).

A number of palynological studies (Leroy et al., 2001; Miebach et al., 2016) have also been conducted on vegetation changes in many lakes of the Marmara region located near the Karacabey Longoz Forests. Sediments from Lake Manyas (Leroy et al., 2001; Kutluk, 2019), Lake Sapanca (Leroy et al., 2009), and Lake Iznik (Ülgen et al., 2012; Miebach et al., 2016) were investigated by pollen analysis. While numerous fossil pollen studies have been conducted in the Marmara region of Türkiye, paleopalynological investigations have been limited, especially in the Karacabey Longoz Forests. Therefore, the research area was chosen as Poyraz Lagoon, surrounded by the unique ecosystems of the Karacabey Longoz Forests. The aim of this study was to determine the vegetation history in the Karacabey Longoz (Floodplain) Forest and surrounding area for the last 250 years.

1. MATERIALS AND METHODS

1.1. Study area

The Karacabey Longoz Forest is located on the northern side of the Karacabey district in Bursa, on the coast of the Marmara Sea at the mouth of the Kocasu Stream (Figure 1). There are three lakes, Dalyan Lagoon, Poyraz Lagoon, and Arapçiftliği Lagoon, in the Kocasu Delta and within this longoz forest (Figure 2).

The Karacabey Longoz Forest consists of a floodplain forest spread over an area of 730 ha and a vast dune belt (Figure 2). The lakes are surrounded by longoz forests composed mainly of ash (*Fraxinus ornus* L.), alder (*Alnus glutinosa* (L.) Gaertn.), and willow (*Salix* sp.), covered with a water layer approximately 1 m deep in most places (Güngördü, 1996; Güngördü, 2001).

Oriental beech (*Fagus orientalis* Lipsky), Field Maple (*Acer campestre* L.), Strawberry Tree (*Arbutus unedo* L.), Oriental Hornbeam (*Carpinus orientalis* Mill.), Chestnut (*Castanea sativa* Mill.), Pink Rockrose (*Cistus creticus* L.), Narrow-leaved Ash (*Fraxinus angustifolia* Vahl), and Common Aspen (*Populus tremula* L.) are among the other important plant species found in the lagoon and its vicinity. The Karadağ mountain massif extends in an east-west direction, hosting the distribution of both moist and dry forest tree species to the south of Poyraz Lagoon. Tree species of moist forests such as *Fagus orientalis, Castanea sativa,* and sessile oak (*Quercus petraea* (Matt.) Liebl.) can be observed on the northern slopes of this massif. Tree species of dry forests such as *Quercus cerris* L. and *Quercus infectoria* Oliv. are distributed on the south-facing slopes, where the elevation decreases towards the Karacabey Plain (Güngördü, 1996; Güngördü, 2001).

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 west Anatolia region, which includes the Karacabey Longoz Forest. The Csa subtype of the Köppen– Geiger climate classification is observed around the Karacabey Longoz Forest. Csa has a typical Mediterranean climate, with mild winters and scalding very hot summers (Öztürk et al., 2017). According to the Thornthwaite method, the region falls under climate type C2 B'2 s2 b'3: semi- humid, mesothermal, experiencing a pronounced water deficit in the summer season and closely resembling an oceanic climate type. The average annual temperature is 15.5°C, with an average annual rainfall of 719 mm (Sarıyıldız et al., 2020).

In the study area, it is possible to observe lithological units from various age intervals ranging from the Palaeozoic to the Quaternary. The foundation of the field is formed by the Kalabak Formation, which consists of schist and metaclastik rock from the Late Palaeozoic era (Figure 3). These rocks, which form the foundation of the area, outcrop in the mountainous massif of Karadağ, extending east to west to the south of the Karacabey Longoz Forest. Another unit that, along with the Kalabak Formation, forms the foundation of the area is a volcanic formation called the "Karacabey metagranite" (Aysal et al., 2012). The Karakaya Complex, which belongs to the Mesozoic era and consists of sandstone, mudstone, and limestone sequences, is exposed over a wide area in an east-west direction to the south of the longoz forest (Okay and Göncüoğlu, 2004). Quaternary units, which are the youngest formations in the field, are represented by alluvion and are observed in extensive areas, including the Kocaçay Delta, the Kocaçay riverbed, the Karacabey Longoz Forest further to the north, and the surrounding areas, which also encompass the Lagoons (Figure 3).

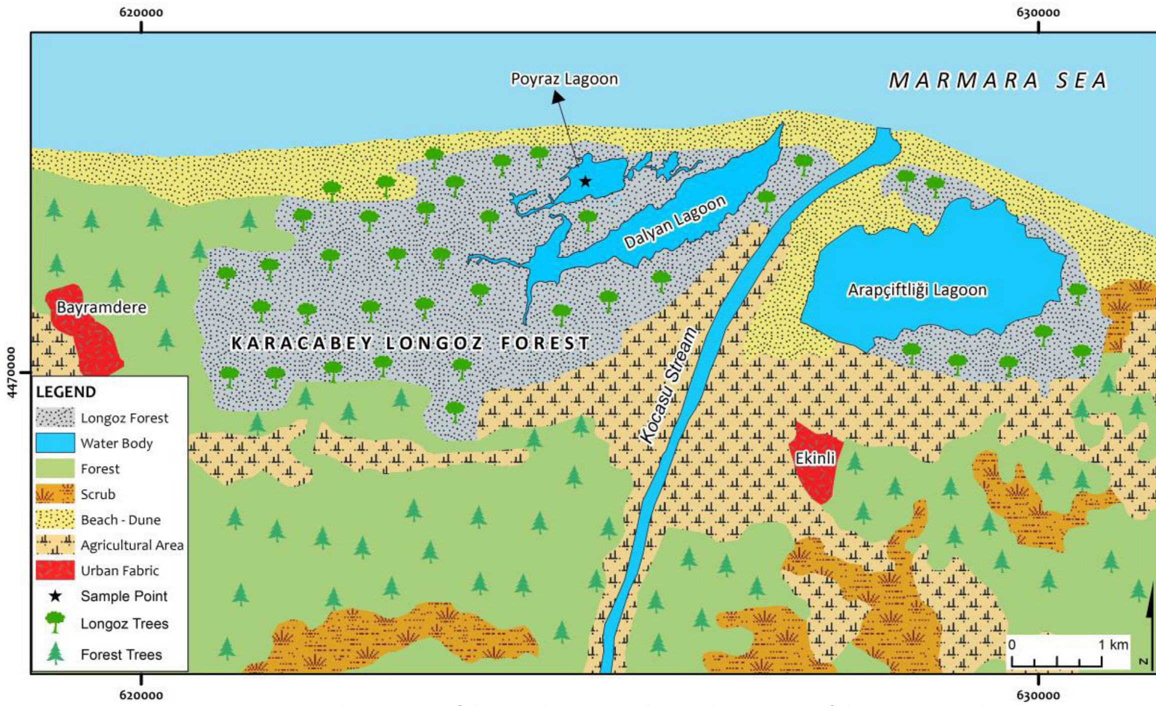

Figure 2. Land use map of the study area and sampling point of the core sample.

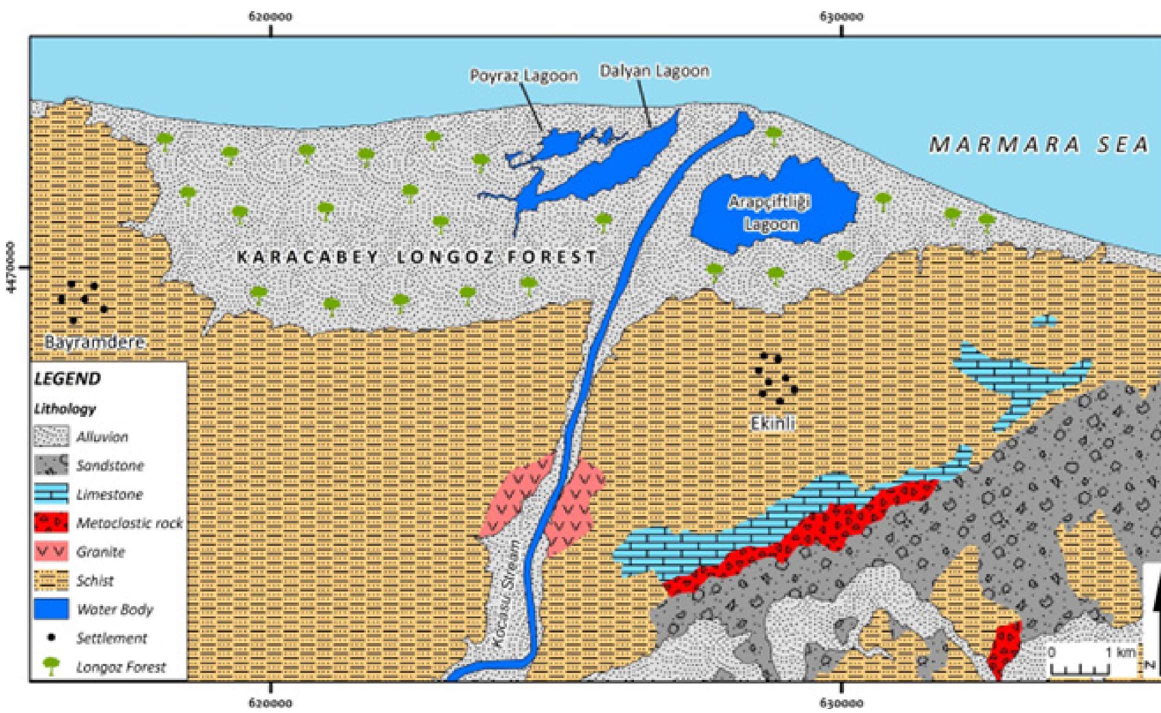

Figure 3. Geological map of the study area.

1.2. Core study and lithology

In the fieldwork, a 24-cm-long core, core KRC (UTM ZONE 35N X: 624949 Y: 4472135) was taken from Poyraz Lagoon for fossil pollen analysis using KAJAK gravity core sampling in 2021 (Figure 2). The core was transported to the Palynology Laboratory of the Forest Botany Department in the Faculty of Forestry of Istanbul University-Cerrahpaşa and split into two. Half of the core was used in lithostratigraphic study and sampled for pollen analysis and radiocarbon dating.

1.3. Radiocarbon dating and age-depth model

A sediment sample collected at a borehole depth of 24 cm was used for radiocarbon sampling. Radiocarbon analysis was performed at the TÜBİTAK Marmara Research Centre 1MV

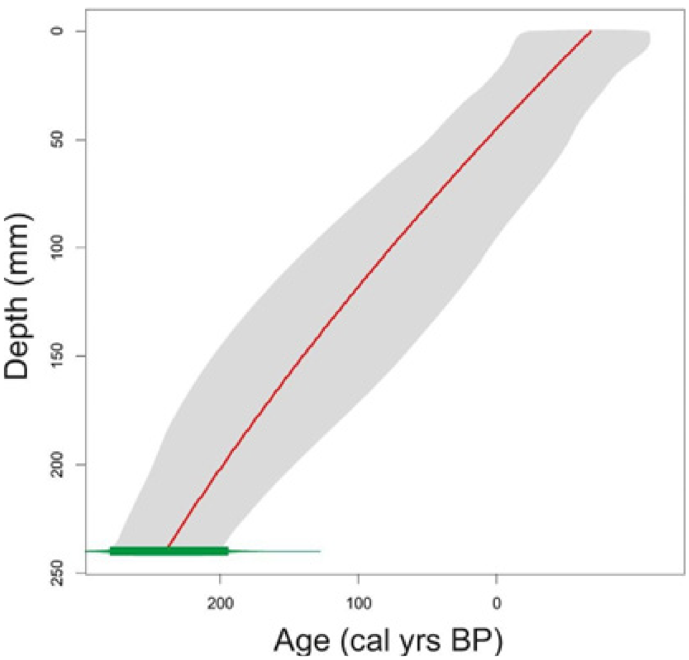

Figure 4. Age-depth model of the KRC core.

National AMS Laboratory. For chemical sample preparation of the sediment, 1g sediment sample was subsampled for analysis. Roots that are fresh and modern are picked with tweezers from sediment. Sample is continuously washed with 0.5M HCl at 70°C until all carbonates are eliminated. The rest of the sample was carbonate-free acid-insoluble total organic material.

The sample is sieved with 180 micrometre sieves to cheque if there are any macrofossils left. There were no macrofossils after the process. The prepared sample was reduced to pure carbon in graphite form and measured using TÜBİTAK AMS. The radiocarbon result was calibrated using the Intcal20 (Reimer et al., 2020) database. Age-depth model was constructed using the top of the core (the most recent sediments ~2021 AD) and 14C dating via "clam" script on R.studio software (Blaauw, 2010). In addition, a 95 % Gaussian interval was used for constructing age-depth iterations (Blaauw, 2010; Figure 4).

1.4. Collection of cores and processing of samples for fossil pollen analysis

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 sampled for fossil pollen analysis according to the standard method (Moore et al., 1991), and sediment samples of 2 g every 4 cm were collected. Identification and counting of pollen grains was performed using a computer-assisted Leica DM750 light microscope. Pollen atlases were used together with reference pollen preparations in the Palynology Laboratory for pollen identification (Erdtman, 1952; Erdtman, 1957; Faegri and Iversen, 1964; Aytuğ et al., 1971; Moore et al., 1991; Beug, 2004). Pollen grains were identified at the family and genus level, and 250 terrestrial pollens were counted in each sediment sample. Pollen percentage data were calculated for each plant taxon, and a fossil pollen diagram was drawn with the programme TILIA (Grimm, 2019). Pollen diagrams are divided into a series of pollen zones called "Local Pollen Assemblages Zones: LPAZ", which are characterised by largely similar pollen content at different stratigraphic intervals. The TILIA programme (Grimm, 2019) was also used for CONISS clustering analyses to facilitate the delimitation of pollen zones in the pollen diagram. The diagram includes an age-depth model that incorporates age information corresponding to each depth level (Figure 5).

2. RESULTS

2.1. Core lithology and chronology

The lithological and textural variations through core KRC documented by visual observation enabled one lithostratigraphic unit labelled as unit K1 (Figure 5). The sedimentary sequence in the core of the KRC reveals that unit K1 mainly consists of grey homogenous clay mud.

The 13δ corrected radiocarbon age was 238±24 BP, was calibrated using the Intcal20 (Reimer et al., 2020) database. Age-depth model was constructed using the top of the core (the most recent sediments ~2021 AD) and 14C dating via "clam" script on R.studio. %95 Gaussian intervals have been used for constructing age-depth iterations (Blaauw, 2010). One radiocarbon date from core KRC (Table 1) allows the construction of an age-depth model for the last about 250 years (Figure 4). Assuming sedimentation was a linear accumulation of 1.01 mm/year calculated.

2.2. Palynological results

The pollen percentage data of arboreal and herbaceous taxa were drawn as a "percentage pollen diagram" in the TILIA (Grimm, 2019). Through CONISS Clustering analysis, the core was partitioned into two main pollen assemblage zones (LPAZ). The core was separated into two local pollen assembly zones (LPAZ) KRC-1 and KRC-2 based on pollen percentage data. The KRC-1 zone of the core includes 24-12 cm and the KRC-2 zone includes 11-0 cm (Figure 5). When the pollen percentage diagram was examined, it was observed that the pollen percentage of arboreal taxa was higher than that of herbaceous taxa (non-arboreal). Pollen identification of 14 arboreal taxa (AP) belonging to Cupressaceae, *Pinus*, *Alnus, Carpinus, Castanea, Corylus,* Ericaceae, *Fagus*, *Fraxinus, Olea, Quercus cerris* type*, Tilia*, *Ulmus,* and Rosaceae are shown in the pollen diagram. Seven non-arboreal plants belonging to the NAP group; namely, Apiaceae, *Artemisia,* Asteraceae, Amaranthaceae (Chenopodiaceae) Caryophyllaceae, *Plantago and* Poaceae are also represented in this diagram. When the total pollen percentage of arboreal and herbaceous taxa was examined, the pollen percentage of arboreal taxa was >70% the entire diagram. The highest pollen percentage in the arboreal taxa belonged to the *Fraxinus*, *Alnus,* and *Quercus cerris* type. Regarding the herbaceous taxa (NAP) in the percentage pollen diagram, the highest pollen percentage of non-arboreal plants belonged to Amaranthaceae and Poaceae (Figure 5).

In the KRC-1 zone (dated to 1710-1847 AD), the pollen percentage of *Fraxinus* was 36% at the beginning of the pollen diagram, and it showed a slight decrease towards the end of this zone. Although the pollen percentage of *Alnus* was 5.7% at the beginning of this zone, it increased to 24.1% at the end of the zone. The pollen percentage of the *Quercus cerris* type started with a value of 11.4 % at the beginning of the zone, slightly increased to 12.8% in the middle of this zone, and decreased to 5.7% at the end of KRC-1. The pollen percentage of *Corylus* at the beginning of the pollen diagram was 12%, and it showed a slight decrease in the end of this zone. The pollen percentage of *Carpinus* started at 6%, decreased slightly, and increased to 18.9% at the end of this zone. The pollen percentages of *Castanea,* Ericaceae, *Fagus, Olea,* Rosaceae*, Tilia,* and *Ulmus* were below 3% in this zone. The pollen percentages of Gymnospermae taxa *Pinus* and Cupressaceae increased throughout this zone. The pollen percentage of Poaceae was determined to be 10% at the beginning of the zone, and it showed a slight decrease in the end of the zone. The pollen percentage of Amaranthaceae started at 8.3% and decreased at the end of this zone. The pollen percentages of Apiaceae, *Artemisia*, Asteraceae, and Caryophyllaceae were below 2% in this zone (Figure 5).

In the KRC-2 zone (dated to 1847-2021 AD), the pollen percentage of *Fraxinus* at the beginning of the pollen diagram was 14.2% and greatly increased to 27% at the end of the zone. The pollen percentage of *Alnus* was 24.1% at the beginning of this zone and increased to 25.2% in the middle of this zone and decreased to 15.6% at the end of the zone. Although the pollen percentage of *Corylus* was 6.1% at the beginning of this zone, it increased to 19.1% and dropped to 7.6% at the end of this zone. The pollen percentage of the *Quercus cerris* type increased and the pollen percentage of *Carpinus* decreased throughout this zone. Pollen percentages of *Castanea*, Ericaceae, *Fagus, Olea*, Rosaceae, *Tilia,* and *Ulmus* were also quite low in this zone. The pollen percentage of *Pinus* fluctuated and showed a slight increase in the end of this zone. The pollen percentage of Cupressaceae started at 4.7 % in this zone and decreased at the end of the zone. In this zone, the pollen percentage of Poaceae and Amaranthaceae increased at the end of the zone. The pollen percentages of Apiaceae, *Artemisia*, Asteraceae, Caryophyllaceae, and *Plantago* were below 2% in this zone (Figure 5).

3. DISCUSSION AND CONCLUSION

Palynological evidence indicates that the vegetation around the Poyraz Lagoon was dominated by *Fraxinus, Alnus, Carpinus, Corylus,* and *Quercus cerris* type (deciduous oaks) for the last 250 years. Based on the KRC core data, the period between 1710 and 1847 AD in the KRC-1 zone of the pollen diagram, is characterised by the dominance of *Fraxinus,* deciduous oaks (*Quercus cerris* type), *Alnus, Corylus,* and *Carpinus*. This zone exhibits widespread ash forests, reaching their maximum distribution. Between 1847 and 2021 AD in the KRC-2 zone, a mixed forest of alder, hornbeam, hazel, and deciduous oaks maintained their dominance in the region surrounding Poyraz Lagoon. These forests consist of various arboreal species such as *Fraxinus, Alnus, Carpinus, Corylus,* and *Quercus cerris* type. In addition, *Castanea, Fagus, Olea,* and *Ulmus* are present in smaller proportions in this zone. From 1901 AD to 2021 AD, notably, the pollen percentages of *Fraxinus, Alnus, Quercus cerris* type, and *Ulmus* have increased since the beginning of the KRC-2 zone. The formation of longoz vegetation in Karacabey Longoz Forests was associated with the onset of increased pollen percentages of *Fraxinus, Alnus,* and *Ulmus* over the last 250 years. In addition, the increase in pollen percentage of *Olea*, Chenopodiaceae, *Plantago,* and Poaceae in the diagram reveals that this longoz forest vegetation was interrupted from time to time by human impact between 1900 and 2021 AD. Pollen grains of these taxa (Poaceae, Chenopodiacece and *Plantago*) are indicator taxa used for monitoring environmental changes, with their presence considered as indicators of agricultural and settlement activities (Behre, 1990; Li et al., 2008).

When examining fossil pollen studies conducted in the lakes of the Marmara Region, it has been observed that there are pollen diagram data for Lake Manyas (Leroy et al. 2001) and palynomorph data for Lake Manyas (Kutluk, 2019), Lake Iznik (Ülgen et al. 2012; Miebach et al. 2016), and Lake Sapanca

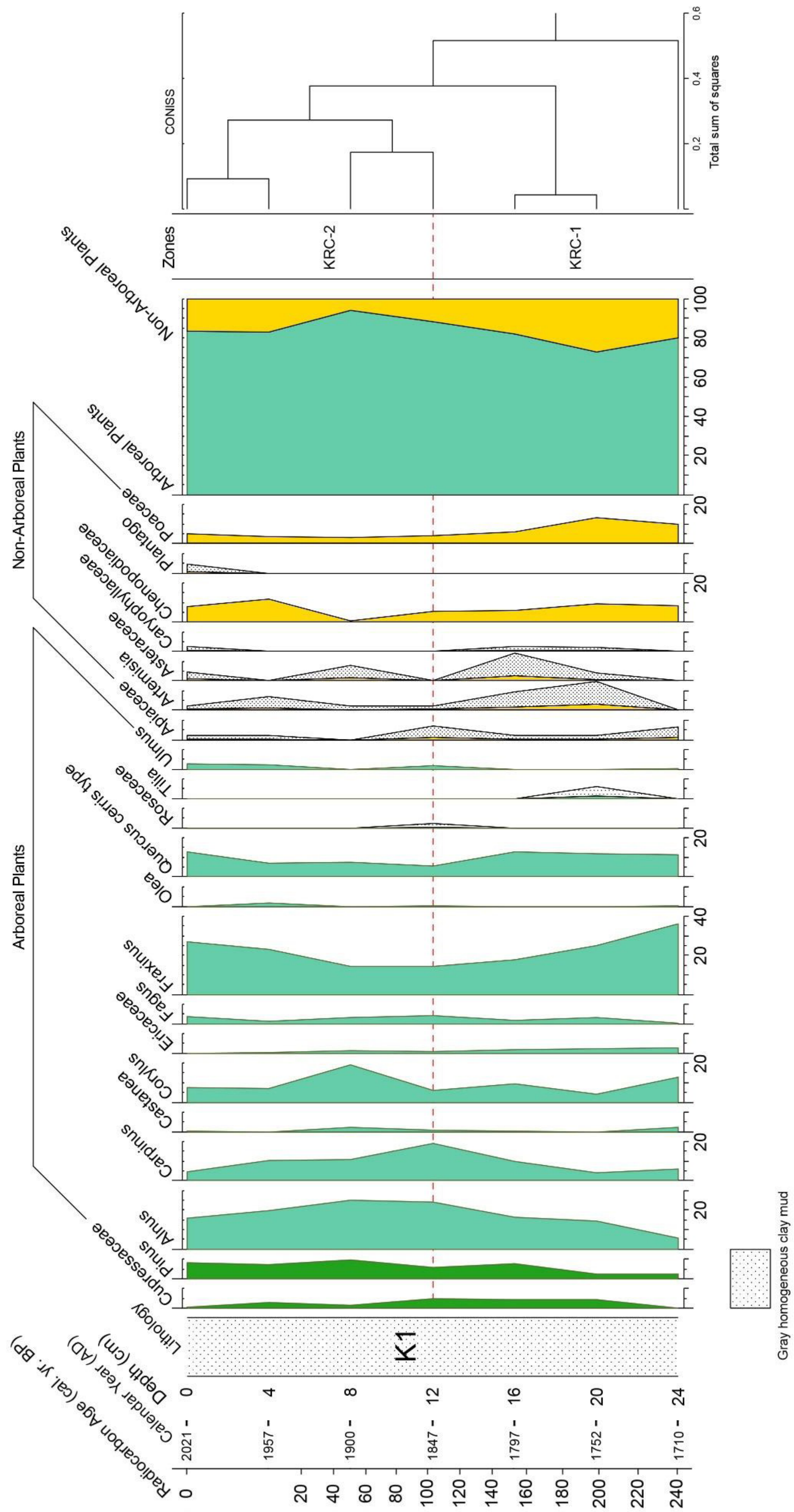

Figure 5. Pollen percentage diagram of arboreal and non-arboreal plant taxa in the KRC core.

(Leroy et al. 2009). The pollen percentage data from these pollen diagrams were compared with the pollen percentage data obtained from the research area of Poyraz Lagoon. When the pollen analysis of the KRC core samples is compared with the study conducted in Lake Manyas, it is observed that deciduous oaks dominate around Lake Manyas. Characteristic taxa of the Longoz (floodplain) forest, such as *Fraxinus* and *Ulmus*, have been found to have a very low pollen percentage in the pollen diagram of Lake Manyas (Leroy et al. 2001; Kutluk, 2019). Furthermore, the absence of *Alnus* pollen, which is representative of longoz vegetation, indicates that the vegetation in and around Lake Manyas is quite different from that of the Karacabey Longoz Forest. When the pollen diagram data obtained from Lake Iznik is compared with the pollen diagram data obtained from the Karacabey Longoz Forest for the last 250 years, it is observed that deciduous oaks still dominate Lake Iznik and its surroundings. *Fagus, Corylus, Carpinus,* and *Alnus* accompany oaks with low pollen percentages (Ülgen et al. 2012; Miebach et al. 2016). When examining the pollen diagram data obtained from Lake Sapanca (Leroy et al. 2009), which is located in close proximity to the Karacabey Longoz Forest, it is observed that the *Quercus cerris* type dominates around the lake and its surroundings, with *Fagus, Carpinus*, and *Alnus* accompanying the oaks. When comparing the fossil pollen data from Lake Sapanca and the Karacabey Longoz for the last 250 years, it was determined that species characteristic of the longoz vegetation are prevalent in the vicinity of the Karacabey Longoz, whereas mixed oak forests dominate in the surroundings of Lake Sapanca. When comparing the fossil pollen results obtained from another study conducted in Lake Mert, surrounded by longoz (floodplain) vegetation in İğneada, it was determined that the area around the lake has been covered with mixed deciduous oak forests for approximately 1360 BP. The pollen percentages of *Alnus, Fraxinus*, and *Ulmus* have experienced a sharp increase in 1360 BP in this study. The distribution of mixed deciduous oak forests experienced a significant decline around 420-BP, according to the upper zone of the pollen diagram. The decrease in arboreal pollen percentages and the rise in pollen diagrams of *Plantago, Ambrosia*, Asteraceae, and Poaceae taxa indicate that there has been a transition of forest areas to agricultural and pasture lands around Lake Mert for the last 420 years (Karlıoğlu Kılıç et al. 2023; Yılmaz Dağdeviren et al. 2024). The increase in *Fraxinus, Alnus,* and *Ulmus,* especially towards the uppermost zone in the pollen diagram obtained from Poyraz Lagoon, similar to the study conducted in Lake Mert (Karlıoğlu Kılıç et al. 2023; Yılmaz Dağdeviren et al. 2024), suggests that the longoz vegetation around Poyraz Lagoon has maintained its existence over the past 250 years.

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