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Problems in dating results on lake sediments: Türkiye

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ABSTRACT

In the dating process on the study of earth sciences, one of the basic assumptions is the equilibrium in the amount of carbon between terrestrial samples and the atmosphere. Most radiocarbon dating results are prepared regarding to this assumption. Although it is frequently used, some invalid situations can be encountered during the subaquatic studies. Recent water samples, aquatic plants, and remnant of animals may present different ages than the actual age. Another problem using the age-depth model is how many dating results should we be used to ensure high accuracy of the model. We also present our field study results about the number of dating points. The aim of this study is to explain how we could solve the problem in dating the freshwater reservoir effect over for short and longtime durations. In order to eliminate the freshwater reservoir effect, the terrestrial material must be dated. Thus, the carbon in the organic material is not affected by the dissolved carbon in the water. The circumstances significantly improve the age-depth model's accuracy.

1. Introduction

Due to the presence of some complexities of the so-called reservoir effects, the dating method, which was created based on the balanced amount of carbon in the atmosphere and terrestrial samples, causes the age data to be either older or younger. Reservoir effects in lake-fluvial and marine deposits has been known for more than 60 years, the marine reservoir effect is still more widely known among archaeologists and earth scientists (Mahaney, 1984; Walker, 2005; Roberts, 2014; Lowe and Walker, 2015) as it is an open system and ^{14}C dating results can be arranged and corrected with the known parameters obtained its own environments. On the other hand, the dating process of lake sediments can seriously be corrupted because they are a closed system at inland areas (Godwin, 1951; Philippsen et al., 2010; Philippsen, 2012). Therefore, the freshwater and hardwater reservoir effect can cause the samples to have unusually older (dissolved C) or younger (deep-seated aquatic plant roots) radiocarbon ages. Examining the amount and degree of variability of the freshwater reservoir effect over short and long durations is the main issue of this study. Due to the decreased solubility of carbon isotopes in water, determined age value will be older than the actual age. If the age data is not corrected, this problem will cause the wrong age-depth model to be constructed. In order to avoid such incorrect age data, terrestrial materials should be selected from the lake sediments and dated accordingly. It is not always possible to find out terrestrial remnants and in this case bulk sediments or shells are preferred for dating (Turney, 1999; Zhou et al., 2015). Therefore, we propose an approach for dating material to obtain accurate age-depth model.

The focus of this study is to discuss the difficulties experienced by different branches of sciences using the dating method during the interpretation of the

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findings, and to present a proposal especially for the applications made in dating strategy for lake sediment samples. In this case, terrestrial pollens are only one remnant transferred from terrestrial to lacustrine environments. Türkiye has very rich pollen contents because of the seasonal and environmental conditions. Thus, many taxa in Türkiye's lakes are identified in the fossil pollen diagram. Terrestrial pollens are also seen in the lake sediments and they are the main material for the ^{14}C dating.

In the usage of fossil pollen remnants obtained from the lake sediment, a critical point must be taken into account. There are a number of aquatic fossil pollens in Türkiye (*Butomus sp., Cyperaceae, Equisetum sp., Juncus sp., Lythrum sp., Myriophyllum sp., Nymphaea, Phragmites sp., Potamegaton sp., Sparganium sp., Typha sp.,* and genera and species belonging to these taxa). Some of these species are perennial (eg *Typha*; Strawberry), while others have a one-year lifespan (eg sub-taxa of Cyperaceae and *Juncus* sp.). Despite the fact that these plants differ depending on the wetland, perennial species can form dense vegetation in or near the wetland (Sultansazlığı Marsh, Engir Lake, Karakuyu Marsh). Every year, as long as their root systems are alive, these plants shed their dead parts into their living environments. Moreover, plants with strong root systems, such as Phragmites sp. (Reed), can settle in the sediment and cause changes in the original features of the sediment. Stratigraphic deterioration may occur in the process of transition of plants to the sedimentation as a result of the changing conditions of aquatic plants due to natural or human causes. Their residues affect sedimentation through natural transport of plants around the wetland, such as floods, rainfall, and streams. Because of this, stratigraphic inconsistencies encountered during the transition period of natural or human-made, wetlands or non-wetland origin plants to sedimentation may reveal that the age to be younger or older than it is. These situations create the problems during the construction of age-depth model.

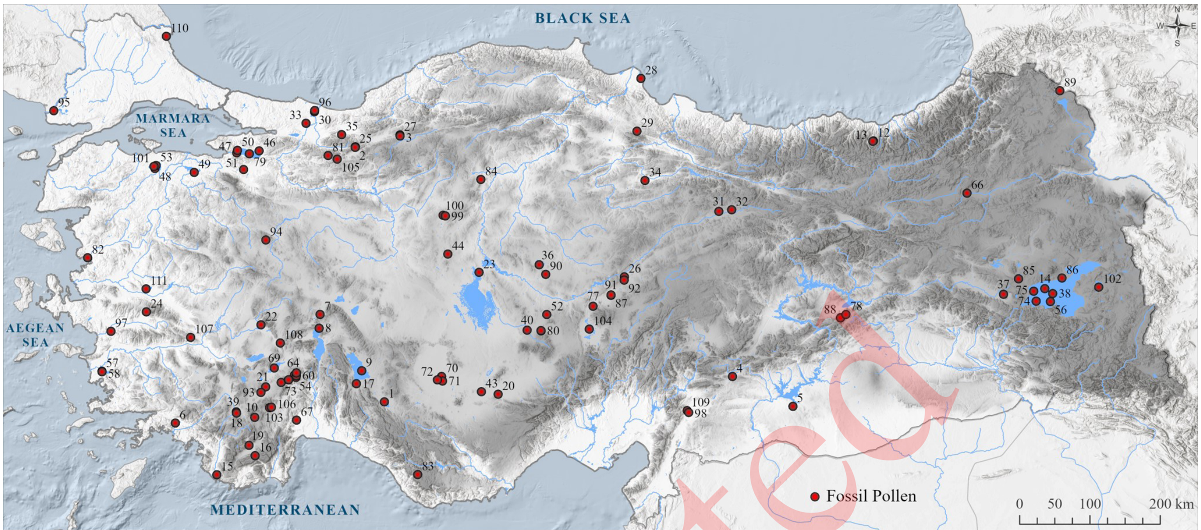
Another important aspect of this study is the number of ages that should be included in an accurate age-depth model along the sediment core. Researchers nowadays that use a multi-proxy set in lacustrine areas as part of paleoecology studies perform mainly radiocarbon dating in order to provide valid age-depth model. This enables the creation of a reliable and comparable event chronology, as well as the comparison of various proxy sets based on a similar time assumption. The factors affecting the results of age-depth model are discussed by using our previous studies (Şenkul et al., 2022*b*).

2. Historical Background of Fossil Pollen Studies in Anatolia

It is difficult to generalize, rank and classify in studies where fossil pollen analyzes are carried out in Anatolia in terms of dating. However, it can be said that the number of studies has increased relatively, the number of dating has increased and the problems encountered in dating have been solved. Among ~111 fossil pollen studies regarding sediment core that were carried out in Anatolia, the cores of ~90 samples were dated (radiocarbon, U-Th and varv dating), while the remaining samples were not dated or could not be dated (for Lake Van, (Van Zeist and Woldring, 1978; Landmann et al., 1996; Wick et al., 2003; Litt et al., 2009) (Appendix Table 1).

The following evaluation can be made about the dating of ~111 cores in the 57-year period between 1967 and 2024, when the first fossil pollen study was carried out (Appendix Table 1 and Figure 1). Some researchers believe it is important to date the cores they have obtained, while other researchers do not. Due to lacustrine processes, little or no pollen density, the inability to get long sediment cores from some lakes, financial constraints in some studies, and other factors, dating cannot be done. The positive contribution of the developments in the field of fossil pollen studies has shaped the dating processes in changing scientific practice.

Different data sets are used today to examine lacustrine/wetland research within the context of paleoecology investigations. Numerous dating techniques, particularly the radiocarbon method, are used to examine the studies done in this context. As a result of using several data sets, a trustworthy and comparable event chronology is obtained. Additionally, a common and more trustworthy assumption of time is revealed. The analysis of radiocarbon dates plays a significant role in paleoecological research and is a technique that can address typical chronology and dating issues in paleoecological studies in the Mediterranean. For instance, a more precise age-depth model was obtained from the survey carried out in the Sultansazlığı Marsh in Central Anatolia using radiocarbon dating analyses with fossil pollen (Şenkul et al., 2022*b*).



CODE 1	STUDY AREA and CORE 1	CODE 2	STUDY AREA and CORE 2	CODE 3	STUDY AREA and CORE 3
1	Konya-Süberde	41	Başköy MV 1A	81	Çubuk Lake
2	Abant Lake I	42	Başköy MV 1B	82	Elaia Harbour
3	Yeniçağa Lake I	43	Paleo-Konya Lake	83	Dağlık Kilikya
4	Gölbaşı Lake	44	Çöl Lake	84	Süleymanlı Section
5	Bozova	45	Gravgaz Marsh 1999	85	Nazik Lake
6	Köyceğiz Lake	46	Çakırca	86	Arin Lake
7	Karamık Lake	47	Gölyaka	87	Engir Lake
8	Hoyran Lake	48	Kuşcenneti II	88	Hazar Lake Hz11-P03
9	Beyşehir Lake I	49	Apolyont	89	Aktaş Lake
10	Söğüt Lake	50	Ilıpınar	90	Mucur Obruk Lake
11	Ağaçbaşı I	51	Yenişehir	91	Engir Lake II
12	Ağaçbaşı II	52	Eski Acıgöl	92	Tuzla Lake II
13	Ağaçbaşı III	53	Manyas Lake	93	Karataş Lake
14	Van I	54	Çanaklı	94	Kureyşler
15	Ova Lake	55	Gravgaz Marsh 1996	95	Enez (Ain50)
16	Avlan Lake	56	Van III	96	Akgöl Lake
17	Beyşehir Lake II	57	Bafa S 1	97	Belevi Lake
18	Gölhisar Lake I	58	Bafa S 6	98	Sağlık II
19	Elmalı	59	Gravgaz Marsh 1998	99	Mogan Lake Core MD
20	Akgöl Adabağ	60	Ağlasun Core 9	100	Mogan Lake Core MS
21	Pınarbaşı	61	Ağlasun Core 13	101	Manyas Lake II
22	Işıklı Lake I	62	Ağlasun Core 6	102	Erçek Lake
23	Tuz Lake	63	Ağlasun Core 12	103	Yelten Sazlığı I
24	Gölcük Lake	64	Core PQ01	104	Sultansazlığı
25	Abant Lake II	65	Core PQ99	105	Sünnet Lake
26	Tuzla Lake I	66	Pasinler	106	Yelten Sazlığı II
27	Yenicağa Lake II	67	Öküzini	107	Buldan Yayla Lake
28	Tatlı Lake	68	Nar Lake I	108	Karakuyu Marsh
29	Ladik Lake	69	Burdur Lake	109	Gavur Lake
30	Adatepe	70	Çatalhöyük	110	Mert Lake
31	Büyükgöl	71	Avrat Hanıhöyük	111	Marmara Lake
32	Demiryurt Lake	72	Kızılhöyük		
33	Küçük Akgöl	73	Bereket		
34	Kaz Lake	74	Van IV		
35	Melen	75	Van V		
36	Seyfe	76	Gravgaz SA06EP1		
37	Söğütlü	77	Çora Maarı		
38	Van II	78	Hazar Lake Hz11-P02		
39	Gölhisar Lake II	79	İznik Lake		
40	Aşıklı Höyük	80	Nar Lake II		

Figure 1- Spatial distribution of fossil pollen studies carried out in Anatolia (the references of the table is given in appendix Table 1).

3. Methodology

A significant development in dating occurred with Willard Libby's article "Radiocarbon from Cosmic Radiation" (Anderson et al., 1947). This new approach is founded on the idea of estimating age by accounting for the half-life of the carbon-14 (^{14}C) isotope present in organic material. The effectiveness of the investigations led to the Nobel Prize in Chemistry being given for the groundbreaking discovery in 1960. Because of its radioactivity, the ^{14}C isotope, which has a half-life of 5730 years, has been called "radiocarbon". Nitrogen loses a proton and changes into ^{14}C as a result of the nuclear process that takes place when it interacts with cosmic neutrons in the upper layers of the atmosphere. Carbon dioxide is created when carbon atoms interact with oxygen in the atmosphere. Through photosynthesis, atmospheric carbon dioxide gets into the plants. These stages lead to a balance between the amount of ^{14}C in the atmosphere and the biosphere. Since the carbon influx (^{14}C) that living things receive into their bodies comes to an end when they die, the amount of ^{14}C in living things will gradually diminish through radioactive decay. The radiocarbon method is based on the idea that age of living thing may be determined using the half-life of ^{14}C. According to this dating, a time period of up to 50,000 years can be accurately determined. There is an uncertainty of 30 years every 5730 years at the radiocarbon dating point and 10 years in more exact readings. 1950 is used as the theoretical starting point for the radiocarbon age, which is taken to be the current year or common era (CE). The calendar age may be determined by subtracting the radiocarbon age from 1950 if the ^{14}C levels in nature remained constant. However, the theoretical curve needs to be calibrated (CalDate) in order to account for variations in ^{14}C levels. The true condition of fluctuating ^{14}C levels in nature is therefore documented in calibration databases. As a result of natural (solar activity, volcanic eruptions) or human actions, the amount of ^{14}C in the atmosphere or biosphere may change (use of fossil fuels, nuclear weapons tests). The need for calibration is also demonstrated by the fact that all of these changes have an impact on the ^{14}C level. It is known that the amount of ^{14}C is balanced in settings other than the atmosphere (the sea, lake, and groundwater), but this equilibrium is not the same as that in the atmosphere. The phenomenon called as the "Marine Effect" is brought on by variations in the biosphere of marine areas. The older or younger age results could be determined regarding the freshwater effect. It will not be correct to use the ages and this problem will cause the wrong age-depth model to be constructed. In order to eliminate this problem, the remnants of completely terrestrial origin should be dated.

Within the scope of this study, the dating processes of terrestrial pollens to be used for the first time in Türkiye were carried out by following a protocol. It has been determined that the age-depth diagram created in the light of the results obtained is quite consistent and the error values are very low because of the enough C amount.

3.1. Fossil Pollen Dating

3.1.1. Field and Sample Preparation

According to results from µXRF analysis, radiocarbon dating points are determined. Age-depth model is configured in light of radiocarbon results. The dating of sediment cores obtained through field studies is completed in several stages. These stages are determined by the total length of the sediment, the time frame reached, and the event chronology. First, a radiocarbon dating is performed on the lowest (deepest) point of the total sediment obtained in this process. Other stages are rescheduled based on the Radiocarbon results. Currently, new analyses for radiocarbon dating are carried out in accordance with the event chronology discovered using µXRF analysis, which deliver the highest-quality and quickest data in paleoecology (this number may vary according to the total budget). The age-depth model developed in response to the recently discovered dating results suggests that potential locations for new dating points are identified by taking into account variables including changes in the sedimentation rate, event timing, and lithological changes. Radiocarbon dating is done step-by-step in accordance with the fresh information discovered throughout the investigation, in accordance with the problems encountered during the study, and in accordance with the other factors described above.

3.1.2. Radiocarbon/AMS ^{14}C Dating of Fossil Pollens: Laboratory Stages

At every stage of performing any Radiocarbon/AMS ^{14}C dating for fossil pollen dating, the samples are protected from external effects and kept away from pollutant exposure at the highest level possible. First and foremost, the sediment cores from which the radiocarbon was created must be preserved. Laboratory pre-treatment of the samples for Radiocarbon dating using fossil pollen is as follows (Sodium Hydroxide; NaOH, Hydrochloric Acid; HCl, filtration, Hydrofluoric Acid; HF), Hydrochloric Acid, Sodium Hypochlorite; NaOCl, washing and drying) after careful and adequate collection of sediment samples preserved in suitable storage environments (+4 °C). These procedures are mostly used to separate fossil pollen from other organic and inorganic substances in preparation for radiocarbon dating.

1) The sediment sample obtained from the sediment cores is put into a falcon tube in the first phase (50 ml volume). The falcon tube containing the sediment sample is filled to capacity with 3M sodium hydroxide, and the falcon tube is then submerged in a water bath with water that is between 70 and 80 °C. Every three minutes or so, the samples in the falcon tube are combined and left in the hot water bath for 30 minutes. The falcon tubes are taken out of the hot water bath once the procedure is finished and placed into the centrifuge. Following the spinning, the chemical inside the tube is then dumped. The first step is administered 2 to 5 times until the reactivity is over because during these processes, the sediment in the tube will react to sodium oxide. The falcon tube is placed into the centrifuge after the previous step, where the fossil pollen in the tube is precipitated. The chemical is then poured into the centrifuge, and the removal procedure is carried out.

2) The hydrochloric acid procedure is used in the second stage. The Falcon tube is filled to its volume with HCL produced at a 1M concentration. After mixing, the sediment in the tube is centrifuged once more. The HCL in the tube is poured out and removed following centrifugation.

3) The sediment in the tube is filtered through 180 and 10 micron sieves with the use of distilled water in the third stage, which comes after the HCL procedure. Following the filtering procedure, distilled water is used to move the samples that are still on the 10 micron sieve to beakers of the proper size. Following sample transfer to the beaker, centrifugation is used on the samples transferred to Falcon tubes. The liquid in the tube is drained out after centrifugation, leaving the sample empty in the tube.

4) In the fourth step, a tube is filled to capacity with hydrofluoric acid, which is introduced at a 29M/48% concentration. For 30 minutes, the tube is combined and held in a water bath with water that is between 70 and 80 °C. The samples are then centrifuged and extracted using hydrofluoric acid as with other liquids.

5) The tubes are filled with HCL that has been manufactured at a concentration of 1M in the fifth step. For 30 minutes, the samples are maintained in a water bath with water that is between 70 and 80 °C. After sitting for thirty minutes in a hot water bath, samples are centrifuged to separate out the solids, which are then eliminated by adding hydrochloric acid like other liquids. To remove all other compounds, particularly hydrofluoric acid, from the samples, this procedure is carried out three to five times.

6) The samples in the tube are mixed with a solution of sodium hypochlorite that is 2-3% solution in the sixth stage. The falcon tubes are filled with sodium hypochlorite, let to sit for five minutes, and then the sodium hypochlorite is poured in and centrifuged out.

7) The samples that have come into touch with a few chemicals are attempted to be purified from the chemicals in the seventh stage by washing with pure water. The samples are washed three to seven times with purified water till the pH level is between 5-7 (at least five washings are recommended). For each wash, distilled water in the amount of the tube is poured into the falcon tube, mixed, and then allowed to sit for three minutes before being placed in the centrifuge and reversing the process to pour water into the tube that emerges from the centrifuge. After the final cleaning, litmus paper is used to determine the pH of the sample that has been placed into the falcon tube of liquid. The drying process is initiated if the measurement yields a suitable pH value.

8) In the eighth and last step, distilled water is used to transport the sample from the Falcon tubes to the proper beaker. Until the samples are totally dry, the beakers with the sample and pure water are kept in the oven. The dried samples are put into containers made of aluminum foil and secured with a lock. Thus, the pretreatment procedure in the lab is finished.

3.1.3. ^{14}C Dating in Lab

When organizing lake cores for laboratory radiocarbon analysis, there are crucial factors to take into account. When a core is being considered for radiocarbon analysis, it is important to first determine what kind of organic residues are present by inspecting the core as a whole. For radiocarbon analysis, it might be possible to subsample from seven distinct materials from any level of the lake sediment core. As sample types that can be found in lake cores, single-piece macrofossils can be categorized as carbonized materials (charcoal), plant and other animal remains, carbonate-containing organic species shells, total microfossils, total macrofossils, total acid-insoluble organic residues (bulk), and pollen types. It could be every material that is categorized at a certain degree or just a certain kind of material that can be analyzed. The material's status as a residue that dates back to the development of that level of core will be the most crucial factor.

Each of the seven types of materials we have identified will have benefits and drawbacks when it comes to accurately characterizing the level's age and radiocarbon sampling. The reservoir impact of shell and aquatic plant remnants in lakes will be another crucial problem to take into account in terms of methodology when determining the age of that level from these seven different types of material. An older outcome with the appearance of a reservoir can be obtained by creating a fossil shell that contains carbonate to represent one level of the core. This does not imply that all levels of the core include the seven different kinds of materials that we have listed. The reservoir effect of the lake must be established if the levels are to be aged using various materials. Our recommendation is to compare the material type that is certain to be terrestrial to the reservoir effect for shells and aquatic plant remains at the same level.

It should be remembered that the reservoir effect may alter over time since the environmental elements that feed the lake may change over time. However, it might not be able to find the reservoir effect at every level because of the high radiocarbon analysis costs, the length of the process, and the scarcity of organic material in the core. The reservoir effect can be made at least once or twice among the several potential time levels. It will be beneficial to perform radiocarbon dating when this information is generated, taking into account the results of µXRF et al initial's analysis of the core collected, and if the pollen of the core is to be analyzed using paleoecology study.

Thus, it is possible to date the core using solely pollen material if a high enough concentration of pollen is found throughout the core. The lack of a reservoir effect and the restricted transit of pollen at lake sediment levels as opposed to other material types are the two most significant benefits of dating with terrestrial pollen. It is a modified method based on our suggested approach for sample preparation for pollen radiocarbon in lake sediments (Brown et al., 1989). Table 1 provides a summary of this protocol's phases.

The reservoir effect can be applied to a level of pollen and other material types if a low level of terrestrial charcoal or pollen density is to be dated along the core. When building the wet depth model, the divergence from the reservoir effect should be taken into consideration. Table 2 provides the suggested sample preparation procedure based on the kind of material being radiocarbon examined.

4. Case Study

Sultansazlığı Marsh is selected area where radiocarbon dating by using fossil pollen data. It has an altitude of 1070 m, a wetland of ~1000 km^2 and a drainage area of 3082 km^2 in Central Anatolia, that a closed basin located on the Develi Plain. Sultansazlığı, surrounded by high mountains, is surrounded by Hodul Mountain (1919 m) in the west, Aladağlar (3756 m) in the south, Develi Mountains (2074 m) in the east and Erciyes Mountain (3917 m) in the north (Figure 2). Sultansazlığı is located in a large Erciyes pull-apart basin along the left lateral Central Anatolian fault zone (Koçyiğit and Beyhan, 1998; Erol, 1999; Koçyiğit and Doğan, 2016). The marsh area includes marshlands and other marshes, from south to north are Camız, Sagittarius, Plain, and Desert Lakes. The wetland is fed by seasonal streams and surrounding springs. For this study, sediment cores were taken from the Camız Lake, which has a water depth of 1-1.5 m and a surface area of 30-35 km^2, in the south of Sultansazlığı Marsh (Şenkul et al., 2022*b*).

AMS ^{14}C dates were carried out at TÜBİTAK Marmara Research Center, Institute of Earth and Marine Sciences (TÜBİTAK-MAM) Accelerated Mass Spectroscopy Laboratory and BETA Analytical Laboratory on 441 cm long sediment cores obtained from Sultansazlığı Marsh. In the formation of the wet depth model, 19 radiocarbon age results made using 6 different materials (macrofossil, microfossil, shell, sediment (bulk), total terrestrial organic, pollen) from 13 different depths were evaluated. Age-depth model and radiocarbon dating results of Sultansazlığı

Table 1- Pollen protocol for ^{14}C dating analysis (protocol adapted from (Brown et al., 1992; Doğan et al., 2021).

Procedure Sequence Number	Concentration	Chemical	Backdrop	Processing Time
1	3M	NaOH	Hot water bath or a heating block set at 70-80 °C, oven, etc.	Repeat 2-5 times for 30 minutes each until no color is observed.
2	1M	HCl		-
3	10µ-180µ	Sieve	* The sieve interval can be narrowed.	-
4	29M/ 48%	HF	Hot water bath or a 70-80 °C heating block, oven, etc. **If 48% HF is not available, a concentration of over 30% can be used as a substitute.	30 minutes
5	1M	HCl	Hot water bath or a 70-80 °C heating block, oven, etc.	30-minute x repeat 3-5 times until no fluoride remains.
6	2-3%	NaOCl	-	5 minutes
7	-	Pure Water	Wash with distilled water until the pH reaches between 5 and 7.	3 Repeat 3-5 times until no fluoride remains x repeat 3-7
8	-	-	Drying in an oven at 70-80 °C.	-

* The sieve size range for filtering samples can be narrowed, but consideration should be given to the sizes of fossilized pollen within the sample to prevent pollen loss.

** It is advisable to consider the presented ratios here, as the concentrations of chemicals used in the analysis may have an impact on the sample.

Marsh were given in Şenkul et al., 2022*b* (Table 1). Measurements of the core sample types given above were used in preparation of these age depth models (Figure 3, 4, 5). Such comparisons are given in Table 3.

As given in the table, reservoir effect can be estimated with the radiocarbon measurements with pollen, sediment, and shell samples in 290 cm level. Considering pollen samples are terrestrial organic fossils, total sediment showed a 0.5k years older and shell sample a 0.6k years older radiocarbon dates. This agrees with the dissolved carbon effect deviation in freshwaters which is suggested to be between 0.25-0.7k and typically 0.4k years (Philippsen, 2013). This implies there may not exist serious dead carbon entrance into the reservoir in other words negligible hard water effect.

The modeling of the outcomes is as crucial as the selection of the materials and the caliber of the analysis in the planning of radiocarbon analysis in lake sediments. The linear interpolation method would be the simplest way to build a wet depth model utilizing radiocarbon values. The radiocarbon ages and the sedimentation rate are taken as given in the fundamental presumptions of the interpolation method. The earliest wet depth models described in the literature employed this technique. Programs like OxCal, Bacon, and Bchron have been employed recently to enhance modeling. The advantage of using one of these programs is the dynamically working ^{14}C wet calibration process.

5. Discussion

Fossil pollen analyses, which provide direct information about changes in vegetation structure, land use, and indirectly, climate change, have been extensively used. Fossil pollen studies conducted in lacustrine areas in Anatolia and the dating of cores taken from fossil pollen studies started in Konya-Süberde (Aytuğ, 1967) (Figure 1 and appendix Table 1). In this study, there is only one radiocarbon dating was performed using organic material. In the same year, the Lake Abant I and Lake Yeniçağa I cores were studied and the Lake Abant I core was not dated, and the reason for which was that no organic materials were

Table 2- Recommended sample preparation procedure for ^{14}C dating samples.

No	Material Types	Amount of Material	Process	Advantages	Disadvantages
1	Carbonized Material	Residue of a single piece, observable with the naked eye, weighing 2-3mg or more, and possessing distinctive qualities.	Washing with acid, or if a sufficient sample is available, washing with acid-base-acid	Provides a result representing a residue in a closed system, representing a single material.	Material may have been transported or mixed between levels. Near-surface levels may contain residues of living organisms mixed as a result of penetration.
2	Plant Residue	Residue of a single piece, observable with the naked eye, weighing 2-3mg or more, and possessing distinctive qualities such as plant remnants	Washing with acid, or if a sufficient sample is available, washing with acid-base-acid	Provides a result representing a residue in a closed system, representing a single material.	
3	Insoluble Organic Residues in Total Acid (Bulk)	Sampling should be conducted from 1-2 grams of sediment.	Washing with acid	It can be used for age determination in sediments that lack macrofossils and are not organically rich.	Due to the presence of residues likely consisting of different organic species in multiple parts, it may not exhibit a homogeneous distribution for age determination.
4	Total Macrofossils	Sampling from 1-2 grams of sediment and sieving with a 180 μ< sieve should be performed.	Washing with acid		
5	Total Microfossils	Sediment should be sampled at 1-2 grams, and sieving should be carried out with a sieve 180 μ>.			
6	Pollen Types		(Brown et al., 1989)	Levels of transportation between layers in lake sediments are rare due to the terrestrial origin of the material and the absence of a reservoir effect.	The sample preparation procedure being lengthy and containing HF acid may make it challenging to obtain a sufficient amount of material.
7	Organic Species Containing Carbonate, Such as Ostracods, are Included in the Category of Total Microfossils.	Shells	Ultra-pure water in ultrasonic bath washing and leaching with weak base	Being a commonly encountered material in lake sediments.	The reservoir effect needs to be calculated.

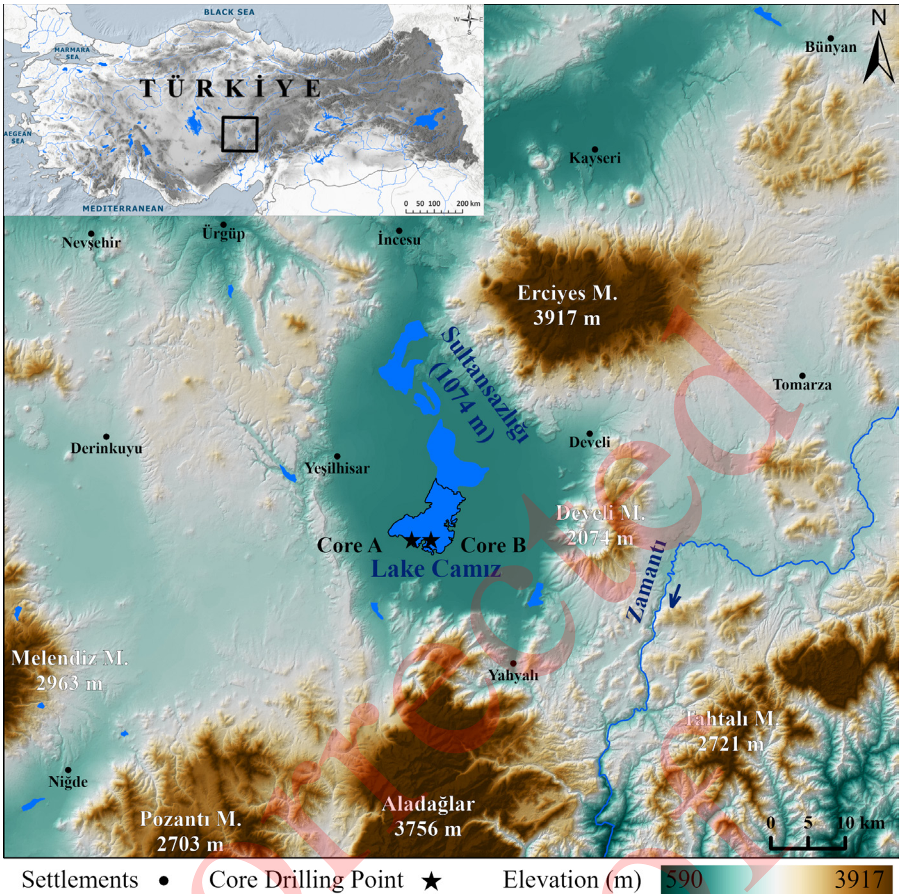


Figure 2- Sultansazlığı Marsh location map (generated from ASTER and GDEM V2).

found (Beug, 1967). Thus, the Lake Yeniçağa I core has 2 dating results (Beug, 1967). Although the importance of radiocarbon dating was known by the researchers, sediment cores could be dated from limited number of samples (Van Zeist et al., 1968, 1975). Paleoecological studies initiated in the 1960's in Türkiye aimed to reconstruct past environmental conditions using various analysis methods and chronological structures of environmental changes (Appendix Table 1 and the references therein).

This study encompasses paleoecological research conducted in Türkiye, situated in the Eastern Mediterranean, with a particular focus on studies related to lake sediments and fossil pollen analysis. The challenges encountered in dating analyses are examined within the scope of the Sultansazlığı data. Prior to proposing an approach for obtaining accurate age-depth models for samples within the sediment, various issues directly affecting dating and age-depth models were identified:

- *The type/number and resolution of analyses used in paleoecological studies in Türkiye over the past ~60 years:* The generally low resolution of different proxies and the types of analyses used in these studies make it challenging to correlate data with both regional and global research. Despite being more pronounced in initial studies, it is essential to acknowledge the success of these early works in shedding light on Anatolian paleoecology under the conditions of that period. Consequently, all these factors negatively impact the reconstruction of Anatolia's paleoecological conditions in a temporal and spatial context.

- *The availability and access to equipment used for sediment collection:* The equipment used in studies over the ~60-year period, particularly in the early stages, influenced sediment quality. Advances in technology now allow the reliable collection of long sediment cores in deepwater areas with high-tech equipment and coring systems (etc. Livingstone piston corer, Gravity corer, Vibracorer, SPT), compared to the initial use of manual force with equipment like Russian Core and Dachnowski in shallow waters.

Table 3- Sultansazlığı Marsh AMS ^{14}C dating results (*results used in creating the age-depth model).

Radiocarbon Age Results (^{14}C yrs BP)						
Depth (cm)	**Macro Fossil**	**Micro Fossil**	**Shells**	**Sediment (Bulk)**	**Total Terrestrial Organic**	**Pollen**
35				2666*		
53				4043*		
80			6691	5776*		
185			8261	8319		
214 (Beta)			9720			
280				7918*		
290 (289-291)						8110*
292					8185	
295			8712	8634		
371					462	7223
383				13586		
436			12330*			
438	8783 (Bitki)		~13000	13119		

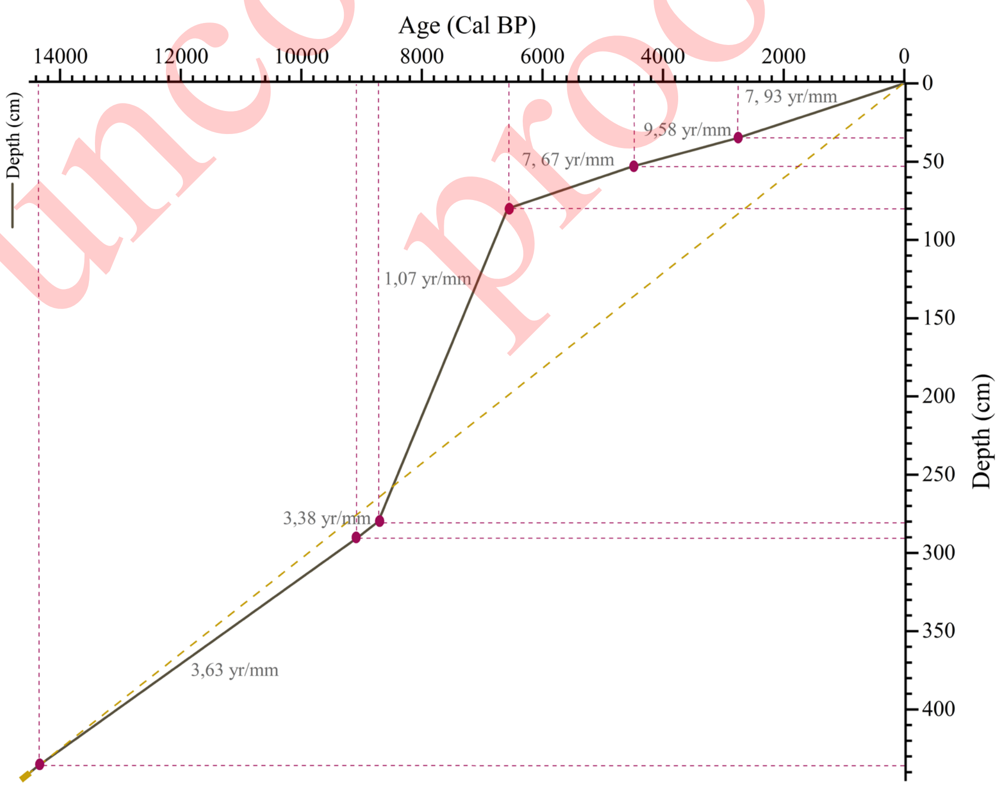


Figure 3- Sultansazlığı Marsh age depth model (Lineer Model, redraw from (Şenkul et al., 2022*b*)).

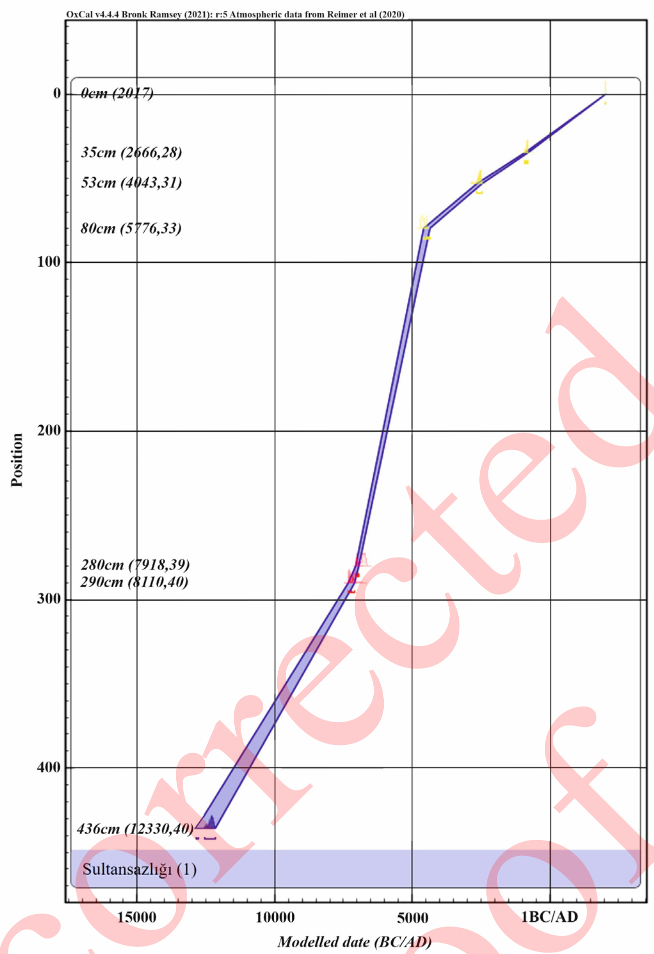


Figure 4- Sultansazlığı Marsh OxCal age depth model (for age depth model, OxCal is used to demonstrate deposition assumed to be random giving approximate proportionality to depth (Ramsey, 2008)).

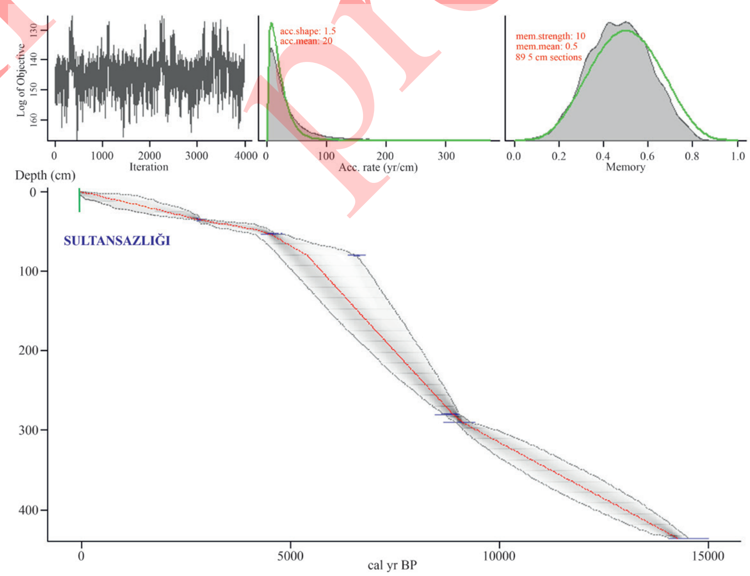


Figure 5- Sultansazlığı Marsh RBacon age depth model (the age-depth modelling for Sultansazlığı is constructed with software RBacon, which uses Bayesian statistics to reconstruct accumulation dates for sediment deposits. RBacon combines radiocarbon dates and bore sample collection date 2017 with prior information on accumulation rates and their variability (Blaauw and Christeny, 2011; Reimer, 2020)).

- *Sediment collection issues:* The lack of continuous stratigraphy in obtained sediment cores directly affects chronological reconstruction.

- *Wetland ecology:* Changes in water levels due to factors like drought, evaporation, and human impact can lead to the loss of wetland characteristics, affecting sediment structure and the presence of organic and biological elements crucial for accurate dating.

- *Hiatus formation in lake/marsh areas:* Hiatus formations, especially during dry periods, can lead to high error rates in dating analyses where sediment accumulation processes have either entirely stopped or significantly slowed down.

- *Variation in the type of samples for dating determination and its direct impact:* The choice between radiocarbon (^{14}C) dating analysis of wood, bulk sediment, macrofossils, or microfossils can influence the results.

- *Different formation processes of lake/marsh areas in Türkiye:* Chemical features and structural characteristics affecting the formation of a lake/marsh area can influence dating analysis results, affecting sample selection, deviation margin, and error rate.

Despite technological advancements and progress in analyses, the chaotic conditions in sediment chronology due to the characteristics of Turkish lake/marsh areas have not been fully overcome. In the last ~60 years, approximately 111 studies have been conducted in ~70 lake/ marsh environments (Some lake/marshland areas have one or more studies), with increased analysis resolutions and the widespread use of multiple analyses (Figure 1, 6 and Appendix Table 1). In addition to the development of paleoecological analyses and results, dating analyses have gained importance for evaluating findings chronologically, establishing spatial relationships, and linking them with global research results.

Various dating analysis methods have been preferred in paleoecological studies in Türkiye, especially in lake/marsh, archaeological settlement, glacier areas, etc. The commonly used dating analyses include Varve Dating, Radiocarbon (^{14}C) Dating Analysis, U–Th Dating, ^{210}Pb (Lead Dating), and K–Ar Dating (Potassium-Argon Dating) (Roberts, 2014; Lowe and Walker, 2015). Examples of the situations described in this section are in the studies conducted in, and Lake Nar (England et al., 2008). A date based on chronology was acquired. In the Paleo Lake Konya (Kuzucuoğlu et al., 1999) and Nar Lake (Roberts et al., 2016*a*) studies, sediment cores were dated by the U–Th method.

Each dating analysis has its purpose, error margins, and applicable time periods, leading to differences in their utilization in specific areas. For example, ^{14}C dates for deep-sea cores are currently estimated at ~400 years for the global ocean, but they are influenced by both spatial and temporal variations in the marine reservoir effect (Stuiver et al., 1986; Ascough et al., 2005). The temporal deviation believed to be caused by the reservoir effect can also result in chronological discrepancies, especially during the Younger Dryas and Early Holocene, due to the increased reservoir effect caused by glacial conditions (Stuiver et al., 1986).

In the realm of paleoecological research in Türkiye, radiocarbon (^{14}C) dating holds significance due to its widespread use, providing diversity in dating methods according to research requirements. However, upon examining the features of radiocarbon use in studies, it is observed that many initial pollen studies (Van Zeist et al., 1975) have only a limited number of ^{14}C dates (or no), with sample ages interpolated among them. Furthermore, the scarcity of dating analyses in pioneering studies also influences the evaluation of data. Since the radiocarbon method is not applicable in the cores taken from some lakes, alternative methods have been chosen. For instance, since there is no organic material in the core of Lake Seyfe and there is no material to be dated in the core of Lake Tuzla and Büyükgöl, a dating analysis could not be performed (Bottema et al., 1993-1994). Gölhisar Lake I, Elmalı, Avlan Lake (Bottema and Woldring, 1984), Gölyaka and Kuşcenneti II (Bottema et al., 2001), Çanaklı (Vermoere et al., 2002), Lake Arin (Kamar, 2018*b*), Manyas Lake II (Kartum, 2021) cores were not or could not be dated for various reasons. In addition, recent studies in which high-resolution wet depth models were created Bereket, (Kaniewski et al., 2007); İznik Lake, (Miebach et al., 2016); Elaia Harbor, (Shumilovskikh et al., 2016); Belevi Lake, (Stock et al., 2020) exists. When considering that in contemporary paleoecology, a reliable chronology can be established with intervals of up to ~500 years depending on the sediment length and focused time, it becomes apparent that the pioneering studies in Anatolia diverge chronologically from current research. Indeed, the number of dating analyses has increased in line with global-scale studies toward the present day (Figure 1 and 6).

The sediment length seems to provide an idea for researchers about the number of dating analyses required. However, when determining the frequency of dating analyses in a study, attention should not solely be given to sediment length. Factors such as sedimentation rate, core length, and anthropogenic effects are crucial in defining the number of ^{14}C points along cores. It is not scientifically sound to define the number of ^{14}C points based solely on the length of cores. In many lacustrine areas in Anatolia, the sedimentation rate can be very low, meaning that one meter of sediment may correspond to several thousand years (e.g., Yelten Sazlığı I, (Bozkurt, 2021)). Thus, factors influencing dating analysis resolution in a study are diverse, and they can vary depending on the environmental conditions of the area where the sediment is obtained.

The question of how many dating analyses should be conducted in a study is as crucial as ensuring the reliability of the results and achieving the most accurate dating possible. Despite scientific and technological advancements in Türkiye, the creation of sediment chronology for Turkish lakes is chaotic due to the varied formation processes and different characteristics of lake/marsh areas. To illustrate this through conducted studies, in some regions, the presence of significant old carbon effects due to volcanic gas emissions related to hard water (reservoir) effects can greatly reduce the value of radiocarbon dating. For instance, in a study conducted at Nar Gölü in Central Anatolia, dating issues were encountered due to insufficient terrestrial carbon content in the obtained sediment cores, the presence of old carbon accumulations (a 15,000-year-old carbon effect related to geothermal activity was identified), and the occurrence of volcanic gas (sulfur gas) emissions. In this case, ^{14}C dating analysis could not be used. To establish chronology, various analysis methods such as Varve dating, U-Th dating, ^{210}Pb and ^{137}Cs dating, Ra–Th dating were applied to different sediment cores taken from the lake (England et al., 2008; Allcock, 2013; Roberts et al., 2016*b*). Similar problems were reported in a paleoecological study conducted at Paleo-Konya Lake in Central Anatolia (Roberts et al., 1999).

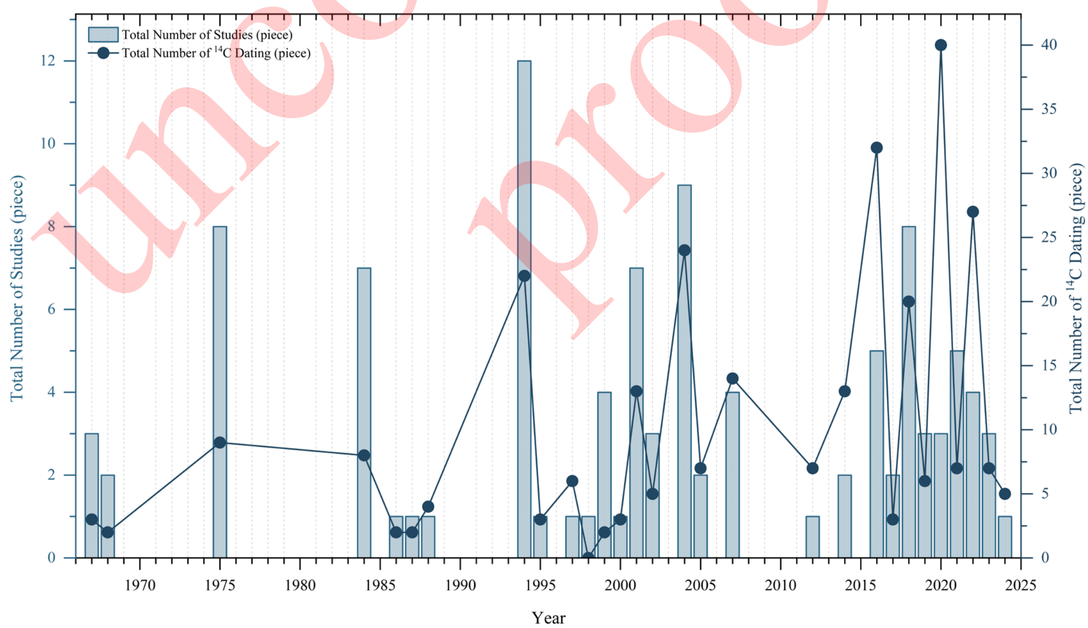


Figure 6- Total fossil pollen analysis studies conducted in Anatolia by year and the total number of dating analyses (the data used to create the graph is presented in Appendix Table 1, please refer to it for details).

In another study at Paleo-Kuleönü Lake in the Lake District, uncertainties and high error rates were encountered in ^{14}C dating analysis due to the low organic matter and carbon ratio in the sediment, especially at levels close to the present day. To overcome this problem, three different samples representing the level were taken (pollen, bulk) and a sample with the highest carbon content), and the result of the sample with the highest carbon content was accepted (Ünlü, 2021). Similar dating challenges have been encountered in studies conducted in the surrounding regions of Türkiye for similar reasons. For example, in studies conducted in Ghap Valley and Hula Lake (Baruch and Bottema 1991; Niclewski and Bottema 1970; Yasuda et al. 2000), ^{14}C dating analysis was performed on soft-shelled samples in Ghap Valley. In this study, a methodology developed in previous studies in the field was used to evaluate the results, considering the potential presence of any effect in the field where previous studies had identified a hard-water effect. The dating results were compared with pollen diagrams and chronological findings (Artemisia and Chenopodiaceae), testing them against drought event chronologies detected in global climate chronologies (Rossignol-Strick, 1995). In the study at Hula Lake, a hard-water effect was detected in the dating results, and a ~700-year shift compared to Ghap Valley results was determined. The same methodology used in the Ghap Valley study was employed in a study conducted by Yasuda et al. (2000), showing that the impact of hard water on radiometric dates of the Ghap Valley sediment core was relatively small or even negligible.

The significant changes that have occurred in Anatolian wetlands over the past 40 years, from 1984 to 2024, are concerning (according to Google Earth images). Indeed, many lacustrine areas, where sediment collection has been carried out since 1967 are now observed to have dried up or transformed into seasonal wetlands. In areas prone to drought and intense evaporation, the water retention capacities of shallow lakes/marsh may exhibit discontinuity (Harmancioglu and Altinbilek, 2020). This discontinuity directly affects sediment structure and, consequently, may influence the results of dating analysis. The disappearance of continuously anoxic conditions due to climate changes can negatively impact the preservation of the widely used bulk sediment structure. It may lead to the loss of dating materials preserved in sediment or result in an increase in deviation values in the analysis results. Additionally, the frequent detection of hiatus developments presumed to be caused by not taking sediment cores from the deepest point (lake surface) raises concerns. The formation of hiatus is believed to occur due to events such as the transformation of wetlands into terrestrial landscapes, the cessation of sources feeding and has been identified in many lake/marsh areas in Anatolia (Bulkan et al., 2018; Eriş et al., 2018; Şenkul et al., 2022*b*). Considering the anticipated reasons for formation, it can be assumed that areas with shallow depths may experience drying and rapid level changes in the face of climatic droughts. Moreover, taking cores from a rapidly changing level in a lake/marsh area, especially from a coastal or near-coastal point, may lead to the detection of hiatus in sediment cores and high-error dating results. Here, what is meant is not only the change in level and terrestrialization but also the potential disruption of sediment integrity by flora and fauna effects (e.g., plant roots negatively affecting sediment development at the lake bottom, leading to stratigraphic inconsistencies in sediment structure). When the faunal activity is assumed to be intense in shallow and coastal areas, the possibility of affecting sediment integrity arises.

Certainly, these predictions and possibilities about the past are uncertain, but in a paleoecological study where past environmental conditions are examined considering current ecological dynamics, they become important. In the face of these uncertainties, to obtain reliable results in dating analysis, different materials can be used instead of bulk as samples, or dating analysis can be performed on multiple materials from the same level, and the results can be compared. This way, the limitations of the analysis and problems that may arise from the type of sample can be overcome, and reliable chronologies can be established.

6. Results

In this study, as a result of the evaluation of palaeoecological studies carried out in lacustrine or marshy areas from the perspective of "dating", basic problems such as lack of dating, dating limitation and chronological incompatibility, which have emerged as an important problem regarding the lacustrine or marshy areas of Anatolia, have been identified. Through the evaluation of paleoecological studies conducted within these environments from a dating perspective, empirical identification of these problems has occurred alongside proposed solutions. In addition, in the context of dating analyses of sediment cores from the Sultansazlığı Marsh, an approach developed in collaboration with TÜBİTAK MAM in 2022 is presented in order to obtain an accurate age-depth model. Technological advancements and scientific developments in dating methodologies in paleoecological studies in Anatolia have made significant strides in dating sediment cores from lake and marshland environments. However, despite these advancements, difficulties persist in establishing reliable chronological reconstruction due to the complex nature of sediment stratigraphy in these environments.

This study aims to comprehensively discuss factors affecting the attainment of a reliable age-depth model. These factors include the physical and chemical properties of lakes or marshlands, equipment used for sediment sampling, location of sampling points, lacustrine processes affecting sediment accumulation, length and continuity of sediment cores, type of samples selected for ^{14}C dating analysis, care taken during sample collection and preservation, sediment length, paleoclimate, density of aquatic plants, complexity of root systems, and the number of reliable chronological analyses consistent with paleoenvironmental conditions. Each of these factors plays a significant role in the reliability of chronological reconstructions.

The study provides procedural solutions and implications for factors affecting the attainment of a reliable age-depth model in paleoecological research conducted with sediment cores in lacustrine or marshland environments. These include:

- Determining the point where sediment deposition shows continuity (stratigraphic accumulation) in the lakes/marshlands and sampling at this point or obtaining different core series from multiple locations.

- Using equipment that can systematically and metrically provide sediment procurement to prevent sample loss and obtain a continuous sediment core series.

- Conducting sediment procurement in the form of A and B core series to ensure continuity of the obtained sediment core series or prevent possible losses.

- Carefully packaging cores to prevent contamination events that may influence paleoecological results.

- Conducting sampling processes for sediment dating analysis in a sterile environment without time loss and with sensitive sampling.

- Considering the type of sample preferred for dating analysis and conducting new dating analyses using the same or different sample types from similar or nearby levels to test the reliability of dating analysis results.

- Taking into account the sediment length and base age of the sediment core when determining the number of dating analyses and conducting dating processes.

- Checking/associating the results with different models in the context of age-depth models created according to the analysis results and determining the appropriate model. In cases of discrepancies encountered in the age-depth models created, comparing the results with events recorded in the global climate chronology and evaluating the findings through biostratigraphic checks.

Ultimately, the reliability of the results of a paleoecology study depends on chronological reconstruction, which directly affects the processes of reaching local, regional, and global correlations and specific findings. Factors affecting dating results have been addressed within the scope of this study, and suggestions have been made by discussing sediment cores from the Sultansazlığı Marsh, proposing pollen dating as a reliable method for obtaining results.

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References

Allcock, S. L. 2013. Living with a changing landscape: Holocene climate variability and socio-evolutionary trajectories, central Turkey. School of Geography, Earth and Environmental Sciences Ph.D., 375.

Anderson, E. C., Libby, W. F., Weinhouse, S., Reid, A. F., Kirshenbaum, A.D., Grosse, A. V. 1947. Radiocarbon from cosmic radiation. Science 105, 576.

Ascough, P., Cook, G., Dugmore, A. 2005. Methodological approaches to determining the marine radiocarbon reservoir effect. Progress in Physical Geography 29, 532–547.

Aytuğ, B. 1967. Konya-Süberde Dolaylarında Neolitik Çağ Florasının İncelenmesi. Ankara, Türkiye.

Aytuğ, B., Merev, N., Edis, G. 1975. Sürmene-Ağaçbaşı Dolayları Ladin Ormanının Tarihi ve Geleceği.

Bakker, J., Kaniewski, D., Verstraeten, G., Laet, V. de, Waelkens, M. 2012. Numerically derived evidence for late-Holocene climate change and its impact on human presence in the southwest Taurus Mountains, Turkey. Holocene 22, 425–438.

Baruch, U., Bottema, S. 1991. Palynological evidence for climatic changes in the Levant ca. 17,000-9,000 BP.

Beug, J. B. 1967. Contributions to the Postglacial Vegetational History of Northern Turkey. In: Cushing, E.J., Wrigth, E. (Eds.), Quaternary Paleoecology. New Haven and London, Yale University Press, Germany.

Biltekin, D., Eriş, K. K., Çağatay, M. N., Ön, S. A., Akkoca, D. B. 2018. Late Pleistocene–Holocene environmental change in eastern Turkey: multi-proxy palaeoecological data of vegetation and lake-catchment changes. Journal of Quaternary Science 33, 575–585.

Blaauw, M., Christeny, J.A. 2011. Flexible paleoclimate age-depth models using an autoregressive gamma process. Bayesian Analysis 6, 457–474.

Bottema, S. 1995. Holocene Vegetation of the Van area: Palynological and chronological evidence from Söğütlü, Turkey. Vegetation History and Archaeobotany 4, 187–193.

Bottema, S., Woldring, H. 1984. Late Quaternary Vegetation and Climate of Southwestern Turkey Part II. Paleohıstoria 26, 12–15.

Bottema, S., Woldring, H., Aytuğ, B. 1993-1994. Late Quaternary Vegetation History of Northern Turkey. Palaeohistoria 13-72.

Bottema, S., Woldring, H., Kayan, İ. 2001. The Late Quaternary Vegetation History of Western Turkey. In: Roodenberg, J. J., Thissen, L. C. (Eds.), The Ilıpınar Excavations II.

Bozkurt, Y. 2021. Fosil Polen Analizlerine Dayalı Yelten Sazlığı Ve Çevresinin Paleovejetasyonu. Süleyman Demirel Üniversitesi, Isparta.

Brown, T. A., Nelson, D. E., Mathewes, R.W., Vogel, J. S., Southon, J. R. 1989. Radiocarbon dating of pollen by accelerator mass spectrometry. Quaternary Research 32, 205–212.

Brown, T. A., Farwell, G.W., Grootes, P. M., Schmidt, F. H. 1992. Radiocarbon AMS dating of pollen extracted from peat samples. Radiocarbon 34, 550–556.

Bulkan, Ö., Yalçın, M. N., Wilkes, H. 2018. Geochemistry of Marmara Lake sediments - Implications for Holocene environmental changes in Western Turkey. Quaternary International 486, 199–214.

Collins, P. E. F., Rust, D. J., Bayraktutan, M. S., Turner, S. D. 2005. Fluvial stratigraphy and palaeoenvironments in the Pasinler Basin, eastern Turkey. Quaternary International 140–141, 121–134.

Dan, A., Başaran, S., Brückner, H., Erkul, E., Pint, A., Rabbel, W., Shumilovskikh, L., Wilken, D., Wunderlich, T. 2019. Ainos in Thrace: Research Perspectives in Historical Geography and Geoarchaeology. Anatolia Antiqua 127–144.

Doğan, M. 2022. Son Buzul Maksimumu'ndan Günümüze Yayla Gölü (Büyük Menderes-Denizli) ve Çevresinin Paleoekolojisi. Süleyman Demirel Üniversitesi, Isparta.

Doğan, T., İlkmen, E., Kulak, F. 2021. A new national 1 MV AMS laboratory at TÜBİTAK MRC in Turkey. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 509, 48–54.

Dönmez, E. O., Ocakoğlu, F., Akbulut, A., Tunoğlu, C., Gümüş, B. A., Tuncer, A., Görüm, T., Tün, M. 2021. Vegetation record of the last three millennia in central Anatolia: Archaeological and palaeoclimatic insights from Moagn Lake (Ankara, Turkey). Quaternary Science Reviews 262.

Eastwood, W.J. 1997. The Palaeoecological Record of Holocene Environmental Change in Southwest Turkey. University of Wales.

Eastwood, W. J., Roberts, N., Boyer, P. 2007. Pollen Analysis at Çatalhöyük. In: Hodder, I. (Ed.), Excavating Çatalhöyük, South, North and KOPAL Area Reports from the 1995-1999 Seasons. British Institute at Ankara, UK, 573–588.

Emery-Barbier, A., Thiébault, S. 2005. Preliminary conclusions on the Late Glacial vegetation in south-west Anatolia (Turkey): The complementary nature of palynological and anthracological approaches. Journal of Archaeological Science 32, 1232–1251.

England, A. 2006. Late Holocene Palaeoecology of Cappadocia (Central Turkey): An Investigation of Annualy Laminated Sediments from Nar Gölü Crater Lake. The University of Birmingham.

England, A., Eastwood, W. J., Roberts, C. N., Turner, R., Haldon, J. F. 2008. Historical landscape change in Cappadocia (central Turkey): A palaeoecological investigation of annually laminated sediments from Nar lake. Holocene 18, 1229–1245.

Eriş, K. K., Gürocak, Z., Akkoca Bal, D., Okan, Ö. Ö., İnceöz, M., İmren, C., Akçer Ön, S., Sancar, Ü., Biltekin, D. 2014. Hazar Gölü'nde (Elazığ) Pleyistosen-Holosen Dönemi Yüksek Çözünürlü İklim ve Su Seviyesi Değişimleri. Ankara, Türkiye.

Eriş, K. K., Ön, S. A., Çağatay, M. N., Ülgen, U. B., Ön, Z. B., Gürocak, Z., Nagihan Arslan, T., Akkoca, D. B., Damcı, E., İnceöz, M., Okan, Ö. Ö. 2018. Late Pleistocene to Holocene paleoenvironmental evolution of Lake Hazar, Eastern Anatolia, Turkey. Quaternary International 486, 4–16.

Erol, O. 1999. A geomorphological study of the Sultansazligi lake, central Anatolia. Quaternary Science Reviews 18, 647–657.

Gauthier, A., Mouralis, D., Kuzucuoğlu, C., Fontugne, M., Atakay, E., Evcimen, Ö. 2014. Environmental Changesin Central Antolia since the LGM: the pollen record from Çora Maar (Erciyes, Türkiye). In: Lakes and Human Interactions, QuicklakeH Workshop. Ankara, Türkiye.

Gemici, Y. 1986. Çivril (Denizli) Sandıklı ve Dinar (Afyon) ilçeleri arasındaki Akdağ ve çevresinin flora ve vejetasyonu. Ege Üniversitesi, İzmir.

Godwin, H. 1951. Comments on radiocarbon dating for samples from the British Isles. American Journal of Science.

Harmancioglu, N., Altinbilek, D. 2020. Water Resources of Turkey, Water Resources of Turkey.

İnceoğlu, Ö., Pehlivan, S. 1986. İç Anadolu Bölgesindeki Tuz Gölü Kuvaterner Tabakalarında Palinolojik Bir Araştırma. Ankara, Türkiye.

Kamar, G. 2018a. Nazik Gölü (Bitlis, Türkiye) Güneybatısından Alınan N3 Karotunun Palinolojik İlk Bulguları Preliminary Palynological Findings of theN3 Core from Southwest of Lake Nazik (Bitlis, Turkey). Yüzüncü Yıl Üniversitesi Fen Bilimleri Enstitüsü Dergisi 23, 291–296.

Kamar, G. 2018b. Palynology of Lake Arin (Eastern Anatolia, Turkey) deposits and its relation with water level change of Lake Van: Preliminary findings. Quaternary International 486, 83–88.

Kamar, G. 2021. Holocene Palynology and Pollen-Based Palaeoclimate Reconstruction of Lake Erçek (Eastern Anatolia); Short-Term Climatic Fluctuations and their Relation with Global Palaeoclimatic Change; Results of Cores E1 and E10. Türkiye Jeoloji Bülteni / Geological Bulletin of Turkey 64, 253–266.

Kaniewski, D., Laet, V. De, Paulissen, E., Waelkens, M. 2007. Long-term effects of human impact on mountainous ecosystems, western Taurus Mountains, Turkey. Journal of Biogeography 34, 1975–1997.

Kaplan, G., Örçen, S. 2011. Van Gölü Kuzey Havzasının Geç Holosen Paleoflorası Late Holocene Paleoflora of Lake Van Northern Basin 32, 139–150.

Karlioğlu, N., Caner, H., Rauh, N. K., Akkemik, Ü., Köse, N., Connor, E. M. 2016. Palynological evidence for human occupation in western Rough Cilicia (southwest Turkey). Quaternary International 401, 109–122.

Karlıoğlu, Kılıç, N., Caner, H., Erginal, A. E., Ersin, S., Selim, H. H., Kaya, H., 2018. Environmental changes based on multi-proxy analysis of core sediments in Lake Aktaş Turkey: Preliminary results. Quaternary International 486, 89–97.

Karlıoğlu Kılıç, N., Yılmaz Dağdeviren, R., Acar, D., Küçükdemirci, M., Makaroğlu, Ö., Karaöz, M. Ö., Şahin Altun, D., Tutar, A., Horuz, A., Gürel, A., Islam, Z., Çağatay, M. N. 2020. Akgöl'de (Sakarya) Fosil Polen Analizine Dayalı Paleovejetasyon Araştırmaları: İlk Bulgular. Journal of Geography 40.

Kartum, Ş. 2021. Manyas (Kuş) Gölü Çökellerinin Paleoiklimsel ve Paleoekolojik Kayıtları. Çanakkale Onsekiz Mart Üniversitesi, Çanakkale.

Kiliç, N. K., Dagdeviren, R. Y., Fural, S., Kökrer, S., Makaroglu, O. 2023. Vegetation history of lake marmara (w.Törkiye) and surrounding area during the last 700 years. Comptes Rendus de L'Academie Bulgare des Sciences 76, 1028–1037.

Koçyiğit, A., Doğan, U. 2016. Strike-slip neotectonic regime and related structures in the cappadocia region: A case study in the salanda basin,central Anatolia,Turkey. Turkish Journal of Earth Sciences 25, 393–417.

Koçyiğit, A., Beyhan, A. 1998. A new intracontinental transcurrent structure: The Central Anatolian Fault Zone, Turkey. Tectonophysics 284, 317–336.

Kuzucuoğlu, C., Bertaux, J., Black, S., Denefle, M., Fontugne, M., Karabiyikoğlu, M., Kashima, K., Limondin-Lozouet, N., Mouralis, D., Orth, P. 1999. Reconstruction of climatic changes during the Late Pleistocene, based on sediment records from the Konya Basin (Central Anatolia, Turkey). Geological Journal 34, 175–198.

Landmann, G., Reimer, A. 1996. Climatically induced lake level changes at Lake Van, Turkey, during the Pleistocene/Holocene transition. Global Biogeochemical Cycles, 10, 797–808.

Landmann, G., Reimer, A., Lemcke, G., Kempe, S. 1996. Dating Late Glacial abrupt climate changes in the 14,570 yr long continuous varve record of Lake Van, Turkey. Palaeogeography, Palaeoclimatology, Palaeoecology 122, 107–118.

Leroy, S., Kazanci, N., Ileri, Ö., Kibar, M., Emre, O., McGee, E., Griffiths, H. I. 2002. Abrupt environmental changes within a late Holocene lacustrine sequence south of the Marmara Sea (Lake Manyas, N-W Turkey): Possible links with seismic events. Marine Geology 190, 531–552.

Litt, T., Krastel, S., Sturm, M., Kipfer, R., Örcen, S., Heumann, G., Franz, S. O., Ülgen, U. B., Niessen, F. 2009. "PALEOVAN", International Continental Scientific Drilling Program (ICDP): site survey results and perspectives. Quaternary Science Reviews 28, 1555–1567.

Lowe, J., Walker, M., 2015. Reconstructing Quaternary Environments, Third Edit. ed. Routledge, Taylor & Francis Group, LONDON AND NEWYORK.

Mahaney, W. C. 1984. Correlation of quaternary chronologies : from a Symposium on Correlation of Quaternary Chronologies, May 26-29, 1983, Atkinson College, York University, Toronto, Canada. Norwich : Geo books.

Miebach, A., Niestrath, P., Roeser, P., Litt, T. 2016. Impacts of climate and humans on the vegetation in northwestern Turkey: Palynological insights from Lake Iznik since the Last Glacial. Climate of the Past 12, 575–593.

Müllenhoff, M., Handl, M., Knipping, M., Brückner, H., 2004. The evolution of Lake Bafa (Western Turkey) - Sedimentological, microfaunal and palynological results. Coastline Reports 1, 55–66.

Niclewski, J., Bottema, S. 1970. A late quaternary pollen diagram from Lake Urmia (Northwestern Iran). Review of Palaeobotany and Palynology 47.

Ocakoğlu, F., Dönmez, E. O., Akbulut, A., Tunoğlu, C., Kır, O., Açıkalın, S., Erayık, C., Yılmaz, İ. Ö., Leroy, S. A. G. 2016. A 2800-year multi-proxy sedimentary record of climate change from Lake Çubuk (Göynük, Bolu, NW Anatolia). Holocene 26, 205–221.

Ocakoğlu, F., Çilingiroğlu, Ç., Erkara, İ. P., Ünan, S., Dinçer, B., Akkiraz, M. S. 2019. Human-climate interactions since the neolithic period in Central Anatolia: Novel multi-proxy data from the Kureyşler area, Kütahya, Turkey. Quaternary Science Reviews 213, 1–17.

Ocakoğlu, F., Akbulut, A., Oybak Dönmez, E., Tuncer, A., Tunoğlu, C., Açıkalın, S., Erayık, C. 2022. Lowstand lake conditions in NW Anatolia during the Little Ice Age: Multi-proxy evidence from Lake Sünnet. Holocene 32, 935–949.

Ören, A. 2018. Kültepe (Kayseri) Çevresinin Fosil Polen Analizleri Işığında Holosen Paleocoğrafyası. Ankara Üniversitesi, Ankara.

Philippsen, B. 2012. Variability of freshwater reservoir effects 189.

Philippsen, B. 2013. The freshwater reservoir effect in radiocarbon dating. Heritage Science 1, 1–19.

Philippsen, B., Kjeldsen, H., Hartz, S., Paulsen, H., Clausen, I., Heinemeier, J. 2010. The hardwater effect in AMS 14C dating of food crusts on pottery. Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms 268, 995–998.

Ramsey, C. B. 2008. Deposition models for chronological records. Quaternary Science Reviews 27, 42–60.

Reimer, P. J. 2020. Composition and consequences of the IntCal20 radiocarbon calibration curve. Quaternary Research (United States) 96, 22–27.

Roberts, N. 2014. The Holocene, Third Edit. ed. Wiley Blackwell.

Roberts, N., Black, S., Boyer, P., Eastwood, W. J., Griffiths, H. I., Lamb, H. F., Leng, M. J., Parish, R., Reed, J. M., Twigg, D., Yig\ Itbas' Iog\ Lu, H. 1999. Chronology and stratigraphy of Late Quaternary sediments in the Konya Basin, Turkey: Results from the KOPAL Project, Quaternary Science Reviews.

Roberts, N., Allcock, S. L., Arnaud, F., Dean, J. R., Eastwood, W. J., Jones, M. D., Leng, M. J., Metcalfe, S. E., Malet, E., Woodbridge, J., Yiğitbaşıoğlu, H. 2016a. A tale of two lakes: a multi-proxy comparison of Lateglacial and Holocene environmental change in Cappadocia, Turkey. Journal of Quaternary Science 31, 348–362.

Roberts, N., Allcock, S. L., Arnaud, F., Dean, J. R., Eastwood, W. J., Jones, M. D., Leng, M. J., Metcalfe, S. E., Malet, E., Woodbridge, J., Yiğitbaşıoğlu, H. 2016b. A tale of two lakes: a multi-proxy comparison of Lateglacial and Holocene environmental change in Cappadocia, Turkey. Journal of Quaternary Science 31, 348–362.

Rossignol-Strick, M. 1995. Sea-land correlation of pollen records in the Eastern Mediterranean for the glacial-interglacial transition: Biostratigraphy versus radiometric time-scale. Quaternary Science Reviews 14, 893–915.

Sekeryapan, C., Streurman, H. J., Plicht, J. van der, Woldring, H., Veen, Y. van der, Boomer, I. 2020. Late Glacial to mid Holocene lacustrine ostracods from southern Anatolia, Turkey: A palaeoenvironmental study with pollen and stable isotopes. Catena 188, 104437.

Şenkul, Ç., Doğan, M. 2018. Fosil ve güncel polen analizleri ışığında Mucur Obruk Gölü çevresinin paleovejetasyon değişimleri. Turkish Geographical Review 70, 19–28.

Şenkul, Ç., Kalıpçı, E. 2019. Güneybatı Anadolu'dan Yeni Bir Paleoekolojik Değerlendirme: Karataş Gölü ve Çevresinin Geç Holosen Paleovejetasyon Değişimleri ve İklim ile İlişkileri. Journal of Geography 0, 35–47.

Şenkul, Ç., Ören, A., Doğan, U., Eastwood, W. J. 2018a. Late Holocene environmental changes in the vicinity of Kültepe (Kayseri), Central Anatolia, Turkey. Quaternary International 486, 107–115.

Şenkul, Ç., Memiş, T., Eastwood, W. J., Doğan, U. 2018b. Mid-to late-Holocene paleovegetation change in vicinity of Lake Tuzla (Kayseri), Central Anatolia, Turkey. Quaternary International 486, 98–106.

Şenkul, Ç., Bozkurt, Y., Ünlü, Y. 2022a. Fosil Polen ve Jeokimyasal (µ-XRF) Analizler Işığında Yelten Sazlığı (Antalya-Korkuteli) ve Çevresinin Son 2.100 Yıllık Paleovejetasyon ve Paleoiklimi. Türk Coğrafya Dergisi 81, 141–156.

Şenkul, Ç., Gürboğa, Ş., Doğan, M., Doğan, T. 2022b. High-resolution geochemical (µXRF) and palynological analyses for climatic and environmental changes in lake sediments from Sultansazlığı Marsh (Central Anatolia) during the last 14.5 kyr. Quaternary International 613, 24–38.

Şenkul, Ç., Bozkurt, Y., Doğan, M., Ünlü, Y. 2023. Göller Yöresinin Orta Holosenden Günümüze Paleovejetasyon Tarihi: Karakuyu Bataklığı ve Çevresi. SDÜ Fen-Edebiyat Fakültesi Sosyal Bilimler Dergisi 58, 144–160.

Shumilovskikh, L. S., Seeliger, M., Feuser, S., Novenko, E., Schlütz, F., Pint, A., Pirson, F., Brückner, H. 2016. The harbour of Elaia: A palynological archive for human environmental interactions during the last 7500 years. Quaternary Science Reviews 149, 167–187.

Stock, F., Laermanns, H., Pint, A., Knipping, M., Wulf, S., Hassl, A. R., Heiss, A. G., Ladstätter, S., Opitz, S., Schwaiger, H., Brückner, H. 2020. Human-environment interaction in the hinterland of Ephesos – As deduced from an in-depth study of Lake Belevi, west Anatolia. Quaternary Science Reviews 244.

Stuiver, M., Pearson, G.., Braziunas, T. 1986. Radiocarbon Age Calibration of Marine Samples Back to 9000 Cal Yr BP. Radiocarbon 28, 980–1021.

Sullivan, D. G. 1989. Human-induced vegetation change in western Turkey: Pollen evidence from central Lydia. University of California.

Topuz, M. 2023. Türk Coğrafya Dergisi The vegetation history of Lake Gâvur and surrounding areas during the last 4400 years BP (Kahramanmaraş, Türkiye) 1 Gâvur Gölü ve çevresinin son 4400 yıllık vejetasyon tarihi (Kahramanmaraş, Türkiye) 2 84, 97–103.

Turney, C. S. M. 1999. Lacustrine Bulk Organic δ 13 C in the British Isles during the Last Glacial-Holocene Transition (14–9 ka 14 C BP) . Arctic, Antarctic, and Alpine Research 31, 71–81.

Ünlü, Y. 2021. Mikro-XRF Verileri Işığında Paleo-Kuleönü Gölü ve Çevresinin Paleoiklim Özellikleri. Süleyman Demirel University.

Vermoere, M., 2004. Holocene Vegetation History in the Territory of Sagalassos (Southwest Turkey) A Palynological Approach.

Vermoere, M., Degryse, P., Vanhecke, L., Muchez, P., Paulissen, E., Smets, E., Waelkens, M. 1999. Pollen analysis of two travertine sections in Baskoy (southwestern Turkey): Implications for environmental conditions during the early Holocene. Review of Palaeobotany and Palynology 105, 93–110.

Vermoere, M., Smets, E., Waelkens, M., Vanhaverbeke, H., Librecht, I., Paulissen, E., Vanhecke, L. 2000. Late Holocene environmental change and the record of human impact at Gravgaz near Sagalassos, southwest Turkey. Journal of Archaeological Science 27, 571–595.

Vermoere, M., Bottema, S., Vanhecke, L., Waelkens, M., Paulissen, E., Smets, E. 2002. Palynological evidence for late-Holocene human occupation recorded in two wetlands in SW Turkey. Holocene 12, 569–584.

Walker, M. 2005. Quaternary dating methods., Quaternary dating methods. John Wiley & Sons, Ltd, UK.

Wick, L., Lemcke, G., Sturm, M. 2003. Evidence of Lateglacial and Holocene climatic change and human impact in eastern Anatolia: High-resolution pollen, charcoal, isotopic and geochemical records from the laminated sediments of Lake Van, Turkey. Holocene 13, 665–675.

Woldring, H. 1998. A pollen diagram from a river sediment in Central Anatolia. Tuba-ar I 105–111.

Woldring, H. 2001. Climate change and the onset of sedentism in Cappadocia.

Yasuda, Y., Kitagawa, H., Nakagawa, T. 2000. The earliest record of major anthropogenic deforestation in the Ghab Valley, northwest Syria: A palynological study. Quaternary International 73–74, 127–136.

Yavuz, N., Culha, G., Demirer, Ş. S., Utescher, T., Aydın, A. 2017. Pollen, ostracod and stable isotope records of palaeoenvironment and climate: Upper Miocene and Pliocene of the Çankırı Basin (Central Anatolia, Turkey). Palaeogeography, Palaeoclimatology, Palaeoecology 467, 149–165.

Yılmaz Dağdeviren, R., Karlıoğlu Kılıç, N., Yakupoğlu, C., Yakupoğlu, N., Eriş, K. K. 2024. The vegetation history of Lake Mert and its surroundings for the last 6600 years (Kırklareli, NW Türkiye). Quaternary International 679, 15–24.

Zeist, W. Van, Woldring, H. 1978. A POSTGLACIAL POLLEN DIAGRAM FROM LAKE VAN IN EAST ANATOLIA. Review of Palaeobotany and Palynology 26, 249–276.

Zeist, W. Van, Timmers, R. W., Bottema, S. 1968. Studies of Modern and Holocene Pollen Precipatation in Southeastern Turkey. Paleohıstoria XIV, 19–39.

Zeist, W. Van, Woldring, H., Stapert, D. 1975. Late Quaternary Vegetation and Climate of Southwestern Turkey.

Zhou, A., He, Y., Wu, D., Zhang, X., Zhang, C., Liu, Z., Yu, J. 2015. Changes in the radiocarbon reservoir age in Lake Xingyun, Southwestern China during the holocene. PLoS ONE 10, 1–12.

Appendix

Table 1- Information on sediment length, number of dating's, and analysis type in fossil pollen analysis studies conducted in Anatolia.

Year of Study	Study Area	Acquired Sediment Length (cm)	Number of Datings	Type of Dating Analysis	Reference
1967	Konya-Süberde	400	1	^{14}C Radiocarbon Analysis	(Aytuğ, 1967)
	Abant Lake I	600	0	^{14}C Radiocarbon Analysis	(Beug, 1967)
	Yeniçağa Lake I	1150	2	^{14}C Radiocarbon Analysis	(Beug, 1967)
1968	Gölbaşı Lake	1345	1	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1968)
	Bozova	190	1	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1968)
1975	Köyceğiz Lake	640	2	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1975)
	Karamık Lake	605	2	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1975)
	Hoyran Lake	435	1	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1975)
	Beyşehir Lake I	545	2	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1975)
	Söğüt Lake	535	2	^{14}C Radiocarbon Analysis	(Van Zeist et al., 1975)
	Ağaçbaşı I	250	0	^{14}C Radiocarbon Analysis	(Aytuğ et al., 1975)
	Ağaçbaşı II	260	0	^{14}C Radiocarbon Analysis	(Aytuğ et al., 1975)
	Ağaçbaşı III	210	0	^{14}C Radiocarbon Analysis	(Aytuğ et al., 1975)
1978	Van I	950	-	Varve Dating	(Van Zeist and Woldring, 1978)
1984	Ova Lake	778	2	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Avlan Lake	270	0	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Beyşehir Lake II	1005	1	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Gölhisar Lake I	235	0	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Elmalı	305	0	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Akgöl Adabağ	607	3	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
	Pınarbaşı	715	2	^{14}C Radiocarbon Analysis	(Bottema & Woldring, 1984)
1986	Işıklı Lake I	330	2	^{14}C Radiocarbon Analysis	(Gemici, 1986)
1987	Tuz Lake	560	2	^{14}C Radiocarbon Analysis	(İnceoğlu and Pehlivan, 1986)
1989	Gölcük Lake	1050	4	^{14}C Radiocarbon Analysis	(Sullivan, 1989)
1993-1994	Abant Lake II	1105	5	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Tuzla Lake I	381	0	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)t al. 1993-1994)
	Yenicağa Lake II	1740	5	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Tatlı Lake	907	1	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Ladik Lake	851	4	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Adatepe	470	1	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Büyükgöl	145	0	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Demiryurt Lake	411	1	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Küçük Akgöl	410	2	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Kaz Lake	1083	2	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Melen	1475	1	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
	Seyfe	464	0	^{14}C Radiocarbon Analysis	(Bottema et al., 1993-1994)
1995	Söğütlü	1379	3	^{14}C Radiocarbon Analysis	(Bottema, 1995)
1996	Van II	855	-	Varve Dating	(Landmann and Reimer, 1996)

1997	Gölhisar Lake II	810	6	^{14}C Radiocarbon Analysis	(Eastwood, 1997)
1998	Aşıklı Höyük	115	0	^{14}C Radiocarbon Analysis	(Woldring, 1998)
1999	Başköy MV 1A	150	0	^{14}C Radiocarbon Analysis	(Vermoere et al., 1999)
	Başköy MV 1B	90	0	^{14}C Radiocarbon Analysis	(Vermoere et al., 1999)
	Paleo-Konya Lake	2500	-	U–Th Dating	(Kuzucuoğlu et al., 1999)
	Çöl Lake	300	2	^{14}C Radiocarbon Analysis	Unpublished
2000	Gravgaz Marsh 1999	800	3	^{14}C Radiocarbon Analysis	(Vermoere et al., 2000)
2001	Çakırca	95	1	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Gölyaka	281	0	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Kuşcenneti II	270	0	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Apolyont	720	0	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Ilıpınar	68	0	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Yenişehir	715	4	^{14}C Radiocarbon Analysis	(Bottema et al., 2001)
	Eski Acıgöl	1480	8	^{14}C Radiocarbon Analysis	(Woldring, 2001)
2002	Manyas Lake	1100	2	^{14}C Radiocarbon Analysis	(Leroy et al., 2002)
	Çanaklı	400	0	^{14}C Radiocarbon Analysis	(Vermoere et al., 2002)
	Gravgaz Marsh 1996	800	3	^{14}C Radiocarbon Analysis	(Vermoere et al., 2002)
2003	Van III	850	-	Varve Dating	(Wick et al., 2003)
2004	Bafa S 1	149	2	^{14}C Radiocarbon Analysis	(Müllenhoff et al., 2004)
	Bafa S 6	971	3	^{14}C Radiocarbon Analysis	(Müllenhoff et al., 2004)
	Gravgaz Marsh 1998	816	0	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Ağlasun Core 9	398	2	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Ağlasun Core 13	784	2	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Ağlasun Core 6	1000	5	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Ağlasun Core 12	800	6	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Core PQ01	519	4	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
	Core PQ99	450	0	^{14}C Radiocarbon Analysis	(Vermoere, 2004)
2005	Pasinler	250	4	^{14}C Radiocarbon Analysis	(Collins et al., 2005)
	Öküzini	542	3	^{14}C Radiocarbon Analysis	(Emery-Barbier and Thiébault, 2005)
2006	Nar Lake I	100	-	Varve Dating	(England, 2006)
	Burdur Lake	-	-	No Data	(England, 2006)
2007	Çatalhöyük	570	1	^{14}C Radiocarbon Analysis	(Eastwood et al., 2007)
	Avrat Hanıhöyük	395	1	^{14}C Radiocarbon Analysis	(Eastwood et al., 2007)
	Kızılhöyük	475	1	^{14}C Radiocarbon Analysis	(Eastwood et al., 2007)
	Bereket	800	11	^{14}C Radiocarbon Analysis	(Kaniewski et al., 2007)
2009	Van IV	900	-	Varve Dating	(Litt et al., 2009)
2011	Van V	449	0	^{14}C Radiocarbon Analysis	(Kaplan and Örçen, 2011)
2012	Gravgaz SA06EP1	300	7	^{14}C Radiocarbon Analysis	(Bakker et al., 2012)
2014	Çora Maarı	1400	10	^{14}C Radiocarbon Analysis	(Gauthier et al., 2014)
	Hazar Lake Hz11-P02	400	3	^{14}C Radiocarbon Analysis	(Eriş et al., 2014)
2016	İznik Lake	1800	17	^{14}C Radiocarbon Analysis	(Miebach et al., 2016)
	Nar Lake II	2100	-	U–Th Dating	(Roberts et al., 2016a)
	Çubuk Lake	300	4	^{14}C Radiocarbon Analysis	(Ocakoğlu et al., 2016)
	Elaia Harbour	800	11	^{14}C Radiocarbon Analysis	(Shumilovskikh et al., 2016)
	Dağlık Kilikya (T1-T5-T8-T9)	210	0	^{14}C Radiocarbon Analysis	(Karlioğlu et al., 2016)
2017	Süleymanlı Section	170	0	No Data	(Yavuz et al., 2017)

2018	Nazik Lake	50	0	No Data	(Kamar, 2018a)
	Arin Lake	70	0	No Data	(Kamar, 2018*b*)
	Engir Lake	393	2	^{14}C Radiocarbon Analysis	(Şenkul et al., 2018a)
	Hazar Lake Hz11-P03	282	6	^{14}C Radiocarbon Analysis	(Biltekin et al., 2018)
	Aktaş Lake	60	3	^{14}C Radiocarbon Analysis	(Karlıoğlu, Kılıç et al., 2018)
	Mucur Obruk Lake	570	2	^{14}C Radiocarbon Analysis	(Şenkul and Doğan, 2018)
	Engir Lake II	717	5	^{14}C Radiocarbon Analysis	(Ören, 2018)
	Tuzla Lake II	337	2	^{14}C Radiocarbon Analysis	(Şenkul et al., 2018*b*)
2019	Karataş Lake	255	2	^{14}C Radiocarbon Analysis	(Şenkul and Kalıpçı, 2019)
	Kureyşler	852	4	^{14}C Radiocarbon Analysis	(Ocakoğlu et al., 2019)
	Enez (Ain50)	950	0	^{14}C Radiocarbon Analysis	(Dan et al., 2019)
2020	Akgöl Lake	100	2	^{14}C Radiocarbon Analysis	(Karlıoğlu Kılıç et al., 2020)
	Belevi Lake	1175	33	^{14}C Radiocarbon Analysis	(Stock et al., 2020)
	Sağlık II	1270	5	^{14}C Radiocarbon Analysis	(Sekeryapan et al., 2020)
2021	Mogan Lake Core MD	120	2	^{14}C Radiocarbon Analysis	(Dönmez et al., 2021)
	Mogan Lake Core MS	400	3	^{14}C Radiocarbon Analysis	(Dönmez et al., 2021)
	Manyas Lake II	55	0	^{14}C Radiocarbon Analysis	(Kartum, 2021)
	Erçek Lake	111	0	No Data	(Kamar, 2021)
	Yelten Sazlığı I	400	2	^{14}C Radiocarbon Analysis	(Bozkurt, 2021)
2022	Sultansazlığı	444	6	^{14}C Radiocarbon Analysis	(Şenkul et al., 2022*b*)
	Sünnet Lake	170	5	^{14}C Radiocarbon AnalysiS	(Ocakoğlu et al., 2022)
	Yelten Sazlığı II	48	1	^{14}C Radiocarbon Analysis	(Şenkul et al., 2022a)
	Buldan Yayla Lake	1796	15	^{14}C Radiocarbon Analysis	(Doğan, 2022)
2023	Karakuyu Marsh	730	4	^{14}C Radiocarbon Analysis	(Şenkul et al., 2023)
	Gavur Lake	500	2	^{14}C Radiocarbon Analysis	(Topuz, 2023)
	Marmara Lake	65	1	^{14}C Radiocarbon Analysis	(Kiliç et al., 2023)
2024	Mert Lake	334	5	^{14}C Radiocarbon Analysis	(Yılmaz Dağdeviren et al., 2024)