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Pollen deposition processes and their significance for vegetation composition reconstructions

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POLLEN DEPOSITION PROCESSES AND THEIR SIGNIFICANCE FOR VEGETATION COMPOSITION RECONSTRUCTIONS

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POLLEN DEPOSITION PROCESSES AND THEIR SIGNIFICANCE FOR VEGETATION COMPOSITION RECONSTRUCTIONS– *Master Thesis*

ΔΙΕΡΓΑΣΙΕΣ ΑΠΟΘΕΣΕΙΣ ΓΥΡΗΣ ΚΑΙ Η ΣΗΜΑΣΙΑ ΤΟΥΣ ΣΤΗΝ ΑΝΑΣΥΣΤΑΣΗ ΤΗΣ ΠΑΛΑΙΟΒΛΑΣΤΗΣΗΣ – *Μεταπτυχιακή Διπλωματική Εργασία*

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Contents

Abstract

Reconstructions of past vegetation are crucial for a better understanding of past ecological and climatic changes. However, parameters like the climatic conditions, the geology, the depositional basins as well as the vegetation of an area can affect pollen production, dispersion and preservation. This creates doubt as to the accuracy to which the fossil pollen records can reflect the vegetation around a site. This problem can be approached by studying the correlation between present-day vegetation and surface samples that contain modern pollen assemblages. In this thesis, we studied multiple surface pollen samples from different areas and depositional environments in Greece. Then we performed statistical analysis of the pollen data as well as the biomization technique to evaluate how well they are reflecting the modern vegetation around each site. Furthermore, we compared the results from each site in order to evaluate which environment provides a more accurate depiction of the present-day vegetation. Finally, we confirmed that the ideal environments for a palaeoecological reconstruction are smaller basins such as temporal ponds and peat bogs. Also, it is of high importance to have a good spatial resolution by collecting multiple samples from various sites even in close proximity. Investigating how modern vegetation is reflected in surface modern pollen samples is key to a better and more accurate depiction of the paleoenvironment.

1. Introduction

Modern pollen samples analysis is crucial for the interpretation and our understanding of the pollen record of the past. The interpretation of fossil pollen records requires a clear understanding of the relationship between pollen as a proxy and the environmental parameter that it may represent (Davis *et al.*, 2013). Therefore, it is necessary to understand how modern vegetation is represented in the pollen record in order to investigate the information that the fossil pollen data can provide for us (Davis et al., 2013).

According to (Bunting *et al.*, 2004) the correlation between pollen data and land cover changes is neither straightforward nor linear. The climatic conditions, the plant species, the vegetation communities, the depositional basins, and many other environmental parameters that may occur in the investigation area, can affect the pollen production, dispersion, and preservation (Sugita, 1994). This brings doubt to the accuracy and the extent to which the fossil pollen records can depict past vegetation changes (de Nascimento *et al.*, 2015). This problem can be approached by studying the relationship between present-day vegetation and surface samples that contain modern pollen assemblages (Davis *et al.*, 2020).

Modern pollen samples have already been used in research, for a great number of reasons such as to interpret past changes in land cover, land use, human impact (Prentice, 1983; Prentice', 1985; Sugita, 1993), the impact of past edaphic and hydroseral changes on vegetation, the effects of past changes in fire, pests, and disease on vegetation (Davis *et al.*, 2020), as well as to understand taphonomic problems with regard to pollen transportation, deposition and preservation (Beaudouin *et al.*, 2007; Carrio, 2002; Cundill *et al.*, 2006; Naughton *et al.*, 2007). Also, modern pollen samples have been used to create large datasets to calibrate "training sets" for the quantitative reconstruction of past climate(Davis *et al.*, 2020). There have also been a great number of studies that use surface samples in order to understand the qualitative relationship between pollen composition and vegetation, in many different environments such as boreal forest (Pisaric *et al.*, 2001), western and southeastern European mountains (Ejarque *et al.*, 2011; Tonkov *et al.*, 2001), Mediterranean woodlands (Lopez-Saez *et al.*, 2010) and wetlands (Amami *et al.*, 2010), temperate open-woodlands (Bunting, 2002; Waller *et al.*, 2012), mountains (Boutahar *et al.*, 2023), and complex diverse regions like the entire Eastern Mediterranean-Black Sea-Caspian Corridor area.

The main goal of this study is to investigate how well the vegetation types can be distinguished from their pollen rain in Greece. Greece is characterized by very complex geological features such as its topography and geomorphology and therefore very diverse and complex vegetational patterns. These features may affect the way pollen disperse and accumulate in sediments, making it difficult to adequately interpret pollen data and thus to make a reliable palaeoenvironmental reconstruction. In order to make that happen, we must take into consideration several factors that control pollen transportation, dispersal and deposition, such as the wind, the water influxes, the climatic conditions, the precipitation, the water circulation, the fluvial discharges and more (Beaudouin *et al.*, 2007; Chmura and Liu, 1990; Dai *et al.*, 2014; Dai and Weng, 2011; Luo *et al.*, 2013; Montade *et al.*, 2011; Mudie and Mccarthy, 1994).

To investigate how modern vegetation is represented in the surface pollen samples, we studied multiple samples from different sediments in various areas in Greece, Specifically, we studied 40 samples from 5 different depositional environments from 19 different areas of Greece. We did a microscopic analysis of the samples, and then we performed statistical analysis to evaluate the similarities between the pollen assemblages from each site. The statistical analysis included cluster analysis, non-metric multidimensional scaling analysis as well as the construction of percentage and concentration diagrams of the pollen. Then we performed the biomization technique to compare the biomes assigned to each site with the actual current vegetation of each area through literature and map observations.

2. Pollen productivity, rain and deposition

Reconstructions of past vegetation are crucial for a better understanding of past ecological and climatic changes. For these reconstructions to be accurate it is required to understand how vegetation is represented in the pollen record. The estimation of pollen productivity and dispersal is fundamental for these reconstructions (Liu *et al.*, 2022).

Pollen productivity is defined as the number of pollen grains produced per unit relative abundance of a plant taxon (Liu *et al.*, 2022). It refers to the amount of pollen produced by a plant taxon, and it can vary significantly, depending on the taxon and the environmental conditions that may occur. Anemophilous taxa, for example, usually produce larger amounts of pollen that is released into the air, leading to higher concentration deposited in soils, compared to the entomophilous taxa that produce only a small amount of pollen (Faegri and Iversen, 1989). On the other hand, pollen dispersal refers to how far pollen grains have traveled before being deposited. Most pollen grains are deposited near their source, but a significant amount can be transported and deposited within far distances. The source area of pollen varies, depending on the basin of interest. For example, the source area of pollen assemblages that have been archived in ocean sediments is more likely to be larger than that of pollen assemblages found in lakes, ponds, or even coastal lagoons (Dai *et al.*, 2014). In any case, knowing the pollen source area is key for the correct interpretations of the pollen data (Dai *et al.*, 2014). Both pollen productivity and dispersal can vary among taxa (Liu *et al.*, 2022). Certain taxa produce pollen grains that rarely reach the sedimentary record because of either pollen production, dispersal, or preservation (Birks and Birks, 1980).

Pollen rain is a term that is related to pollen dispersal but describes the process of pollen grains being released from plants and dispersed in a particular area, reflecting the diversity of plant species and their reproductive activity (Martin, 1963; Shen *et al.*, 2021). Pollen rain can be influenced by factors such as pollen production, wind patterns, and precipitation. Studies on pollen rain have provided valuable insights into the vegetation and ecological changes in various landscapes (Shen *et al.*, 2021).

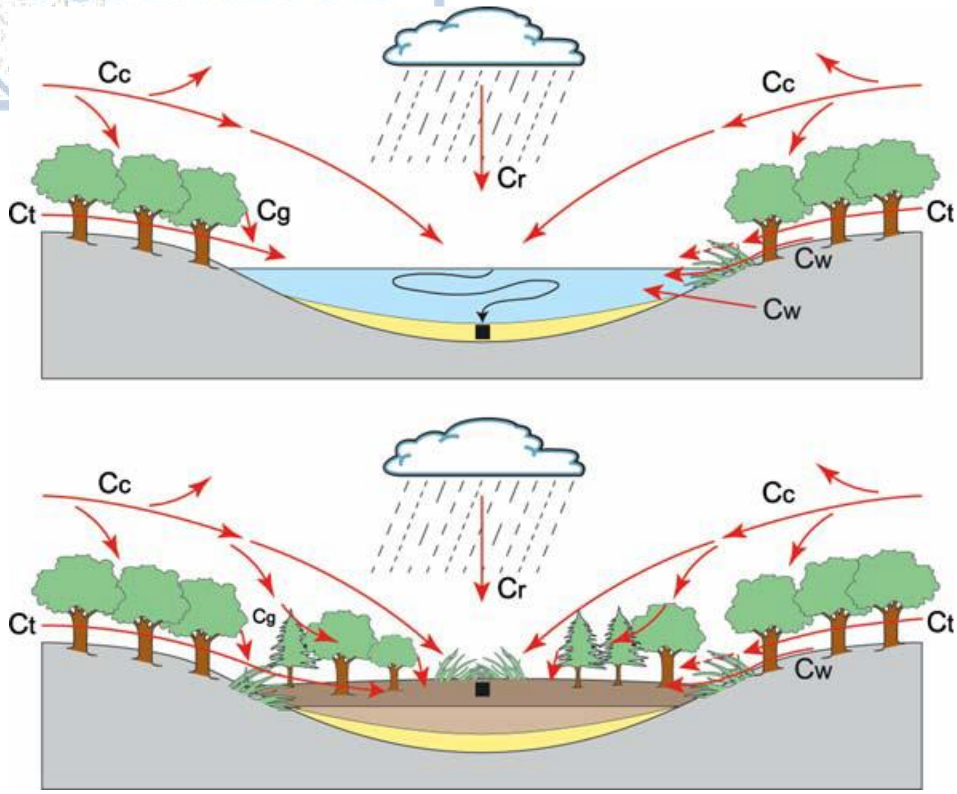


Figure 1: Figure that shows (a) different routes by which pollen is transported into lake sediments and (b) some of the effects of wetland surface vegetation on these transport functions (Tauber, 1965; Jacobson and Bradshaw 1981). Cr: component carried in precipitation, Cc: in above canopy airflow, Ct: by airflow below the canopy in the trunk space, Cg: direct deposition under gravity, Cw: component carried in surface runoff, inflowing water channels and groundwater (Bunting, 2008)

The transportation mechanisms of pollen involve complex processes that are crucial for plant reproduction (Figure 1). Pollen can be transported by various means, including the wind, water masses and animal pollinators. Pollen grains, especially those produced by anemophilous plants, are dispersed in the air, washed out by the precipitations, and then are deposited on the ground or on water surfaces (Valle *et al.*, 2021). The wall that surrounds the pollen cell consists of sporopollenin which is an extremely durable substance and can be preserved in soils and sediment layers at the bottom of ponds, peats, lagoons, lakes, or oceans (Valle *et al.*, 2021). Nevertheless, the environmental conditions in the depositional environment can play a crucial role in the preservation of the pollen grains (King *et al.*, 1975). The depositional environments that favor pollen preservation are those that are characterized by anoxic conditions of low energy, such as peat bogs, lake sediments, ponds, and even marine sediments (King *et al.*, 1975).

There are various techniques that can be used to collect modern pollen samples in order to use them as climate calibration data or as modern analogues for reconstructing vegetation from fossil profiles (Lisitsyna *et al.*, 2012). Pollen traps, moss pollsters and surface sediment samples are some of them. These techniques have differences in the way of data collection, so it is important to compare the way they affect the reconstruction of the surrounding vegetation.

Modern moss and surface sediment samples are easy to obtain which gives the advantage of good spatial coverage in a relatively short time, while pollen trap data are not representative unless the trap has collected more than 2 years' worth of pollen (Lisitsyna et al., 2012). On the other hand, pollen trap data have the advantage that pollen accumulation rates (deposition of grains per cm^2 per year) can be calculated in addition to pollen percentages (Lisitsyna *et al.*, 2012). Also, studies have shown that pollen traps have lower tree pollen values than the surface sediments and the moss samples

(Lisitsyna *et al.*, 2012; Räsänen *et al.*, 2004). Furthermore, mosses can preserve large pollen grains better than small grains with thin exines (Spieksma *et al.*, 1994; Vermoere *et al.*, 2000), so the diversity of herbaceous pollen taxa is usually higher in pollen traps (Lisitsyna *et al.*, 2012; Räsänen *et al.*, 2004). Additionally, the study of Lisitsyna *et al*. (2011), showed that lake surface sediment samples tend to have an over-representation of tree taxa as opposed to the moss samples. Also, regardless of the vegetation zone, pollen traps had lower *Pinus* percentages than the moss polsters. Finally, it is safe to assume that, especially at large geographical scales, it is best to combine different types of modern samples to have a more representative image of modern vegetation.

3. Study areas

40 samples have been studied for this thesis from 5 different depositional environments, from 18 different areas in Greece (Figure 2, Table 1): 8 samples from marine environments (4 from Saronikos Gulf, 2 from Corinth Gulf, 2 from Thermaikos Gulf), 12 from coastal lagoons (11 from Prokopos Lagoon, 1 from Elos Lagoon), 14 from lake surface samples (1 from Lake Yliki, 2 from Lake Trichonida, 2 from Lake Lysimachia, 1 from Lake Ozeros, 1 from Lake Amvrakia, 1 from Lake Megali Prespa, 1 from Lake Kastoria, 3 from Lake Vegoritida, 1 from Lake Petron, 1 from Lake Doirani), 3 from temporal ponds (2 from Oiti Mountain, 1 from Mt Kallidromo) and 3 from peat bogs from Rhodope Mountains (Table 1). Each area is distinguished by certain characteristics concerning the geology, the climatic conditions, and the current vegetation. Knowing this information can improve the interpretation of the pollen data.

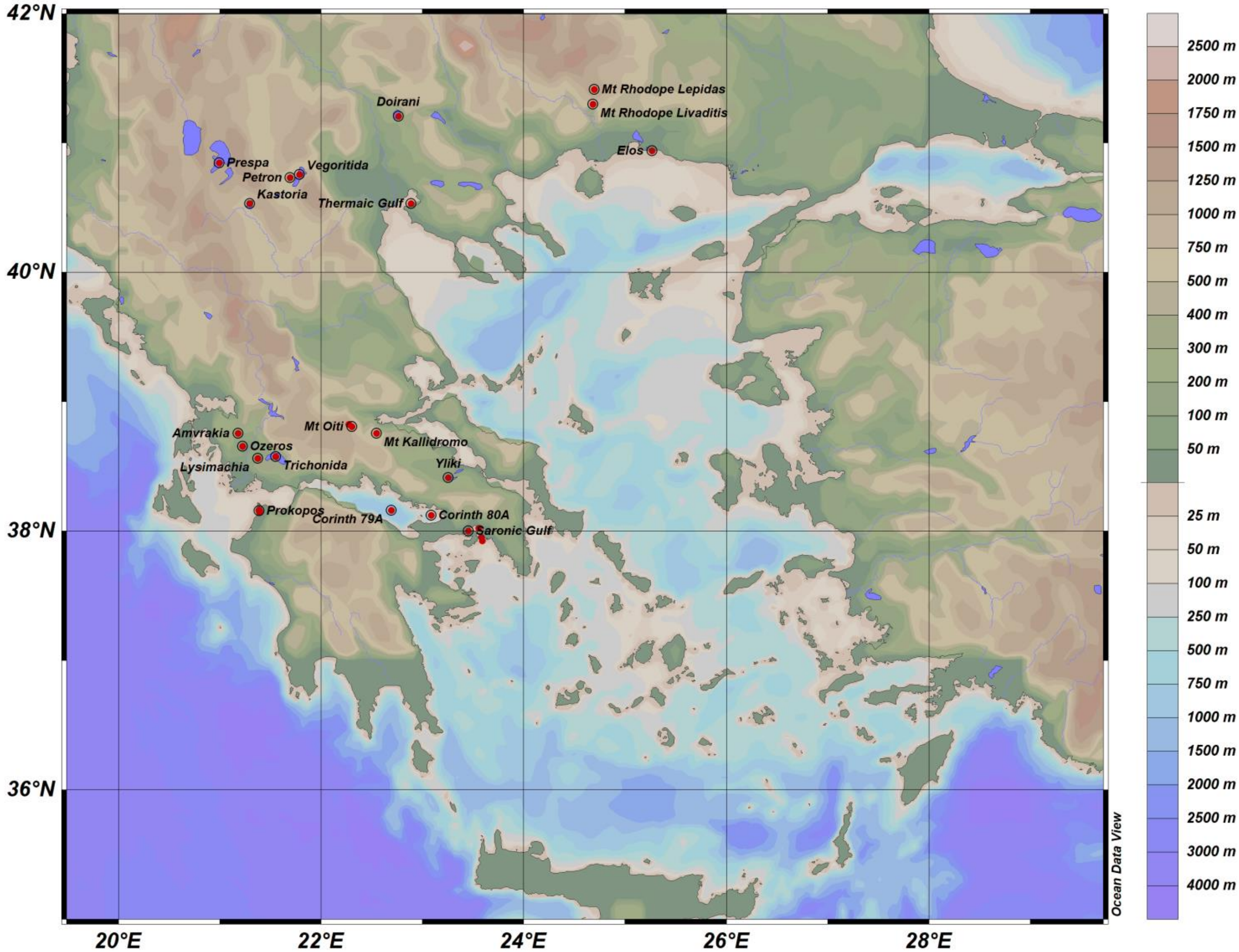


Figure 2: Map of Greece with the sites' locations

3.1. Saronikos Gulf

Saronikos Gulf is located in the Eastern Mediterranean in the western part of the Aegean Sea in Greece (Figure 3). It is a semi-closed coastal marine ecosystem, which covers around 3000 km^2 and has an average depth of 300m. The Saronikos Gulf is separated into two sub basins, the western and the eastern, by a shallow N-S trending platform that extends from Methana Peninsula to Salamis Island. Furthermore, the eastern basin is separated into the Inner and Outer Saronikos Gulf (Papanikolaou *et al.*, 1988). The samples that have been studied for this research are collected from Elefsis Bay (S1, S2, S3) and the Inner Saronikos Gulf (S7) (Dimiza et al., 2022).

The Elefsis Bay is located in the northern part of the Saronikos Gulf, and it connects with it through two narrow shallow straits (Papanikolaou *et al.*, 1988). It covers an area of 68km^2 and it is surrounded by the Pateras, Pastra and Parnitha mountains. The torrents of Sarantapotamos and Katsimidis drain the Pateras and Pastra mountains and discharge into the sea (Alexouli-Livaditi *et al.*, 1997). The bay is relatively shallow with a maximum depth of 33 m.

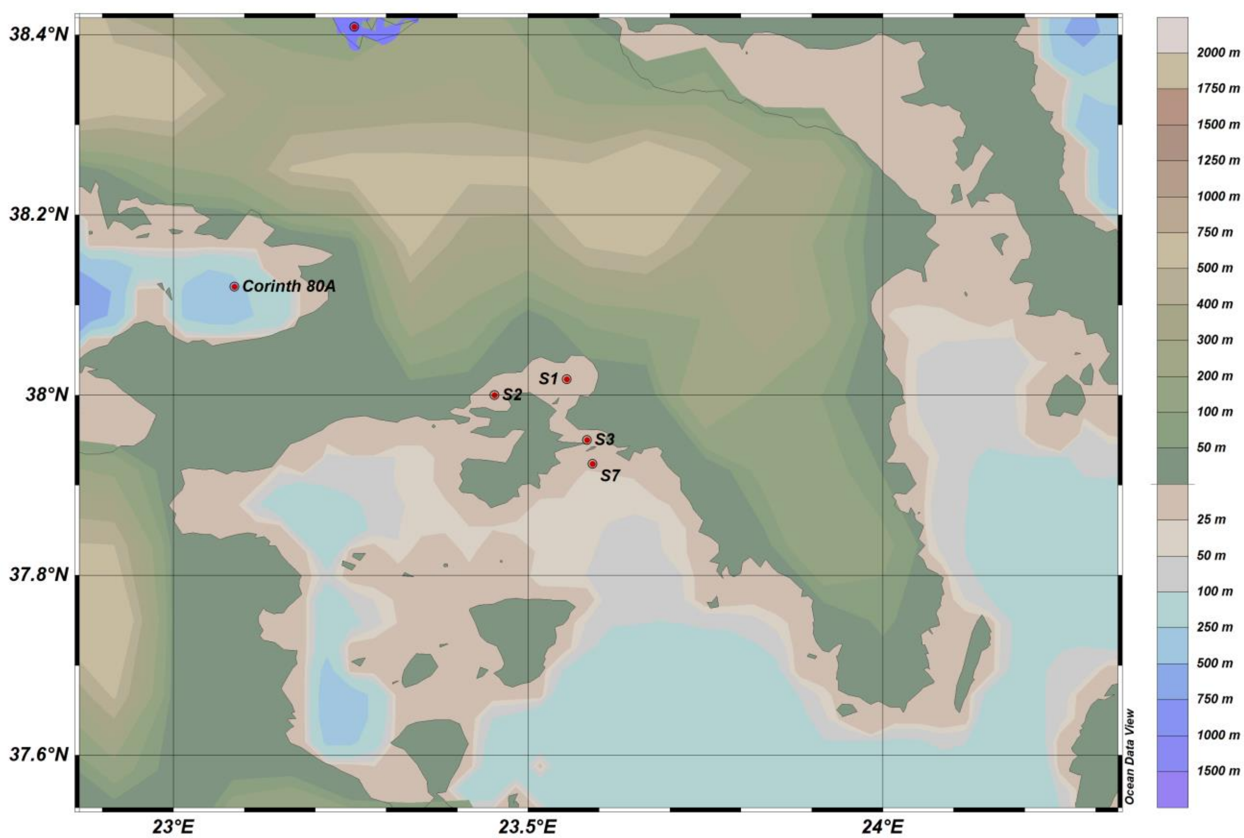


Figure 3: Map of the sites in the Saronikos Gulf

Elefsis Bay is surrounded by sedimentary rocks like limestones and clastic formations, while the lower altitude area is covered by post-alpine sediments like talus cones and scree (Lekkas, 2001).

The present-day climate of the Attica region is typically Mediterranean and is characterized by dry, warm summers and wet mild winters (Kambezidis *et al.*, 1998; Sakellariou and Kambezidis, 2000). Here, the ombrothermic diagram of the Saronikos Gulf is presented based on data from the Climatic atlas of Greece (Figure 4). The dry period of the Saronikos Gulf area is rather long, and it is limited from April till October.

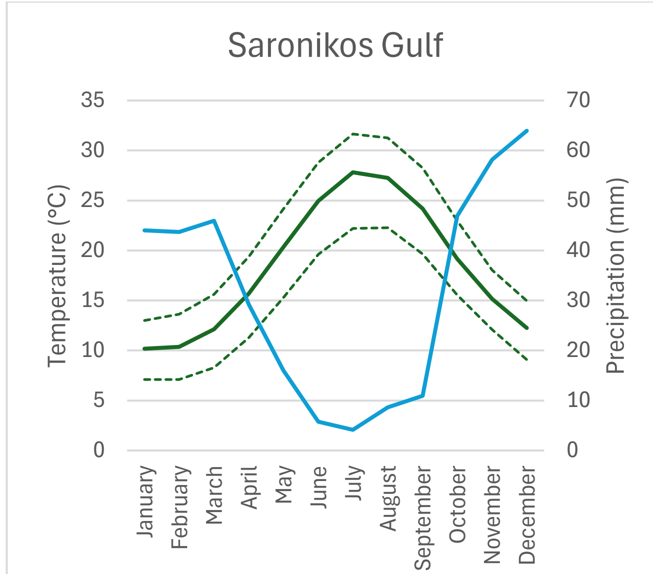


Figure 4: Ombrothermic diagram of the Saronikos Gulf area according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017

The vegetation of the area around the Saronikos Gulf and Elefsis Bay is highly affected by human activities since it is the most heavily urbanized and industrialized coastal region of Greece. The lowland is partly covered by olive trees as a result of intense grazing and farming. The main vegetation reservoir in the area is Parnitha mountain (Kyrikou *et al*., 2020).

The vegetation that distinguishes Parnitha mountain is categorized in three vegetation zones,

- 300-800 m.a.s.l.: pine forests, Mediterranean evergreen shrublands and phrygana
- higher than 800 m.a.s.l.: coniferous forests with pines and Greek firs (Abies cephalonica)
- 900-1400 m.a.s.l.: Greek fir forests, shrublands with Juniperis oxycedrus, few open grasslands in the highest mountain summits: spiny juniper shrubs

Also, riverine vegetation occurs in the riverbanks and the mountains steep slopes where chasmophytes and deciduous oaks have been observed (Kyrikou *et al.*, 2020) as well as other trees like *Cedrus libani, Quercus frainetto, Quercus petraea, Ulmus minor, Populus alba* and *Pinus pinea* that have been planted either along roadsides or recreation areas (Aplada, 2003).

3.2. Corinth Gulf

Corinth Gulf is a long, semi closed gulf that is located between Central Greece and the Peloponnese. It extends from the west in the Ionian Sea, and spreads to the east until the Isthmus of Corinth (Figure 5).

The samples that were studied for this research were recovered during the IODP expedition 381, that took place in the Corinth Gulf during October of 2017. The first sample belonged to the top core of the M0079A site and the second belonged to the top core of the M0080A site (Figure 5).

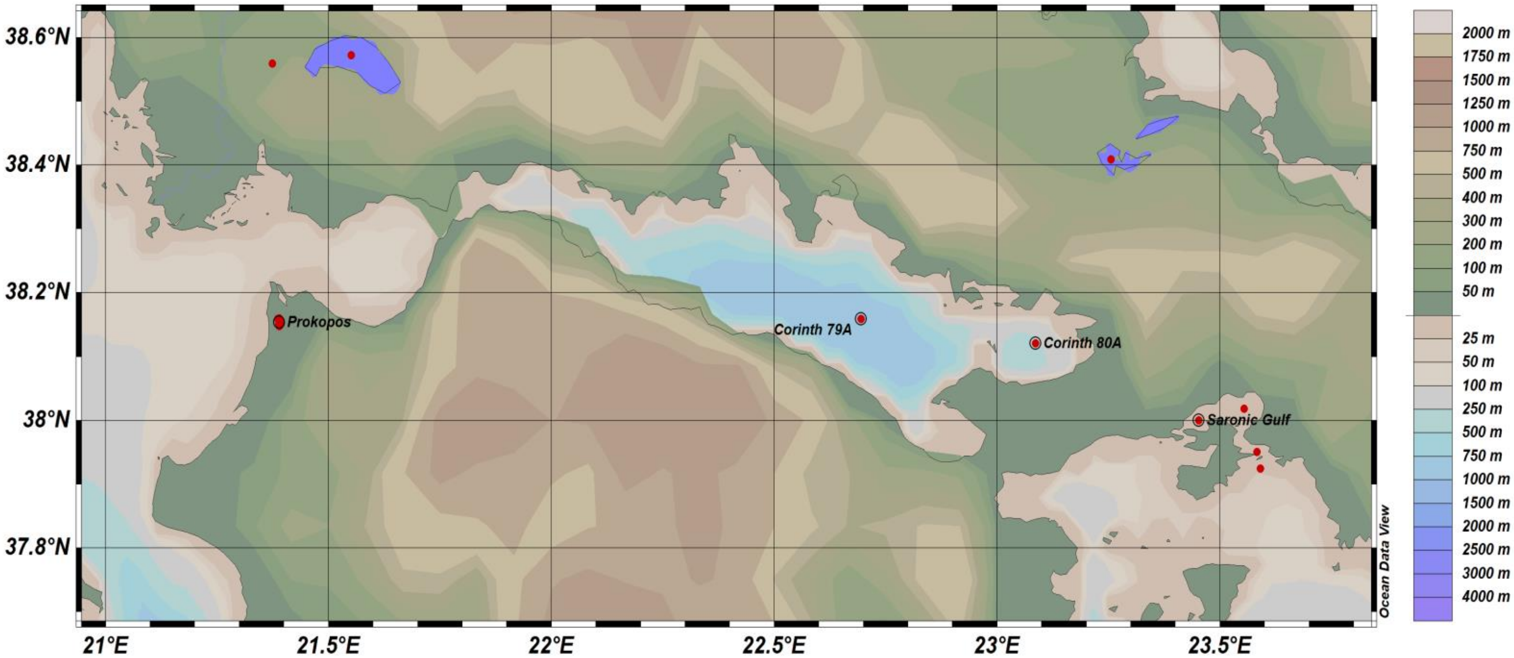


Figure 5: Map of the Corinth Gulf and the sites of interest

The climate of the area is typically Mediterranean with dry, warm summers and wet mild winters. The ombrothermic diagram was reconstructed for the area using climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017 (*Figure 6*). The dry period of the Corinth Gulf area resembles the one of the Saronikos Gulf and is also limited from April till October.

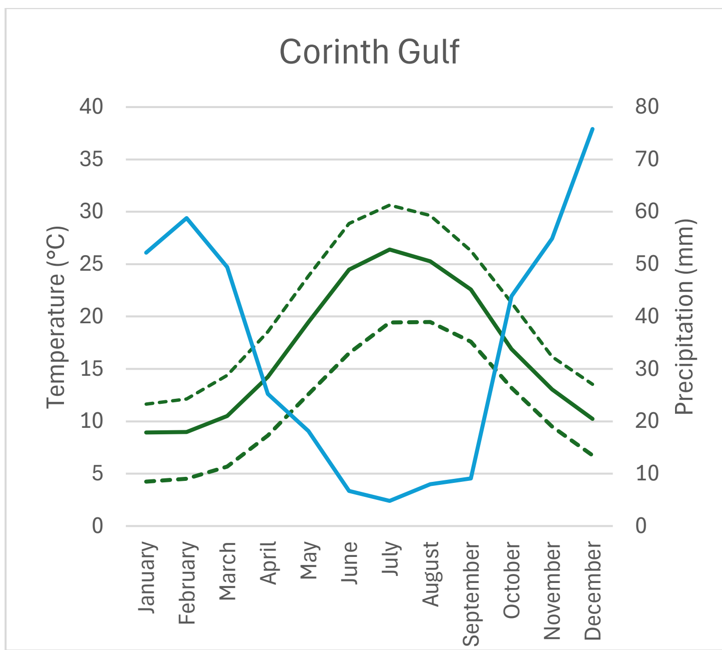
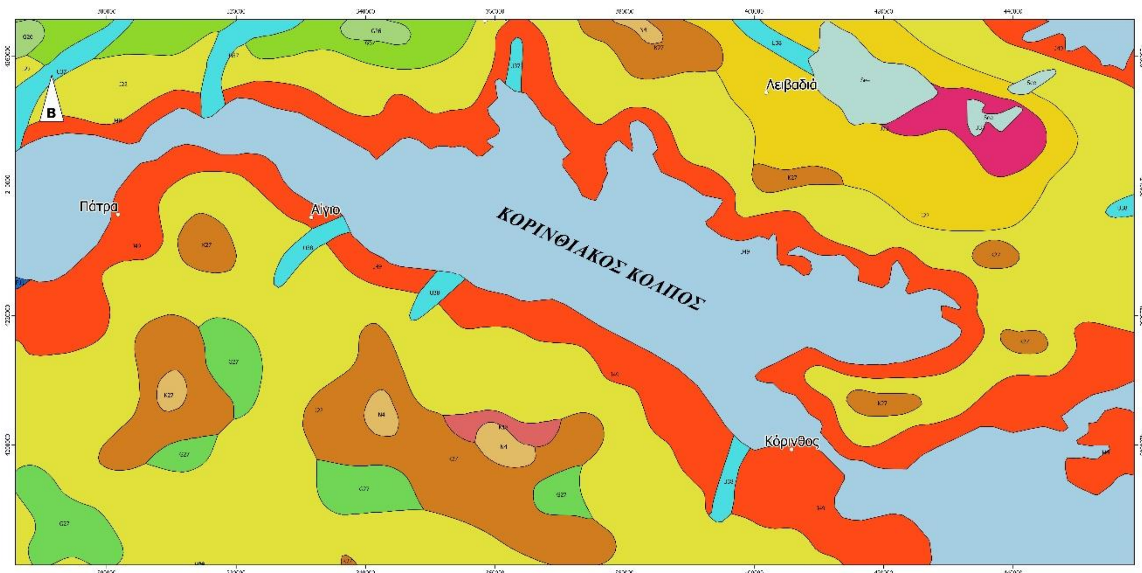


Figure 6: Ombrothermic diagram of the Corinth Gulf area according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017

The vegetation that surrounds the Corinth Gulf is characterized by great biodiversity and is categorized into vegetation zones (*Figure 7*). All around the coastlines of the Corinth Gulf, Eastern Mediterranean forests prevail, consisting of *Ceratonia siliqua, Olea europaea* subsp. *Oleaster*, and shrublands that include *Pistacia lentiscus, Quercus coccifera* (*Figure 7*). The Eastern Mediterranean forests are often disrupted by vegetation of flooded grasslands, or rivers' delta. That type of vegetation is characterized by alluvial forests and lowland shrublands and the most representative species are *Fraxinus angustifolia, Platanus orientalis, Nerium oleander, Tamarix spp*. In medium altitudes Mediterranean *Quercus ilex type* and *Quercus coccifera* forests are typical. Forests that consist of *Abies cephalonica* trees are common in higher altitudes both in the south of the Gulf in northern Peloponnese and in the north of the Gulf in southern Central Greece. Also, in higher altitudes, in the northern Peloponnese, the vegetation consists of deciduous forest with the main representative species the broadleaved deciduous oak (*Quercus frainetto*).



	G (26&27): Southern and Eastern Balkan semi-mountainous/mountainous Oak forests
	J (22&33): Mediterranean sclerophyllic forests and shrublands
	J49: Eastern-Mediterranean Olea europaea forests
	K18: Xerophytic conifer forests, shrublands
	K27: Southern Greece forests with Abies cephalonica
	N4: Mountainous xerophytic vegetation
	P11: Mediterranean sand dune vegetation
	U35: Periodically overwhelmed oak forests
	U (37&38): Mediterranean/sub-Mediterranean wet plains, alluvial forests and shrublands

Figure 7: Modern vegetation that surrounds the Corinth Gulf and legend (https://www.korinthiakos.info/content/%CF%87%CE%BB%CF%89%CF%81%CE%AF%CE%B4%CE%B1)

3.3. Thermaikos Gulf

Thermaikos Gulf is located in the northwestern part of the Aegean Sea in Greece (Figure 2). It is a semi-enclosed gulf, and it is considered to be a microtidal marine environment with great biodiversity. Water mass circulation is controlled by thermal circulation, water mixing and climatic conditions. Water masses of the North Aegean Sea enter Thermaikos Gulf, and then flow towards the south, following an anticlockwise direction (Poulos et al., 2000). The gulf is affected by the discharges of three major rivers, Axios, Aliakmon and Pinios River, and by two minor ones, Gallikos and Loudias river, as well as ephemeral streams (Lykousis et al., 2005; Poulos et al., 2000). The annual discharges from the previously mentioned sources can reach tones of sediment, forming a submarine delta on the west part of the gulf and causing the constant occurrence of dissolved solids in the water column (Koukousioura *et al.*, 2023). During the high precipitation period (Figure 8), the freshwater intrusion extends to a major part of the gulf (surface salinities <25), while during the whole year more saline waters from the northern Aegean flow towards the northeast, entering the gulf (Koukousioura *et al.*, 2023).

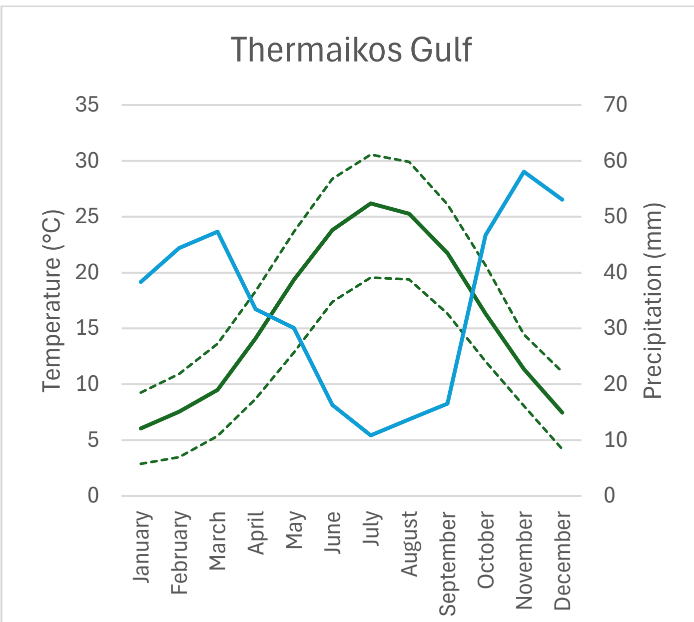


Figure 8: Ombrothermic diagram of the Thermaikos Gulf according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017

The climate is considered as terrestrial Mediterranean to humid continental (Poulos et al., 2000). The ombrothermic diagram of the Thermaikos Gulf is presented. It is based on climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017) (Figure 8). According to the diagram the dry period in the generic Thermaikos Gulf area lasts from late April till late September.

The discharge basin of the Thermaikos Gulf is huge as a result of the big rivers discharging in it. The borderlands of the gulf fall within various bioclimatic zones starting from Thermomediterranean along the coastal areas, as well mesomediterranean and Oromediterranean on the mountainous areas. A big part of the basin is used as agricultural land or is considered urban area. A large part of the Macedonian plain that is the main part of the discharge basin, is covered by rice fields.

3.4. Prokopos Lagoon

Prokopos Lagoon is located in the northwestern part of the Peloponnese (Figure 9). On its north end it connects with mountainous range of Mavra Vouna (240 m), on its west it communicates with the Ionian Sea through the Larisos River, which runs through the Strofylia forest and ends up to the sandy Kalogria beach and to the Ionian Sea. In the south of Prokopos Lagoon, Metochi village is located, as well as Lake Lamia, while at its eastern part there are cultivated areas and the National Airport of Araxos.

Prokopos lagoon extends at approximately 6 km^2, although its range changes depending on the season (Ασημακόπουλος *et al.*, 1996). The lagoon has an average depth of 30 cm, and a maximum depth of 1 cm. It is covered by reeds, especially during the summer season. It can be clearly separated into three distinct ponds (Palades 0.12 km^2, Cheirovolia 0.2 km^2, Mikrolimni 0.03 km^2) that are all connected by wide channels (Iliopoulos *et al.*, 2015). Prokopos Lagoon is invaded by fresh water from the eastern and southern parts where Larisos river and Fousias side river emit.

The bottom of the lagoon consists mostly of loose clayish sediments. The fact that these sediments include large quantities of shells in a depth of 90 cm, lead to the conclusion that they are sea deposits (Ασημακόπουλος *et al.*, 1996). The lagoon's floor is also rich in organic matter.

Figure 9: Satellite image of Prokopos Lagoon and the location of the samples that were studied for this research (P1, P2..., P11: samples code names)

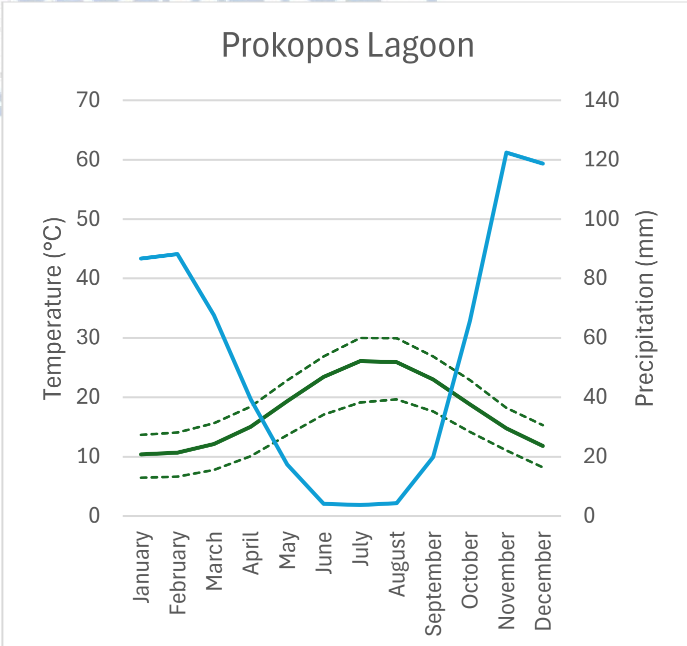


Figure 10: Ombrothermic diagram of the Prokopos lagoon area according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The climate in the western Peloponnese in general is considered to be Mediterranean, with wet winters and mild temperatures. The summers tend to be warm and dry with long periods of sunlight. On the right, the ombrothermic diagram of Prokopos lagoon area is presented. It is based on climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017) (*Figure 10*). The dry period of the Prokopos lagoon lasts from late April until late September.

Prokopos Lagoon hosts several different environments such as various lakes, lagoons, marshes, river streams, sandy coastlines with dunes, pine, and oak forests, as well as human settlements and cultivated areas.

According to the EUNIS habitat classification, 22 habitat types have been recorded in the area with three of them being of high priority:

1. 1150* Coastal lagoons
2. 2250* Coastal dunes with *Juniperus* spp.
3. 2270* Wooded dunes with *Pinus pinea* and/or *Pinus pinaster*

In the north of Prokopos lagoon, in Mavra Vouna, many taxa of shrubs grow such as, *Pistacia, Juniperus phoenicea, Olea oleaster, Cercis siliquastrum, Pyrus amygdaliformis, Phlomis fruticose* (Μ.Δ. Εθνικού Πάρκου Στροφυλιάς και Προστατευόμενων Περιοχών δυτικής Πελοποννήσου - Ο.ΦΥ.ΠΕ.Κ.Α., 2023)

In the general region of the Strofylia forest, grows the largest *Pinus pinea* tree forest in Greece. It expands for 89 km^2 and covers a coastal forest line with an average width of 1250 m. The fact that fresh and saline water often co-exist gives the area extremely rich biodiversity with both water and terranean environments.

Therefore, the main tree species in the Strofylia forest are *Pinus pinea*, and *Pinus halepensis* and *Quercus macrolepis*. Other less grown plant species are the *Pyrus amygdaliformis*, *Pistacia terebinthus*, *Juniperus phonica*, *Quercus coccifera* and *Fraxinus augustifolius*. In the coastal dune areas, also grow many plant species such as the *Pancratium maritimum*, *Ammophila arenaria* and *Galactites tomentosa*.

The total number of species that have been recorded in the general area of the Kotychi lagoon is 582 according to the OFYPEKA organization (Μ.Δ. Εθνικού Πάρκου Στροφυλιάς και Προστατευόμενων Περιοχών δυτικής πελοποννήσου - Ο.ΦΥ.ΠΕ.Κ.Α. 2023).

3.5. Elos Lagoon

Elos lagoon is located in northeastern Greece in Thrace (Figure 2). It is a coastal lagoon that is surrounded by the Northern Aegean Sea from the south, the Ptelea Lake from the west and the Xanthi-Komotini plain from the north. Elos is part of a complex of coastal brackish and freshwater lakes, that includes Lake Ptelea, Aliki lagoon, Karatza lagoon, Xirolimni lagoon and Porto Lagos lagoon. It extends approximately for 10 km^2 while its coastline extends for 7 km. Elos lagoon is very shallow and is separated by the Thracian Sea in the southeast, through a long and narrow strip of land where several coastal sand dunes can be encountered. In the southern part of the Elos lagoon, lays the Molyvotis peninsula.

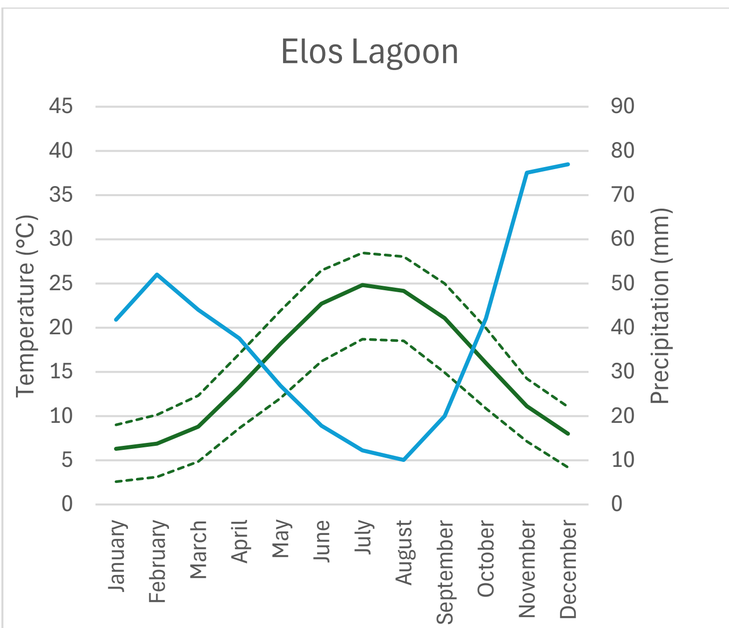


Figure 11: Ombrothermic diagram of the Elos Lagoon area according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

Rhodope mountains are a natural boundary for the mediterranean and continental climate (Επαγγελματικό και Βιοτεχνικό Επιμελητήριο Ροδόπης). South of the mountains the climate of the region is considered to be Mediterranean. As we can see from the ombrothermic diagram, 2/3 of the rain fall in the first and last trimester of the year while the 1/3 of the rain fall in spring and summer (Figure 11). The dry period of the area begins on late April/early May and lasts until late September/early October.

Many ecosystems lie around the Elos lagoon, such as various channels and islands, marine water lagoons, muddy areas, rivers' deltas, marshes, wet meadows, as well as sandy beaches with dunes and rocky coastlines. Near the beach grow various plant life such as, *Anchusa procera, Glaucium flavum, Euphorbia paralias, Euphorbia peplis, Anthemis tomentosa, Silene euxina, Silene grisebachii, Dittrichia viscosa, Ammophila arenaria, Halimione portulacoides, Scolymus hispanicus, Salicornia perennans, Pancratium maritimum, Eryngium maritimum, Cakile maritima, Salicornia perennans* and *Carduus acicularis* (Λιμνοθάλασσα Έλους Ροδόπης). The Xanthi-Komotini plain is covered with cotton crops which is the main agricultural activity in the area, although there are some areas that grow cereals, wheat, beets, tomatoes and some vegetable and fruit crops. In addition, on the edges of the Rhodope mountains, tobacco is produced while in the western part of the plain grow cherry trees (Κατσιμίγας, 2007).

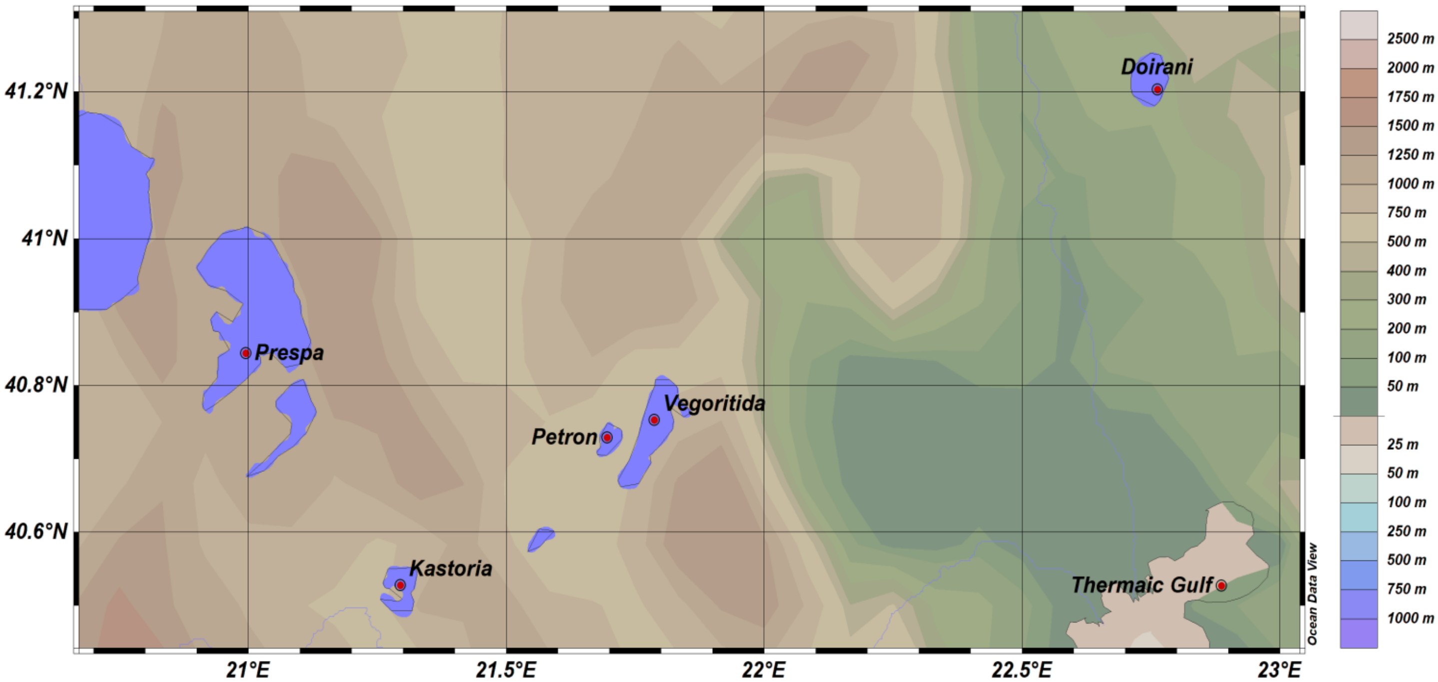


Figure 12: Lakes in Macedonia and the sites of interest

3.6. Lake Vegoritida and Lake Petron

Lakes Vegoritida and Petron are located in the northcentral Greece (40°49' to 40°39' N, 21°40' to 21°50' E) (Figure 12). They are mostly calcareous, and they extend for 130.3 km^2 at an altitude ranging from 500 m to almost 850 m a.s.l. The area represents a Natura 2000 network site called Limnes Vegoritida-Petron (GR-1340004) where several protected species and environmental types have been recorded.

The surrounding hills consist mostly of limestone and marbles. Old and recent talus cones and screes are massed at the foothills, due to erosion of the calcareous substrate, and the aquatic ecosystems develop mainly on recent alluvial deposits around the lakes

The climate of the area is sub-mediterranean to sub-continental and it is characterized by harsh winters and mild dry summers. The bioclimate has been distinguished as sub-humid but transitional to semi-arid, with harsh winters, according to the Emberger's method (Emberger, 1955; Pirini *et al.*, 2014; Μαυρομμάτης, 1980). Below, the ombrothermic diagrams of Lake Vegoritida and Lake Petron are presented based on climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017) (Figure 13,Figure 14). According to the diagrams, the dry period in both the areas is shorter than the dry periods of the forementioned regions, and it lasts from late May/early June till late August/early September.

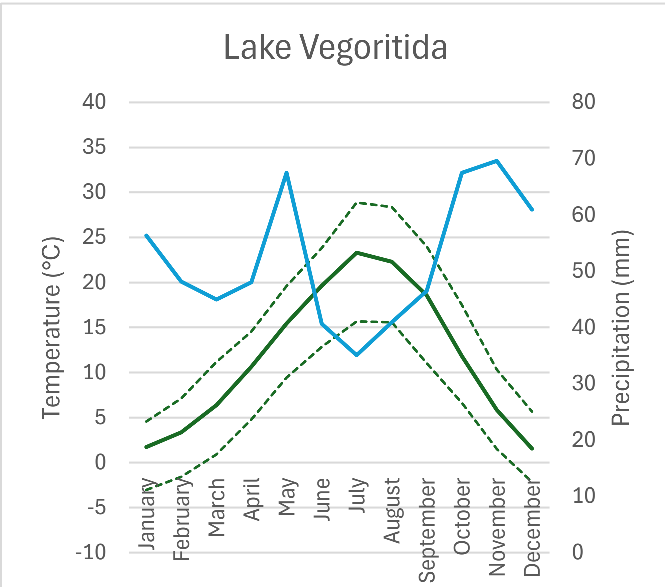


Figure 13: Ombrothermic diagram of Lake Vegoritida according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

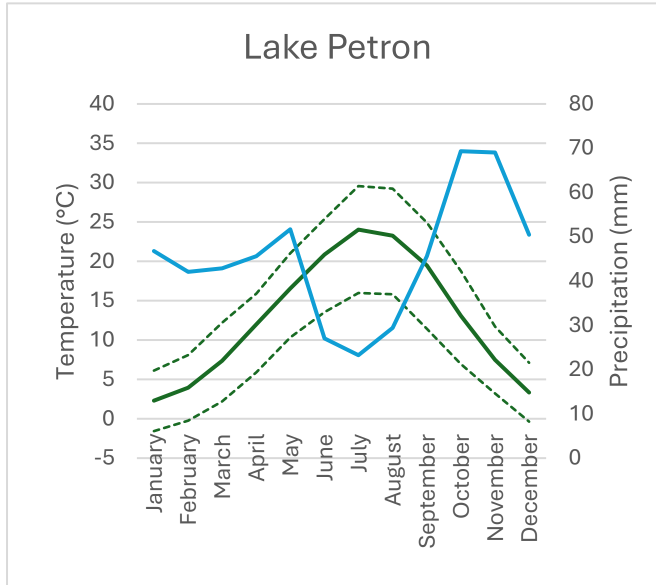


Figure 14: Ombrothermic diagram of Lake Perton according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

Concerning the vegetation of the area*, Quercus trojana* is a species that is very common in the hills around the lakes. *Juniperus spp., Fraxinus, Pistacia terebinthus, Phillyrea latifolia, Rhus cotinus,* are the most common taxa in the hills, and as far as the rivers sides *Salix* and *Alnus glutinosa* are the most characteristic species (Λίμνες Βεγορίτιδας και πετρών - Ο.ΦΥ.ΠΕ.Κ.Α. 2023). The aquatic flora is characterized by *Myriophyllum, Polygonum amphibium, Ceratophyllim demersum* and *Vallisneria spiralis*, and lastly there are vast reeds that consist mostly of *Phragmites australis* that end up in wet meadows which are very important for the various ecosystems (Λίμνες Βεγορίτιδας και πετρών - Ο.ΦΥ.ΠΕ.Κ.Α. 2023). Regarding to the agricultural activities around the lakes, they involve mainly cereal cultivation as well as legume, corn and wheat (Στατιστικά καλλιεργειών νομού Φλωρίνης, 2023).

3.7. Lake Doirani

Lake Doirani is located in the northern Greece and is a transboundary lake at the border between North Macedonia and Greece (Figure 12). It sits at an altitude of 144m above sea level (a.s.l.), in a karst depression between two mountain ranges, Belles in the northeast with a peak of 1870m a.s.l. and Krousia in the southeast with a peak that reaches 860m a.s.l. (Anastasiadis *et al.*, 2005). The lake has an elliptical shape and covers an area of 43 km^2 with a maximum depth that reaches 4m. The lake is being fed by various rivers, creeks and groundwaters (Masi *et al.*, 2018).

The regional climate is Mediterranean considering there is only the Thessaloniki plain between the lake and the Aegean Sea. The proximity of the lake to the sea and the local morphology are two factors that affect the climatic conditions in the area and cause the temperatures to be higher than in other regions in Macedonia (Anastasiadis *et al.*, 2005; Bonacci *et al.*, 2015). Here, the ombrothermic diagram of Lake Doirani is presented according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed http://climatlas.hnms.gr; Mamara et al., 2017) (Figure 15). The dry period in the Lake Doirani area is rather short and it lasts from early June until early October.

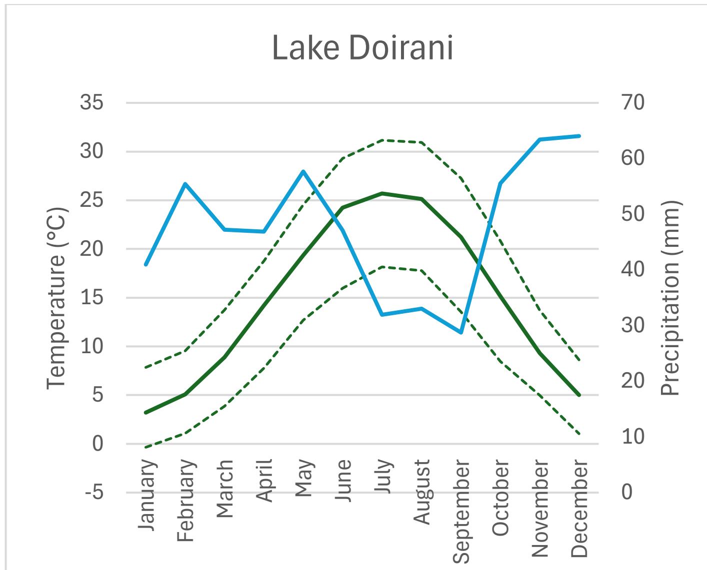


Figure 15: Ombrothermic diagram of Lake Doirani according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The natural vegetation of the area is distinguished by many Mediterranean taxa which compose evergreen forests dominated by *Pinus halepensis, Quercus coccifera, Quercus ilex* type and *Juniperus oxycedrus*, while deciduous forests are dominated by *Quercus pubescens, Carpinus orientalis, Osrtya carpinifolia, Pistacia terebinthus, Fraxinus ornus* and *Acer* (Masi *et al.*, 2018). The mountainous forests in higher altitudes between 700 and 1700m a.s.l. consist of *Abies* and *Juniperus* (Masi *et al.*, 2018). Sub-alpine and Alpine vegetation can be found above 1700m altitude (Eastwood, 2004). Vegetation near shores is typical pseudomaquis and consists of *Quercus coccifera* L., *Quercus pubescens* Willd., *Carpinus orientalis* Mill., *Clematis flammula* L., *Juniperus oxycedrus* L., *Pistacia terebinthus* L., *Ulmus minor* Mill., *Ficus carica* L. and *Rhamnus saxatilis* subsp. *rodopea* (Velen.) (Čarni *et al.*, 2003). The vegetation around the lake shore consists of reed beds with most common taxa the *Phragmites australis* (Cav.) Steud., *Schoenoplectus lacustris* (L.), *Typha angusifolia* L., *Typha latifolia* L., *Sparganium neglectum* and *Sparganium erectum* aggr. (Masi *et al.*, 2018). The cultivation of the surrounding area involves mainly cereals but also grapes, vegetables, and tobacco in the area has affected the vegetation around the lake (Bojovic *et al.*, 2016).

3.8. Lake Kastoria

Lake Kastoria is situated in northern Greece (Figure 12), at an altitude of 627m a.s.l. It is a small and shallow lake that extends for 32.4 km^2 and has a mean depth of 4.5m. It has a natural outlet to the Aliakmon River (Karkanas *et al.*, 2011). Xeropotamos is a stream that discharges into the lake from its eastern shoreline amongst other various streams that discharge in it from all the other sides. The sediments of lake Kastoria are mainly clastic, and they include some percentage of organic matter (Panagos *et al.*, 1989).

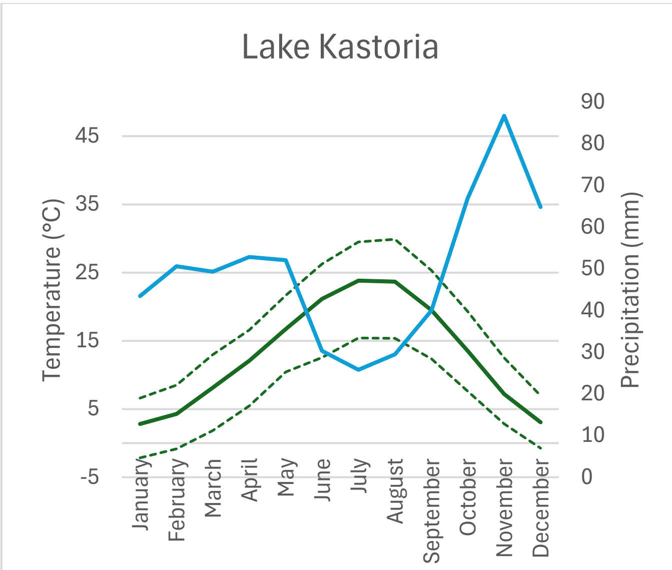


Figure 16: Ombrothermic diagram of Lake Kastoria according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The climate around the region of Lake Kastoria is considered to be semi-humid to humid with moderate dry summers. Here, the ombrothermic diagram of Lake Doirani is presented according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017) (Figure 16). The dry period in the generic Lake Kastoria area last from late May until September. Around 44% of the Lake Kastoria catchment area is exploited for cultivational purposes mainly in the plain fields (Karkanas *et al.*, 2011). The agricultural activities around lake Kastoria involve mainly apple trees, cereals, legumes, corn, tobacco, potatoes and vines. The mixed deciduous oak forests with *Quercus* sp. alternate with open shrubby vegetation and stands of *Castanea* sp. are encountered in higher altitude hilly areas (Karkanas *et al.*, 2011). At higher altitudes, in the montane areas of Verno mountain range, grow *Fagus* sp. and coniferous forests. Closer to the lake grow willows (*Salix* sp.), poplars (*Populus* sp.), plane trees (*Platanus orientalis*), elms (*Ulmus* sp.) and other trees and shrubs. Lastly, in the shorelines of the lake grow reeds (*Phragmites australis*) and rushes (*Typha* sp.) which form extensive marshes, especially in the southern shore of the lake where the historic Neolithic Settlement of Dispilio (Karkanas *et al.*, 2011).

3.9. Lake Megali Prespa

Megali Prespa lake is part of a lake complex located in the borders between Albania, Greece, and North Macedonia (Figure 12). It is situated at an altitude of 849m a.s.l. and it is surrounded by mountains, the highest peak of which is at 2601m a.s.l. in Baba Mountain to the northeast of the lake, as well as several other peaks around 2000m a.s.l. to the west and the north (Panagiotopoulos *et al.*, 2013). The catchment of Prespa extends for 1300 km^2 and includes the two Prespa Lakes: Megali and Mikri with surface area of 253.6 km^2 and 47.4 km^2 respectively (Hollis and Stevenson, 1997; Panagiotopoulos et al., 2013).

The Prespa catchment is separated into two distinct parts: the western and southern parts of the basin where karstic dolomites and limestones dominate, and the northern and eastern part where granites and gneiss dominate. This geological division also determines the vegetation types (Fremuth *et al.*, 2014; Panagiotopoulos *et al.*, 2013). The central part of the depression is filled with alluvial sediments as expected. Megali Prespa lake does not have a surface outflow, though it is connected with its neighbor Lake Ohrid through karstic channels traversing the Galicica Mountain (Fremuth *et al.*, 2014; Matzinger *et al.*, 2006).

The climate of the region is Mediterranean with continental influences and is also characterized as continental-central European. It is distinguished by wet cold winters and warm but moderate summers (Fremuth *et al.*, 2014). Here, the ombrothermic diagram of Lake Doirani is presented based on climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017) (Figure 17). Lake Prespa is distinguished by a dry period that begins in late May and lasts up to early September.

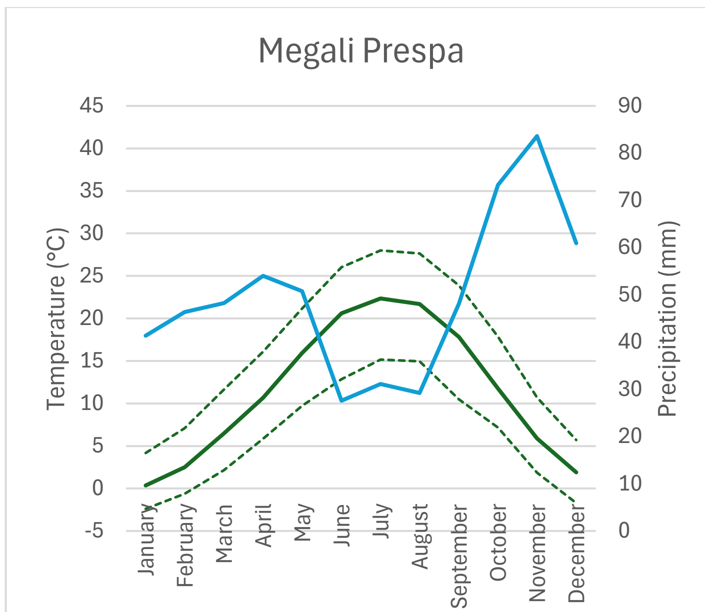


Figure 17: Ombrothermic diagram of Lake Megali Prespa according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The presence of lakes, wetlands and mountains, in combination with the region's complex geology and great Mediterranean influence climate wise, have made the Prespa catchment a very biodiverse environment with rich and diverse plant communities. More than 1800 plant species have been recorded in the Greek part of Prespa alone, as well as 45 habitat types, 7 of which are included in the Natura 2000 project (Society for the Protection of Prespa, 2023). Due to the area's transitional climatic character, the vegetation is composed of a mixture of European, Mediterranean and Balkan endemic species (Polunin, 1987). West of the lake grows a mixed deciduous forest which consists of *Carpinus* (*Carpinus betulus* and *Carpinus orientalis/Ostrya carpinifolia*) with characteristic transitional Mediterranean elements (pseudo-maquis), such as deciduous *Pistacia terebinthus* and evergreen *Phillyrea latifolia* (Panagiotopoulos *et al.*, 2013). On the southern part of the lake, in the limestone hills a mixed evergreen deciduous scrub is encountered, that includes maquis species as well as Greek and Stinking *Juniper* (*J. excelsa* and *J. foetidissima*), *Buxus sempervirens*, and *Quercus trojana* (Panagiotopoulos *et al.*, 2013). On the other hand, the mountainous landscapes in the eastern part of the region is covered by *Pinus peuce* communities that associate with *Pteridium* and *Vaccinium* at higher elevations (Panagiotopoulos *et al.*, 2013).

The main altitudinal categorization is as such:

- Littoral zone: wet meadows and grasslands
- Below 1600m a.s.l.: mixed deciduous oak forests (dominated by *Q. trojana, Quercus cerris* type*, Quercus frainetto, Quercus pubesens, Quercus petreae, Quercus robur type*)
- Below 1800m a.s.l.: montane deciduous forests (dominated by *Fagus sylvatica*)
- Below 2200m a.s.l.: montane conifer woods (*Abies borisii-regis, P. peuce, P. sylvestris, P. nigra, P. heldreichii*)
- Above treeline: subalpine and alpine meadows

(Pavlides, 1997).

The agricultural activities around the area involve mainly the cultivation of legumes, beets and potatoes (Δήμος Πρεσπών, Πρωτογενής Τομέας 2015).

3.10. Lake Trichonida and Lake Lysimachia

Lakes Trichonida and Lysimachia belong to the western chain of Greek wetlands running along the coast of the Ionian Sea (Figure 18). They are located in the Aetolo-Acarnania district in Greece. Besides the extensive coastal delta and lagoon areas, the wetland system includes the inland lakes and marshes of Aetoloakarnania and Epirus (Zotos *et al.*, 2007). Both the lakes are included in the European Ecological Network Natura 2000.

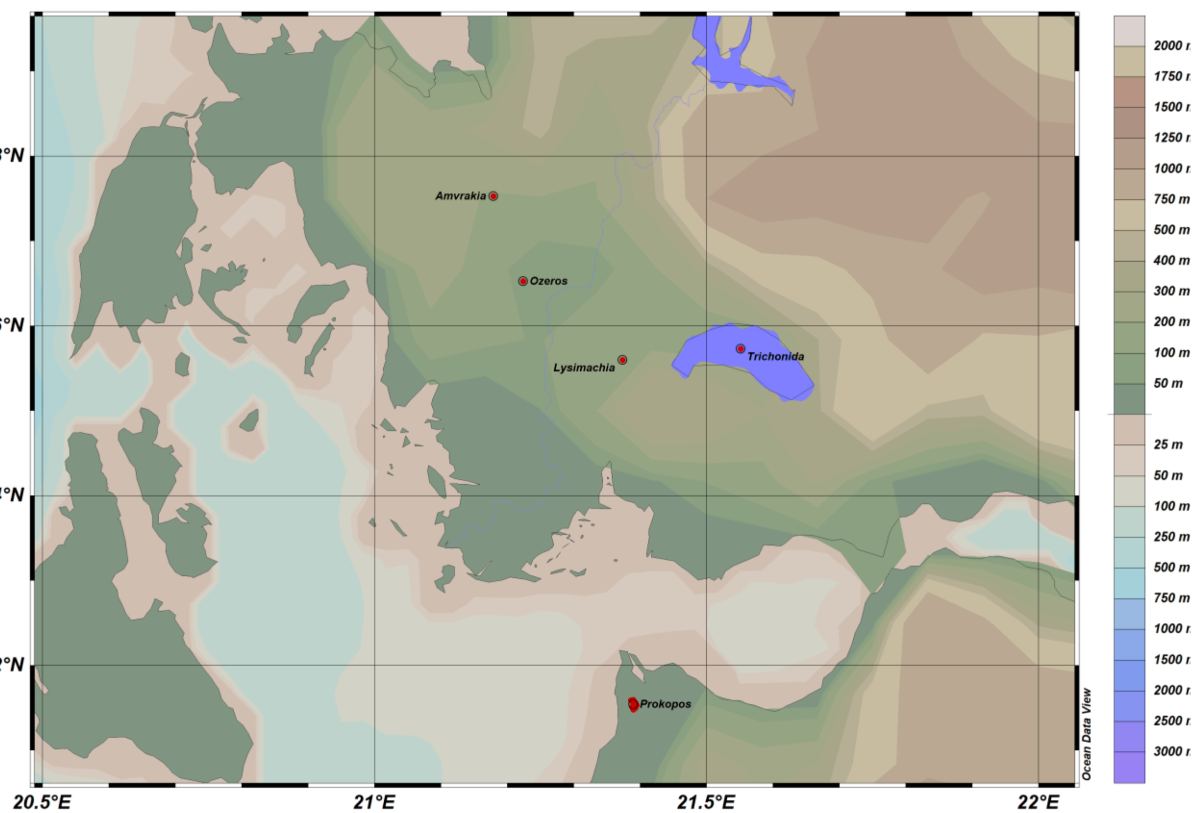


Figure 18: Lakes of Western Central Greece

Lake Trichonida (38° 34'N, 21° 30'E) extends for 96.9 km^2 and it is the largest fresh water natural lake in Greece, both in size and water volume (3 x 10^9 m^3) (Zotos *et al.*, 2007). Lake Lysimachia (38° 34'N, 21° 23'E) on the other hand, is situated 2.8km west of Lake Trichonida and has a surface of 13.2 km^2. The Trichonida and Lysimachia catchment is delineated by Mt Panetoliko on the NE, by Mt Arakinthos on the SW and by Acheloos River on the west. Both lakes are the result of a post-alpine tectonic subduction, created mainly by the two fault systems of E-W and NW-SE direction (Zotos *et al.*, 2007).

The climate of the area is Mediterranean with wet winters and hot dry summers. The ombrothermic diagrams of the climatic conditions of the lakes were constructed with climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from https://climateatlas.hnms.gr; Mamara *et al.*, 2017) and are presented below (Figure 19, Figure 20). According to the ombrothermic charts of the region, we can see that both areas are characterized by a dry period that lasts from early May up until late September.

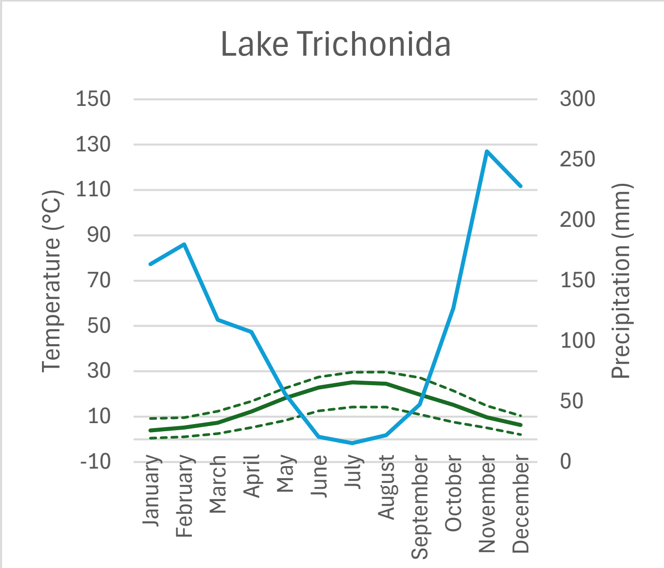


Figure 19: Ombrothermic diagram of Lake Trichonida according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

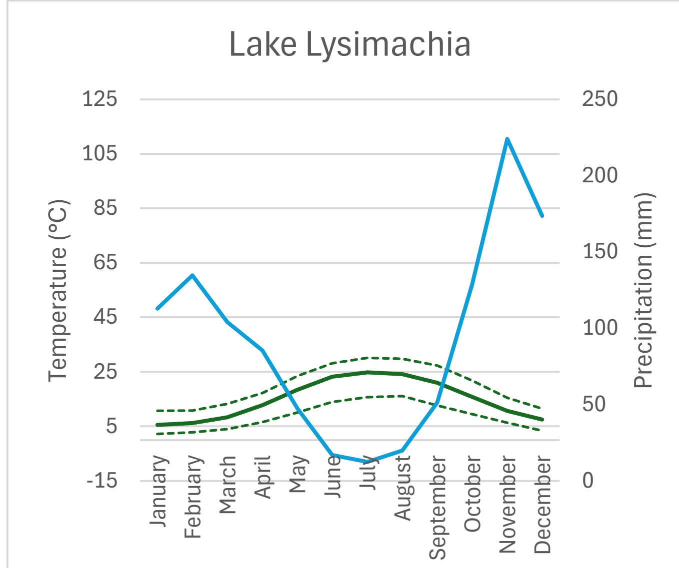


Figure 20: Ombrothermic diagram of Lake Lysimachia according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The vegetation of the mountains that surround the lakes is expected to be found in the pollen record and so it is important to study it. More specifically, Panetoliko mountain is characterized by forest vegetation. In altitudes of 700-1600m *Abies cephalonica* is the dominant species of the conifer forest (Zotos *et al*., 2007). Due to the human activities that occur in the area, at altitudes of 600 to 800m, scrubs with evergreen, sclerophyllous vegetation exist, that is distinguished by *Quercus ilex* type, *Q.coccifera* and *Juniperus*. The phryganic communities may include taxa such as *Cistus, Rosa*, and *Origanum*. Also, the broadleaved deciduous forests that are composed of deciduous *Quercus*, occur within the maquis vegetation or at transitional zones between the evergreen vegetation and the coniferous forests (*NatureBank - Βιότοπος natura - Oros Panaitoliko*).

Closer to the lakes some of the vascular plants that have been recorded in both of them have led to the conclusion that they are controlled by eutrophic and mesotrophic conditions (Κουμπλή-Σοβατζή, 1983). In both lakes, in the littoral and sublittoral zone the herbaceous vegetation is dominated by *Berula erecta, Lythrum* sp., *Carex* sp. and *Veronia angallis aquatica*. The species *Vitex agnus-castus* and *Rubus sanctus* have been recorded in the shrub layer and the species *Platanus orientalis*, *Salix alba* and *Populus alba* grow in the tree layer.

Specifically for Lake Trichonida, the upper sublittoral zone, where alluvial deposits lay, is characterized by *Phragmites australis, Typha domingensis*. In the mid sublittoral zone grows plenty of floating leaved *Nymphaea alba* and in the lower sublittoral zone various submerged macrophytes are encountered (Zotos *et al.*, 2007).

As for the vegetation of lake Lysimachia, in the littoral and sublittoral zone, the herbaceous layer is characterized by the forementioned taxa that have been recorded in Lake Trichonida as well as species like *Cyperus longus, Pspalum paspaloides, Ludwigia peploides montevidensis*. The shrub and tree layers are the same as in Lake Trichonida (Zotos *et al.*, 2007).

3.11. Lake Amvrakia and Lake Ozeros

Lake Amvrakia (38 45'N, 21 10'E) is situated 5 km north of Lake Ozeros and covers a surface area of 14 km^2 (Figure 18). Its maximum water depth has been recorded at 50m. It is a deep mesotrophic lake (Chalkia and Kehayias, 2013) and it has the highest concentration of sulphates amongst all the lakes of the Greek state area (Zacharias *et al.*, 2002) due to the extensive gypsum sediments, particularly in its western parts (Zacharias *et al.*, 2002; Zotos *et al.*, 2007).

Lake Ozeros (38 39'N, 21 13'E) is a shallow lake with a maximum depth of 5.6m and a surface area of 10.1 km^2 (Zacharias *et al.*, 2002). The lake is supplied with water from seasonal streams that occur mainly in the east-southern part, and it is also connected to Acheloos river through an artificial canal where the river overflows to the lake (Kehayias *et al.*, 2014). The lake receives large amounts of fertilizers from the surrounding cultivated area, as well as wastes from nearby farms and industries, which lead to the lake's eutrophication (Chalkia and Kehayias, 2013). Lake Ozeros is also part of the European Ecological Network Natura 2000 as a habitat for migratory birds and several endemic species of fish.

The climate of the area is Mediterranean with wet winters and hot dry summers. The ombrothermic diagrams of the climatic conditions of the lakes were constructed with climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017):

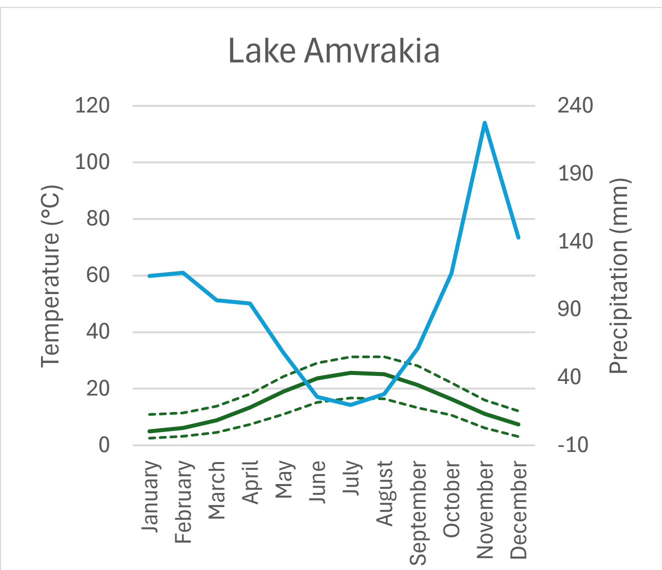


Figure 21: Ombrothermic diagram of Lake Amvrakia according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

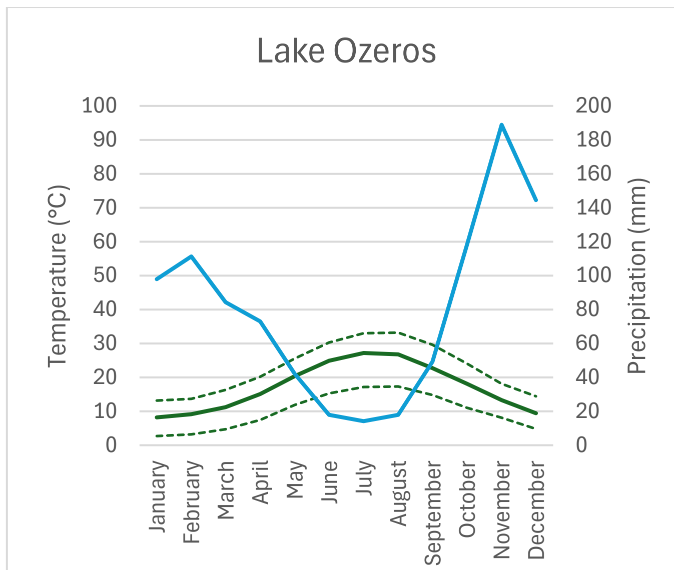


Figure 22: Ombrothermic diagram of Lake Ozeros according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The vegetation of Lakes Ozeros and Amvrakia is very similar to the one that characterizes Lake Trichonida and Lake Lysimachia, since they sit in the same basin and thus are affected by the same climatic conditions and have very similar pollen pathways. A recent study conducted by Zotos et al., in 2021, recorded a total of 152 taxa belonging to 35 families and 102 genera. The Mediterranean taxa that were recorded proved the Mediterranean character of the flora of the lakes.

3.12. Lake Yliki

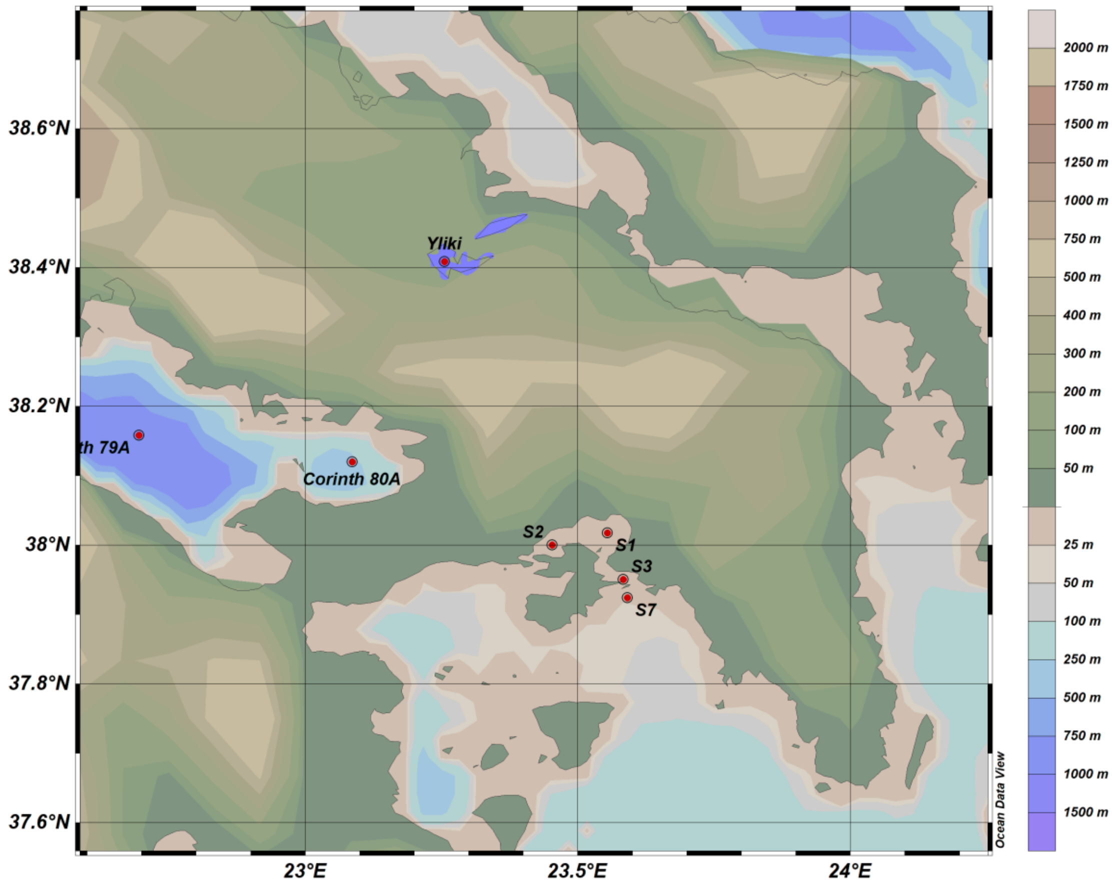


Figure 23: Map of Central Greece and sites of interest

Lake Yliki (38 24' N, 23 16' E) is situated in Central Greece, in the prefecture of Viotia (Figure 23). The catchment of Yliki is bordered by Mount Sphingeio to the west, Mt Ptoos to the north, Mt Messapio to the east and some lower hills to the south. It has a surface area that extends for approximately 25 km^2, a maximum depth of 38.5m, a watershed of 2423 km^2 and a maximum capacity of 590 million m^3 (Cavoura *et al.*, 2023). Its basin receives the waters of the dried Lake Copaida through the Kifissos River of Viotia but is also invaded by underground springs and other smaller water streams from the mountains that surround it. It is also connected to the nearby Lake Paralimni through a 2.5 km long canal.

The bottom of the lake is mainly of calcific composition and shows many underground karstic formations and cesspools, which allow the water to drain to the Paralimni neighbor lake and to the northern Evoikos Gulf (Κουσούρης, 2015)

The climate of the area of Lake Yliki is Mediterranean with wet winters and hot dry summers. The ombrothermic chart of Lake Yliki area was created according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017) and is presented on the right (Figure 24). According to it, the dry period of the area expands for five months, from the late April till the early October.

The area around Lake Yliki is distinguished almost entirely mediterranean maquis vegetation and shrubs. In the lake's perimeter, the species *Quercus coccifera* and *Pistacia lentiscus* are encountered (Κουσούρης, 2015)

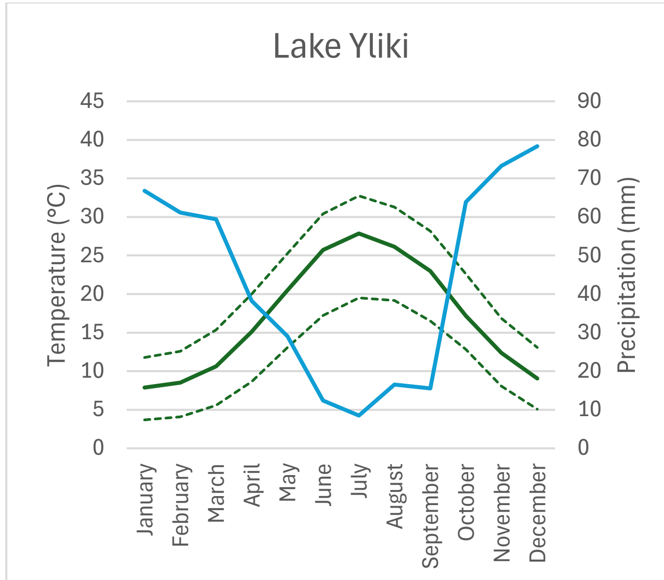


Figure 24: Ombrothermic diagram of lake Yliki according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

3.13. Mount Oiti

Mediterranean temporary ponds are habitats, usually small in size, that can host a large number of flora and fauna species, some of which can be very rare endemic species. They are mainly formed in small depressions in the soil or the rocks, where atmospheric precipitation and rainwater is collected and preserved throughout the wintertime. During the summer season the water usually dries up due to the evaporation that occurs (Διατήρηση Δασών και Δασικών Ανοιγμάτων Προτεραιότητας στον Εθνικό Δρυμό Οίτης και στο Όρος Καλλίδρομο της Στερεάς Ελλάδας, 2015).

The general pattern for the temporary ponds of Mount Oiti is that they are flooded from November to May and dry from June to October. Although most of the area is covered by limestone, there are also large areas that are covered by flysch. Northern Oiti mountain is characterized by a large number of streams that end up filling Sperchios river (Διατήρηση Δασών και Δασικών Ανοιγμάτων Προτεραιότητας στον Εθνικό Δρυμό Οίτης και στο Όρος Καλλίδρομο της Στερεάς Ελλάδας, 2015).

The temporal pond that is found in Livadies site at the altitude of 1810m, is located in the southwest part of the mountain (Figure 25). It is formed on top of flysch that is a part of the Eastern Greece geological zone. It is a small and shallow pond that is entirely rain fed. The geological subterrain consists of coarse-grained sandstones alternating with argillaceous shale and sandy marls. Also, some layers of limestone and cobblestone have been observed (Διατήρηση Δασών και Δασικών Ανοιγμάτων Προτεραιότητας στον Εθνικό Δρυμό Οίτης και στο Όρος Καλλίδρομο της Στερεάς Ελλάδας, 2015).

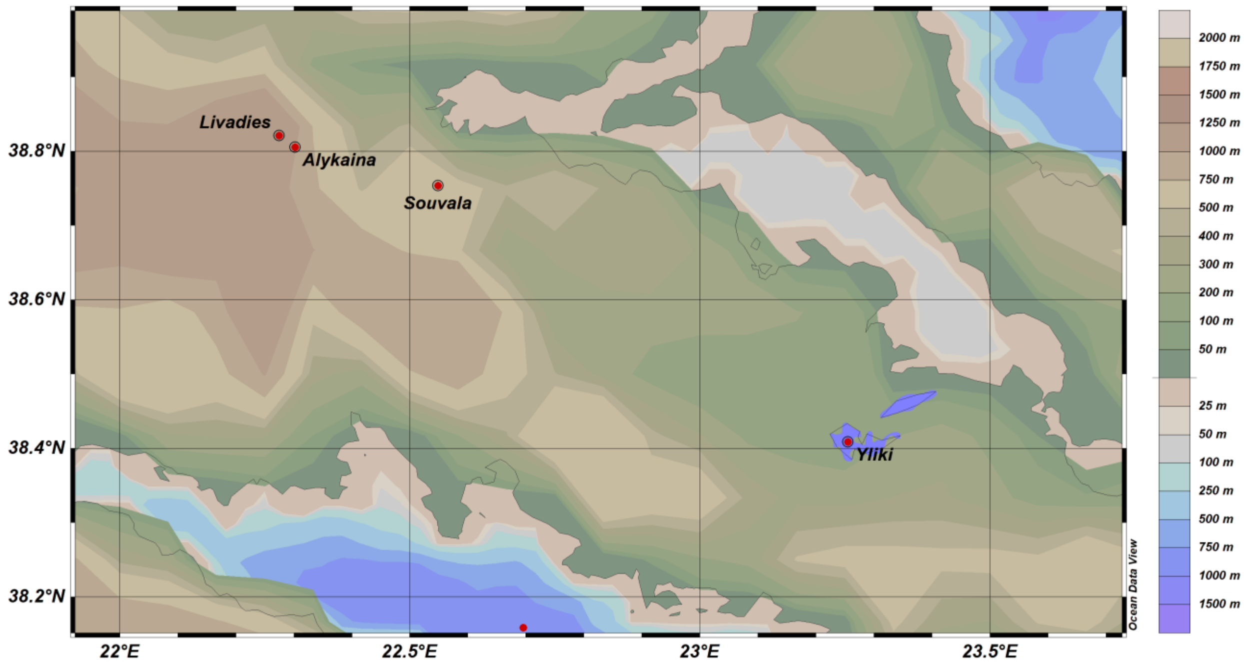


Figure 25: Locations of Livadies, Alykaina and Souvala sites

The temporal pond of Alykaina is located at an altitude of 1920m on Oiti mountain (Figure 25). It is a small and shallow temporal pond that is entirely rain fed. Just like the Livadies temporal pond, the Alykaina temporal pond is located on top of flysch that belongs to the Eastern Greece zone. The flysch also consists of coarse-grained sandstones alternating between argillaceous shale and sandy marls. Again, just like in Livadies, there have been observed some layers of limestone and cobblestone inside the flysch. West of the Alykaina pond, in a close distance, lay the Upper Jurassic limestones of the Western Greece zone that overthrust the flysch of the Eastern Greece zone. East of the pond lay the Upper Cretaceous limestones of the Eastern Greece zone.

Mount Oiti acts as a barrier to the northwestern temperature recession, since the Vardousia mountains are located southern. This provides an explanation for the large amounts of precipitation that Oiti mountain receives in its western parts (Καρέτσος *et al.*, 2014). The ombrothermic diagram was constructed with climate data data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017) (*Figure 26*). As we can see, the dry period in the sites region is extremely short and lasts only for a very short amount of time during the month of July, and possibly for a few days during September.

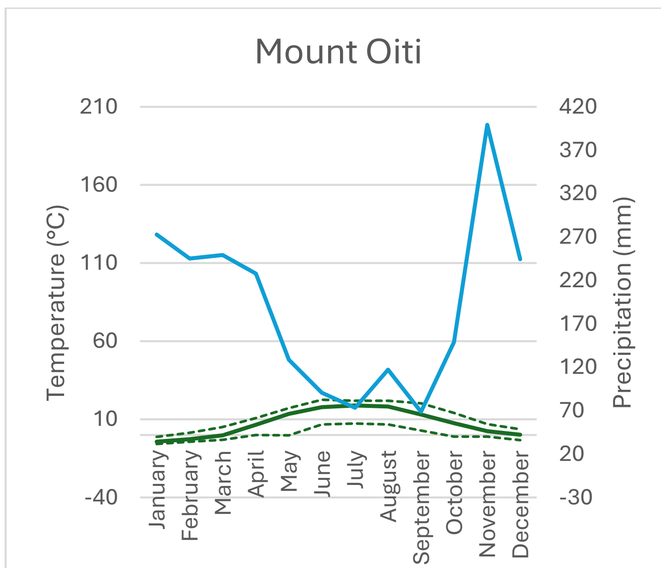


Figure 26: Ombrothermic diagram of Mountain Oiti according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

In general, mount Oiti is an ideal place for *Abies*, deciduous oak, and *Pinus nigra* forests to grow but human activities tend to limit them (Καρέτσος et al., 2014).

The ponds of Mt. Oiti have a more regular alternation of the wet and dry ecophase and the dry ecophase starts earlier as a whole. The plant communities are mainly flowering in late spring or early summer. Their main typical species are the annuals *Lythrum thymifolia, Limosella aquatica, Ranunculus lateriflorus, Myosurus minimus*, and *Veronica oetaea*. Grassland species are restricted to the margins of the ponds. The ponds host no aquatic vegetation and the typical temporary pond communities are succeeded by pioneer nitrophilous vegetation with *Polygonum arenastrum* in late summer and autumn. The pond Livadies is rarely grazed or trampled by either animals or vehicles. The pond of Alykaina is grazed more often, but still not heavily.

The samples that were studied for this research were collected from Livadies and Alykaina, in October 2015 (Delipetrou *et al.*, 2015).

3.14. Mount Kallidromo

The Souvala temporal pond is located on the western part of Kallidromo mountain (Figure 25). The pond is hosted by fluvial deposits that sit on top of the flysch of the Eastern Greece geological zone.

The climate in Kallidromo mountain is considered to be Mediterranean and is depicted in the ombrothermic diagram according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017) (Figure 27). The dry period of the area expands from late May until late September.

Little is known about the habitat of this pond. The vegetation consists mostly of the spring-summer aquatic flora with species like *Myosurus minimus, Polygonum aviculare, Juncus bufonius, Ranunculus lateriflorus, Gnafalium uliginosum, Mentha cervine* and *Isoetes heldreichii*.

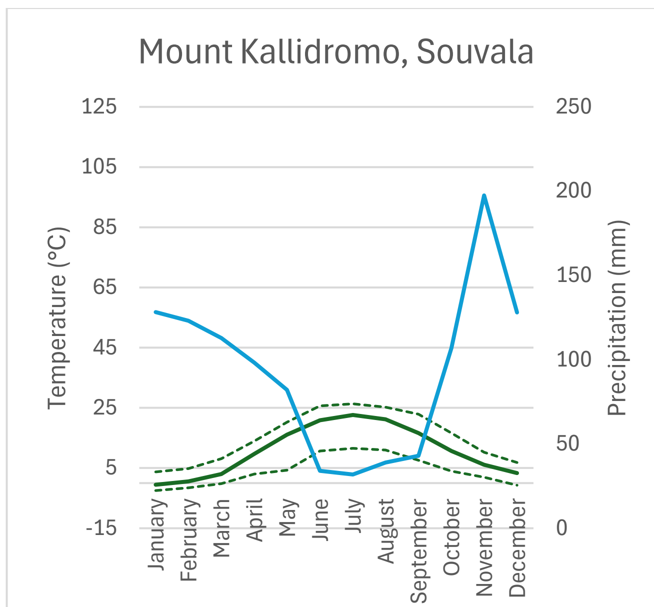


Figure 27: Ombrothermic diagram of Souvala temporal pond according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The samples that were studied for this research were collected from Souvala temporal pond in October 2015 (Delipetrou *et al.*, 2015)

3.15. Rhodope Mountains

The two study areas are located in the southern part of the Rhodope Mountain Range (Figure 28). The Livaditis peat bog is located in the southeast of the Livadites village (41º 17' 42,75", 24º 41' 4,38"), inside of the Haidou forest, at an altitude of 1350m. The bog spreads for 5 km^2 and its highest depth is 2.15m (Theodoropoulos *et al.*, 2010). The Lepidas peat bog is located northeast of the Dipotama village of Dramas, close to the Greek-Bulgarian borders, at an altitude of 1480m. The bog spreads for 26.9 km^2 and its highest depth is 1.20m.

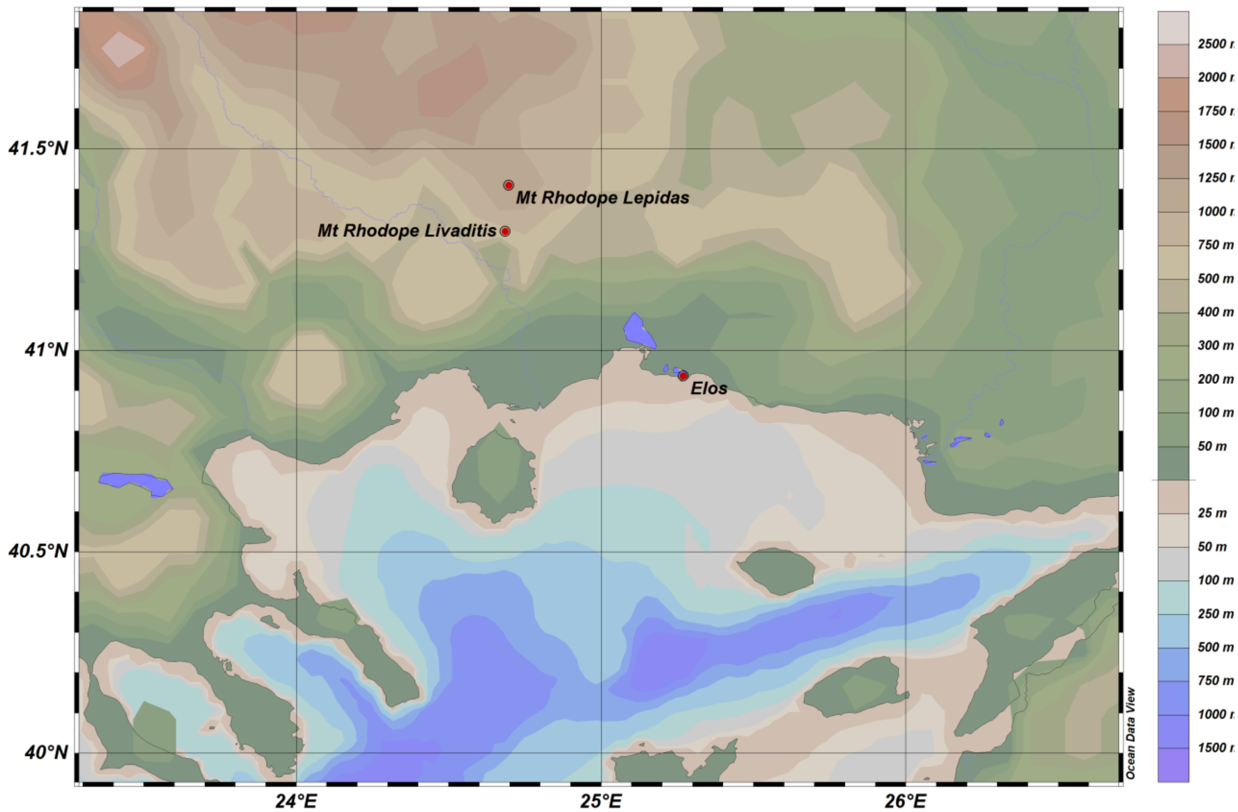


Figure 28: Map of the sites in Rhodope Mountain

The landscape, in both locations, is characterized by high altitudes and steep slopes that create a very complex hydrographic system throughout the region (Kouli, 2020).

The geological background of the area consists of crystalline rocks that belong to the Rhodope metamorphic core complex (Kouli, 2020). West-Thracian gneiss, that contain quartzofeldspathic and pelitic gneisses and schists, migmatites, amphibolites and ultramafic bodies, have been observed at the Livaditis area (Dinter, 1998; Papazisimou *et al.*, 2002).

The climatic conditions in the Livaditis bog are distinguished by a mean annual precipitation of 1000mm and a mean annual temperature of 8.4ºC (HNMS climate atlas). The climate of the area is classified as warm-summer humid continental climate (Dfb), with cold winters and long, cool summers (Kouli, 2020). The ombrothermic diagrams of the two locations were constructed according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara *et al.*, 2017) (*Figure 29*, *Figure 30*). In both cases, the dry period appears to be very short and lasts during the month of September in the Lepidas site and during the months of September and October in the Livaditis site.

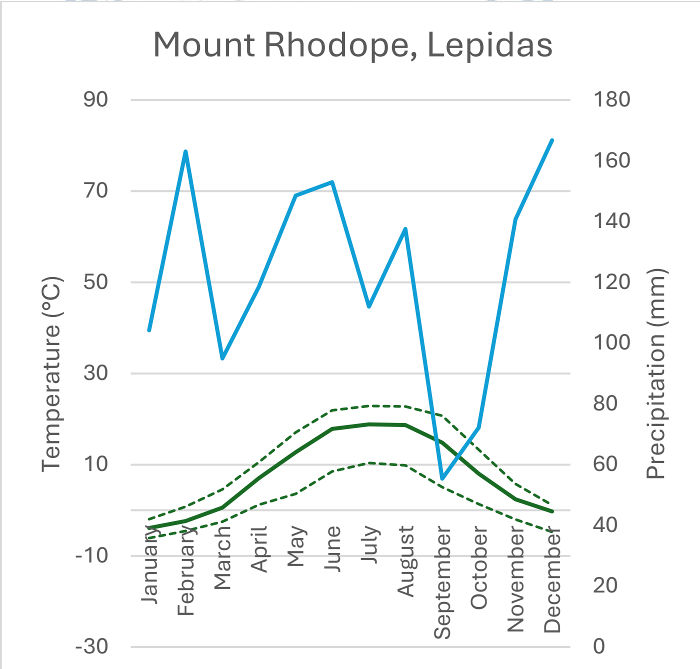


Figure 29: Ombrothermic diagram of the peat bog Lepidas in Mount Rhodope according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

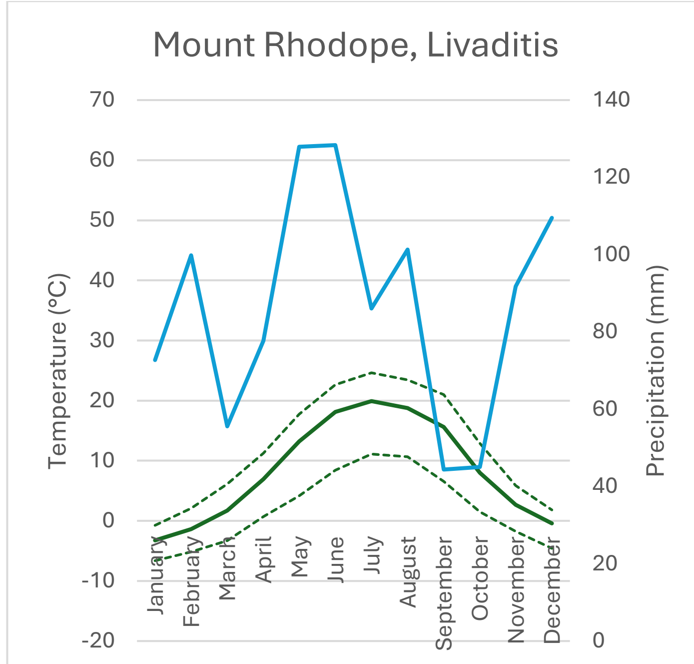


Figure 30: Ombrothermic diagram of the peat bog Livaditis in Mount Rhodope according to climate data of 1971 – 2000 (from Climate Atlas of Greece, assessed from http://climatlas.hnms.gr; Mamara et al., 2017)

The Rhodope Mountain Range consists of a great variety of habitats that are characteristic of central and southern Europe as well as the Balkans. The fact that it didn't freeze during the last glacial in the Pleistocene, makes it a place of great biodiversity. Almost 60% of the species of the European flora, have been recorded in the Rhodope Mountain Range (Φορέας Διαχείρισης Οροσειράς Ροδόπης). It is a refuge for 211 rare and/or endangered species (Φορέας Διαχείρισης Οροσειράς Ροδόπης).

The main modern vegetation zones that have been observed in the surrounding area are as follows,

- ***Quercetalia pubescentis* zone** up to an altitude of 1100m, and it includes *Ostrya carpinifolia Scop., Carpinus orientalis* Miller, and *Quercus coccifera* L. at low altitudes and *Quercus pubescens* Willd., *Quercus conferta* Kit., *Quercus dalechampii* Ten., *Quercus cerris* type L., *Quercus petraea* (Matt.) Liebl.*, Tilia cordata* Mill., *Castanea sativa* Mill., *Acer pseudoplatanus* L., and other deciduous trees at higher altitudes.

- ***Fagetalia* zone**, with *Fagus sylvatica* L., *Fagus moesiaca* and *Abies* spp. Miller. prevails above the *Quercetalia pubescentis* zone and up to 1500-1800 m a.s.l. In this zone*, Betula pendula* forms stands in the woodlands, while *Pinus nigra* may also be present depending on the local and soil conditions.

- the high-altitude areas are covered by the **Vaccinio-Picetalia zone** (subalpine conifer zone) that is represented mainly by *Pinus sylvestris* L., and *Picea abies*.

- In the Alpine and subalpine zone that is present above the forest limits, low vegetation (shrubs and herbs), belongs to the **Astragalo-Acantholimonetalia zone**. (Kouli, 2020)

Regarding the flora, specifically in the two bogs of interest, it has been observed that the local vegetation in the Livaditis bog does not exceed 25cm in height and it covers 95 to 100% of the ground. Likewise, in the Lepidas bog, the local vegetation does not exceed 45cm in height and it also covers 95-100% of the ground. Today, the human impact of farming and stock raising is intense and obvious in both bogs.

Table 1: Areas, Samples code names and sites' coordinates

Areas	Samples code names		Coordinates
Saronikos Gulf	S1	Top core	38º 01.05' N 23º 33.27' E
Saronikos Gulf	S2	Top core	38º 00.00' N 23º 27.18' E
Saronikos Gulf	S3	Top core	37º 57.00' N 23º 35.00' E
Saronikos Gulf	S7	Top core	37º 55.42' N 23º 35.45' E
Thermaikos Gulf	THG4, THG5	Top core	40°31'36.19"N 22°53'13.17"E
Corinth Gulf	M0079A	Top core	38°9'30.24" N 22°41'43.44" E
Corinth Gulf	M0080A	Top core	38°7' 12" N 23°5'10.68" E
Prokopos Lagoon	P1	Surface sediments	38º9'31.392" N 21º23'10.392" E
Prokopos Lagoon	P2	Surface sediments	38º9'33.392" N 21º23'22.740" E
Prokopos Lagoon	P3	Surface sediments	38º9'20.304" N 21º23'33" E
Prokopos Lagoon	P4	Surface sediments	38º9'28.404" N 21º23'17.34" E
Prokopos Lagoon	P5	Surface sediments	38º9'22.176" N 21º23'21.264" E
Prokopos Lagoon	P6	Surface sediments	38º9'13.572" N 21º23'23.532" E
Prokopos Lagoon	P7	Surface sediments	38º9'6.156" N 21º23'28.248" E
Prokopos Lagoon	P8	Surface sediments	38º9'10.62" N 21º23'40.416" E
Prokopos Lagoon	P9	Surface sediments	38º8'59.568" N 21º23'33.468" E
Prokopos Lagoon	P10	Surface sediments	38º8'51.54" N 21º23'22.848" E
Prokopos Lagoon	P11	Surface sediments	38º9'2.268" N 21º23'16.944" E
Elos Lagoon	ELOS	Surface sediments	40°56'11.93"N 25°16'8.30"E
Lake Yliki	YLIKI	Surface sediments	38°24'31.00"N 23°15'19.66"E

Lake Trichonida	TRICH 1up, 3up	Surface sediments	38°34'20.89"N 21°33'5.68"E
Lake Lysimachia	LYSIM 1up, 3up	Surface sediments	38°33'34.90"N 21°22'25.57"E
Lake Ozeros	OZEROS	Surface sediments	38°39'8.58"N 21°13'26.56"E
Lake Amvrakia	AMVRAKIA	Surface sediments	38°45'8.79"N 21°10'45.05"E
Megali Prespa Lake	PRESPA	Surface sediments	40°50'37.73"N 20°59'43.43"E
Lake Kastoria	KASTORIA	Surface sediments	40°31'40.45"N 21°17'41.28"E
Lake Vegoritida	Vegoritida 1up,8up,18up	Surface sediments	40°45'10.91"N 21°47'13.14"E
Lake Petron	PETRON	Surface sediments	40°43'42.65"N 21°41'45.23"E
Lake Doirani	DOIRANI	Surface sediments	41°12'11.77"N 22°45'45.45"E
Mt Oiti Livadies	LIV	Top core	38°49'15.81"N 22°16'29.00"E
Mt Oiti Alykaina	ALY	Top core	38°48'19.7352"N 22°18'8.2836"E
Mt Kallidromo Souvala	SOU	Top core	38°45'13.19"N 22°32'55.31"E
Mt Rhodope Lepidas	LEP-2 (21cm), (25cm)	Top core	41°24'37,42" N, 24°41'47,8" E
Mt Rhodope Livaditis	LIV-1	Top core	41°17'42.75" N, 24°41'4.38" E

4. METHODS AND MATERIALS

For this master thesis, a total of 40 modern pollen samples were studied from 19 different regions in Greece and 5 different depositional environments. All the samples were collected from surface sediments or top cores (Table 1). Eight of the samples originated from three different sea gulfs, i.e. four from the Saronikos Gulf (S1, S2, S3, S7), two from Thermaikos Gulf (THG4, THG5) and two from the Corinth Gulf (M0079A, M0080 top core). Eleven samples were collected from the Prokopos Lagoon (P1, P2..., P11), one from Elos Lagoon and one from each lake, Yliki, Ozeros, Amvrakia, Megali Prespa, Kastoria, Petron, Doirani. Two samples from Trichonida (Trich1up, Trich3up) and Lysimachia (Lisym1up, Lysim3up) and three from Lake Vegoritida (Vegoritida 1up, 8up, 18up). Also, two samples were collected from Mount Oiti from the temporal ponds of Livadies and Alykaina, one from Mount Kallidromo on the Souvala temporal pond and two samples from the Lepidas peat bog and one from the Livaditis peat bog in Rhodope Mountain range (Table 1).

4.1. Chemical treatment of the samples

The outer and most durable layer of pollen and spores is called the exine. It is composed of very resistant polymers that are mainly sporopollenin and smaller portions of polysaccharide. The exine is highly resistant to acids so, to separate the palynomorphs from the sediment or the rock there are specific processes that must be followed. The goal is to achieve the dissolution of the non-palynomorph bodies from the sediment.

For pollen treatment, approximately two grams of sediment were weighted for each sample and chemically treated according to the standard methodology for Quaternary sediments proposed by Faegri & Iversen (1989). Each sample was placed in a tube and chemically treated with 10% hydrochloric acid (HCl) and left in a water bath at 100°C for 20 minutes in order to dissolve the carbonates. To estimate the total palynomorph concentration and the reliability of quantitative data, a Lycopodium spore tablet was placed into each sample during the HCl treatment. After the removal of the hydrochloric acid, 38% hydrofluoric acid (HF) was put in each sample to dissolve the silicates. The samples were placed in the orbital shaker for about two hours and then left for 48-72 hours to rest. For the HF to be neutralized, the HCl treatment was repeated. After every chemical treatment the samples are washed up with deionized water. The chemical treatment is complete, and each sample goes through a 250μm sieve and then through a 10μm sieve with the help of an ultrasound machine. Afterwards they are repeatedly washed with ethanol. At the end of the chemical processing and sieving, a minimum of one slide was mounted in glycerin gelatin and sealed with paraffin wax for each sample.

4.2. Microscopical analysis

Microscopical analysis was performed using a Zeiss optical microscope at 40x and rarely at 100x magnification. Pollen, spores, non-pollen palynomorphs, dinoflagellates and foraminifera linings have been identified and counted for each sample. An average of 470 pollen was counted for each sample whereas in the minimum was 20 pollen grains identified and in the maximum was 1154. The pollen sum for percentage calculation includes arboreal, herbaceous, shrub and wide distribution pollen taxa, while fern spores and algae were excluded.

The identification of pollen and fern spores was based on comparison with specific references such as the *Leitfaden der Pollenbestimmung* by Beug (2004), *Pollen Atlas* by Reille (1992, 1996), *Pollen analysis* (Moore *et al.*, 1991), *Pollen and spore keys for Quaternary deposits in the northern Pindos Mountains, Greece* (Chester and Raine, 2001) and *The Northwest European Pollen Flora* by (Janssen *et al.*, 2006). The differentiation between Poaceae and Cerealia pollen types was based on the annulus diameter size (Chester and Raine, 2001).

The identification of dinoflagellates was accomplished by using the online version of “A determination key for modern dinoflagellate cysts” (Zonneveld and Pospelova, 2015). The non-pollen palynomorphs were identified using the non-pollen palynomorph Database by Shumilovskikh L.S., Shumilovskikh E.S., Schlütz F., van Geel B (2022) and *Applications of non-pollen palynomorphs: From palaeoenvironmental reconstructions to biostratigraphy* (Marret *et al.*, 2021).

4.3. Statistical analysis

Palynomorph counts were expressed as percentages and concentrations using the Tilia and the Tiliagraph software program (Grimm, 1991). Knowing the quantity of the Lycopodium spores that was inserted into each sample during the chemical treatment, we were able to calculate the concentration of pollen and NPPs (grains/cm^3).

Non-metric Multidimensional Scaling (nMDS) was performed using PAST software version 4.16c with distancing based on Bray-Curtis similarity index. Cluster analysis was also performed using past software.

Afterwards, the biomization technique was performed for the pollen assemblages of all the samples. The biomization technique classifies the taxa present in each pollen assemblage into a small number of plant functional types (PFTs) and then into larger terrestrial vegetation groups called biomes (Marinova *et al.*, 2018)

In this study, the biome scheme consists of the 13 major biomes that exist in the study areas. Each biome is constructed by a specific combination of Plant Functional Types. It is often that many PFTs can occur in more than one biome, though the PFT that distinguishes one biome from another is not necessarily the dominant one (Marinova *et al.*, 2018)

The aquatic taxa as well as the spores of the pollen assemblages were excluded from the data matrix. The rest of the 135 pollen taxa were assigned to PFTs based on the allocations given by (Bigelow *et al.*, 2003; Elenga *et al.*, 2000; Marinova *et al.*, 2018; Prentice *et al.*, 1996; Tarasov *et al.*, 2000). Many pollen taxa are assigned into more than one PFT and that is especially for those that represent higher taxonomic categories (e.g. family, genus) and those that have a broad ecological range (e.g. *Pinus, Quercus, Abies*). The pollen taxa that are over-represented in the pollen sum can make it difficult to distinguish some biomes (Marinova *et al.*, 2018). The solution to that problem is to assign them only to the PFTs for which they are diagnostic. The final allocation of the taxa to the PFTs in this study was based on Marinova *et al*., (2017) where "the categorization reflects both botanical information and the importance of a taxon to the PFT" within the region of study (Table 2).

Table 2: Assignment of pollen taxa to plant functional types (PFTs) used in the Eastern Mediterranean (Marinova et al., 2017)

Plant function type	**Code**	**Pollen taxa found in this study**
Arctic forb	FAF	Polygonaceae, *Polygonum* type, Ranunculaceae, *Rosa* type, *Saussurea*, *Saxifraga*, Scrophulareaceae, *Thalictrum*
Rosette or cuhsion forb	FRCF	*Artemisia*, Asteraceae, *Euphorbia, Scabiosa*
Drought-tolerant forb	FDTF	*Achillea* type, *Adonis aestivalis* type, Chenopodiaceae, *Artemisia*, Cannabaceae, Caryophyllaceae, *Centaurea*, *Centaurea scabiosa*, *Euphorbia*, *Gypsophila* type, *Heliotropium* type, *Knautia arvensis, Limonium, Scabiosa*, Scrophulariaceae, *Siderites*
Other forb	FOF	*Achillea* type, *Alchemilla*, Chenopodiaceae, Apiaceae, Asteraceae, Brassicaceae, Cannabaceae, Caryophyllaceae, *Centaurea, Centranthus, Cerastium* type, Cichorieae, *Cirsium* type, *Dianthus* type, *Filipandula*, *Galium* type, *Helleborus,*

		Hypericum type, Leguminosae, *Lysimachia, Matricaria* type, *Papaver*, Papaveraceae, Plantaginaceae, *Plantago, Plantago coronopus* type, *Plantago lanceolata*, Plantago *major, Plantago maritima* type, *Plantago media*, Polygonaceae, *Polygonum* type, *Potentilla* type, *Primula*, Primulaceae, *Prunella* type, Ranunculaceae, *Rumex, Sanguisorba, Sanguisorba minor* type, Scrophulariaceae, *Senecio* type, *Silene* type, Solanaceae, *Solanum, Spergula* type, *Spergularia* type, *Stachys* type, *Teucrium, Trifolium* type, *Urtica, Verbascum* type, *Xanthium*
Halophyte	Fhal	*Calligonum,* Chenopodiaceae, *Tamarix*
Geophyte	Fgeo	*Iris*
Succulent	Fsuc	Chenopodiaceae, *Euphorbia, Sedum* type
Grass graminoid	Fgra	Poaceae, *Secale* type
Sedge graminoid	FSeGra	*Carex* type, Cyperaceae
Arctic dwarf shrub	FADS	Betula, Ericaceae type, *Potentilla* type, *Primula*, Primulaceae, *Rubus, Salix*
Switch plants	FSP	*Ephedra distachya, Ephedra fragilis*
Climber/liana/vine	Fcli	*Cuscuta*, *Humulus*, Ranunculaceae, Solanaceae, *Solanum*, *Vitis*
Boreal low-to-high shrub	FBLHS	Ericaceae type, *Pinus*
Temperate low-to-high shrub	FTLHS	*Berberis*, Chenopodiaceae, *Cistus, Cornus*, Ericaceae type, *Prunus* type, *Rhamnus, Rosa* type, *Rubus, Sambucus* type, Scrophulariaceae, *Viburnum*
Warm-temperate low to-high shrub/small tree	FWST	*Carpinus orientalis* type, *Carpinus/Ostrya*, Chenopodiaceae, *Cistus, Cornus*, Ericaceae, *Fraxinus ornus*, *Juniperus*, Leguminosae, *Ligustrum*, Oleaceae, *Phillyrea*, *Pistacia, Rhamnus, Rhus, Sambucus*, Solanaceae, *Ulex*
Xerophytic shrub	Fxero	*Artemisia, Capparis*, Chenopodiaceae, *Cistus*, Ericaceae, *Euphorbia, Juniperus, Rhamnus*
Boreal cold-deciduous malcophyll broadleaved tree	FBCBLT	*Alnus incana, Betula, Populus, Salix*
Boreal evergreen needle lleaved tree	FBENLT	*Abies, Pinus*
Boreal needle-leaved deciduous tree	FBDNLT	Pinaceae
Cool-temperate evergreen needle-leaved tree	FCTENLT	Pinaceae

Eurythermic evergreen needle-leaved tree	FEEVNLT	*Juniperus, Pinus*
Temperate (frost induced late budburst) cold deciduous malacophyll broadleaved tree	FTfiCDBLT	*Acer, Cornus, Corylus, Fraxinus, Populus, Prunus, Quercus, Quercus* (deciduous), *Quercus robur* type, *Salix, Sorbus* type, *Tilia*
Temperate (spring frost tolerant) cold-deciduous malcophyll broadleaved tree	FTsftCDBLT	*Carpinus betulus, Fagus, Fraxinus ornus*, Leguminosae, *Pistacia, Prunus* type, *Quercus, Quercus cerris* type, *Rhamnus, Ulmus*
Temperate (spring frost intolerant) cold-deciduous malcophyll broadleaved tree	FTsfitCDBLT	*Carpinus, Carpinus/Ostrya, Castanea, Celtis, Ceratonia, Fagus, Juglans*, Leguminosae, *Ostrya* type, *Punica, Rhamnus*
Temperate evergreen needle-leaved tree	FTENLT	*Abies, Pinus*
Warm temperate evergreen malcophyll broadleaved tree	FWTEBLT	Leguminosae
Warm-temperate sclerophyll tree	FWTST	Leguminosae, *Olea, Quercus, Quercus* (evergreen), *Quercus ilex* type
Warm-temperate needle-leaved evergreen tree	FWTNLET	*Juniperus, Pinus*

Firstly, the pollen percentage values were transformed into square roots to increase the signal-to-noise ration and correct the over-representation of the pollen taxa that produce large quantities of pollen (Marinova *et al.*, 2018; Prentice *et al.*, 1996). We included only the taxa that had a minimum threshold of 0.5%. Each of the pollen spectrum was assigned to the biome to which it has the highest affinity score. The affinity scores between the pollen spectrums and the biomes were calculated as the sum of pollen percentages for the taxa in the PFTs that may occur in that biome. Some PFTs may be assigned to more than one biome and such biomes may have very similar or even identical affinity scores. When that happened, we followed the order shown by Marinova *et al.*, 2017:

Mediterranean Biome	**Code**
Tundra	TUND
Desert	DESE
Graminoids with Forbs	GRAM
Xeric Shrubland	XSHB
Warm-temperate evergreen sclerophyll broadleaf shrubland	WTSHB
Cold evergreen needleleaf forest	CENF
Cool evergreen needleleaf forest	COOL

Warm-temperatue deciduous malcophyll broadleaf forest	WTDF
Temperate deciduous malacophyll broadleaf forest	TEDE
Cool mixed evergreen needleleaf and deciduous broadleaf forest	CMIX
Warm-temperate evergreen needleleaf and sclerophyll broadleaf forest	WTEF
Evergreen needleleaf woodland	ENWD
Deciduous broadleaf woodland	DBWD

5. Results

135 taxa of pollen, 6 taxa of spores and 6 taxa of aquatic plants have been identified in all the samples combined. From the 135 pollen taxa that were identified, 52 were trees and shrubs and 83 were herbaceous pollen taxa (Figure 31, Figure 32). In addition, 6 species of green algae as well as 10 taxa of dinoflagellate cysts, 12 taxa of fungal ascospores, 1 taxon of cyanobacteria, 1 of plant remains, and 7 taxa of animal remains including 2 Cladocera, 1 flatworm, 1 testate amoeba, 1 taxon of Acritarch were identified. The concentration of the various pollen taxa range from zero to 10,000 grains per grammar of sediment (g/g), while the concentration of spores and aquatics range from zero to 1,000 g/g. The concentrations of the non-pollen palynomorphs range from zero to 6,000 particles/g (p/g).

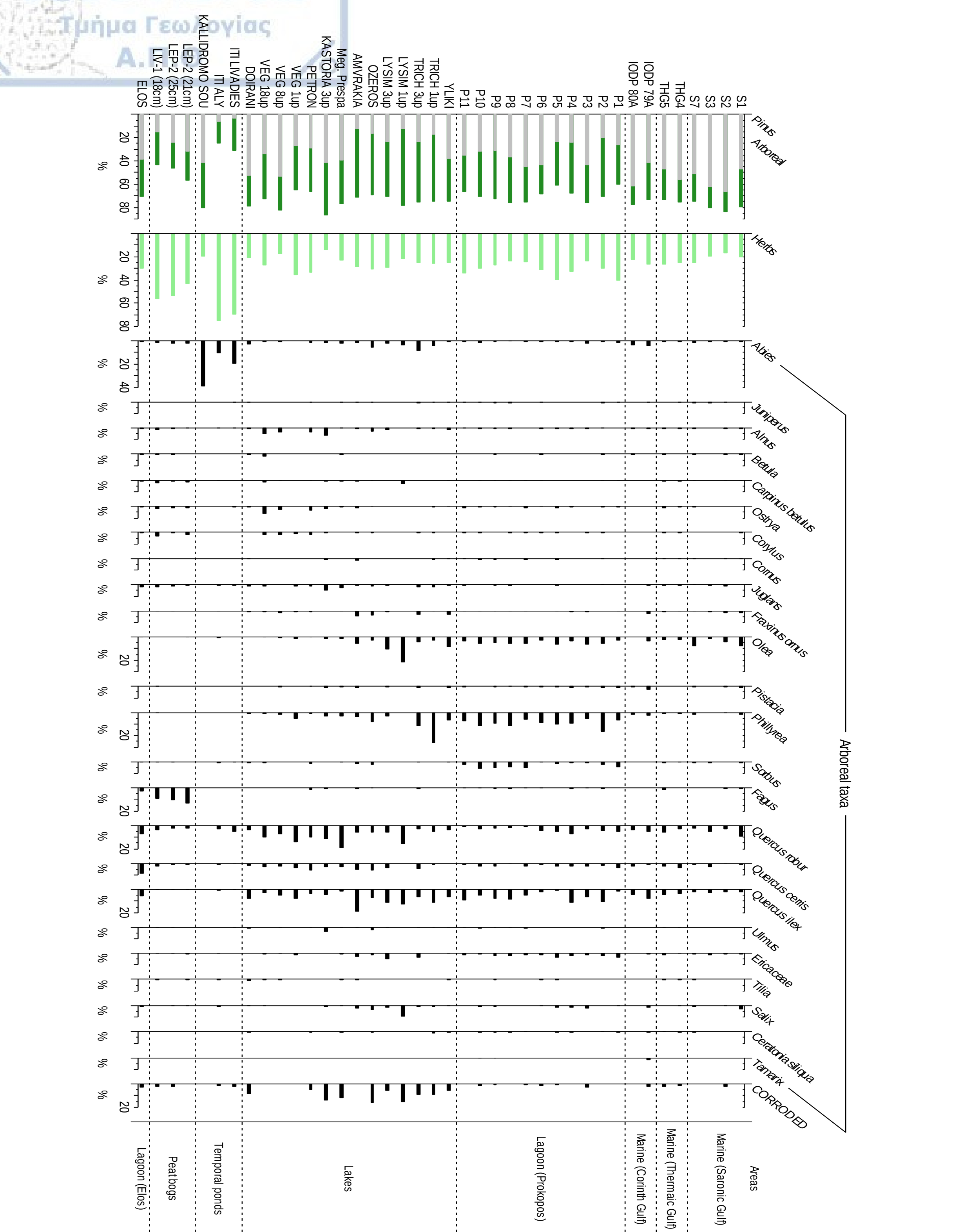


Figure 31: Percentages of the arboreal pollen taxa

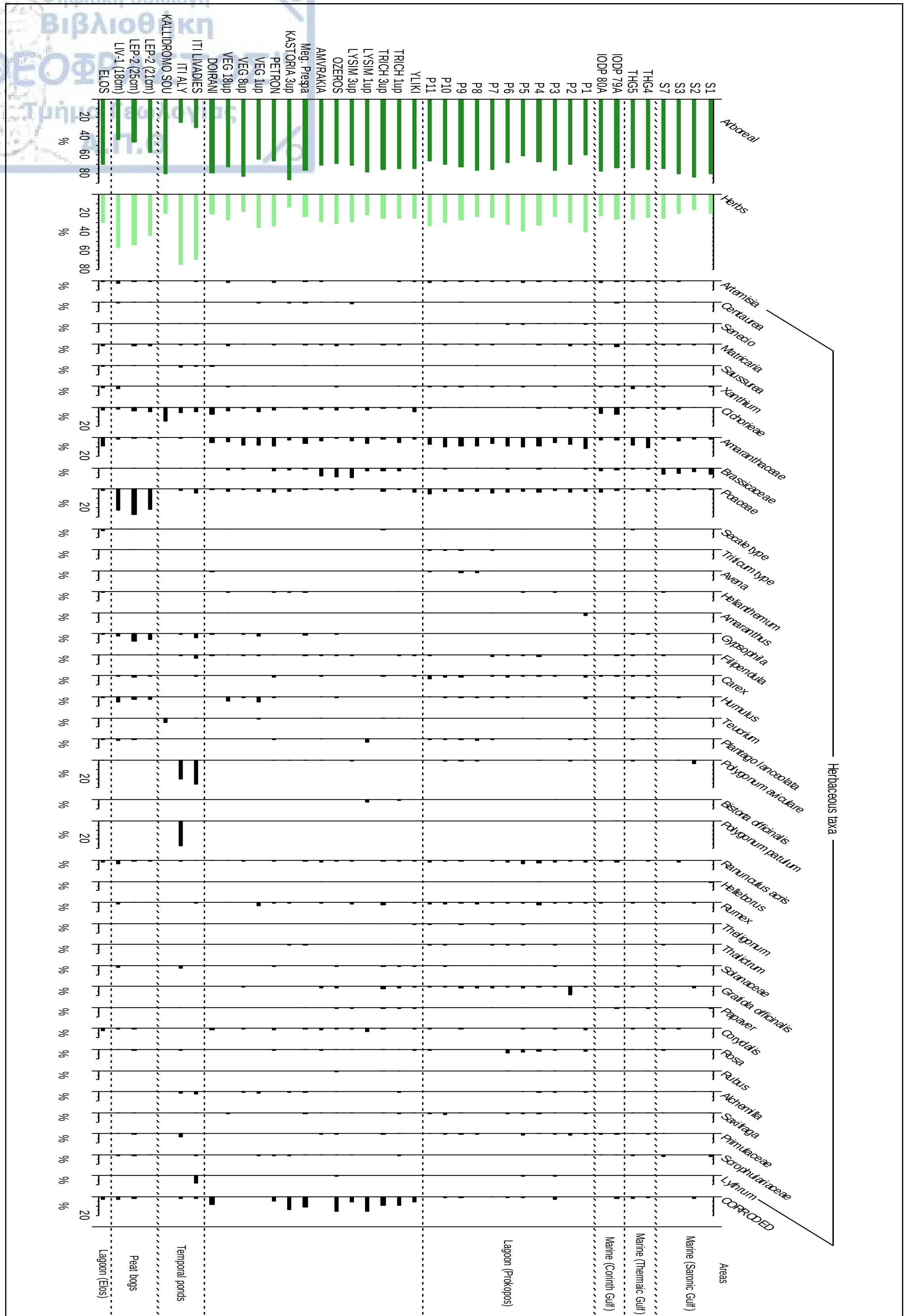


Figure 32: Percentages diagram of herbaceous pollen taxa

5.1. Pollen assemblages from sea top sediments

5.1.1. Saronikos Gulf

The palynological analyses of the Saronikos Gulf surface samples identified a total of 75 pollen taxa in all four samples (Figure 3) that were studied combined. Trees and shrubs showed frequencies that exceeded 80% while the herbaceous pollen taxa were significantly lower (16-19.8%). In all four samples, *Pinus* is the dominant pollen taxon with frequencies that range from 47.1% in S1 to 66.6% in S2. The differences of the pollen dispersal and deposition in the different samples lies as such:

- In S1, the most frequent pollen taxon is *Pinus* (47.1%) followed by *Quercus robur* type (9.4%), *Olea* (7.8%) and Brassicaceae (6.3%).
- In S2, *Pinus* pollen reaches 66.6%, followed by *Polygonum* (4.3%), Brassicaceae (4.1%), *Olea* (4%) and *Quercus robur* type (3.1%).
- In S3, *Pinus* pollen reaches high frequencies (62.3%), and is followed by Brassicaceae (5.8%), *Quecurs robur* type (5.1%) and Chenopodiaceae (3.6%). In these samples *Olea* appears to have a lower percentage value (1.45%) than the other ones.
- In S7, that lies in the Inner Saronikos Gulf, *Pinus* pollen taxon is again the dominant one and it reaches 51.1%. *Olea* (7.7%) and Brassicaceae (6.75%) also appear to have high percentage values.

A significant difference between the samples that were collected from Elefsis Bay (S1, S2, S3) from the one that was collected from the Inner Saronikos Gulf is the existence of Zygnemataceae algae in the latter one.

5.1.2. Thermaikos Gulf

Sixty-six taxa were identified in the two surface sediment samples from the Thermaikos Gulf. In the THG4 sample, trees and shrubs pollen reach 75.2% of the pollen assemblage. *Pinus* is the dominant tree pollen taxon (55.9%) and is followed by *Quercus cerris* type (4%). The most abundant herbaceous pollen taxon is Chenopodiaceae (10.65%).

In the THG5 sample, the arboreal pollen types also reach high percentages (73.5%) while the non-arboreal pollen types are low. *Pinus* reaches 47.1% followed by Chenopodiaceae (8.1%), *Quercus robur* type (5.6%) and *Quercus ilex* type (3.9%). In both samples *Olea* percentage values are worth mentioning.

5.1.3. Corinth Gulf

Forty pollen taxa were identified in a total of two top core samples from the Corinth Gulf. More specifically, in the sample that originates from the inner Corinth Gulf (M0079A, Figure 5), the arboreal pollen types are more frequent (75.2%) than the non-arboreal pollen types (24.8%). *Pinus* is the dominant pollen taxon with a frequency of (41.1%) followed by *Quercus ilex* type (7.6%), Cichorieae (7.3%), *Abies* (4.1%) and *Quercus robur* type (4.7%).

In the sample that residues in the Alkyonides Gulf (M0080A, Figure 5) the frequency of the tree and shrub pollen is higher (61.4%) than that of the herbaceous pollen (22.2%). After the *Pinus* pollen

(61.4%), Cichorieae is the pollen taxon with the highest percentage value (6.3%) followed by *Quercus ilex* type (4.2%), *Quercus robur* type (3.7%) and *Abies* (3.2%).

5.2. Pollen assemblages from the lagoons surface samples

5.2.1. Prokopos Lagoon

A total of 103 pollen taxa were identified in eleven samples from the surface sediments of Prokopos Lagoon (Figure 9). All the samples showed high percentage values of *Phillyrea* pollen with the lowest being 5.3% in the P3 sample, and the highest being 16.1% in the P2 sample. Also, in almost all the samples of the study area, *Quercus ilex* type is a taxon that shows high percentage values (lowest 1% in P5 sample and highest 11.1% in P4 sample). Chenopodiaceae pollen family has a range of percentages that fluctuates from 5.45% in the P3 to 11.9% in P1. The presence of Cerealia pollen is also significant, mostly *Secale*, *Avena* and *Triticum*.

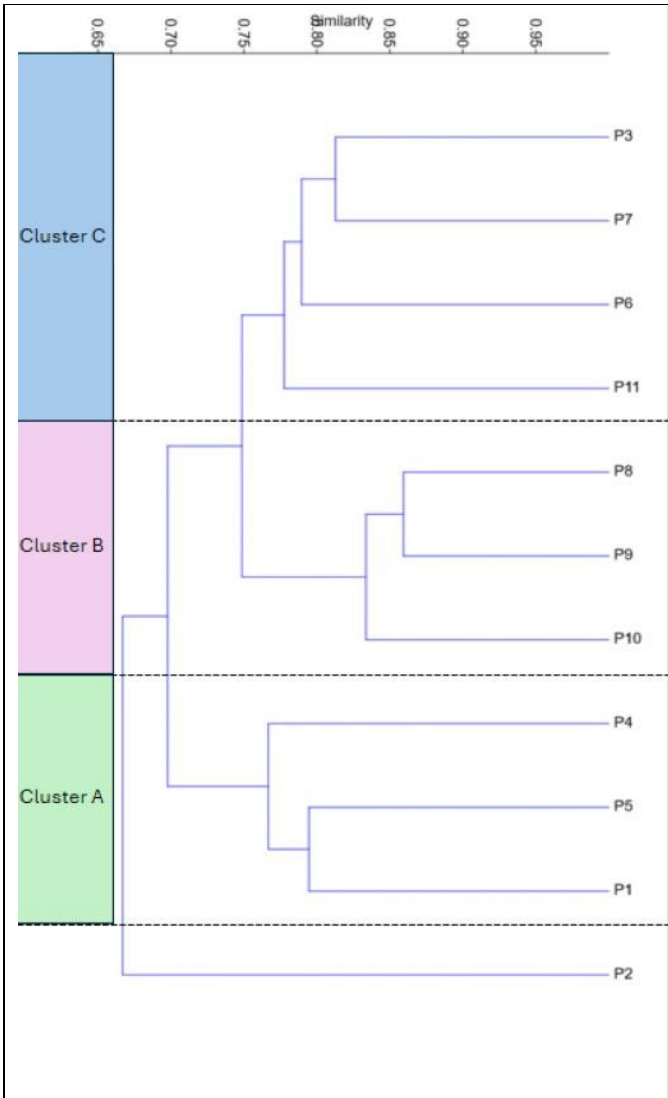


Figure 33: Cluster analysis for the pollen assemblages from the Prokopos sites

The samples can be grouped together according to their pollen assemblages through cluster analysis that was conducted using the Bray Curtis similarity indicator (Figure 33). It is clear from Figure 33 that the pollen assemblages are separated into three clusters A, B, and C.

5.2.2. Elos Lagoon

Forty pollen taxa were identified in a single sample from Elos Lagoon. The pollen assemblage is characterized by higher percentage values of arboreal pollen type (70.6%) than those of the herbaceous pollen type (29.4%). The Chenopodiaceae pollen family follows *Pinus* pollen (38.5%) as the most frequent taxon (8.6%) followed by *Quercus cerris* type (8.4%), *Quercus robur* type (6.85%), *Quercus ilex* type (5.8%), Asteraceae (4.1%) and Cichorieae (2.8%). There is also a significant amount of *Fagus* pollen (2.5%) as well as *Secale* type (2.5%) and Poaceae (2%).

5.3. Pollen assemblages from Lake surface sediments

5.3.1. Lake Vegoritida

Fifty-one pollen taxa were identified from three samples total from Lake Vegoritida. The samples that were studied for this research (Vegoritida 1up, Vegoritida 8up and Vegoritida 18up) are from the top sediments of the lake, specifically 0-2cm.

It is worth mentioning that sample Vegoritida 1up is considered to be problematic because it lacked the appropriate pollen concentration.

The pollen assemblage of sample Vegoritida 1up is characterized by a high *Pinus* pollen percentage value (26.8%) followed by *Quercus robur* type (14.4%), *Quercus ilex* type (7.8%), *Humulus* (5.2%) and *Quercus cerris* type (3.9%). In general, the arboreal pollen cover 64.7% of the pollen assemblage, whereas the herbaceous pollen represent the 35.3%.

Sample Vegoritida 8up is also distinguished by a high *Pinus* pollen percentages (52.9%) followed by Chenopodiaceae (8.3%), *Quercus robur* type (7.4%), *Quercus ilex* type (4.6%) and *Alnus* (3.7%). In general, the arboreal pollen cover the 82.5% of the pollen assemblage, whereas the herbaceous pollen cover 17.5%.

Lastly, the pollen assemblage in sample Vegoritida 18up is characterized by high *Pinus* percentages (33.6%), followed by *Quercus robur* type (10%), *Alnus* (5.2%), Chenopodiaceae (4.8%) and *Humulus* (4.1%). In general, the arboreal pollen types cover 73.1% of the pollen assemblage, whereas the herbaceous pollen types cover 26.9%.

5.3.2. Lake Petron

Forty-four pollen taxa were identified in the surface sediments of Lake Petron. Being in the same catchment area as Lake Vegoritida, the sample showed similar pollen assemblages to the Lake Vegoritida ones. The arboreal pollen taxa are more frequent (67.1%) than the herbaceous pollen taxa (32.8%) and the most abundant pollen taxon besides *Pinus* (28.9%) is *Quercus robur* type (10.1%). Some other pollen taxa with significant percentage volumes are *Quercus cerris* type (6.1%), *Alnus* (3.5%), *Quercus ilex* type (3.3%), *Carpinus/Ostrya* type (3.3%). The dominant herbaceous pollen taxa are Chenopodiaceae (9.15%), Poaceae (3.8%), Brassicaceae (3.5%) and Cichorieae (3%).

5.3.3. Lake Prespa

The pollen assemblage of the sample from Lake Prespa is characterized by 51 pollen taxa total. The most frequent pollen taxon is *Pinus* (39.1%). It is distinguished by significantly high percentage values of *Quercus robur* type pollen that reaches 19.2%. Chenopodiaceae is also a frequent pollen taxon (6%) as well as *Quercus cerris* type (3.2%), *Phillyrea* (2.8%), *Juglans* (2.3%) and *Ranunculus acris* type (2.1%). There is also a significant percent of *Abies* pollen (1.7%).

5.3.4. Lake Kastoria

A total of twenty-nine pollen taxa were identified in the surface sediments of Lake Kastoria. The pollen assemblage is characterized by high percentage values of *Pinus* (41.6%), *Quercus robur* type (11.4%), *Alnus* (6.3%), *Juglans* (4.5%), *Quercus ilex* type (4.5%) and *Ulmus* (3.4%). The dominant herb pollen taxa in Lake Kastoria, turned out to be Poaceae (2.8%), Chenopodiaceae (2.3%) and Brassicaceae (1.7%).

5.3.5. Lake Doirani

Thirty pollen taxa were identified in the surface sediments of Lake Doirani. The sample revealed a pollen assemblage rich in tree pollen taxa such as *Pinus* (52.5%), *Quercus ilex* type (7.7%), *Quercus robur* type (3.6%), *Abies* (2.8%), *Juglans* (1.2%), *Fraxinus* (1.2%), *Phillyrea* (1.2%) and many more. The herbaceous pollen taxa are also plentiful with the most abundant being the Cichorieae (7.7%), Chenopodiaceae (5.7%), Papaveraceae (1.6%) and more.

5.3.6. Lake Lysimachia

Thirty-nine pollen taxa were identified in two samples (Lysim 1up, Lysim 3up) (Figure 18) total from the surface sediments (0-2cm) of Lake Lysimachia.

We should mention that sample Lysim 1up, is problematic because during the microscopic analysis, only 32 pollen grains were counted. Nevertheless, *Olea* appears to be the dominant pollen taxon (21.9%) in this sample, followed by *Quercus robur* type (15.6%), *Quercus ilex* type (12.5%) and Pinus (12.5%).

The pollen assemblage of sample Lysim 3up is dominated by *Pinus* pollen taxon (23.5%), followed by *Quercus ilex* type (10.8%), *Olea* (10.4%), Brassicaceae (10%), *Quercus robur* type (5.8%) and Ericaceae (5%).

5.3.7. Lake Trichonida

A total of 64 pollen taxa were identified in the two samples (TRICH 1up, TRICH 3up) of Lake Trichonida. The pollen assemblage in both samples seems to be dominated by tree and shrub pollen taxa reaching almost 75% total.

In TRICH 1up the pollen assemblage is characterized by high percentages of *Phillyrea* (26.3%) followed by *Pinus* (16.9%), *Quercus ilex* type (10.9%), Chenopodiaceae (5.7%), *Quercus robur* type (5.2%) and *Abies* (4%). On the other hand, the pollen assemblage of TRICH 3up is dominated by *Pinus* (22.9%) followed by *Phillyrea* (11.1%) and *Abies* (8.3%). Also, *Olea*, *Fraxinus* and Ericaceae have higher percentage values in TRICH 3up than in TRICH 1up.

5.3.8. Lake Ozeros

Fifty-one pollen taxa were identified in one surface sediment sample from Lake Ozeros. The pollen assemblage is distinguished by high percentages of *Pinus* (16.2%), *Phillyrea* (7.7%), *Quercus ilex* type (6.8%), *Quercus robur* type (5.6%), *Quercus cerris* type (5.6%), *Abies* (5.5%), *Salix* (4%) and also *Fraxinus* (3.7%). Brassicaceae (9.35%) is the dominant pollen taxon of the herbaceous type of pollen.

5.3.9. Lake Amvrakia

The palynological analysis of the sample from Lake Amvrakia identified 49 pollen taxa. Trees and shrubs showed frequencies greater than 70% in the assemblage. The most dominant tree taxon turned out to be *Quercus ilex* type (18.7%) followed by *Quercus robur* type (5.9%), *Olea* (5.5%), *Quercus cerris* type (4.9%) and *Fraxinus ornus* (4.7%). Brassicaceae (8.3%) is the most common followed by Chenopodiaceae (3.5%) and Primulaceae (2.85%).

5.3.10. Lake Yliki

Fifty-five pollen taxa were identified in the sample from Lake Yliki. The analysis showed that the taxon with the highest percentage value is *Pinus* (37.7%) and then comes *Olea* (8.1%), *Phillyrea* (6.6%), *Quercus ilex* type (6.6%), *Quercus robur* type (3.8%) and *Fraxinus ornus* (3.2%). The herbaceous types are dominated by Cichorieae (5.1%) followed by Poaceae (3.2%) and Chenopodiaceae (1.7%). A significant amount of *Capparis spinosa* (1.3%) was also observed as well as Solanaceae (1.3%) and Rubiaceae (1.3%).

5.4. Pollen assemblages from temporal ponds

5.4.1. Mountain Oiti

Temporal pond in Livadies

A total of 43 pollen taxa were identified during the palynological analysis of the sample from the top sediments of the temporal pond in Livadies. Here, the herbaceous pollen types prevail with very high percentage values that reach 69.3%. *Polygonum aviculare* is the most dominant herbaceous taxon (25.8%), followed by *Lythrum* (7.85%), Poaceae (4.1%), Fabaceae (4.1%) and Asteraceae (2.9%). The arboreal pollen are dominated by *Abies* with significantly high percentages of almost 20%, followed by *Quercus robur type* (4.75%). In these samples *Pinus* have relatively low frequencies that reach 3.3%.

Temporal pond in Alykaina

Thirty-nine pollen taxa were counted and identified in the sample from Alykaina temporal pond. Like in Livadies, in the pollen assemblage in Alykaina the herbaceous pollen types outmatch the tree and shrub pollen types with a percentage value that reaches 74.8%. Here, the most abundant taxon is *Bistorta officinalis* (27.3%) followed by *Polygonum aviculare* (21.6%). The analysis also showed a great amount of Cichorieae (5.9%), Rosaceae (3.7%) and Asteraceae (3.5%). The most dominant tree is *Abies* (10.7%).

Lastly, it is worth mentioning that both the samples from Livadies and Alykaina are the only samples from this study, where any taxa, in this case *Abies*, exceeded the abundance of *Pinus*.

5.4.2. Mountain Kallidromo (Souvala)

The sample from the Souvala temporal pond is the poorest one regarding the number of pollen grains that were counted in it. Only 4 pollen taxa were identified. As such, *Pinus* is the most dominant taxon (41.4%) followed by *Abies* (39%), Cichorieae (14.6%) and *Teucrium* (4.9%).

5.5. Pollen assemblages from peat bogs

5.5.1. Lepidas peat bog

Two samples were studied from the Lepidas peat bog in Mountain Rhodope. One was from a depth of 21-21.5cm (LEV-2 21-21.5cm) and the other one was from a depth of 25-25.5cm (LEV-2 25-25.5cm).

In the shallower sample (LEV-2 21) the arboreal pollen (56.8%) exceed the non-arboreal ones (43.2%). *Pinus* appears to be plentiful (31.7%) as well as Poaceae (22.2%), *Fagus* (12.9%), Caryophyllaceae (5.8%) and Cichorieae (4.6%).

On the other hand, in the deepest sample (LEV-2 25) the herbaceous pollen types (53.8%) seem to exceed the arboreal pollen (46.2%). The pollen assemblage is characterized by high percentage values of *Pinus* (23.9%), Poaceae (27.4%), *Fagus* (10.6%), Caryophyllaceae (8.2%) and Cichorieae (4.2%).

5.5.2. Livaditis peat bog

In the Livaditis peat bog, the pollen assemblage resembles the one from the Lepidas location. Fifty-three pollen taxa were identified from palynological analysis. The herbaceous pollen appear to be more (56.2%) than the tree and shrub (43.8%). Poaceae is the dominant pollen type (22.3%) followed by *Pinus* (15.2%), *Fagus* (9.2%), *Humulus* (5.8%), *Ranunculus acris* type (3.8%), *Quercus robur* type (3.6%), Asteraceae (3.1%) and *Corylus* (2.9%).

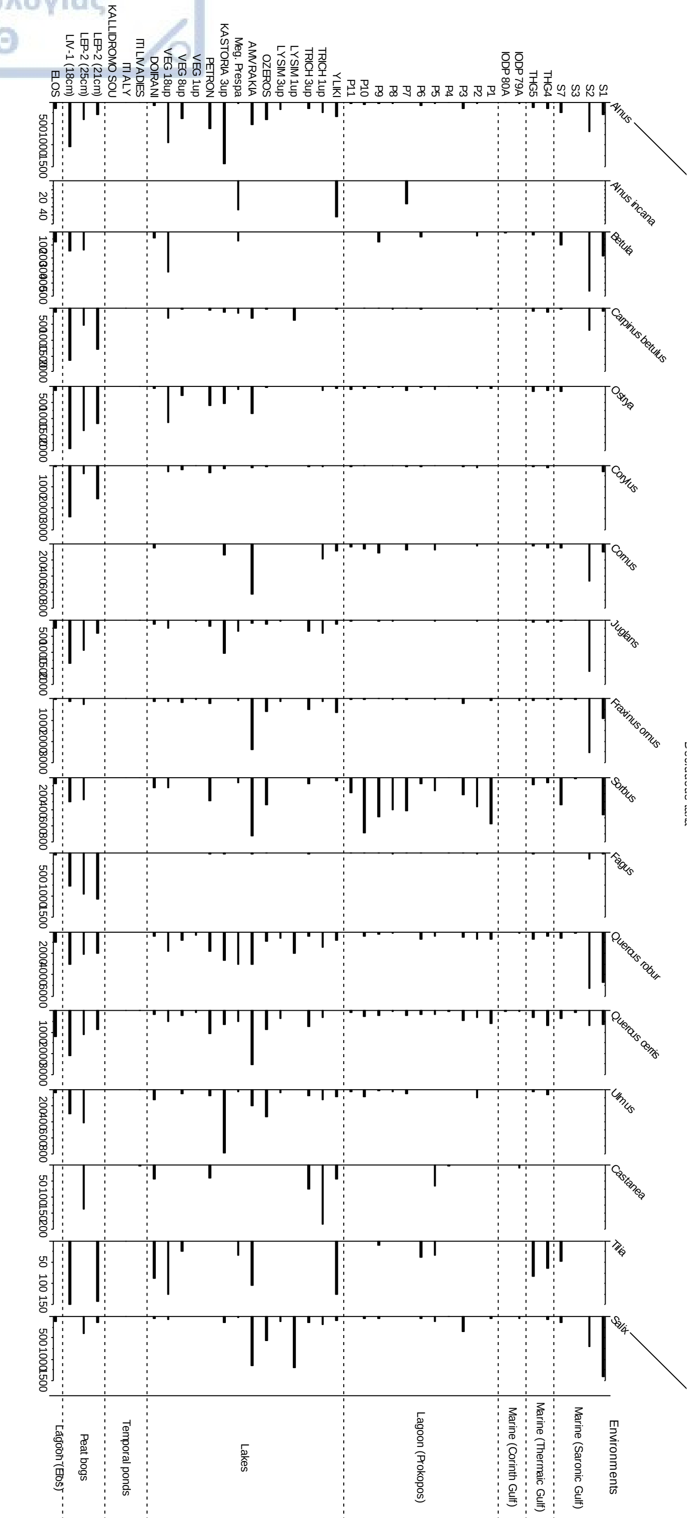


Figure 34: Concentrations of deciduous pollen taxa

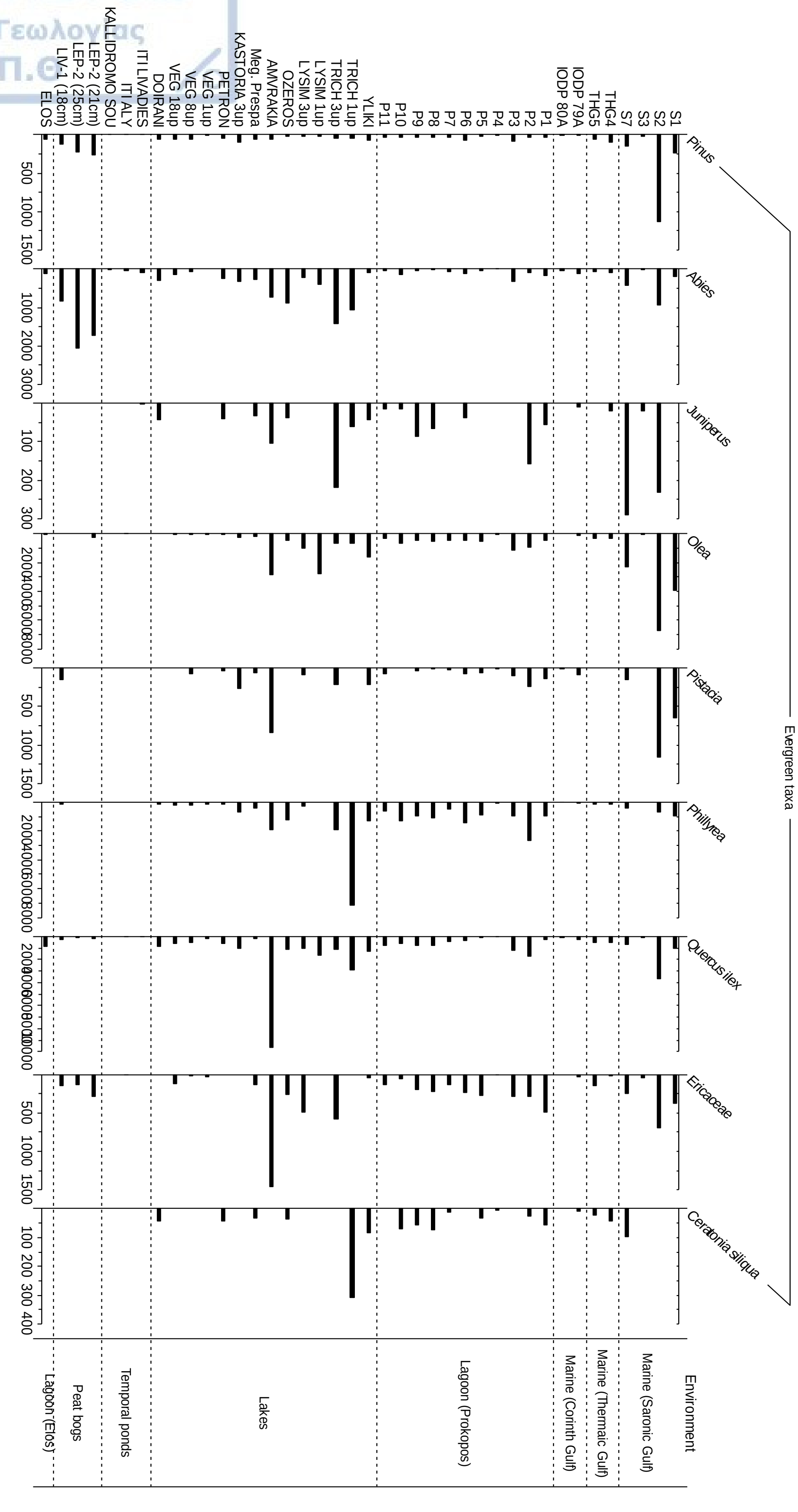


Figure 35: Concentrations of evergreen pollen taxa

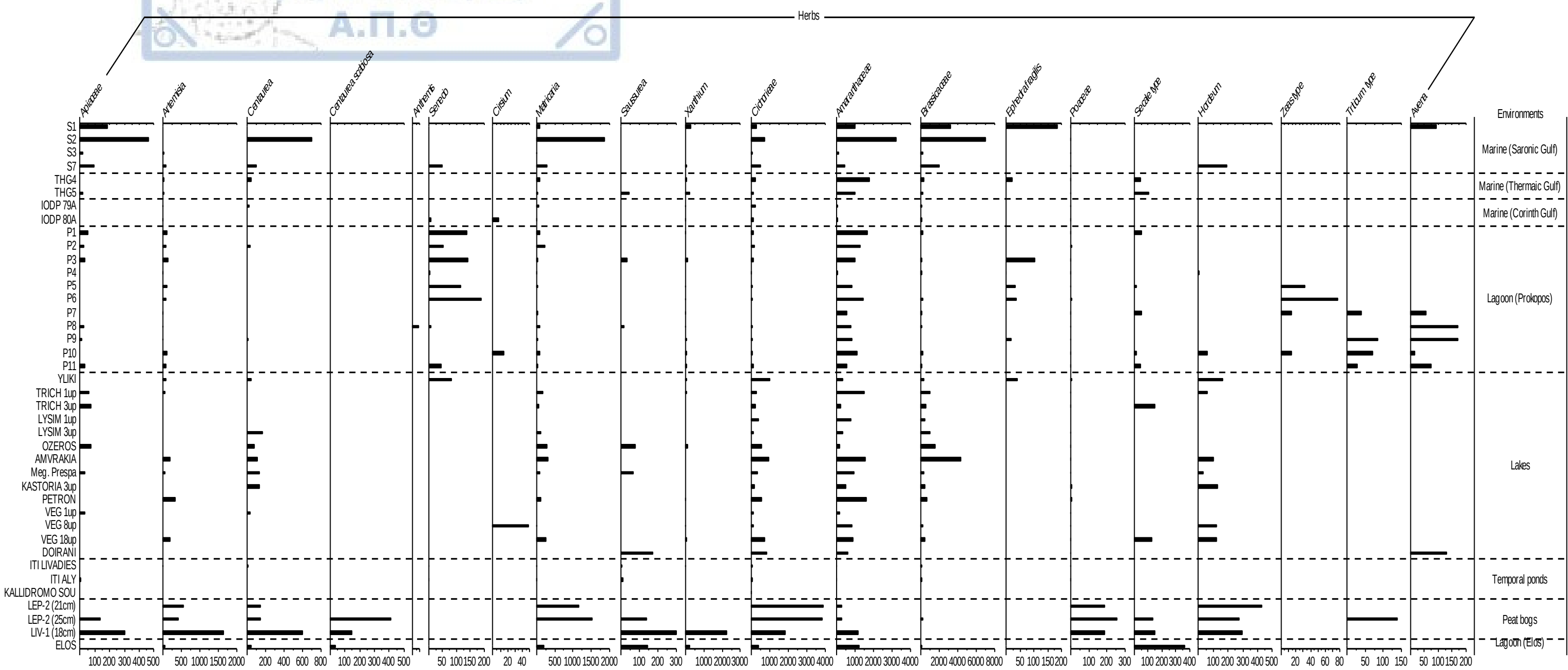


Figure 36: Concentrations of herbaceous pollen taxa

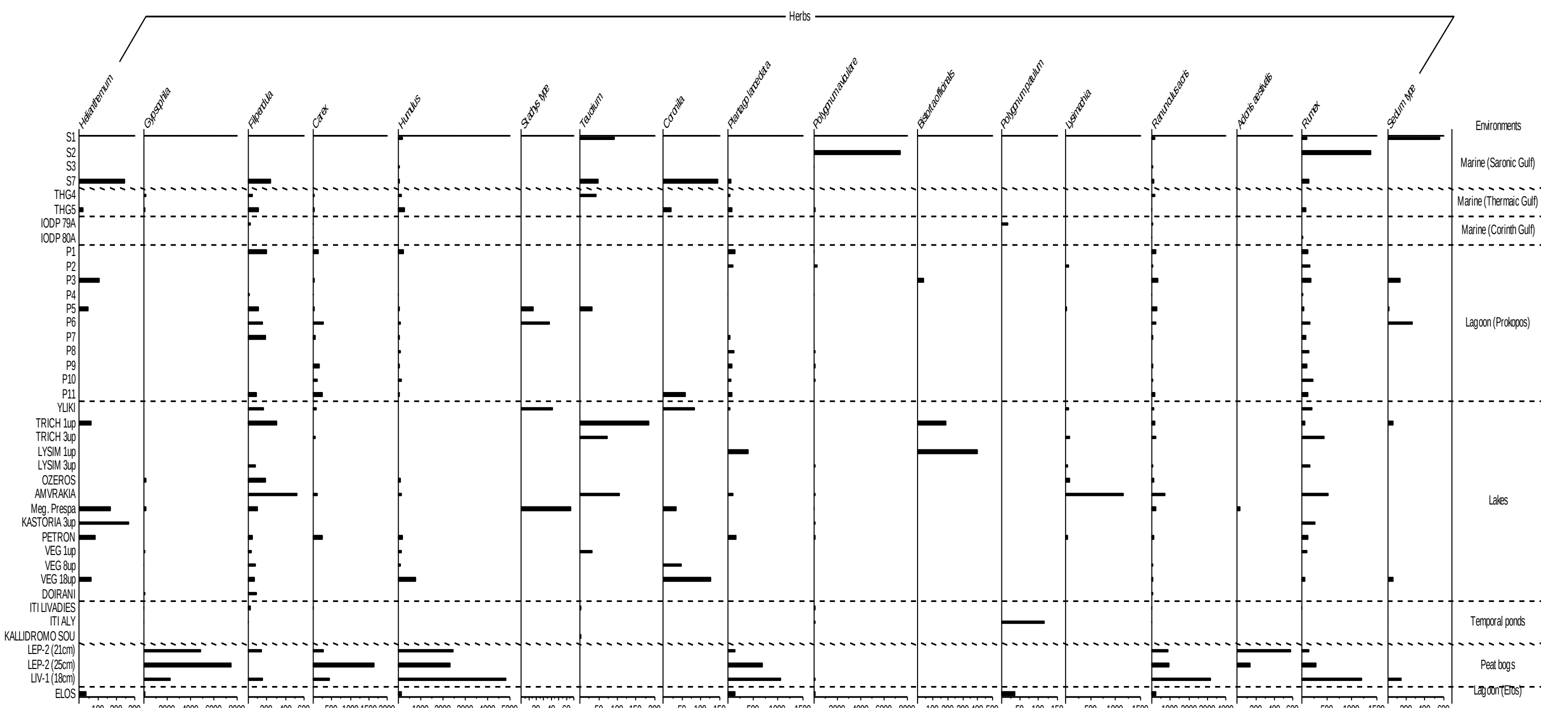


Figure 37: Concentrations of herbaceous pollen taxa

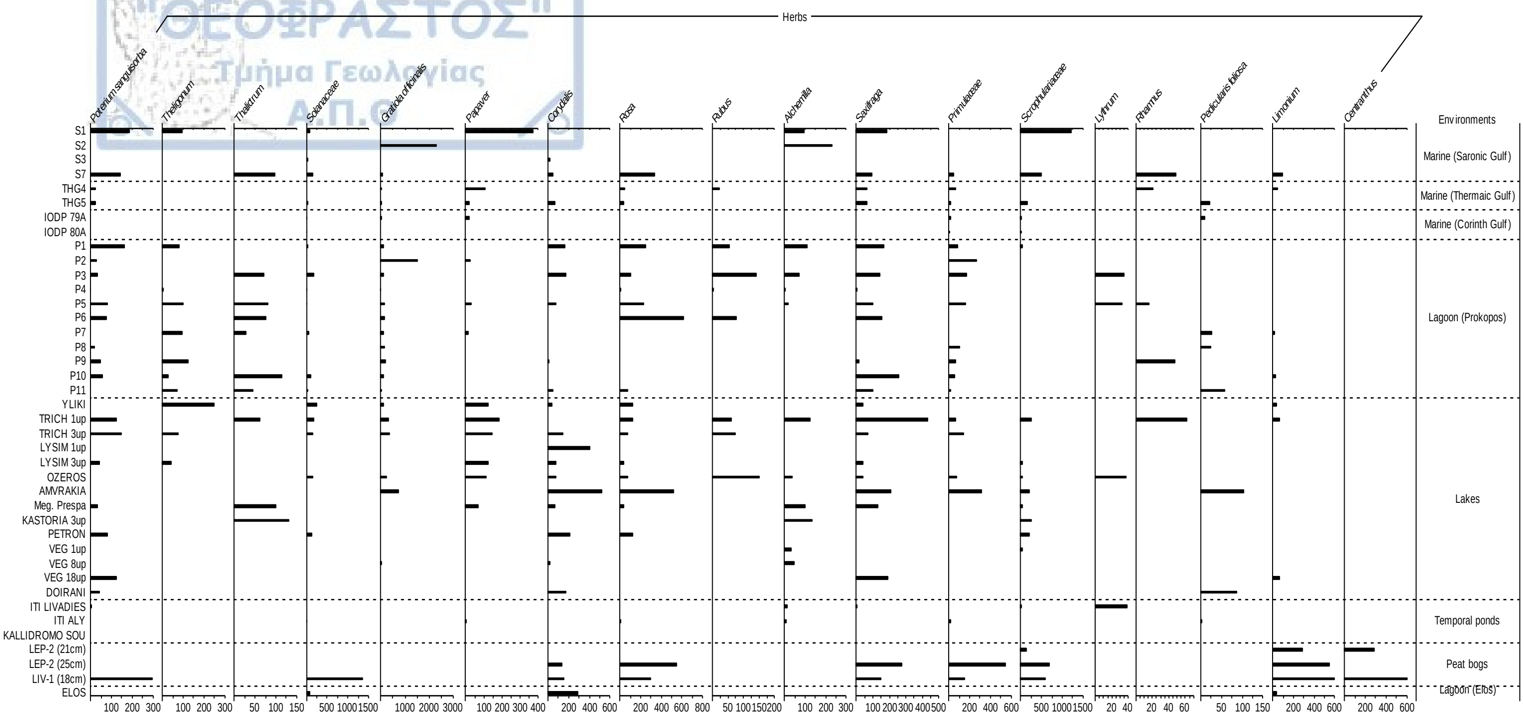


Figure 38: Concentrations of herbaceous pollen taxa

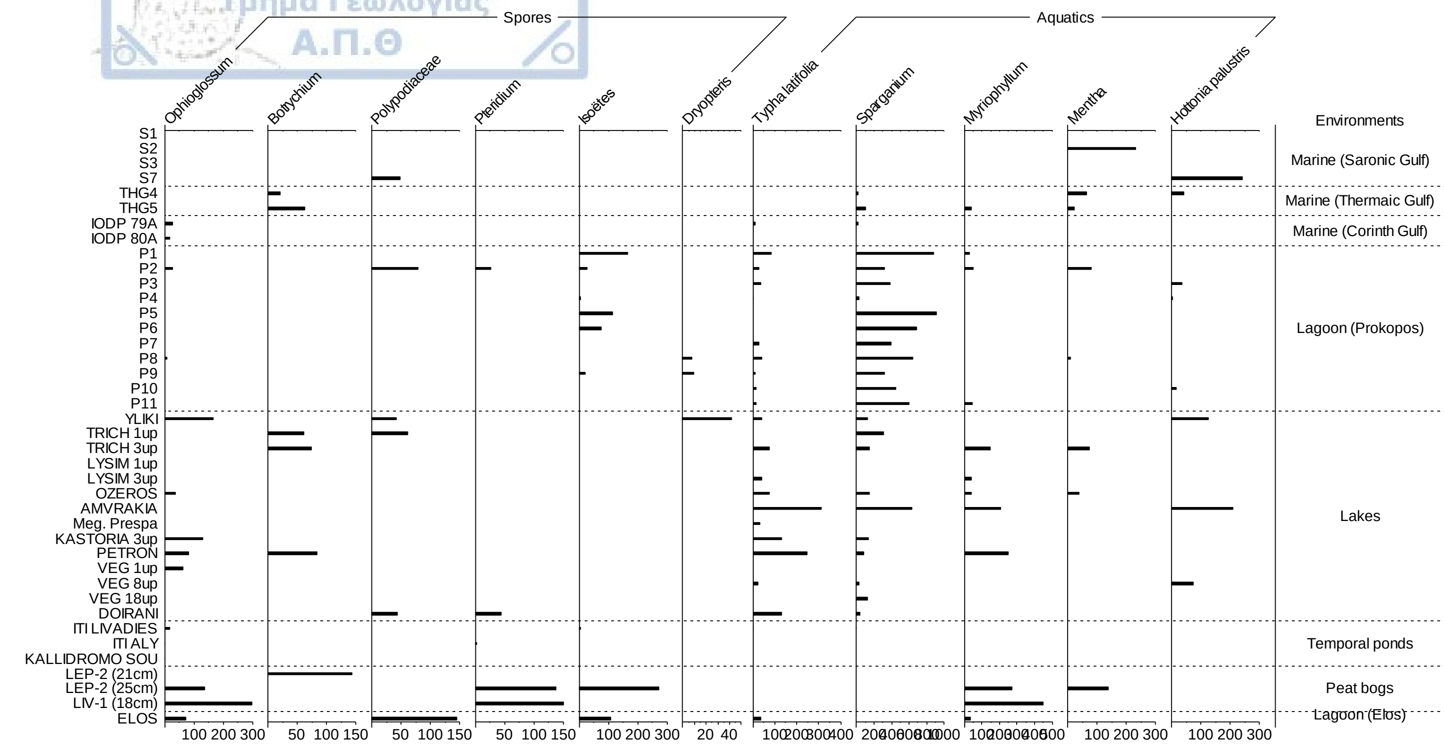


Figure 39: Concentrations of spores and aquatic pollen

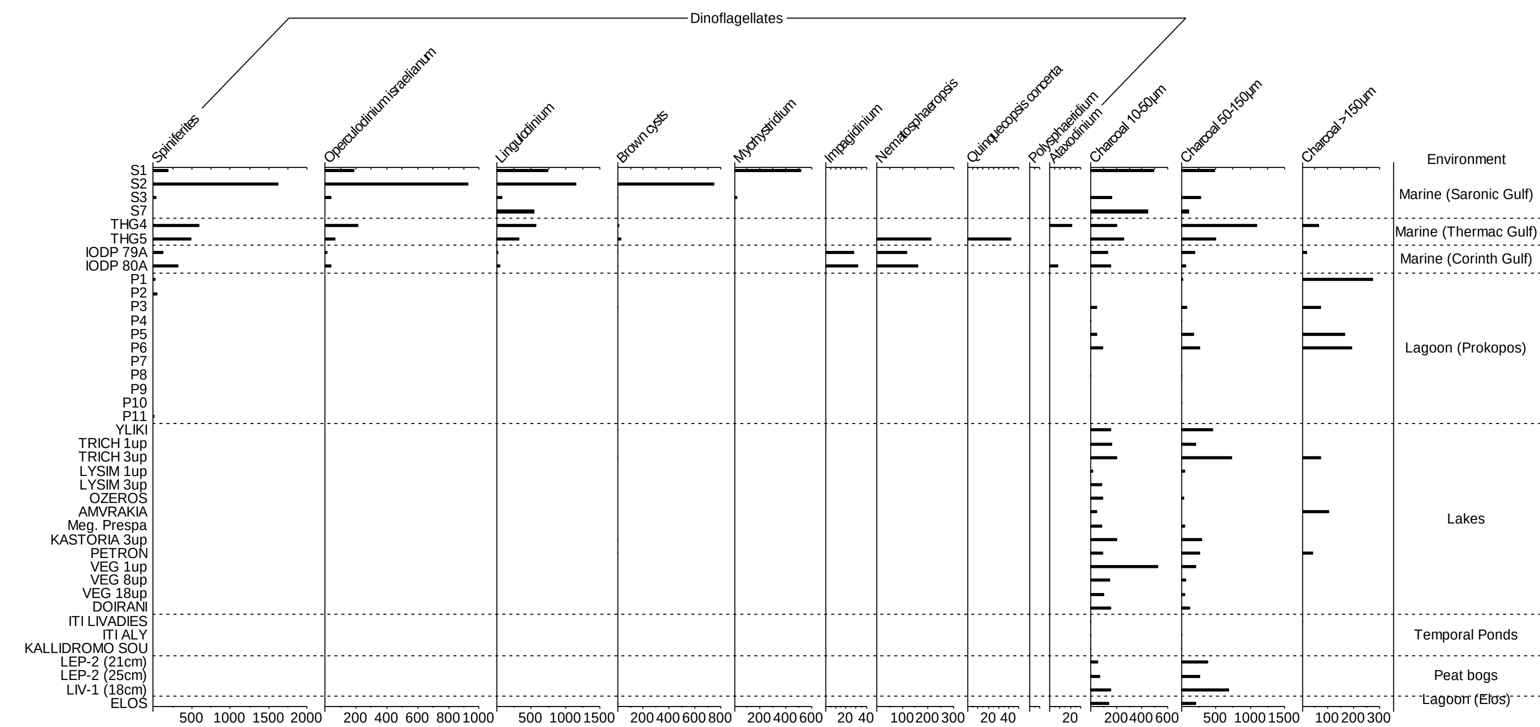


Figure 40: Concentrations of dinoflagellate cysts and charcoal

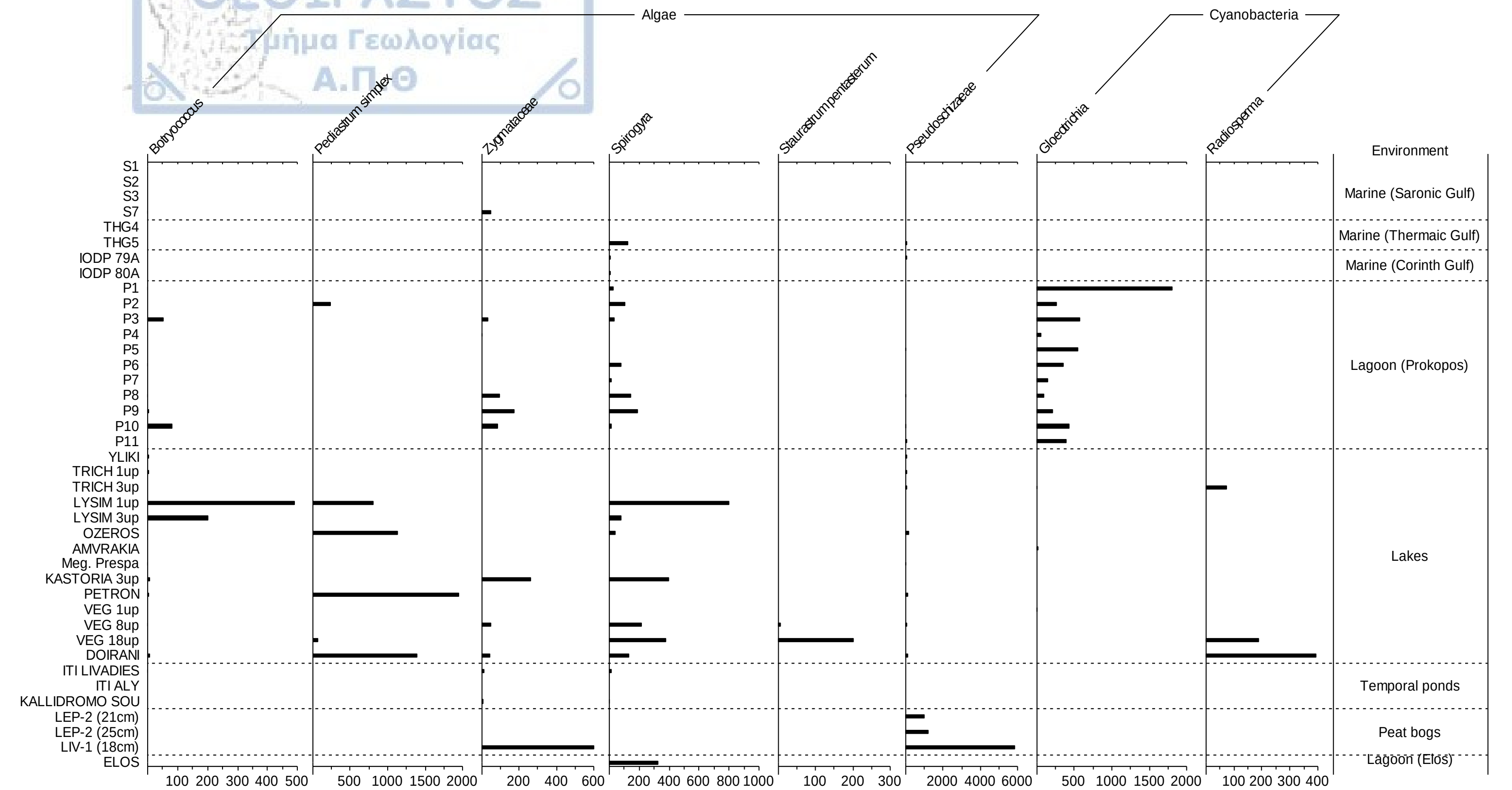


Figure 41:Concentrations of algae and cyanobacteria

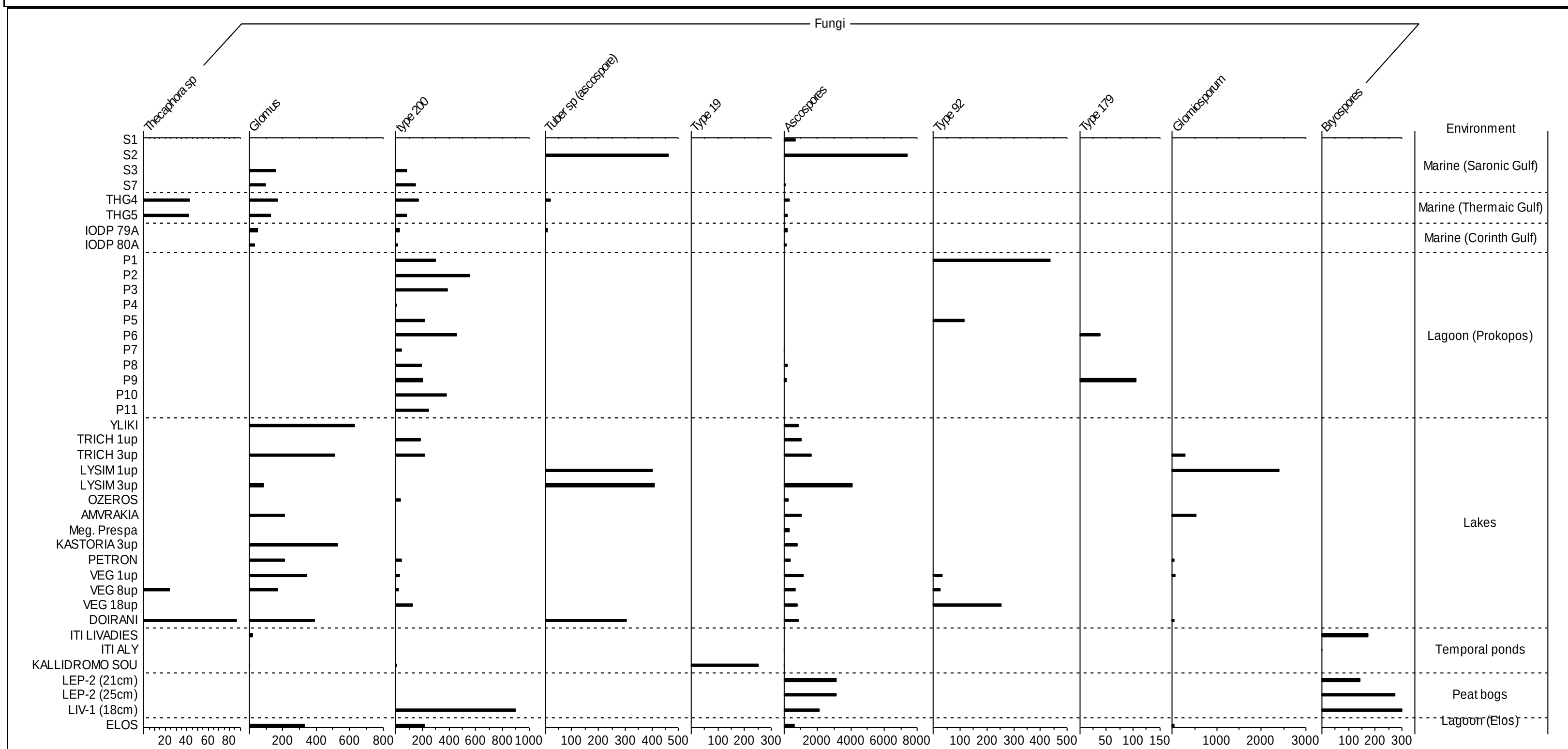


Figure 42:Concentrations of fungal remains

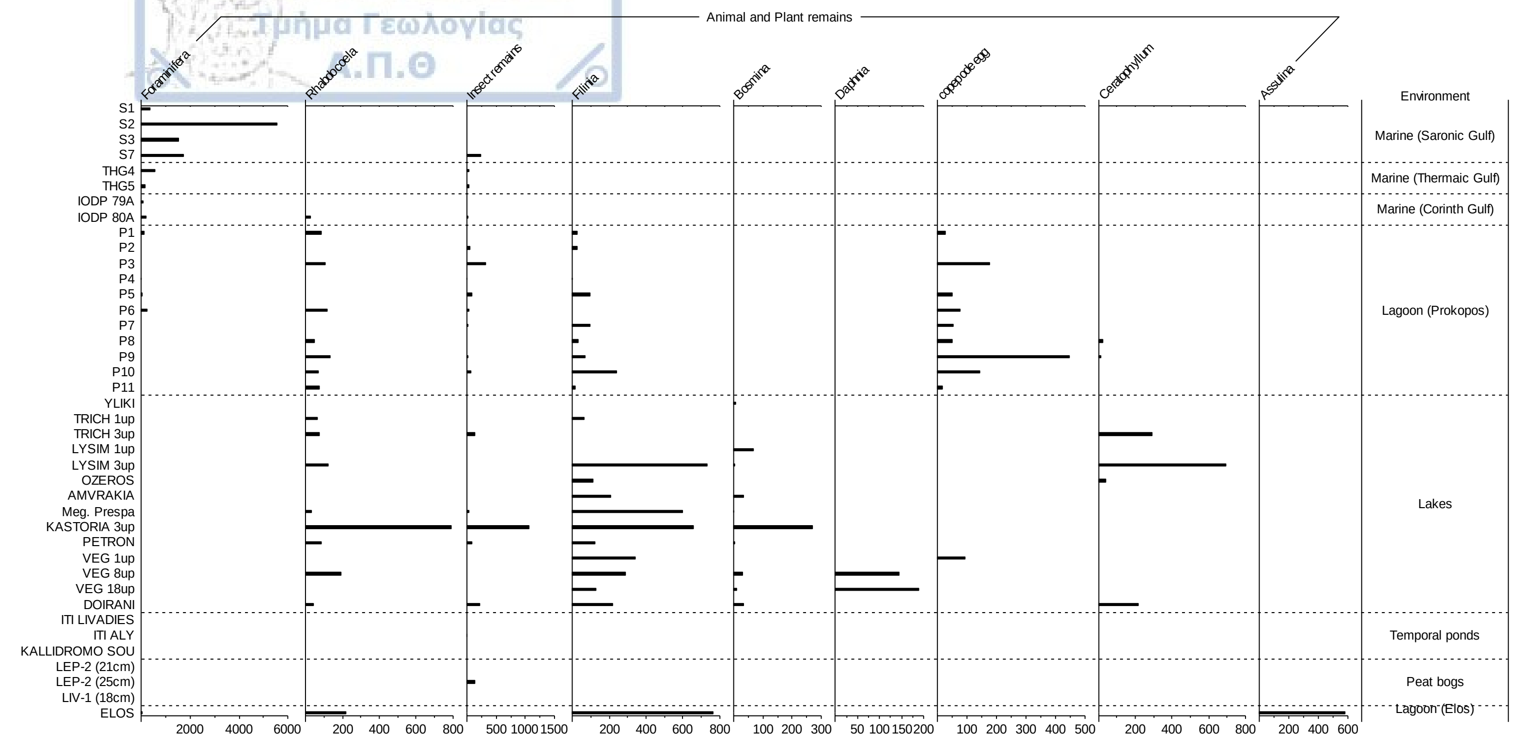


Figure 43: Concentrations of animal and plant remains

5.6. Results of the Biomization technique

According to the results of the biome reconstruction, 5 biomes are dominant in all the samples total. These are the Cool mixed evergreen needleleaf and deciduous broadleaf forest (CMIX), the Evergreen needleleaf woodland (ENWD), the Deciduous broadleaf woodland (DBWD), the Warm-temperate evergreen sclerophyll broadleaf shrubland (WTSHB) and the Warm-temperate evergreen needleleaf and sclerophyll broadleaf forest (WTEF). The following matrix plot (Figure 44) was created with the Past 4.16c (PAleontological STatistics) software. It shows the reconstructed biomes that distinguish each sample's pollen assemblage and the affinity scores of every biome that is present to each one of the samples. As we can see in Figure 44, in some cases, there are more than one biomes that were reconstructed from just one sample, with very similar biome affinity scores to the dominant one. For example, in the sample from Lake Ozeros, the biome affinity score of the dominant reconstructed biome which is (CMIX), is very close to the affinity score of the DBWD biome.

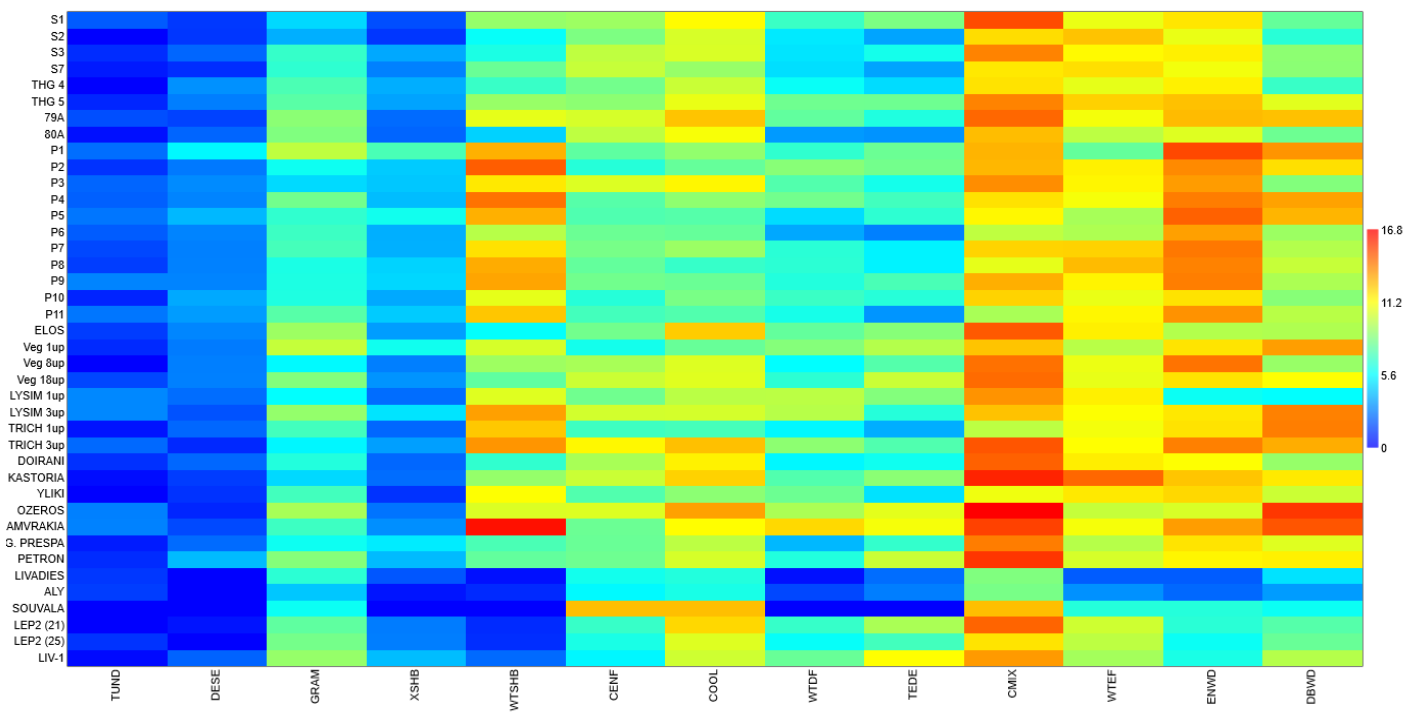


Figure 44: Matrix plot for the biomes present in each sample

Table 3: The dominant biomes of each sample

Sample	Biomes code	Biomes description
S1	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
S2	WTEF	Warm-temperate evergreen needleleaf and sclerophyll broadleaf forest
S3	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
S7	WTEF	Warm-temperate evergreen needleleaf and sclerophyll broadleaf forest
THG 4	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
THG 5	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
79A	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
80A	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
P1	ENWD	Evergreen needleleaf woodland
P2	WTSHB	Warm-temperate evergreen sclerophyll broadleaf shrubland
P3	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
P4	WTSHB	Warm-temperate evergreen sclerophyll broadleaf shrubland
P5	ENWD	Evergreen needleleaf woodland
P6	ENWD	Evergreen needleleaf woodland
P7	ENWD	Evergreen needleleaf woodland
P8	ENWD	Evergreen needleleaf woodland
P9	ENWD	Evergreen needleleaf woodland
P10	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
P11	ENWD	Evergreen needleleaf woodland
ELOS	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
Vegoritida 1up	DBWD	Deciduous broadleaf woodland
Vegoritida 8up	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
Vegoritida 18up	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LYSIM 1up	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LYSIM 3up	DBWD	Deciduous broadleaf woodland
TRICH 1up	DBWD	Deciduous broadleaf woodland
TRICH 3up	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
DOIRANI	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
KASTORIA	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
YLIKI	ENWD	Evergreen needleleaf woodland
OZEROS	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
AMVRAKIA	WTSHB	Warm-temperate evergreen sclerophyll broadleaf shrubland
MEG. PRESPA	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
PETRON	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LIVADIES	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
ALY	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
SOUVALA	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LEP-2	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LEP-2	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest
LIV-1	CMIX	Cool mixed evergreen needleleaf and deciduous broadleaf forest

6. Discussion

The main goal of this study was to discover how modern vegetation around each site can be reflected through pollen assemblages that have been preserved in different sediments in various areas in Greece. This could be achieved through comparisons and correlations between the pollen assemblages in various areas.

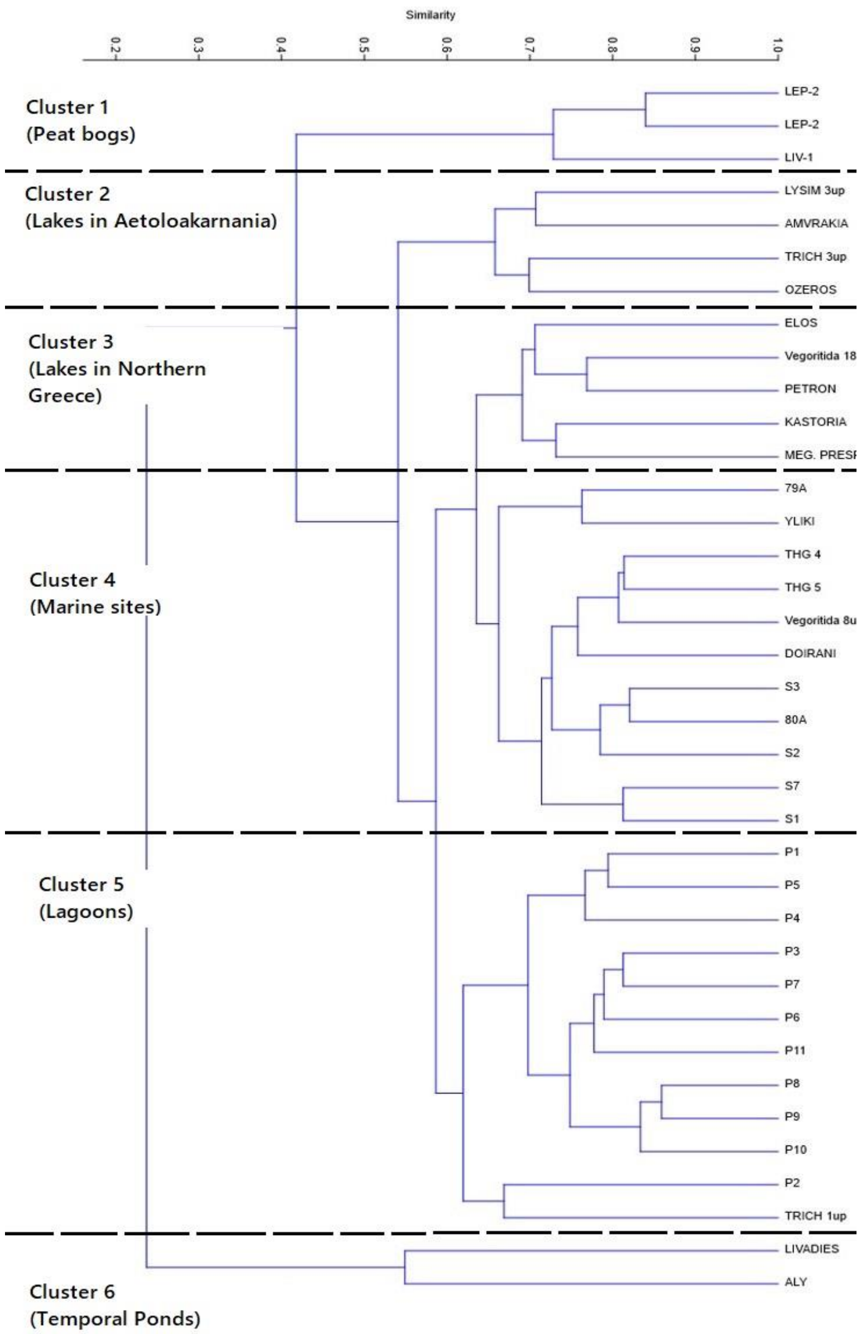


Figure 45: Cluster analysis, created using the Bray-Curtis similarity index, for the pollen assemblages of all the samples. Three defective samples were excluded from the analysis (Souvala, Vegoritida 1up, LYSIM 1up).

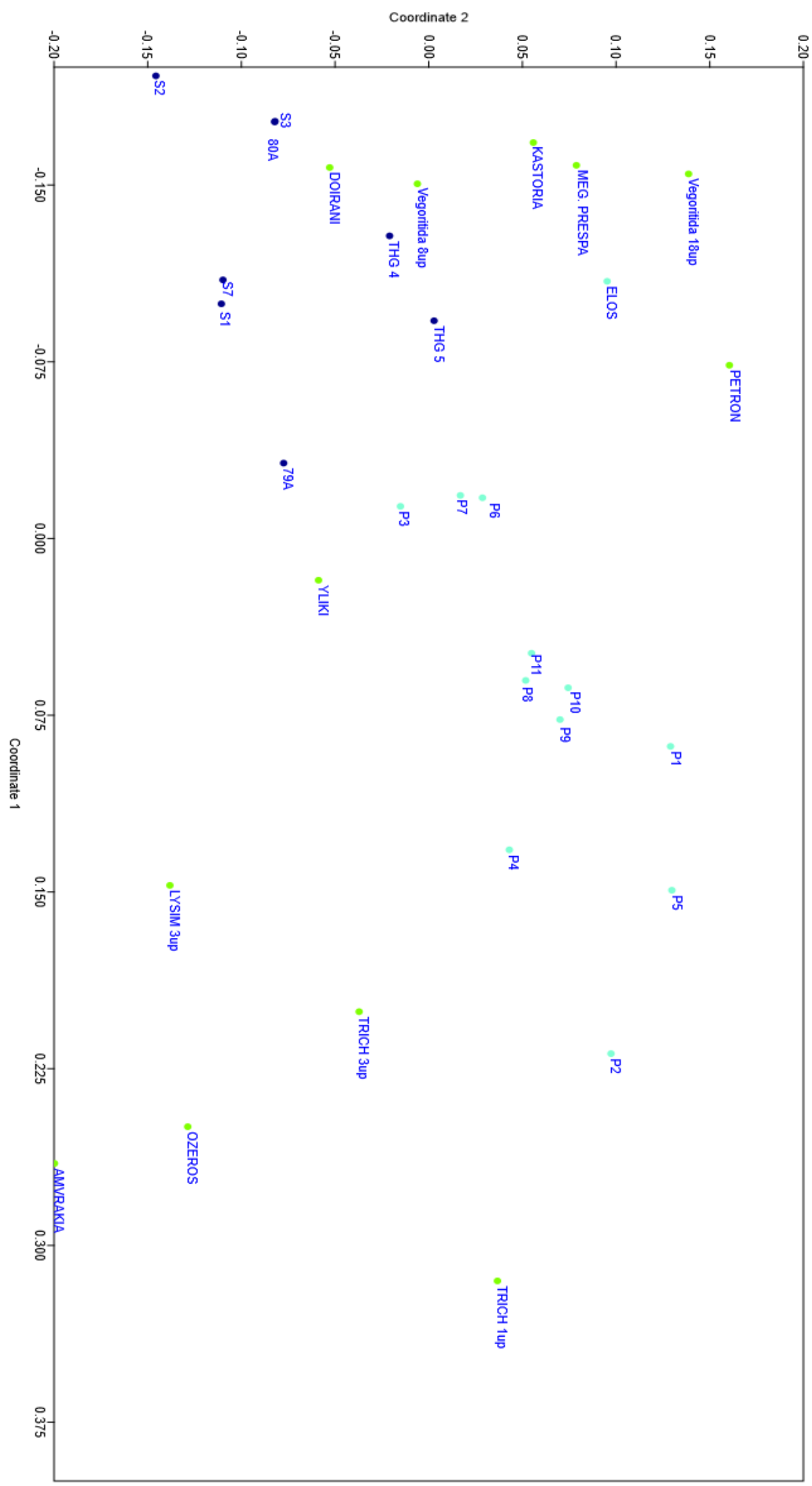


Figure 46: Non-metric multidimensional scaling. The samples from Mt Rhodope, Mt Oiti, Mt Kallidromo as well as samples Vegoritida 1up and Lysim 1up were not included in this analysis because they were either characterized by different features that disturbed the rest of the distribution or their concentration in pollen was not adequate. The nMDS diagram was constructed using the square roots of the pollen percentages.

Stress factor: 0.1647

6.1. Marine Environments

Eight samples from 3 marine gulfs were studied for this thesis (Table 1). It is clear both from the NMDS (Figure 46) analysis and the cluster analysis (Figure 45) that the pollen assemblages that derive from marine environments are grouped close together. This means that they present certain similarities. All the samples showed greatly high frequencies of woody taxa.

From the cluster analysis (*Figure 45*), we see that Cluster 4 includes all the marine sites, although it also contains some samples that derive from lakes, such as Vegoritida 8up, DOIRANI and YLIKI. This means that even though the pollen assemblages of the samples from marine environments are similar to each other, they are also similar to the aforementioned lake samples.

It is known that large basins have larger pollen source areas and therefore receive larger amounts of pollen from various pathways (Marinova *et al.*, 2018). The similarity between the marine sites and the lake sites may be due to the fact that they can share similar pollen pathways.

According to the cluster analysis (*Figure 45*), the pollen assemblages of the lake samples Vegoritda 8up and Doirani resemble the pollen assemblages of the marine samples of the Thermaikos Gulf. It is possible that lake Doirani and the Thermaikos Gulf share similar pollen pathways, since lake Doirani drains into Axios (Vardar) river, that emits in Thermaikos Gulf. As for the sample from lake Vegoritida, it is placed in cluster 4 because of the high percentages of *Pinus* and Chenopodiaceae, that resemble the pollen assemblages from the Thermaikos Gulf (Figure 31, Figure 32). Furthermore, since the Macedonian plain is covered by vast areas of rice fields, we were expecting high frequencies of Poaceae. Nevertheless, we recorded low frequencies of Poaceae. The fact that the Thermaikos Gulf receives large amounts of river influxes (see chapter 3.3), means that the pollen source area is large, and the pollen signal is not highly representative of the current surrounding vegetation.

The pollen assemblages of the Lake Yliki and the 79A sample from the Corinth Gulf are grouped together both in the cluster and in the nMDS diagram (*Figure 45*, Figure 46). This may be because of some similarities in the vegetation that surrounds them and therefore in their pollen percentages. More specifically, they present similar percentages of Mediterranean taxa such as *Pinus, Quercus ilex, Olea, Phillyrea* and *Fraxinus*. The assemblage from sample S3 in the Saronikos Gulf resembles the 80A sample from the Corinth Gulf for the same reasons.

Moreover, we must take into consideration that the marine gulfs of interest (Saronikos, Thermaikos, Corinth) are small semi-enclosed gulfs. This can provide a further explanation as to why they have similarities with some of the lakes that are also relatively small basins.

One of the differences between the assemblages from the marine sites is that the assemblages from the Corinth Gulf are characterized by greater amounts of *Abies* than the ones from the Saronikos and the Thermaikos Gulfs. The topography of the area that surrounds the Corinth Gulf is characterized by very steep slopes which makes it easier for pollen from higher altitudes, where fir forests exist, to be deposited in the gulf. Another difference is that the Saronikos Gulf has higher percentages of Olea pollen.

Finally, the biomes that were reconstructed for the pollen assemblages from the marine environments were the Cool mixed evergreen needleleaf and deciduous broad leaf forest (CMIX).

However, the biome reconstruction recorded the high biome variability that exists today around the Saronikos Gulf despite the proximity of the analyzed sites. The most dominant biomes of the marine sites turned out to be the "Cool mixed evergreen needleleaf and deciduous broadleaf forest" and the "Warm-temperate evergreen needleleaf and sclerophyll broadleaf forest". Other biomes are shown to be participating in the samples with lower densities (Figure 44), but all of them represent the most dominant vegetation types of the large pollen source area of the Saronikos Gulf.

Overall, the depiction of the vegetation that derives from the marine sites reflects the modern vegetation of their borderlands, however an over-representation of the woody taxa is evidenced as expected by previous studies (Marinova *et al.*, 2018).

6.2. Lakes

6.2.1. Central Greece

Seven samples (Table 1: Areas, Samples code names and sites' coordinatesTable 1) from five lakes in Central Greece were analyzed for this study. Lakes Amvrakia, Ozeros, Lysimachia, Trichonida are in the western part of central Greece close to each other, and Lake Yliki that is in the eastern part of central Greece (Figure 2). Sample Lysim 1up was not included in the cluster analysis and the nMDS since its concentration in pollen grains was not adequate.

The cluster analysis (*Figure 45*) has shown that the pollen assemblages from the samples Lysim 3up, Amvrakia, Trich 3up and Ozeros are similar and so are grouped together as such. Since the four lakes are close to each other geographically and are surrounded by very similar vegetational patterns, it is expected that their pollen assemblages are very similar. The nMDS analysis (Figure 46) is also in agreement with the cluster analysis as it groups together the four lakes at the bottom right of the diagram based on the similarity of their pollen assemblages. Sample Trich 1up, has some dissimilarities than the other sites, as it is assumed by their distance in the diagram, and it is placed close to the samples of Prokopos lagoon. This can be attributed to the similar percentages of *Pinus* and *Phillyrea* in those sites.

The biomization technique reconstructed different biomes for those sites even though they are situated close to each other (Table 3, Figure 44). We see that the reconstructed biome for Trich 3up and Ozeros is "Cool mixed evergreen needleleaf and deciduous broadleaf forest", while in Lysim 3up is "Deciduous broadleaf woodland", and in Amvrakia is "Warm-temperate evergreen sclerophyll broadleaf shrubland" (Table 3, Figure 44). We understand that Lakes Trichonida and Lysimachia are surrounded by Mt Panetoliko and Mt Arakinthos and thus we must consider that their pollen signal includes vegetation of those areas too. The reconstructed biomes are not only a representation of the vegetation around each site but are also related to the climate and the soils composition. Therefore, the reconstructed biome for Lake Yliki is "Evergreen needleleaf woodland" and is different from the biomes that were reconstructed for the lakes in Western Greece, since it is located in an environment with different climatic and environmental conditions.

All the reconstructed biomes are in agreement with the current vegetation that surrounds the lakes (see pages 29, 32, 33). Especially for the lakes that are situated in western Greece, the landscape that surrounds them is characterized by very complex topography as well as a very wet climate (Figure 19,Figure 20,Figure 21, Figure 22). All these factors make the vegetational patterns of the pollen source areas very complicated and hard to accurately represent by pollen assemblages. This can provide a further explanation as to why so many different biomes were reconstructed from the sites despite their proximity.

The representation of the regional vegetation that came out of the analysis of the assemblages of the lakes in western Greece is considered to be of higher accuracy and reliability than that of the marine sites. It is known that smaller basins provide more adequate results of the vegetational reconstructions (Marinova *et al.*, 2018).

6.2.2. North Greece

Seven samples from five lakes in northern Greece were studied for this research (Table 1). Sample Vegoritida 1up was not included in the cluster nor in the nMDS analysis because the pollen concentration was very low.

According to the cluster analysis, the pollen assemblages from lakes Vegoritida, Petron, Kastoria, and Megali Prespa were similar and constitute Cluster 3 (*Figure 45*). The assemblage of the sample from Lake Doirani as well as the shallowest sample of lake Vegoritida (Vegoritida 8up) group together with the assemblages of the marine environments as discussed in the previous chapter (p.65).

The pollen assemblage from Elos lagoon also appears to have similarities to the assemblages from lakes Vegoritida, Petron, Kastoria and Prespa, as it is grouped together with them both in Cluster 3 and in the nMDS analysis where it is located close to the other samples (Figure 46). As it is mentioned in the previous chapters (3.6, 0, 3.8, 0), the lakes of northern Greece are surrounded not only by the natural vegetation but by the domesticated vegetation as well. The four lakes are surrounded by areas that are cultivated with cereals, legumes, and other fruits and vegetables. Despite that, the pollen signal from these sites do not show high frequencies of either of the above plants. An explanation may lay to the fact that Cerealia pollen do not travel over long distances due to their large size and low dispersion and thus they are underrepresented in the pollen record (Glais et al., 2016; Weiberg et al., 2019).

The reconstructed biome for the five lakes in north Greece (Figure 12) is Cool mixed evergreen needleleaf and deciduous broadleaf forest (CMIX) (Table 3, Figure 44). All the PFTs and the pollen taxa that correspond to that biome compose the current vegetation around each site. It is noted that the CMIX biome that was reconstructed for each site, is a representation of the vegetation that exists around them at various altitudes. For example, in Megali Prespa Lake, the modern vegetation is characterized by deciduous oak forests up to 1600m a.s.l., deciduous forests dominated by Fagus up to 1800m a.s.l. and conifer woods between 1800 and 2200m a.s.l. This applies to the rest of the sites (see chapters 3.6, 0, 3.8). It becomes clear that the biomization technique does not provide a very clear image of the altitudinal vegetation zonation (Marinova *et al.*, 2018).

6.3. Lagoons

6.3.1. Prokopos lagoon

Eleven samples that cover the entire Prokopos lagoon were studied for this thesis (Figure 9, Table 1). The evaluation process based on the cluster analysis using the Bray-Curtis similarity index (Figure 33) and the non-metric multidimensional scaling analysis (Figure 46), showed that the lagoon is separated into three section that match the three sub-basins we already know exist in the lagoon (Katsaros, 2014).

- Samples P1, P4, P5, set the boundaries of the Pallades sub-basin. It extends for 0.48 km^2. The area is distinguished by low frequencies of Pinus and high frequencies of *Quercus robur* type. The Pallades sub-basin communicates with the Ionian Sea through a 2.3 km long channel from where it receives sea water or gives fresh water depending on the hydrological state of the ecosystem throughout the seasons (Fyttis, 2012). The communication of Prokopos Lagoon with the Ionian Sea can provide further explanation as to why some dinoflagellate cysts were found in samples P1 and P2 (Figure 40).
- Samples P3, P6, P7, P11, distinguish another sub-basin called Chirovolia. Chirovolia is the largest of the three sub-basins as it extends for 0.8 km^2. The pollen assemblages are distinguished by high frequencies of *Pinus*, *Quercus ilex* type, Chenopodiaceae and a significant amount of Poaceae.
- Samples P8, P9, P10 distinguish the smaller sub-basin called Mikrolimni that expands for 0.12 km^2. The pollen assemblages are differentiated from the others because of the higher frequencies of the cultivated cereal types of *Avena* and *Triticum*.

The results of the biomization technique showed that different biomes were reconstructed even within the smaller groups of samples that have been established by the forementioned statistical techniques. For example, in the Pallades sub-basin two biomes were reconstructed, the Evergreen needleleaf woodland (ENWD) and the Warm temperate evergreen sclerophyll broadleaf shrubland (WTSHB), while in the other sub-basins the reconstructed biomes are the Evergreen needleleaf woodland (ENWD) and the Cool mixed evergreen needleleaf and deciduous broadleaf forest (CMIX) (Figure 44). The diverse environment that surrounds the sites in Prokopos lagoon may be the explanation as to why so many biomes were reconstructed in such close areas. According to the map of the sites (Figure 9), the sites with the WTSHB biome (P2 and P4) were in the north of the basin, and close to Mavra Vouna, where evergreen sclerophyll shrublands thrive (see chapter 3.4). On the other hand, the ENWD and the CMIX reconstructed biomes are accurately depicting the vegetation of the nearby Strofylia Forest (see chapter 3.4). It is clear that the deposition of the pollen was affected not only from the surrounding vegetation but also from the different depths of the sub-basins.

6.3.2. Elos

According to the cluster analysis (*Figure 45*) and the nMDS analysis (Figure 46), Elos lagoon is categorized together with the lakes of North Greece in Cluster 3 and in the top right of the diagram respectively. This means that their pollen assemblages have certain similarities. In addition, the reconstructed biome for Elos lagoon is the Cool mixed evergreen needleleaf and deciduous broadleaf forest.

According to the literature (see chapter 3.5), Elos lagoon is surrounded from the north by the Xanthi-Komotini plain, an area that is highly exploited agriculturally where they grow mostly rice and cereals. The fact that there were low frequencies of Poaceae and Cerealia pollen, confirms the fact that they are underrepresented in the pollen record (Glais *et al.*, 2016; Weiberg *et al.*, 2019). On the contrary, the pollen assemblage is characterized by high frequencies of woody taxa and especially *Pinus* and *Fagus*. The explanation for that phenomenon may lay on the fact that pollen from trees can migrate in long distances from their source, as opposed to the herbaceous types that decrease while the distance from their source grows longer (Yang *et al.*, 2016). In this particular case, the increased number of tree pollen comes from the Rhodope Mountain that is close to the site. It becomes clear that the over-representation of woody taxa creates a problem with the reconstruction of the biomes of the area.

According to (Cordova *et al.*, 2009), coastal lagoons and basins on the shelves of adjacent marine waters are suitable for the accurate representation of the regional vegetation as opposed to wind-exposed coastal regions.

6.4. Temporal ponds

Three samples from three temporal ponds were studied for this research (Table 1). The sample from the Souvala site in Mt Kallidromo was excluded from the statistical analysis since it lacked the appropriate amount of pollen grains and was considered to be unreliable.

Both the assemblages, from the Alykaina site and the Livadies site, are particularly similar to each other. According to the cluster analysis (*Figure 45*) as well as the nMDS analysis (Figure 46), they are always grouped together and apart from all the other samples. They are characterized by significantly high percentages of *Abies* pollen and, they are the only two locations were *Polygonum* and *Lythrum* were found.

The dominant reconstructed biome is Cool mixed evergreen needleleaf and deciduous broadleaf forest (CMIX) (Table 3), but other reconstructed biomes with high affinity scores are Cold evergreen needleleaf forest (CENF) and Cool evergreen needleleaf forest (COOL) (Figure 44). Because the sites are located in small upland basins it was expected to have an accurate depiction of the surrounding vegetation (Marinova *et al.*, 2018). The lack of aquatic vegetation was also expected, since the samples were collected during the summer season when the ponds were dry.

6.5. Peat bogs

Three samples from two peat bogs were investigated for this thesis (Table 1). Two of them are from the same site but from different depths (Lep-2) and one is from a different site (Liv-2) (Figure 28). From the cluster and the nMDS analysis we are led to the conclusion that the assemblages from these sites are similar to each other, as they group together in every case (*Figure 45*,Figure 46). The pollen assemblages are characterized by high frequencies of woody taxa such as *Pinus*, *Fagus* and *Quercus robur* type and herbaceous taxa such as Poaceae, *Gypsophila* and *Humulus*.

The dominant reconstructed biome is the Cool mixed evergreen needleleaf and deciduous broadleaf forest (CMIX) (Table 3). Other reconstructed biomes include the Cool evergreen needleleaf forest (COOL) and the Temperate deciduous malacophyll broadleaf forest (TEDE) (Figure 44). Again, because the sites are in small upland basins it was expected that they would accurately represent the current vegetation of the surrounding area. Furthermore, the anoxic conditions and the low energy of the peat bogs favor the preservation of the pollen grains (King *et al.*, 1975). Overall, the peat bogs provided an accurate depiction of the surrounding vegetation.

6.6. Comparisons

By comparing larger basins, such as the marine environments, to smaller ones, such as the lakes, ponds or the lagoons, we conclude that the smaller ones can provide us with a more accurate depiction of the modern vegetation.

Pollen grains that are deposited into the marine sediments are often transported from greater distances. Rivers, winds, vegetation patterns, ocean circulation patterns and fluvial discharges are only some of the factors that control pollen dispersal and transportation (Beaudouin *et al.*, 2007; Chmura and Liu, 1990; Dai *et al.*, 2014; Dai and Weng, 2011; Luo *et al.*, 2013; Montade *et al.*, 2011; Mudie and Mccarthy, 1994).

The Corinth, the Saronikos and the Thermaikos Gulf, are large basins that receive large amounts of influx from rivers' deltas, which can influence greatly the pollen transportation and deposition. We know that river inflows play an important role in pollen transportation, because higher concentrations have been observed in sediments that have been collected near river estuaries (Beaudouin *et al.*, 2007; Chmura and Liu, 1990). A study conducted in the western Mediterranean Sea showed that fluvial transportation is more important on continental margins. They also showed that the total pollen concentrations decreased with increasing distance from source, while the concentration of airborne pollen increased (Beaudouin *et al.*, 2007).

On the other hand, smaller basins, provide us with more reliable information about the modern vegetation around each site (Marinova *et al.*, 2018; Sugita, 1994). This may be because of the size of the pollen source areas and the amount of river inflow that each basin receives. For example, the pollen assemblages that gave us the most accurate reconstructions of the modern vegetation were collected from small basins that laid in high altitudes and were isolated environments that had very few or zero influxes. These were from the temporal ponds (sites Livadies, Alykaina) and from the peat bogs in the Rhodope Mountain range (sites Lep-2, Liv-1)

Apart from the factors that control the transportation and the dispersal of pollen, we must take into consideration the environmental conditions that control pollen preservation. From the results of this thesis, it is confirmed that environments which are more stable and have less intense water circulation can preserve pollen grains better than, for example, marine environments where water circulation can be more intense and complex (King *et al.*, 1975). Another factor that controls the preservation of pollen grains is the chemical conditions of the environment. Pollen grains are best preserved in sediments and environments that are anoxic, cool and have neutral to slightly acidic pH (Sangster and Dale, 1964). This is why the best-preserved pollen grains were observed in the samples that were collected from the peat bogs, the temporal ponds, and Prokopos Lagoon. These samples were distinguished by higher pollen concentrations than the other ones (Figure 34,Figure 35,Figure 36,Figure 37,Figure 38).

According to the results of this thesis, the pollen assemblages from Prokopos lagoon yielded great information about the surrounding vegetation as well as the topography and geomorphology of the basin. Lagoons can act as natural pollen traps, accumulating pollen from a wide area and preserving it in sediments because of the environmental conditions that distinguish them (Azuara *et al.*, 2019). Furthermore, we found that even in small distances, the pollen assemblages may show significant variability. The fact that eleven samples, which covered the whole lagoon, were studied played a vital role in the accuracy of the results. By collecting pollen samples from multiple locations in the same area, researchers can account for microenvironmental variations that may influence pollen dispersal patterns and deposition rates, leading to a more robust reconstruction of past vegetation dynamics (Abraham *et al.*, 2021).

7. Conclusions

This palynological study focused on how modern vegetation is reflected in pollen assemblages from surface sediment samples in various depositional environments. The goal was to make comparisons and correlations in order to investigate which depositional environment holds the pollen assemblage that can provide us with the most accurate information about the modern vegetation and therefore which environment is most ideal for a palaeoecological reconstruction. The key conclusions are:

- Pollen dispersal and deposition in large basins are controlled by several complicated factors. Pollen assemblages from large basins represent the vegetation of a much larger pollen source area, and thus it is often that they do not adequately represent the local vegetation around each site.
- The most reliable reconstructions derive from samples that come from relatively smaller basins, such as lakes, temporal ponds, peat bogs, and even lagoons.
- The biochemical conditions of the depositional environment can play a vital role in the preservation of the pollen grains, and therefore in the reconstruction of the vegetation.
- Finally, collecting samples from multiple sites even within the same small basin can help us have a more reliable and sufficient reconstruction.

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