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LATE HOLOCENE VEGETATION DYNAMICS IN A MOUNTAINOUS ENVIRONMENT IN THE TERRITORY OF SAGALASSOS, SOUTHWEST TURKEY

(LATE ROMAN TILL PRESENT)

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Abstract

Anatolia is characterized by a very complex history of climate and human related vegetation change, which varies strongly from location to location. The region forms a bridge between Europe, Asia, and Africa for plants as well as human civilisation. The regional climate is equally influenced by North Atlantic, Asian, and African climatic forces and may vary regionally due to the rough topography of Anatolia. While palynological data are available for the Eastern Mediterranean, well dated records focussing on the period from the end of the Roman Imperial period to the present are rare for Anatolia and absent for SW Turkey. Additionally, while climatic data are available for the Eastern Mediterranean, no climatic records exist for SW Turkey. The aforementioned complexity of the climatic system makes it impossible to reliably use existing climatic proxies for locations for which such data are not yet available.

The Sagalassos Archaeological Research Project has been involved in excavating the classical city of Sagalassos, in the Western Taurus Mountains, Turkey. Since 1993, the archaeological project has had an interdisciplinary character, not only focussing on classical archaeology, but also involving palaeo-environmental research in an effort to understand the history of not only the city itself, but also its surrounding rural landscape.

In recent times, archaeological research has been focussed at the Late Roman and Early Byzantine periods, while in the next years, the focus will shift towards the interval from the Early Byzantine period to the present. The present research has been performed as part of the Sagalassos Archaeological Research Project, and the research results may contribute to a better understanding of vegetation dynamic and human impact within the territory, while the archaeological data may help explain the nature of the environmental changes observed in the data. Additionally, the climatological aspect of the research, as well as the fact that no detailed palaeoecological records exist which cover the most recent 2000 years in detail in SW turkey, give the research results a regional significance, providing an important new insight in the complex patterns of vegetation and climate change in the Middle East.

Two well dated palaeoecological records from the territory of Sagalassos provide a first relatively detailed record of vegetation dynamics in Southwest Turkey focussing on the period from late Roman times until the present. Combining pollen, non-pollen palynomorphs and charcoal data with multivariate statistics, sedimentological and archaeological data, allows for the disentangling of climatic and anthropogenic influences on vegetation change in this under-researched region of the Eastern Mediterranean.

The palynological and sedimentological data revealed several periods of human occupation in the pollen record, previously unknown for SW Turkey. Signs of intensive crop cultivation in the two records started to decline after the mid 3rd century AD, completely disappearing from one basin. A further, more complete shift from crop cultivation to livestock herding, possibly (semi)pastoralism, occurred in the mid 7th century. Resurgence in human impact, in the form of deforestation, livestock herding, and limited crop cultivation occurred from the mid 10th to the mid 12th century AD, after which human impact declined abruptly and completely, allowing for the establishment of a pine forest at both sites. This pine forest persisted until the mid 16th century, after which there was a gradual deforestation of the area, in combination with signs of grazing, perhaps linked to livestock herding. A pollen spectrum representative of the modern day agricultural practices in the study area only occurred in the topmost part of the available pollen record.

The numerical analyses revealed a succession of relatively wet and relatively dry bioclimatic trends occurring throughout the study area and surrounding territory, and corresponding with well-defined European climate shifts, allowing the assessment of the exact timing and impact for the first time in this region of Anatolia. The data show a shift towards increased moisture availability occurs during the 3rd century and from the mid 10th to the early 14th century AD. Relatively dry conditions prevailed prior to the mid 3rd century AD, from the mid 7th to the mid 10th century AD, and from the early 13th century AD onwards. A shift towards moister environmental conditions in the 18th century may be an artefact caused by the deforestation of the study area at that time.

The available sediment records from the study area, as well as an external tree ring record, implied that a more realistic estimate for the end of the second wet phase was the mid 13th century AD. Additionally the tree ring record indicated that both the bioclimatic proxy and calcium carbonate record from one of the locations were accurate records of regional climatic change and that the estimated chronology for this location was also highly accurate.

Statistical analyses performed on the charcoal record from both records revealed that fire activity in the rural landscape from the Early Byzantine period onwards was limited. Only a few fires were recorded and these were mostly reasonably small, no fires were recorded simultaneously at both sample sites. Only a small amount of the recorded fires appeared to be connected to human activity. Most others were primarily connected to fuel availability, and their occurrence was not related to specific environmental conditions.

Research into the pollen production and dispersal of some important plant taxa in the study area revealed that for many of the plant taxa included in the analyses, the relevant source area of pollen is relatively small, likely due to the rough topography of the study area. As a consequence, when researching regional changes in climate and vegetation through time, it is vital to study multiple records from the same study area in order to distinguish between local and regional environmental phenomena. When studying more local phenomena, such as human impact in the vicinity of a sample site of a pollen record, it is vital to keep in mind that the pollen signal may only represent the vegetation within a relatively short distance around the sample site. Changes in human activity, especially when they occur simultaneously in multiple records, may still be representative of larger scale changes in human impact in the research area, especially when coinciding with marked changes observed in the climatological or archaeological record, but they must not be seen as representative of how human impact changed throughout the territory.

Comparing the research results with the historical and archaeological record of Sagalassos and historical, archaeological, and palaeoecological data from the wider region of Anatolia revealed how human impact and climate drove environmental change, both together as well as individually.

The decrease in intensive crop cultivation at both sample sites differed from the regional trend of increased anthropogenic activity during this relatively moist period, and is also at odds with the archaeological record of Sagalassos, which indicates the city and territory remained relatively prosperous during this period. The decrease in human impact may be a local phenomenon and a result of the local wetlands increasing in size, encroaching onto formerly arable land. However, the possible role of political, economical and military instability throughout the wider region may not be ignored. The further shift to animal grazing/herding coincided with a climatic deterioration during the mid 7th century, as well as the start of Arab incursions into Anatolia. During the $8^{th}/9^{th}$ centuries AD, the Byzantine Empire underwent a political, economical and military revival, but at Sagalassos, as well as at other locations, a true increase in human impact only occurred during the mid 10th century, coinciding with the start of the Medieval Climate Anomaly (MCA) in the Eastern Mediterranean. It is proposed that, while the local population had the financial means to expand their agricultural practices; it was the start of the MCA which made the rural basins in the territory of Sagalassos suitable for agriculture. The disappearance of agriculture during the 12th century does not appear to be connected to environmental change, and may be driven by the political instability of that period and changes in land ownership at the cost of small-scale independent farmers. Gradual deforestation occurring from the 16th century onwards has been linked to changes in landscape use during the ottoman reign, rather than climatic change.

Samenvatting

Door haar ligging, als het ware een brug vormend tussen Europa, Azië en Afrika, wordt Anatolië gekenmerkt door een zeer complexe geschiedenis van klimaatsverandering en door de mens gedreven vegetatieverandering. Door haar locatie wordt het klimaat van Anatolië beïnvloed door weerfenomenen uit het Noord Atlantische gebied, zowel als de Aziatische en Afrikaanse moessonregens. De complexe situatie wordt nog verergerd door de ruwe en gevarieerde topografie van het gebied. Hierdoor kan het klimaat, maar ook de impact van klimaatsverandering, sterk verschillen van gebied tot gebied.
Hoewel er veel palynologische datasets voor handen zijn voor het Oostelijk Mediterraan gebied, is er een groot tekort aan gedetailleerde, goed gedateerde datasets die een focus hebben op de periode van de Laat Romeinse periode tot het heden. Dergelijke informatie is zeldzaam voor Anatolië en zelfs helemaal onbestaand voor het zuidwestelijk deel van Turkije. Daarbij zorgt de hiervoor al genoemde complexe topografie van het gebied er voor dat bijvoorbeeld een klimaatproxy voor gebied A hoogstwaarschijnlijk niet te gebruiken is voor gebied B, ook al liggen gebieden A en B betrekkelijk dicht bij elkaar.
Het Sagalassos Archaeological Research Project is sinds begin jaren 90 betrokken bij de opgravingen van de klassieke stad Sagalassos, in het westelijk Taurus gebergte in Turkije. Vanaf 1993 heeft het opgravingproject een interdisciplinair karakter waarbij er niet meer enkel op de klassieke archeologie gefocust wordt, maar waar er ook ruimte is voor overige takken van wetenschap die zich binnen het kader van het Sagalassos project toeleggen op het onderzoeken van de relatie tussen de stad en haar omliggende gebieden. Recentelijk lag de focus van het interdisciplinair onderzoek op de Laat Romeinse en Vroeg Byzantijnse periodes. In de komende jaren zal de focus verschuiven naar het latere interval, inclusief de periodes van de Selşuken, Beyliks, en Ottomanen.
Het onderzoek voor deze thesis is uitgevoerd als onderdeel van het Sagalassos project en de resultaten zullen een bijdrage leveren aan een beter begrip betreffende vegetatie verandering, klimaatverandering en veranderingen in menselijke activiteit in het gebied rond Sagalassos gedurende deze meest recente periode. Aan de andere kant kan de archeologische en historische kennis van deze periode een bijdrage leveren aan de correcte interpretatie van de bevindingen van het palaeoecologisch onderzoek. Ten slotte zullen de onderzoeksresultaten niet enkel van belang zijn voor het Sagalassos project. Door de afwezigheid van gedetailleerde kennis over deze meest recente periode zijn de hier gepresenteerde onderzoeksresultaten ook regionaal van belang.
Twee, van een robuust chronologisch framework voorziene, palaeoecologische datasets afkomstig uit het territorium van Sagalassos, geven voor het eerst een relatief gedetailleerd beeld van vegetatiedynamiek in het zuidwestelijk deel van Turkije voor de periode van de Laat Romeinse periode tot het heden. Door de beschikbare pollen, non-pollen, houtkool en sedimentdata te analyseren met behulp van nieuwe multivariate analyses is het mogelijk geworden om in de data onderscheid te maken tussen de invloed van klimaatsverandering en de invloed van veranderingen in bewoning van het gebied.
De data laten twee, voor zuidwest Turkije, nieuwe periodes van menselijke impact in pollendata zien. Intensieve landbouw begon te verdwijnen vanaf het midden van de 3^{e} eeuw AD. In het midden van de 7^{e} eeuw werd dit proces tot een einde gebracht wanneer er een verdere abrupte omslag plaatsvindt van landbouw (vooral het cultiveren van bomen als olijf) naar het laten grazen van (klein)vee. Van het midden van de 10^{e} tot het midden van de 12^{e} eeuw ziet men een terugkeer van menselijke invloed, die zich in dit geval kenmerkt door ontbossing, een toename van begrazing (nadat deze tijdens voorgaande eeuwen steeds was verminderd), en een zeer kleine terugkeer van cultivatie van gewassen. Menselijke impact in de nabijheid van de twee bassins viel opvallend abrupt weg, waarna er zich een secundair naaldbos kon vormen. Dit bos bleef aanwezig tot het midden van de 16^{e} eeuw, waarna er een geleidelijke ontbossing plaatsvond. De dominantie van kleine struiken zijn een aanwijzing dat het land begraasd is gedurende deze periode. Een pollenspectrum wat representatief is voor de huidige landbouwpraktijken blijkt pas zeer recent op te duiken in de data.
De gebruikte statistische analyses brachten de aanwezigheid van vijf opeenvolgende bioklimatische periodes aan het licht die zich kenmerkten door persistent relatief droge of relatief vochtige omstandigheden. Deze data bleken niet enkel representatief te zijn voor bioklimatische omstandigheden voor het hele onderzoeksgebied. De verschillende periodes kwamen qua timing ook overeen met goed gekende Euraziatische klimaatsperiodes. Vochtige periodes van het midden van de 3^{e} tot het midden van de 7^{e} eeuw, en van het midden van de 10^{e} tot de late 13^{e} eeuw bleken overeen te komen met respectievelijk de Roman Warm Period en de Medieval Climate Anomaly (het Middeleeuws Klimaatoptimum).

Droge periodes tussen het midden van de 7e eeuw en het midden van de 10e eeuw, en na de late 13e eeuw bleken de lokale manifestatie te zijn van respectievelijk de Dark Ages Cold Period en de Little Ice Age (Kleine IJstijd).
Verdere statistische analyses brachten aan het licht hoe de impact van natuurlijke en door de mens aangestoken branden minimaal was vanaf de vroeg Byzantijnse periode tot nu. De hoeveelheid branden was klein en hun impact op het landschap in de meeste gevallen te verwaarlozen. Een minderheid van de aangetroffen branden bleek waarschijnlijk door de mens te zijn aangestoken. De meeste branden waren natuurlijke branden en hun voorkomen had meer te maken met de algemene beschikbaarheid van brandstof (in de vorm van naaldbos), en met bepaalde klimaatsomstandigheden.
Onderzoek naar de pollenproductie en pollenverspreiding van een aantal plantensoorten liet zien dat het gebied waarover pollen hoofdzakelijk zal worden verspreid redelijk klein is. Dit is waarschijnlijk het gevolg van de zeer ruwe topografie van het onderzoeksgebied. Het gevolg hiervan is dat het zeer belangrijk is om data te verzamelen van verschillende locaties binnen het onderzoeksgebied, wil men een betrouwbaar onderscheid kunnen maken tussen lokale en regionale veranderingen in de natuurlijke omgeving. Wanneer men specifiek lokale fenomenen bestudeert, zoals menselijke impact in de omgeving van één bepaalde locatie, dan is het belangrijk om te beseffen dat het pollensignaal misschien weergeeft dat er een bepaalde verandering heeft plaatsgevonden, maar enkel voor een zeer beperkte omgeving weergeeft hoe deze verandering er heeft uitgezien.
Een vergelijking van de palaeoecologische onderzoeksresultaten met de historische en archaeologische data die voor Sagalassos en omgeving beschikbaar zijn, laat zien hoe zowel menselijke impact als klimaat de drijvende kracht zijn achter vegetatieverandering, zowel elk apart als gezamenlijk.
De afname in menselijke impact vanaf het midden van de 3e eeuw AD wijkt af van het patroon wat men elders in het Midden Oosten en Noord Afrika ziet. Voor die gebieden was deze periode juist een van extra voorspoed en een toename in landbouwopbrengsten. Ook de archeologische data laten zien dat het de stad Sagalassos en diens territorium nog behoorlijk voor de wind ging. Het is waarschijnlijk dat de geobserveerde afname van menselijke impact een lokaal fenomeen is. De vernatting die plaatsvond vanaf het midden van de 3e eeuw zal er voor hebben gezorgd dat moerassen zich konden uitbreiden, waardoor er op die plekken minder landbouw mogelijk was. Drogere valleien zullen hier geen last van hebben gehad. Een toename in vochtigheid zal voor die gebieden zelfs een verbetering zijn geweest.
De verdere omslag van het verbouwen van gewassen naar het hoeden van vee in de 7e eeuw komt overeen met de start van een zeer droge klimaatsperiode. Maar ze komt echter ook overeen met het begin van Arabische invallen in het deel van Anatolië waar Sagalassos zich bevond.
De terugkeer van menselijke impact gedurende het midden van de 10e eeuw komt overeen met de start van het Middeleeuws Klimaatoptimum. De verbeterde klimaatsomstandigheden gedurende deze perioden zouden wellicht een katalysator kunnen zijn geweest voor de uitbreiding van menselijke impact. Het Byzantijnse rijk kende een tijdelijke periode van militaire successen en economische voorspoed vanaf de 8e eeuw. Het is mogelijk dat men daarom voor het midden van de 10e eeuw al de middelen had om het landbouwareaal uit te breiden, maar dat de lokale omstandigheden in beide onderzoeksgebieden pas na het begin van het Middeleeuws Klimaatoptimum goed genoeg waren om daadwerkelijk tot ontginning over te gaan.
Er is geen duidelijk verband tussen het abrupte verdwijnen van menselijke impact tijdens de 12e eeuw en een verandering in het klimaat. Ook een duidelijk verband met een gekend historisch fenomeen ontbreekt. Het is het meest waarschijnlijk dat deze verandering te maken heeft met de algemene terugval van het Byzantijnse rijk, meer specifiek de veranderingen in de aard van het landeigendom en landgebruik die plaatsvonden tijdens deze periode. Ook de geleidelijke ontbossing en toename van begrazing in deze periode lijken eerder gedreven te zijn door veranderingen in landgebruik dan enige klimaatsverandering.

General introductory remarks

All geographic coordinates given in the text and tables are given as northings and eastings in the UTM (36N) coordinate system.

In general, all ages are given in calendar years BC/AD. Ages given in years BP occur only in chapter 1 and 2. In these cases the time period indicated was of such a magnitude and age that the added value of recalculating dates to BC/AD was negligible. Except in chapters 1 and 2, dates taken from external publications are always presented in BC/AD. If such dates have been recalibrated (re)calibrated to calendar years before inclusion in this thesis, this will be mentioned explicitly in the text.

Changes in vegetation and sediment composition are described in the present tense in the Results chapters of this thesis as they describe observations made in the present. In the discussion chapters of this thesis, changes in vegetation, human impact, and environmental conditions, are discussed in past tense as they describe possible occurrences in the past.

All units given in the tekst are SI units and identified with the common abbreviations. Other abbreviations used in the text are defined/explained when mentioned for the first time. Nevertheless, for reasons of clarity, a list of the most commonly used acronyms is given here:

In this thesis, the term ‘detritic’ is used in the meaning of a geological term used to describe the particles of rock produced by weathering, rather than decayed organic matter.

Common abbreviations

AD: *Anno Domini*. Equal to CE (Common Era)
AMS: Accelerator Mass Spectronometry radiocarbon dating
a.s.l.: Above sea level (m)
BC: Before Christ, Equal to BCE (Before Common Era)
BO Phase: Beyşehir Occupation Phase
BP: Before Present (defined as AD 1950)
CA: Cluster Analysis
Cal: Calibrated
CC: Calcium Carbonate
cm: Centimeter
DACP: Dark Ages Cold Period
DCA: Detrended Correspondence Analysis
e.g.: *exempli gratia* (“for example”)
g: Gram
kg: Kilogram (1000 grams)
LIA: Little Ice Age
m: Meter (100 cm)
m/s: Meters per second
MCA: Medieval Climate Anomaly
NE: North-east
NPP: Non-pollen palynomorph
NJ: Neighbour Joining
NW: North-west
OM: Organic matter
PCA: Principal Component Analysis
PDVP: Pollen Derived Vegetation Pattern
PPE: (Relative) Pollen Production Estimate
PFT: Plant Functional Type
RSAP: Relevant Source Area of Pollen
RWP: Roman Warm Period
SD: Standard Deviation
SE: South East
SW: South West

Appendices

This thesis contains seven appendices, providing basic data and additional information. Except for appendices 1 and 5, the data contained within is usually too extensive to reproduce in the present thesis in any readable way. As an alternative, the *.xls and *.csv files of which these appendices consist, have been made digitally available for download via dropbox.

A .zip compressed version of the appendices is available via the following link:
http://dl.dropbox.com/u/57642672/Appendices%20PhD%20Thesis%20Johan%20Bakker.zip

A .rar compressed version of the appendices is available via the following link:
http://dl.dropbox.com/u/57642672/Appendices%20PhD%20Thesis%20Johan%20Bakker.rar

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Chapter 1

Introduction

1.1. General introduction

Anatolia is characterized by a very complex history of climate and human related vegetation change, which varies strongly from location to location. The region forms a bridge between Europe, Asia, and Africa for plants as well as human civilisation (McNiel, 1992; Eastwood et al., 1998; Oğuz, 2004; Magyari et al. 2007). The regional climate is equally influenced by North Atlantic, Asian, and African climatic forces, resulting in regional differences in the extent, intensity and impact of climatic change (Cullen and deMenocal 2000; Cullen et al. 2002; Bolle 2003; Luterbacher 2006a). Furthermore, the rough topography of the mountainous areas in this region (e.g. the Taurus Mountain range) further increases the complexity of the climatic systems in the Eastern Mediterranean.

These factors, as well as the long history of human impact on the landscape and the rough topography of the region, has resulted in a very complex history of climate related and human influenced vegetation change which may vary strongly from location to location (Behre 1990; Bottema and Woldring 1990).

Palaeoecological and palaeoclimatological research can provide valuable insights into the length, nature and severity of human impact on the vegetation, the role of climate change on vegetation change, and the way vegetation, climate and human impact influence one another. When combined with archaeological and historical records, these data sources are potentially mutually complementary. Palaeoecological and palaeoclimatological research can provide crucial information concerning the environmental framework within which human impact developed and evolved, while archaeological and historical data may provide evidence concerning the nature and mechanisms of anthropogenic vegetation change (England et al. 2008).

In Turkey, only a relatively low amount of Holocene palaeoecological studies have been performed in comparison with Northern and Western Europe. Furthermore, the focus of many earlier palynological research projects covers a larger time period, focussing on the most important and lengthy periods of vegetation and climatic change during the Holocene (e.g. van Zeist et al. 1975; Bottema and Woldring 1984; Roberts et al. 2001). While having resulted in a wealth of new information concerning the vegetation history of Anatolia, the longer time period studied, as well as the relatively low sampling resolution of many older pollen records makes it difficult to properly study or even recognize changes in vegetation on a centennial scale or smaller. The low number of radiocarbon dates used to construct the chronology of many older records also makes it difficult if not impossible to properly date periods/trends/events which mainly occur on a scale of a few centuries or less (Table 1.1). This creates difficulties when trying to properly link environmental data from such records to other external palaeoecological, historical, or archaeological data sources.

Records covering the late Holocene in Turkey often have a focus on the Beysehir Occupation Phase (BO Phase). The BO Phase is a period first identified by van Zeist et al. (1975), and now identified in numerous pollen records in the Eastern Mediterranean (Bottema 1982; Bottema and Woldring 1990; Bottema et al 1993; Triantaphyllou et al. 2009). It is characterized by signs of intense human impact in the eastern Mediterranean, particularly arboriculture. The BO Phase occurred roughly between 3000 and 1300 years before the present, although the start and end dates can vary quite significantly between sites, even among relatively well dated records. This focus caused that anthropogenic impact in periods preceding and succeeding the BO Phase received relatively little attention. Specifically the region of SW Turkey, where much important pioneering palynological work has been performed by van Zeist et al. (1975), Bottema and Woldring (1984), Eastwood et al. (1998, 1999, 2007), Vermoere et al. (2002a, b), Kaniewski et al. (2007a, b, 2008), no palynological records exist which cover the post-BO Phase in detail. Therefore it is unknown for important parts of the Eastern Mediterranean how the vegetation was affected by changes in anthropogenic activity during the time of the 7th century Arab invasions, the 8th-12th century Byzantine “Golden Age”, or the subsequent periods of Selşuk and Ottoman rule of the region.

Table 1.1. An overview of the main characteristics of a selection of published palynological records from Turkey, featuring the sampling sites, references, age of the oldest sample and the number of radiocarbon dates.

Region	Location	Core	First published in	age of oldest sample (14C years BP)	Number of carbon dates
Southwest Turkey (Territory of Sagalassos)	Sagalassos: Gravgaz	SA06EP1	Bakker et al. 2011a	1850	7
	Sagalassos: Bereket	SA09JBDrill02	Bakker et al. in press	2370	17
	Sagalassos: Canaklı		Vermoere et al. 2002b	unknown	0
	Sagalassos: Başköy		Vermoere 2004	Early Holocene	1
	Sagalassos: Ruined city	Potters' Quarter	Vermoere 2004	All samples Hellenistic/Roman	4
	Sagalassos: Ruined city	Roman Baths	Vermoere 2004	All samples Early Byzantine	0
	Sagalassos: Ağlasun	Core 6	Vermoere 2004	8760	5
	Sagalassos: Ağlasun	Core 12	Vermoere 2004	7640	5
	Sagalassos: Ağlasun	Core 13	Vermoere 2004	7840	2
	Sagalassos: Bereket	BKT1/2	Kaniewski *et al.* 2007a, 2007b	3260 (until Early Byzantine period)	11
	Sagalassos: Gravgaz	G96	Vermoere *et al*. 2002b	2600	7
	Sagalassos: Gravgaz	G99	Vermoere *et al*. 2002b	2540	7
Southwest Turkey	Beyşehir Gölü	I	van Zeist et al. 1975	6500	2
	Beyşehir Gölü	II	Bottema and Woldring 1985	16000	1
	Sögüt Gölü		van Zeist et al. 1975	19500	2
	Pinarbaşı		Bottema and Woldring 1984	17000	2
	Köyceğiz Gölü		van Zeist et al. 1975	5697	2
	Gölhisar Gölü		Eastwood et al. 1999	4000	8
	Ova Gölü		Bottema and Woldring 1984	6655	2
	Hoyran Gölü		Bottema and Woldring 1984	4000	1
	Avlan Gölü		Bottema and Woldring 1984	unknown	0
	Elmalı		Bottema and Woldring 1984	unknown	0
	Karamık Bataklığı		Bottema and Woldring 1984	20000	2
West Turkey	Bafa Gölü		Knipping et al. 2008	4000	5
	Manyas Gölü		Leroy et al. 2002	2100	2
	Yenişehir		Bottema and Woldring 1995	unknown	0
North Turkey	Akgöl Adatepe		Bottema et al. 1993	900	1
	Küçük Akgöl		Bottema et al. 1993	3900	2
	Melen Gölü		Bottema et al. 1993	4000	1
	Tatlı Gölü		Bottema et al. 1993	Unknown	1
	Kaz Gölü		Bottema et al. 1993	> 10000	2
	Demiryurt Gölü		Bottema et al. 1993	2000	1
	Abant Gölü		Bottema et al. 1993	13580	5
	Büyük Gölü		Bottema et al. 1993	Unknown	0
	Seyfe Gölü		Bottema et al. 1993	Unknown	0
Central Turkey	Tuzla Gölü		Bottema et al. 1993	Unknown	0
	Eski Acıgöl		Roberts et al. 2001	16000	16
	Nar Gölü		England et al. 2008	1700	Varve chronology
	Akgöl		Bottema and Woldring 1984	13050	3
East Turkey	Van Gölü		van Zeist and Woldring 1978	13000	Varve chronology
	Van Gölü		Wick et al. 2003	13000	Varve chronology
South Turkey	Bozova Gölü		Bottema 2009a	unknown	0
	Gölbasi Gölü		Bottema 2009b	unknown	0

Although there is a wealth of information available concerning Late Holocene climate change in the Eastern Mediterranean (e.g. Luterbacher et al. 2006b; Touchan et al. 2007; Hajar et al. 2010), less attention is given to how important periods of climatic change, such as the Little Ice Age (LIA) or Medieval Climate Anomaly (MCA) influenced vegetation dynamics during this period in Turkey (e.g. Neumann et al. 2007a, b; Kaniewski et al. 2010, 2011a, b). Furthermore, the complexity of the climatic systems and cultural history in this geographical region necessitate an understanding of the timing, nature and impact of climatic change on a more localized scale when attempting to study the interconnectedness of climate, vegetation, and human impact. Climatic reconstructions on a hemispherical scale (e.g. Mitchell et al. 2004; Moberg et al. 2005;

Luterbacher et al. 2004, 2009) are therefore of little use in such studies. For Turkey, studies providing a detailed overview of climatic change, vegetation change, and changes in human impact, which includes the post-BO Phase time period, are rare. Thus far, only the palynological records from Nar Gölü, central Anatolia (Roberts et al. 2001; England et al. 2008), and Van Gölü (van Zeist and Woldring, 1978; Lemcke and Sturm 1997; Wick et al. 2003), both supported by a detailed chronological framework based on varve counts, provide such information. However, being located in central and eastern Anatolia respectively, they cannot be used as a template for changes in vegetation, climate and human impact in other locations in Turkey which are characterized by different climatic conditions, vegetation types, and cultural history.
There are two important gaps in the current knowledge on palaeoecology and palaeoclimatology in Turkey. First of al there is a temporal gap. The number of detailed high-resolution pollen records, supported by a solid chronological framework, is increasing (e.g. England et al. 2008). However, their number remains very low. More studies are needed in order to gain a better understanding of vegetation change and climate change for these periods. Second of all there is a geographical gap. As Anatolia is a complex region, both in terms of geography, climate, vegetation, as well as cultural history, it is vital to obtain knowledge concerning vegetation and climate change from locations from which data concerning certain time intervals is still lacking.
While studies which focus on climatic and (anthropogenic or natural) vegetation change can provide important new insights into the way ecosystems and landscapes changed and how the natural landscape and human impact influenced one another over time, it is vital that the existing gaps in understanding are filled in, in order to properly understand the natural and cultural history for this important and unique region as a whole.

1.2. The main aims of this dissertation

As palaeoecological data concerning the post BO Phase is still absent for the region of SW Turkey and extremely rare for Turkey as a whole, this dissertation aims to remedy this situation by providing the first relatively detailed overview of vegetation change and changes in human impact through time for the post-BO Phase period in SW turkey.
This dissertation also aims to provide the first overview of the timing and impact of climatic change for the most recent two millennia in SW Turkey. It was decided to use the pollen record as a basis for the creation of a climatic proxy. Using newly developed numerical analyses, a bioclimatic proxy of relative changes in moisture availability through time was constructed. The use of multiple pollen/sediment records allows for the distinction between the impact of local and regional environmental change on the pollen/sediment record and will reveal to what extend the pollen-derived bioclimatic proxy is representative for the wider region, rather than only the direct surroundings of the sample site. A further comparison with independent climatic records may verify that the bioclimatic proxy responds to regional environmental change. Such a proxy can provide valuable additional information concerning the palaeoclimate in this complex region. This dissertation also aims to use such numerical methods to provide the first overview of the occurrence, origin, and impact of fire for the post-BO Phase period in Turkey. These analyses will also provide new information concerning post disturbance vegetation succession following the abandonment of agricultural land.
By combining this new knowledge concerning climate change, human impact and vegetation change with one another and with external archaeological, historical, palaeoclimatological, and palaeoecological data, this dissertation aims to provide a detailed overview of the interrelations of climate, man, and vegetation, and how each change in one of these factors influences the others through time.
Finally, using recent developments in modelling techniques, this dissertation aims to take the first steps towards a quantitative reconstruction of the vegetation in order to gain a better understanding of the vegetation present in the landscape during various points in time, and gain a better understanding of the relation between the pollen signal and the actual vegetation around a sample site.

The main focus of this dissertation is vegetation change, climatic change, and anthropogenic change in SW Turkey from the late Roman Imperial period (AD 300) to the present. The main research questions are as follows:

- Is human impact still discernable in the pollen record after the end of the BO Phase and if so, when and what is its nature?
- How does the natural vegetation respond to disturbances such as human impact or (natural or anthropogenic) fire activity and how fast does the succession towards a secondary climax vegetation take?
- Is it possible to distinguish late Holocene climatic trends in the pollen signal, and if so, what is the timing, nature and impact of periods of climatic change? And how does the pattern of climatic change differ or coincide with that of the surrounding regions?
- Is it possible to adapt existing vegetation reconstruction models used in Northern Europe, so that an accurate estimation can be made concerning the relevant source area of pollen for the major plant species in the most important vegetation types in the area? If so, is it possible to create a reasonable estimation of how much of the historic landscape was covered by each vegetation type?
- What is the interrelationship between climate, human impact and vegetation? Which changes in the environment and vegetation were caused by human impact and which by climate change? Is it possible to link episodes of climatic change to notable changes in human impact, and is it possible to convincingly link changes in human impact distinguished in the pollen record to social, economical, or political changes that took place in the territory of Sagalassos, or in the wider region?

1.3. Thesis outline

This dissertation is divided into three parts. The first part will consists of an introductory section, incorporating the present introduction chapter, while chapter 2 presents a critical, overview of previous palynological research in the same study area, mapping vegetation and environmental change from the early Holocene until the end of the BO Phase, and displaying the scientific foundations upon which the current research is built.
The second part will concern itself with the palynological, sedimentological, and statistical analyses. Chapter 3 provides an overview of vegetation change and changes in human impact through time for the post-BO Phase period in SW turkey. The resulting pollen data are used as a basis for multiple numerical analyses. In Chapter 4 these techniques will be used to reveal the timing and impact of climatic change during the most recent two millennia. Chapter 5 provides an analysis of the occurrence, origin and impact of fires in the region for the post BO Phase period. Finally, chapter 6 will cover the two first steps of the process witch which it is possible to create quantitative reconstructions of past vegetation using present pollen production and dispersal data. In this chapter the relative pollen production and relevant source area of pollen for the major plant species per vegetation type will be determined. When the relative pollen production and relevant source area of the most important pollen types are known, it is possible to run simulations in order to test hypotheses concerning past vegetation change. A further analysis of the topography of the landscape, the ecology and the links between vegetation cover and geomorphologic processes will be implemented in the doctoral thesis of Hanne de Brue.
The third part of this thesis will present a final overview of the findings of the previous chapters and how the newly acquired knowledge may aid our understanding of the history of human impact and climate change in the region. In chapter 7 the findings of the three preceding chapters are combined and compared with the available archaeological and historical record for the territory of Sagalassos and beyond. This chapter then presents an overview of the way climate, human impact, and vegetation influence one another and how this interconnectedness changes through time. Finally, chapter 8 will present an overview of the general conclusions of this research project and some suggestions for future possible palynological research projects.
Chapter 2 is based on Bakker et al. (2011a), chapter 4 is based on Bakker et al. (2011b), and Chapters 3, 5 and 6 are primarily based on Bakker et al (in prep).

1.4. A short introduction to Palynology

As this dissertation is meant to be read by researchers specialized in other disciplines than palaeoecology, and therefore with limited knowledge of palynology, the following section will present a short overview of the underlying principles of palynology. Fig. 1.1 shows a flowchart presenting a summary of the factors influencing the end result of a palynological analysis, based in part on Faegri and Iversen (1989).

Palynology entails the study of contemporary, as well as fossil palynomorphs (a particle of a size between five and 500 micrometers (µm) found in deposits and composed of organic material). The most important of these are pollen, but the study of non-pollen palynomorphs (NPP) such as spores, dinoflagellate cysts, coccolithophores, and diatoms is increasingly commonplace.

The basic principle underlying palynology is that the study of palynomorphs, and the way their relative abundances change through time, reveals information concerning changes in the actual vegetation and environmental (climatological, physical, etc.) conditions through time. Just as various factors such as human impact, climate, and geological events, may influence pollen production and transport, the relative importance of pollen (or non-pollen palynomorph) types in pollen samples may reveal information about these factors at the time of deposition on the sample site.

In some cases it is possible to reconstruct past landscapes by assessing the current bioclimatic ranges of plant taxa encountered in fossil pollen spectra (Klotz 1999; Sorell et al. 2007). Another method groups plant taxa into vegetation associations which occur within a reasonably uniform bioclimatic range and tries to assess which of these so-called “Biomes” were most important in fossil pollen records (Prentice et al. 1996; Tarasov et al. 1998). Such research may also reveal the timing and impact of past occurrences of climatic change.

Pollen grains are the most common palynomorphs studied in palynology since they are produced in very large numbers and are more widely and evenly spread than larger (sub)fossils. They are also extremely durable if deposited in a waterlogged environment such as a peat or a lake floor. Because of this they form a relatively easily retrievable proxy of vegetation change. Their abundance also enables the implementation of statistical analyses, controlling quantitative variations in pollen records.

The term NPP may imply all palynomorphs that are not pollen. In this dissertation the term only indicates microscopic remnants and spores of algae, fungi, and cyanobacteria, insofar as they can be observed and determined in the pollen samples. Many of these palynomorphs are indicative of specific local conditions and help answer questions concerning the nature of the local environment. NPP’s may also reveal extra information concerning possible problems with pollen deposition and preservation such as fast sedimentation rates or periods of local dryness.

Palynology combines earth science (geology, geography) and biology (particularly botany) and the findings of palynological research may be used to answer a wide range of questions. In a biological context, palynology can help map vegetation change and reconstruct past landscapes. In a climatological framework, the study of past plants and plant communities can reveal changes in climatological variables such as temperature or precipitation. In a geographical framework, reconstructions of past vegetation and vegetation change may help disentangle the relations between plant cover and landscape use, erosion, and sedimentation. When used in an archaeological context, the study of palynomorphs can reveal valuable information concerning changes in human impact-driven vegetation change, dietary habits, economic activities, or help reconstruct the vegetation surrounding an archaeological site.

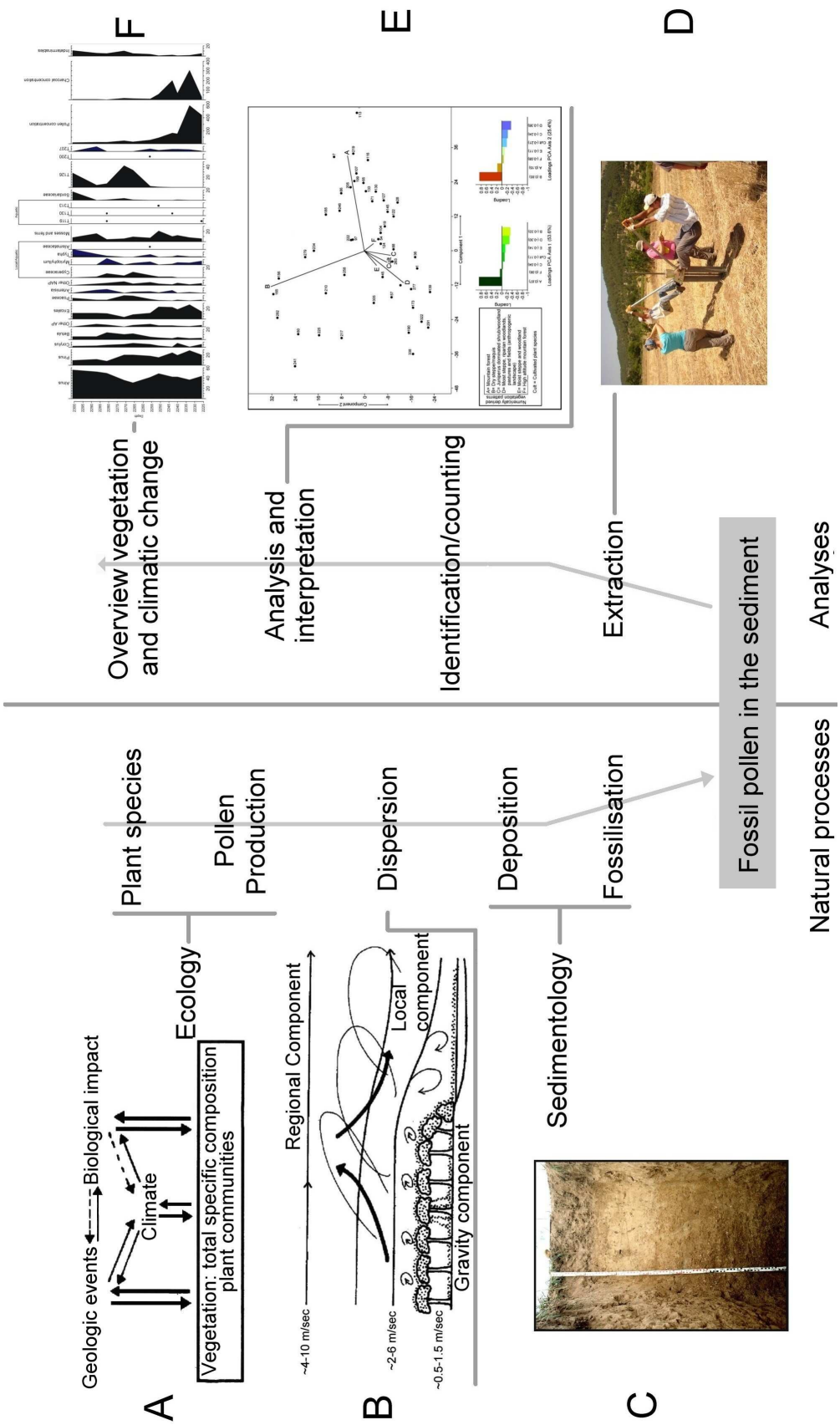


Fig. 1.1. Flow chart summarizing the factors influencing the pollen analytic registration in fossil samples (after Faegri and Iversen 1989). Section A indicates the interrelatedness of climatic, pedologic, and biological forces (e.g. human impact, grazing pressure, plant disease) in influencing the vegetation and pollen production of that vegetation. Section B indicates the components by which pollen may be transported from parent plant to sample site, and includes a regional component consisting of pollen transported by wind currents above the tree line, a local component consisting of pollen output which goes into diffusion more or less parallel to the upper surface of the vegetation, and a gravity component, consisting of pollen being deposited directly below the parent plant. Section C indicates the role of sediment type and sedimentation rate in pollen concentration and preservation. Sections D, E, and F indicate the steps involved in acquiring, preparing and handling pollen records. The methods used in these steps may differ considerably from research project to research project. The exact methods used for this dissertation are described in detail in the appropriate chapters.

1.5. Study area

1.5.1. Physical setting

The study area is situated within the territory that was under control of the ancient city of Sagalassos during its Roman Imperial heyday. It is therefore commonly referred to as 'the territory of Sagalassos'. It is situated in the province of Burdur, roughly 100 km to the north of Antalya, near the present-day village of Ağlasun.
The study area is located within the SSW-NNE mountain ranges of the Western Taurus, near the apex of the Isparta Angle (Dilek and Rowland 1993). The central mountain area in the territory is composed primarily of limestones and ophiolite Mélange of the Lycian nappe (Degryse et al. 2008). The eastern part of the territory is dominated by the Bey Dağlari massif, consisting primarily of limestone (Six, 2004; Degryse 2008; Verhaert et al. 2006). A large zone of marl deposits (the "Badlands of Burdur") occurs between the Lycian nappe and Lake Burdur Basin (Six et al. 2008; Degryse 2001). The northern boundary of the study site is formed by the mountain ridge north of the ancient city of Sagalassos while the southern boundary was formed by the mountains south of the plains of Hisarköy, Çanaklı, and Çeltikçi-Bağsaray, and the hills south of the Düğer plain. The Eastern border was mainly formed by the Isparta River, while the western border was formed by the Via Sebaste, running east of Lake Burdur and the Düğer plain (Vermoere 2004; Waelkens et al. 2000a; Waelkens et al 2003). The valley floors are commonly filled with clay sediments, mainly from alluvial and colluvial origin (Poisson 1975; Robertson 1993;Waelkens and Degryse 2003; Six et al. 2008). A topographical and geological overview of the territory of Sagalassos is provided in Fig. 1.2.

1.5.2. Climate

The region of which the study area is a part is considered to have continental climate. However, the high altitude of the study area means that the climate prevalent in the study area has an Oro-Mediterranean character, characterized by cool, wet winters with pronounced precipitation. Temperatures frequently drop below freezing during the winter months. Summers are generally dry and hot (Paulissen et al. 1993; Türkeş et al. 2002; Türkeş and Erlat 2005). A summery of modern-day climatic conditions is presented in Table 1.2. The Anatolian Peninsula is located between humid regions in the north and arid regions in the south. The principal weather systems in the region originate from the Atlantic Ocean, passing over Europe or the Mediterranean Sea. Relatively cold air leaving Turkey moves in a southern direction, colliding with warmer Saharan air over Cyprus, forming a front along which winter storms may travel eastward, bringing rain and snow into the Middle East (LaFontaine and Bryson 1990; Luterbacher et al. 2009). As the region is a climatic transition zone, the Eastern Mediterranean is sensitive to fluctuations in natural environmental parameters, such as rainfall, temperature, vegetation types, the origin and pattern of storm tracks, and the location of the desert boundary (Bar-Matthews et al. 1999). The palaeoclimate of this region has been previously studied by Touchan et al. 2005, 2007. Unfortunately these records only fully cover the LIA and subsequent periods, while no link with the influence of climatic change on vegetation is made.

Table 1.2. A summery of modern-day climatic conditions in the study area as collected by the weather station in Ağlasun (located at 37°39'N 30°32'E, and at an altitude of 1150 m a.s.l.). The table presents average values of data collected between 1972 and 2004 (Ağlasun Meteorology Station. Turkish State Meteorological Service, Ankara).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Okt	Nov	Dec	Annual
Mean Maximum Temperature (℃)	11,79	13,69	19,10	22,61	27,20	30,57	33,09	32,96	30,51	27,08	20,12	14,11	23,57
Mean Minimum Temperature (℃)	-9,15	-9,14	-6,44	-0,60	1,98	6,18	9,24	9,23	4,72	-0,11	-4,70	-7,30	-0,51
Mean Average Temperature (℃)	1,15	1,83	5,17	9,26	13,80	18,26	21,45	20,83	16,98	11,66	6,18	2,91	10,79
Total precipitation (mm)	109.82	97.97	70.77	87.47	69.77	41.05	17.82	20.32	18.68	63.81	67.03	99.76	764.25

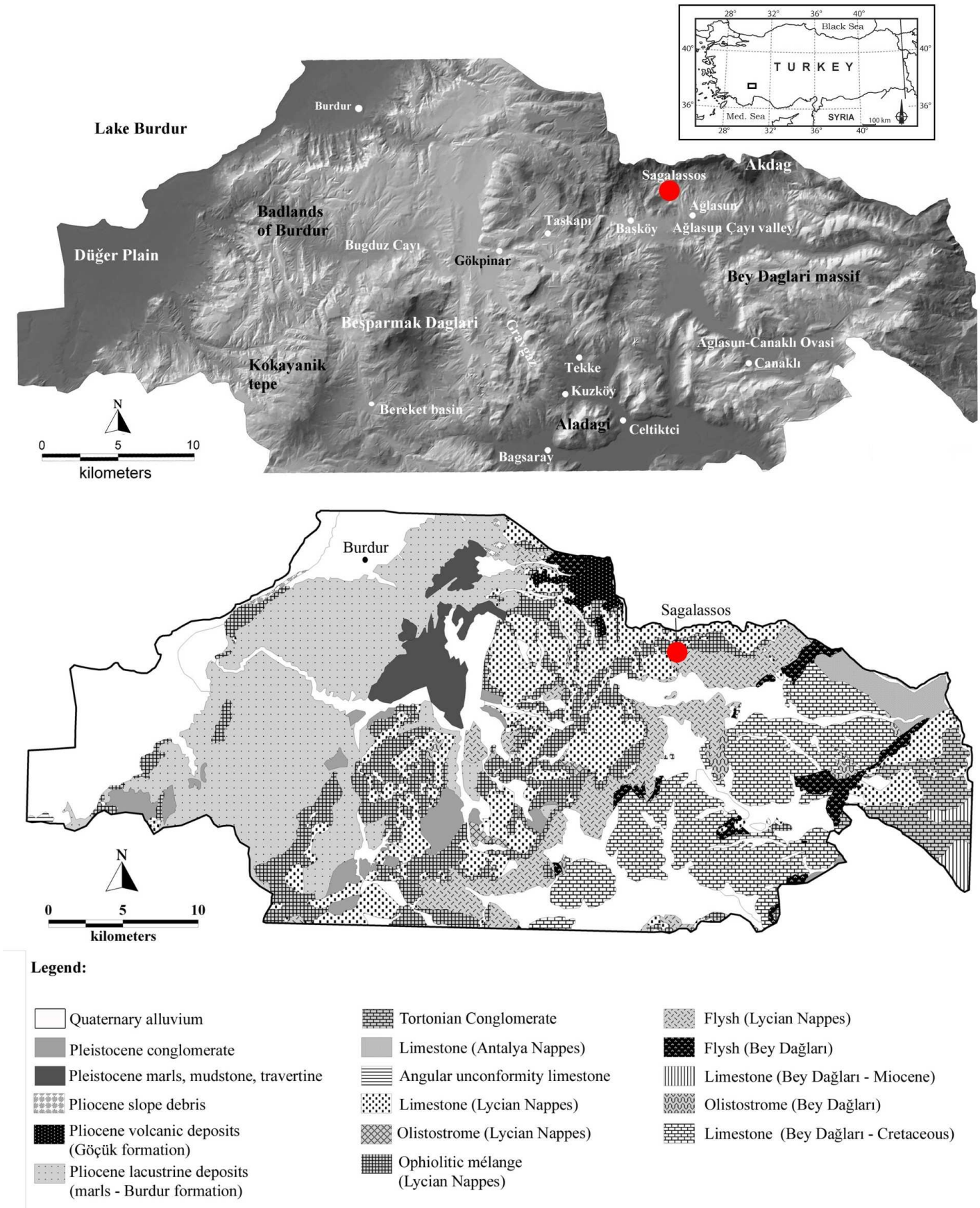


Fig. 1.2. Top: A topographical map of the study area with the main towns indicated in regular text and the main topographical features indicated in bold (After De Laet 2006). Bottom: A geological map of the study area (after Şenel 1977a,b,c).

1.5.3. Vegetation

Anatolia is located between the continents of Africa, Asia and Europe and thus acts as a gateway for plant taxa between continents (Oğuz 2004). The diversity of arboreal and non-arboreal plant taxa is therefore relatively high and comparable to that of central Europe, despite centuries of intensive human impact on the landscape (Zohary 1973; Barthlott et al. 2005). However, very little remains of the natural vegetation in the study area as it had been subjected to intensive overgrazing. The study area is located within the upper unit of the Oromediterranean vegetation zone according to van Zeist et al. (1975) and at the highest vegetation zone according to Fontaine et al. (2007), although alpine vegetation can be found at altitudes above c. 2000 m a.s.l. The lower part of the Oromediterranean vegetation belt consists mainly of deciduous (e.g. *Quercus cerris*) and *Pinus brutia* forests. *Pinus nigra* is more dominant in the upper parts of the Oromediterranean belt (van Zeist et al. 1975).

The vegetation nowadays present in the study area primarily consists of a mixture of Mediterranean forests and woodlands, mainly composed of *Pinus nigra*, *Juniperus excelsa* and *J. oxycedrus*, and to a lesser degree *Quercus coccifera*. In accordance with the earlier description, the lower lying pine forests (800-1200 m) are mainly dominated by *P. brutia*, while at higher altitudes, the forest is dominated by *P. nigra* (Fig. 1.3). *Cedrus libani* and *Abies cilicica* both form part of the climax tree vegetation in these areas, establishing themselves within already extant pine forest (Van Zeist et al. 1975; Fontaine et al. 2007). Unfortunately naturally occurring forests and woodlands of these two species have become rare within the study area, only a few degraded stands remaining. However, recent reforestation efforts have resulted in a number of new, *Cedrus* or *Abies* dominated forest plantations.

The most fertile areas are mainly under cultivation with *Triticum durum*, *Cicer arietinum*, *Beta vulgaris*, *Medicago sativa* and *Helianthus annuus* (Fig. 1.4). Intensive grazing pressure has resulted in the lower slopes surrounding agricultural fields being covered by short, open vegetation dominated by *Q. coccifera* (Fig. 1.5). Depending on local environmental conditions, Juniper species such as *J. oxycedrus* may also be an important part of this shrub vegetation, as well as *Artemisia herba-alba* and *Astragalus* (Kaniewski et al. 2007a). Intense agricultural activities also facilitate the establishment of a meadow-steppe-like grassland, generally consisting of grasses, meadow herbs (*Plantago lanceolata, Centaurea solstitalis, Sanguisorba minor*) and common forbs such as Apiaceae, Asteraceae, Brassicaceae, Lamiaceae and *Scabiosa*. Riparian oak groves, dominated by deciduous *Q. cerris*, occur in the wetter parts of the region and have not been encountered above an altitude of 1300 m a.s.l. (Vermoere 2004; Kaniewski et al. 2007a). While van Zeist et al. (1975) report that *Q. cerris* may also form dense undergrowth in Anatolian pine forests, Kaniewski et al. (2007a) only found *Q. cerris* in destroyed deciduous forest vegetation associated with *P. brutia*.

Apart from *Q. cerris*, important deciduous trees include *Platanus orientalis*, a riparian species found along river banks. *Salix* is very common in villages and is also found lining drainage and irrigation ditches on valley floors. Plantations and rows of *Populus* (*nigra* or *alba*) are also a frequent feature of the wetter parts of valley floors. However, the present *Populus* species are recent cultivars.



Fig. 1.3. Mixed Pinus nigra and P. brutia forest located in the vicinity of the town of Dereköy. to the north-east of the site of Sagalassos



Fig. 1.4. An overview of the Çanaklı basin, showing most major components of the current landscape within the study area. The valley floor is used for intensive crop cultivation (primarily cereals), while the mountain sides are predominantly covered in degraded *Quercus coccifera* and *Juniperus* shrub. The hillside on the foreground is covered in a mixed *Pinus nigra/P. brutia* forest.



Fig. 1.5. Degraded *Quercus coccifera* shrubs above the basin of Gravgaz. *Q. coccifera* may grow into a small tree (6-10 m tall), but occurs mainly as small shrubs due to overgrazing limiting growth and development.

1.5.4. Occupation history

The oldest habitation in the region dates from the Late Epipaleolithic period (c. 13000-6500 cal BC; Düring 2011). However, finds dating from this period are extremely rare within the study area. The earliest signs of habitation within the study area, a cave near the present-day town of Dereköy, date from c. 10000 cal BC (Vermeersch et al. 1997, 2000).

More permanent types of settlements appeared along the edge of Lake Burdur during the Late Neolithic/Early Chalcolithic period (6500-5500 BC for the study area; see Düring 2011), evidenced by surveys and excavations on the Burdur plain (Mellaart 1970; Wesley 1970; Duru 1987; Waelkens et al. 2011). The early Holocene climatic optimum, and the resulting spread of woodland and maquis vegetation in the region, would have provided ideal conditions for crop cultivation and animal breeding to late Neolithic people, although hunting-gathering was still practiced alongside sedentary agriculture (Vanhaverbeke and Waelkens 2003).

The Late Chalcolithic/Early Bronze Age I (4000-2000 BC) onwards saw an increase in the number of settlements, which now appeared in the more interior basins (Waelkens and Poblome 2011). This increase in the number of settlements was most likely facilitated by increased temperatures during the middle Holocene, which caused intramontane (temporal) lakes and wetlands to dry, increasing the amount of land available for agriculture (Vanhaverbeke and Waelkens 2003; Vermoere 2004), as well as developments in agriculture (Vanhaverbeke and Waelkens 2003). During the Early Brone Age II, farming settlements of the hüyük type also appear. The distribution of these hüyüks throughout the study area, each controlling an individual valley, is seen as an indication that the region may have been divided into territories to some degree during this period (Waelkens, 2000; Vanhaverbeke and Waelkens 2003).

These settlements disappeared again towards the end of the Early Bronze age II. Throughout Anatolia, sites were abandoned or destroyed around 2300/2200 BC. The Middle and Late Bronze Ages are hardly defined, little archaeological and historical information being available for the study area for the period until c. 800 BC (Duru 2008). However, recent survey results revealed the existence of settlements dating back from the 9th-8th century BC, indicating that the decrease in human presence during this period was not as absolute as previously assumed (Poblome pers. comm.; Waelkens pers. comm.).

During the Iron Age, the number of settlements in the study area increases again. These settlements included major settlements within large agricultural plains, permanently occupied mountain sites or fortified “kales" overlooking large swathes of territory with adjoining settlement areas, and agricultural sites along the Düğer

and Burdur Rivers (Waelkens 1995; Waelkens et al. 1997; Vanhaverbeke et al 2011b; Waelkens and Poblome 2011). From the tenth to the seventh century AD, the Phrygians settled in central Anatolia, their influence extending to the borders of what would later become the Territory of Sagalassos. They built a sizable city on a peninsula in a salt lake to the southwest of the Burdur valley. The Persian period (546-333 BC) saw the development of proto-urban sites, and the conquest of the city of Sagalassos by Alexander the Great in 333 BC onward increased the process of Hellenisation, which already started during the preceding Persian period (Waelkens and Poblome 2011). This period also showed a further increase in the number of settlements, as well as a diversification in settlement types (Vanhaverbeke and Waelkens 2003). While some settlements continued to be located on defendable hilltop locations, a denser settlement pattern concentrated in the planes, started to emerge from the 2nd century BC onwards.

The Roman Imperial period (25 BC - AD 300) was one of unparalleled prosperity for the study area. Human impact increased almost immediately after the onset of the Roman Imperial period in the wider region, Galatia showing a drastic increase in cereal cultivation (Mitchell 2007). The fertile land in the study area allowed for a surplus production of grain and olives while the presence of clay beds allowed for the development of an industrial production of high quality table ware known as Sagalassos Red Slip Ware (SRSW) in the city of Sagalassos, the economic and political centre of the area. The construction of a road system, creating a link with Pisidian Antioch and the Pampylian ports (the *Via Sebastè*), and the relatively peaceful conditions of the Pax Romana allowed for trade to flourish. The intensive agriculture of this period put the landscape under maximum pressure (Vanhaverbeke and Waelkens, 2003) and erosion of the hillsides was at its most intense during this period (Six 2004; Dusar et al. in press). The number of settlements increased further, appearing on fertile, flat areas and showing a variety in form and function, while the city of Sagalassos continued to expand (Vanhaverbeke and Waelkens 2003; Vanhaverbeke et al. 2007, 2009, 2011a).

While the region continued to be relatively prosperous throughout the late Imperial Roman (AD 300-450/75) and the first half of the early Byzantine period (AD 450/75-602/20), signs of a changing relationship between the city of Sagalassos and the territory under its control emerged. Sagalassos started to decrease in importance as a regional centre of trade and industry, as the result of changing political practices and increased external threats. The Late Roman Imperial period saw the abolition of the classical system of municipal organisation. The subsequent system, where the financial burdens of being part of the council of a city became ever greater, led to the emergence of a new provincial ruling class consisting of ex members of the provincial administration, who were exempt from taxes because of their earlier services. This ruling class was under direct control of the provincial governor and their attachment to the city and interest in maintaining the infrastructure and appearance of that city declined. The result was a decrease in the authority and importance of cities in organizing and ruling the surrounding region (Haldon 1990; Liebeschuetz 2001; Gregory 2010).

From the middle of the 5th century AD onwards, the number of smaller settlements on the fertile plains decreased in favour of larger, better protected villages located near water sources on strategic, defendable locations such as hill tops (Vanhaverbeke et al. 2004, 2007, 2009, 2011a). This process of nucleation corresponds with an increased level of self-reliance of these settlements, rural sites becoming increasingly involved in economic activities previously confined to Sagalassos itself (Poblome et al. 2000; Degryse et al. 2003; Vanhaverbeke and Waelkens 2003). At the same time the (sub)urban area of Sagalassos seems to become increasingly rural (Vanhaverbeke et al. 2011a; Fuller et al. Submitted). Nevertheless, evidence indicates that the countryside within the study area, as well as the city of Sagalassos itself remained relatively prosperous. Between the mid 5th and the first quarter of the 6th century AD, numerous buildings in the city of Sagalassos suffered severe damage. Part of this damage may have been caused by a heavy earthquake which occurred at the beginning of the 6th century AD, but other damage seems to be older (Waelkens and Poblome 2011). However, archaeological evidence shows that measures were taken to repair the damage to the city and major renovation works took place during the second quarter of the 6th century AD. The gradual decline of the city of Sagalassos it thought to have taken place from the mid 6th century onwards, caused by multiple factors such as the continuing political and military instability, and the Justinian Plague of 541 AD (Gregory 2010). Another heavy earthquake, estimated to have taken place between 602 and 620 AD, devastated the city (De Cupere et al. 2009; Waelkens and Poblome 2011). Some repair attempts were undertaken, but the city never recovered. After the earthquake, Sagalassos continued to exist as a large rural village (Waelkens and Poblome 2011).

From the mid 7th century AD onwards, the number of settlements appeared to decrease considerably, although it may well be that sites dating from this period are underrepresented due to the survey methods used in the past (Vanhaverbeke et al. 2009). The nature of the settlements within the study area changed from sizable settlements on defendable locations to small rural sites (Vanhaverbeke and Waelkens. 2003; Vanhaverbeke et al. 2009).
At present, archaeological evidence concerning the settlement pattern and land use of the study area remains limited for the period from the 7th century AD to the modern day. Recent archaeological evidence indicates that Sagalassos had been inhabited until the 13th century. The large rural village, which covered most of the area once occupied by the city, existed at least until the 7th century. This large settlement was then succeeded by a number of individual hamlets. One of these hamlets, on the location of the former temple of Hadrian and Antonius Pius, was fortified (Vanhaverbeke et al. 2009; Vionis et al., 2009a, b; Waelkens and Poblome 2011).
After 1204 AD, the study area came under Selçuk rule as part of the sultanate of Rum (Gregory, 2010). Although amount of data concerning the settlement pattern in the study area is limited for this period, the construction of a hamam (bath house) and keravansaray (a roadside inn, built along important trade routes) in the village of Ağlasun, below the site of Sagalassos, implies a relatively peaceful continuation of human presence within the study area, despite the apparent violent destruction of the fortified site located on Alexander's hill, in the close vicinity of the site of Sagalassos (Poblome and Taloen 2005; Vionis et al. 2010). Vanhaverbeke and Waelkens (2003) indicate how the more peaceful Ottoman rule saw an increase in the population of the region during the 15th and 16th centuries, although data on the settlement pattern and land use remain scarce.
The 19th century saw a gradual sedentarization of the nomad population. At the same time, the increasing importance of Antalya as a harbour, the construction of better roads and the introduction of a railway system with Burdur and Isparta as stations, expanded the possibilities for the export of products produced within the study area. These changes coincided with an intensification of agriculture and a shift to a more concentrated settlement pattern. Most provincial and local centres date to this period.
An overview of the amount and location of archaeological sites within the study area is displayed in Fig. 1.6, while an overview of the historical periods determined for the sample site is displayed in Table 1.3.

1.5.5. The Sagalassos Archaeological Research Project

From the 14th century onward, the remnants of ancient Sagalassos, once the main political and economical centre of the region, lay forgotten by all except the local population. Several individual European travellers had visited the site of the ruins since the 18th century AD (e.g. Paul Lucas in 1706, the reverend F.V.J Arundell in 1824, W.J. Hamilton in 1842), and a first survey was organized by the Polish count K. Lanckoronski in AD 1884 and 1885, producing the first map of the site. However, no systematic exploration was performed until the second half of the 20th century AD.
From 1985 onward, the British Pisidia Survey project, started in 1982 by S. Mitchell (then University College, Swansea, UK), began a systematic exploration of the ruins. This initial short survey was followed by 4 additional campaigns from 1986 to 1989 in collaboration with Marc Waelkens. A rescue excavation was undertaken in 1989 by Marc Waelkens, in collaboration with S. Başer, director of the Museum of Burdur. The following year the excavations at Sagalassos became a Belgian project, led by Marc Waelkens.
From the outset in 1990 onwards, the archaeological research project at Sagalassos intended to break with the traditions of classical archaeology by using a holistic approach, where all aspects of the environment and daily life in antiquity is documented by sampling and studying the preserved material evidence, regardless of its nature (e.g. Waelkens et al. 1999). The aim is to not only describe what happened, but also why things changed the way that they did. This was in contrast to the main trend of classical archaeology, with its focus on civic monuments and the more representative aspects of archaeology, such as sculptures and other works of art. From 1993 onwards, the disciplines involved with the Sagalassos research project came to include an array of natural sciences, including archaeozoology (De Cupere et al. 2009; Fuller et al. submitted), archaeobotany (Baeten et al. in press), chemistry (Kimpe et al. 2001), geology and geography (Paulissen et al. 1993; Poesen et al 1995; Muchez et al. 2003; Sintubin et al. 2003; Dusar et al. in press), palynology (Vermoere et al. 2002a, b; Kaniewski et al. 2007a,b) or combinations thereof (Viaene et al. 1993; Arndt et al. 2003; Degryse and Waelkens 2008; Romanus et al. 2009; Kaptijn et al. Submitted). Over ten different disciplines have worked or continued to work for the research project. The combined efforts of all specialities

involved in the Sagalassos project, working both in Sagalassos itself, as well as in the surrounding landscape, provide valuable information, helping to reconstruct the palaeoeconomy and palaeoecology of the city and its territory (Waelkens et al. 1997). In 2007, the Centre for Archaeological Sciences was established, which aims to support archaeological research projects with its expertise in the fields of exact science and engineering.
The current palynological research forms part of this interdisciplinary project, the research results will not only shed new light on vegetation change, climate change and human impact for SW Turkey as a whole, but they will also help to further the understanding of the development of the rural areas of the territory of Sagalassos and the relationship between the city and its territory in the currently under-researched time interval from the 7th to the 20th century AD. At the same time, the research results from other disciplines active within the Sagalassos Archaeological Research Project may aid the proper interpretation of the palynological data.

Table 1.3. Overview of the start and end dates of archaeological and historical periods, based on Waelkens and Poblome (2011). These dates apply specifically to the territory of Sagalassos and dates may differ from similar overviews covering larger areas.

Date (BC-AD)	Period	Notes
AD 1922 - present	Turkish republic	
AD 1481 - 1922	Ottoman period	
AD 1243 - 1481	Beylik period	Although the Ottoman empire existed since the 14th century AD, the study area is added to the empire in AD 1481.
AD 1204 - 1243	Selçuk period	The territory of Sagalassos falls under Selçuk rule since AD 1204. The late Byzantine period does not occur here.
AD 867 - 1204	Mid Byzantine period	
AD 450/75 - 876	Early Byzantine period/Dark Ages	In the territory of Sagalassos, the Byzantine Dark Ages are considered to start in AD 602/20, the estimated date of the earthquake that destroyed the city.
AD 300 – 450/75	Late Roman period	
25 BC - AD 300	Roman Imperial period	In 25 BC, the city becomes part of the Roman Empire and subsequently thrives during the reign of Emperor Augustus (emperor from 27 BC-AD 14)
333 - 25 BC	Classical period (Hellenistic)	The city of Sagalassos is conquored by Alexander the Great in 333 BC.
546 - 333 BC	Classical period (Persian: Achaemenid)	In 546 BC, the city and its territory was conquored by the Persian Empire, after which it underwent a process of "Hellenisation".
690 - 546 BC	Archaic period (Lydian)	
750 - 690 BC	Archaic period (Phrygian)	
1200 - 750 BC	Early Iron Age	
1650 - 1200 BC	Late Bronze Age	
2000 - 1650 BC	Middle Bronze Age	
3000 - 2000 BC	Early Bronze Age	
4000 - 3000 BC	Late Chalcolithic	
5500 - 4000 BC	Middle Chalcolithic	
6000 - 5500 BC	Late Neolithic/Early Chalcolithic	
7000 - 6000 BC	Ceramic Neolithic	
9600 - 7000 BC	Aceramic Neolithic	

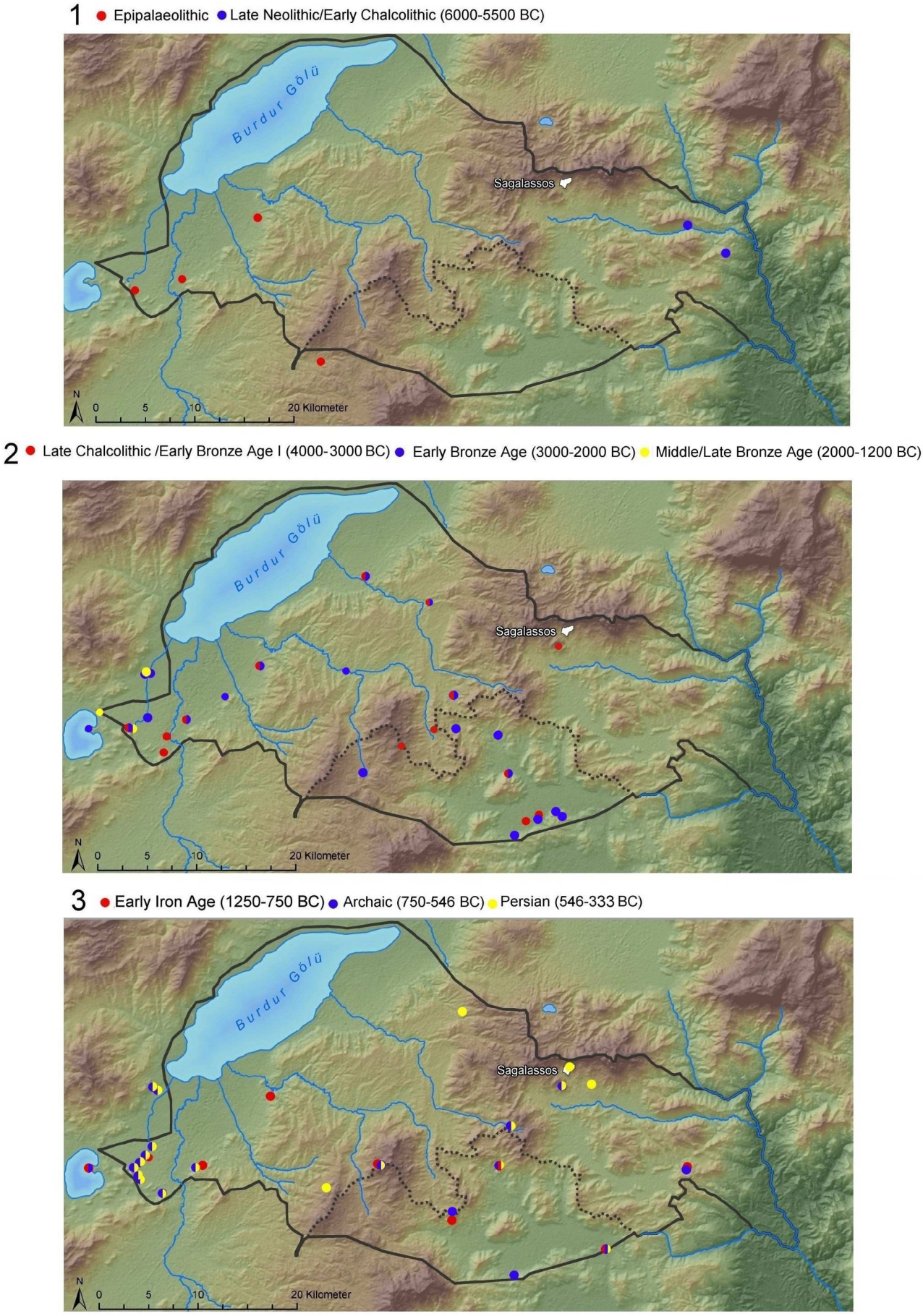


Fig. 1.6a. An overview of the number and location of archaeological sites located within the territory of Sagalassos. The dating of the time intervals is based on Waelkens and Poblome (2011). It must be noted that most of the data on these maps are based in extensive surveys, with a focus on the Burdur valley. Their contents may therefore be considered tentative and especially map number 3 may be biased towards the southern Burdur valley.

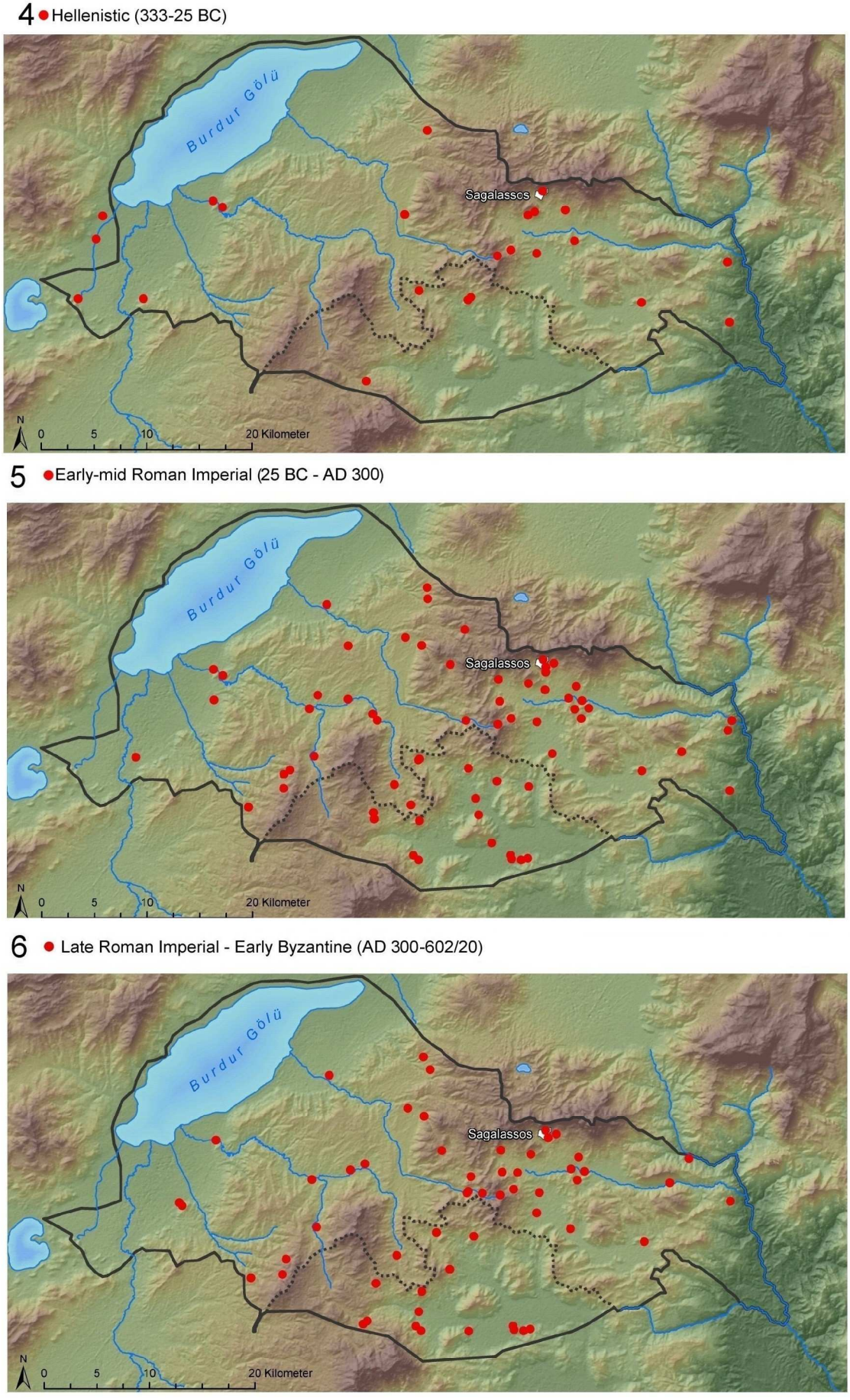
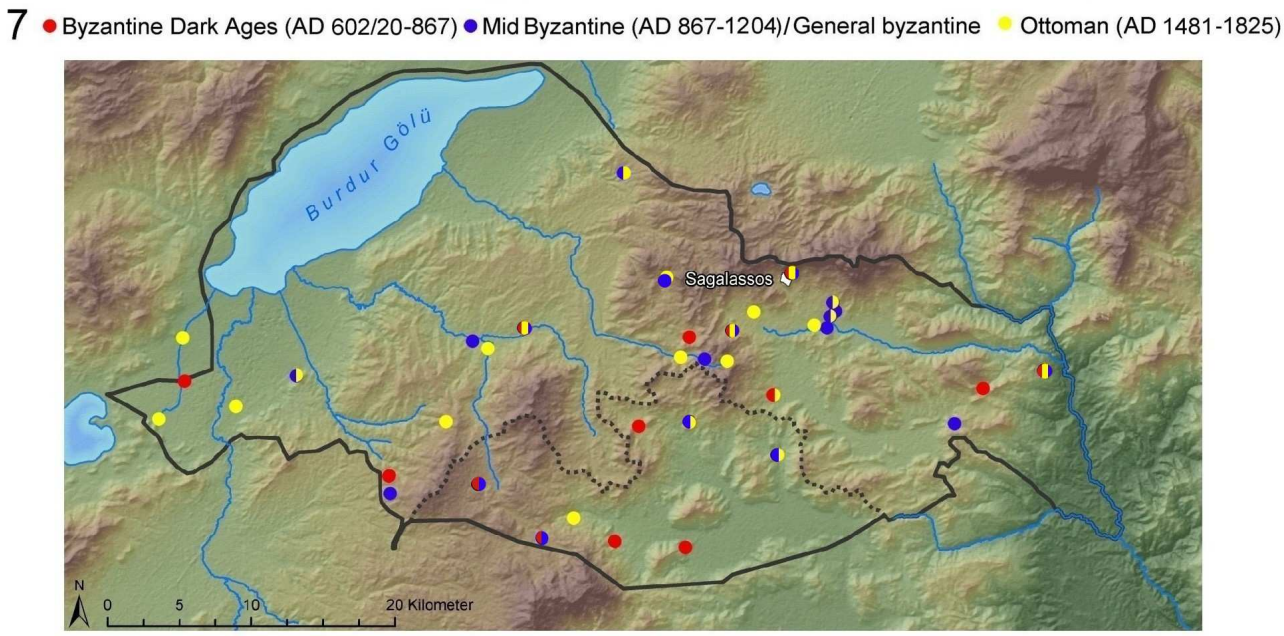


Fig. 1.6b. Same as 1.6a



Maps 1-6 based on:

Vanhaverbeke and Waelkens (2003)
Vanhaverbeke et al. (2011b)
Waelkens et al. (2011)

Map 7 based on:

Vanhaverbeke et al. (2009)

Fig. 1.6c. Same as 1.6a

Chapter 2

Vegetation dynamics in the territory of Sagalassos from the Early Holocene to the mid 7th century AD: a state of the art

This chapter is based on/adapted from:

Bakker J, Paulissen E, Kaniewski D, De Laet V, Verstraeten G, Waelkens M (2011a) Man, vegetation and climate during the Holocene in the Territory of Sagalassos, Western Taurus mountains, SW Turkey. Vegetation History and Archeobotany DOI 10.1007/s00334-011-0312-4

2.1. Introduction

The previous palynological research carried out in the territory of Sagalassos has revealed detailed information concerning important periods of change in vegetation, climate and human impact for the last eight millennia (Vermoere et al. 2000, 2002a, b; Vermoere 2004; Kaniewski et al. 2007a, b).
Palaeoecological research was first attempted in the territory of Sagalassos in the year 1992. Two cores were collected from the seasonal lake of Canaklı and analyzed by Prof. Dr. Sytze Bottema, Ing. Henk Woldring, and Prof. Dr. Hendrik Reinder Reinders. Dr. Marleen Vermoere extensively studied vegetation change through time for a period spanning the entirety of the Holocene, but with a special focus on the Beyşehir Occupation phase (BO Phase). Her work mapped important periods of climatic change, human impact and vegetation for the last eight millennia and tried to link the vegetation evolution with the settlement history of the territory of Sagalassos (Vermoere *et al*., 2000, 2002a, 2002b). Other work included research into the relationship between pollen rain and vegetation, and the analysis of pollen data from several travertine deposits, as well as locations within the ruins of the city of Sagalassos (e.g. Vermoere 1996; Vermoere 2004).
Prof. Dr. David Kaniewski has worked on a palaeoecological reconstruction based on two cores drilled within a former marsh near the Bereket basin. His findings resulted in three articles (Kaniewski et al. 2007a, 2007b, 2008a). A high-resolution overview of vegetation change was presented spanning the period from the fourth century BC to the present. Unfortunately problems with the chronology of the top part of the record resulted in the record being unreliable for the period from seventh century AD until the present. Additionally, the present and past human impact on Mediterranean ecosystems was investigated and fire impact and post-fire regeneration respectively was analyzed.
This chapter presents a comprehensive overview of vegetation change in the territory of Sagalassos during the Holocene. Results from past palaeoecological research in the territory of Sagalassos have been coupled to current research concerning vegetation and climate change throughout the Eastern Mediterranean region, assessing the past research results in light of more recent insights into their subject matter.

2.2. Study areas

Palynological data have been collected from a number of locations within the territory of Sagalassos. An overview of the locations of sites where usable palynological records were collected is given in Fig.2.1. The work of Bottema and Woldring (1995) and Vermoere (2004) concerning the palynological research performed on material collected in the seasonal lake of Canaklı is not referred to in this chapter as these cores are not supported by a chronological framework. The short sections from the travertines and ruins of Sagalassos analyzed by Vermoere (2004) only cover a very short time period, have a very limited chronological framework, and/or have a very low sampling resolution. These pollen records are therefore of limited use for creating an extensive overview of regional vegetation change through time, and will also not be included in this overview. This overview will focus on pollen data collected in the Ağlasun Çay valley, and the Gravgaz and Bereket basins. It will cover the time period from the 8th millennium BC to the mid 7th century AD.

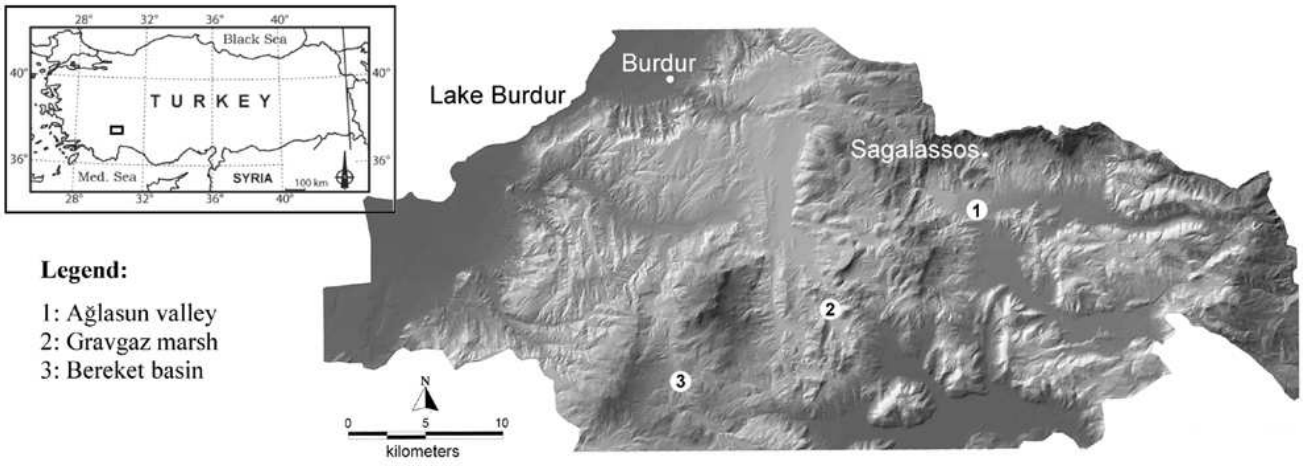


Fig. 2.1. A map of the territory of Sagalassos indicating the locations of the three sample sites: Ağlasun valley, Gravgaz marsh, and the Bereket basin.

2.3. Methods

This chapter discusses the pollen and, where available, charcoal data obtained from these three locations. Table 2.1 provides an overview of the time period captured within the records used for this section and shows the number of radiocarbon dates upon which chronological framework is based. Summary percentage pollen diagrams of the six records described here are given in Figs. 2.2 and 2.3. All chronologies are based on accelerator mass spectrometer (AMS) radiocarbon dates on above-ground plant material. The individual radiocarbon dates upon which the chronological frameworks of the previous research is based, are presented in Table 2.2.

Where possible, the radiocarbon ages B.P. have been (re)calibrated using the IntCal09 calibration curve with the Calib Rev 5.0.1 software (Reimer et al. 2009) and recalculated to calendar ages BC/AD For all cores, an age-depth model was constructed based on interpolated ages between adjacent pairs of AMS dates.

As all dates in calendar ages mentioned in the text are the results of inter- or extrapolations based upon the original AMS dates, there is a certain degree of uncertainty concerning their precision, especially considering the very low number of radiocarbon dates in some of the older pollen records. Therefore, all dates mentioned in the text are rounded to centuries in order to prevent a false idea of accuracy.

The following sections present an overview of vegetation change through time and a discussion on the interpretation of these vegetation changes. These descriptions and discussions have been subdivided into three time periods, each corresponding with several cultural periods distinguished for the study area (Table 1.3; Waelkens and Poblome 2011).

Table 2.1. An overview of the main characteristics of all the records from the three locations within the territory of Sagalassos.

Site	Core	First published in	Depth (cm)	*n* samples	Oldest sample (^{14}C BP)	*n* radiocarbon dates	Estimated start of BO-Phase (^{14}C BP)	Estimated end of BO-Phase (^{14}C BP)
Ağlasun	Core 6	Vermoere 2004	1,000	39	8760	5	3940*	2040*
	Core 12	Vermoere 2004	800	60	7640	5	2800	1010
	Core 13	Vermoere 2004	834	68	7840	2	2650	1250
Bereket	BKT1/2	Kaniewski et al. 2007a, b, 2008	800	207	3260	11	2200	1580
Gravgaz	G96	Vermoere et al. 2002b	800	43	2600	3	2270	1270
	G99	Vermoere et al. 2002b	770	120	2540	6	2280	1480

* early date may be a result of a dating error or of the presence of a hiatus in the pollen record

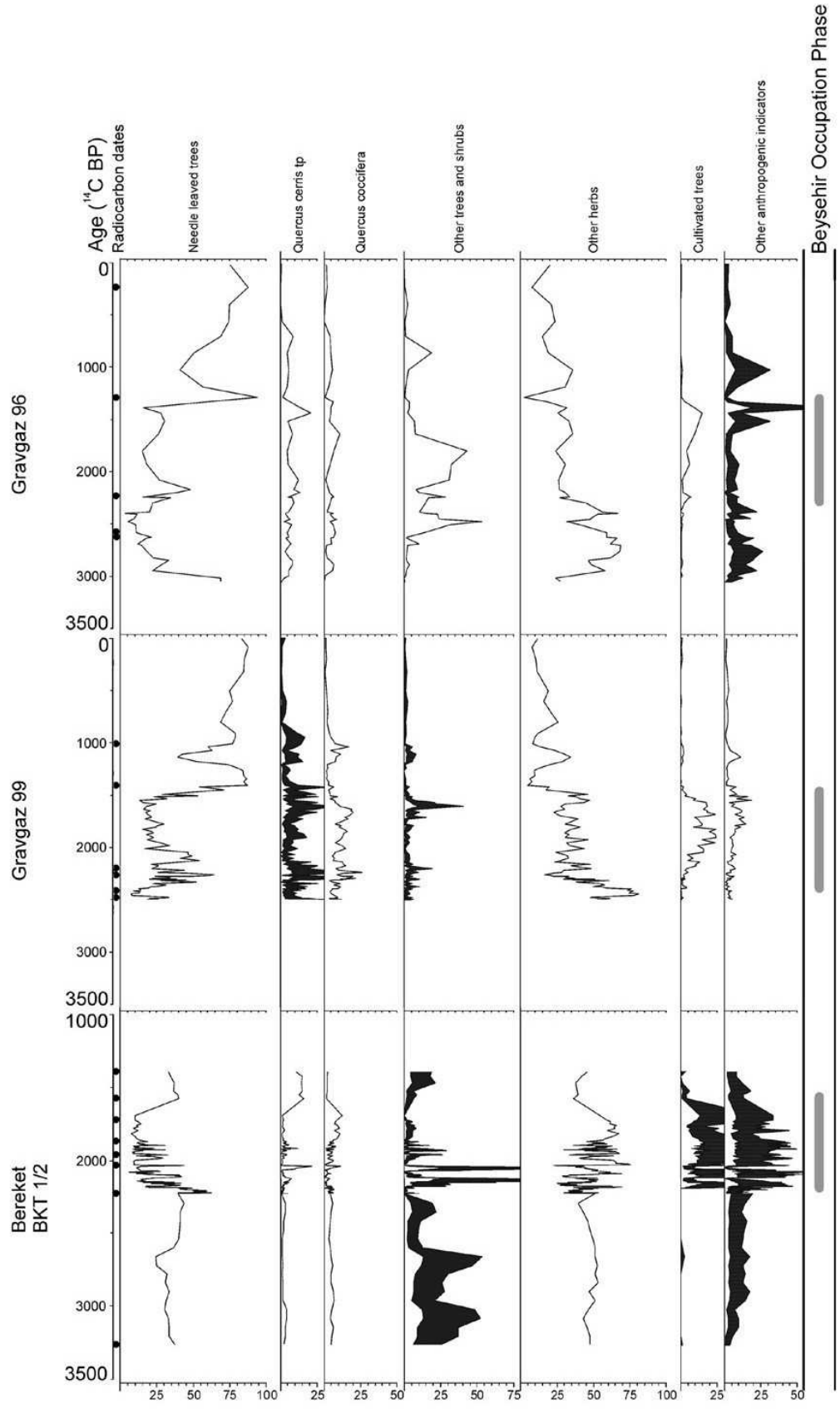


Fig. 2.2. Summery percentage pollen diagrams of the records from Gravgaz and Bereket analyzed by Vermoere et al. (2002a, b) and Kaniewski et al. (2007a, b), displayed along a time axis. The vertical grey bar indicates the part of the diagram corresponding with the BO-Phase. Black dots along the time axis indicate the radiocarbon dates for that record.

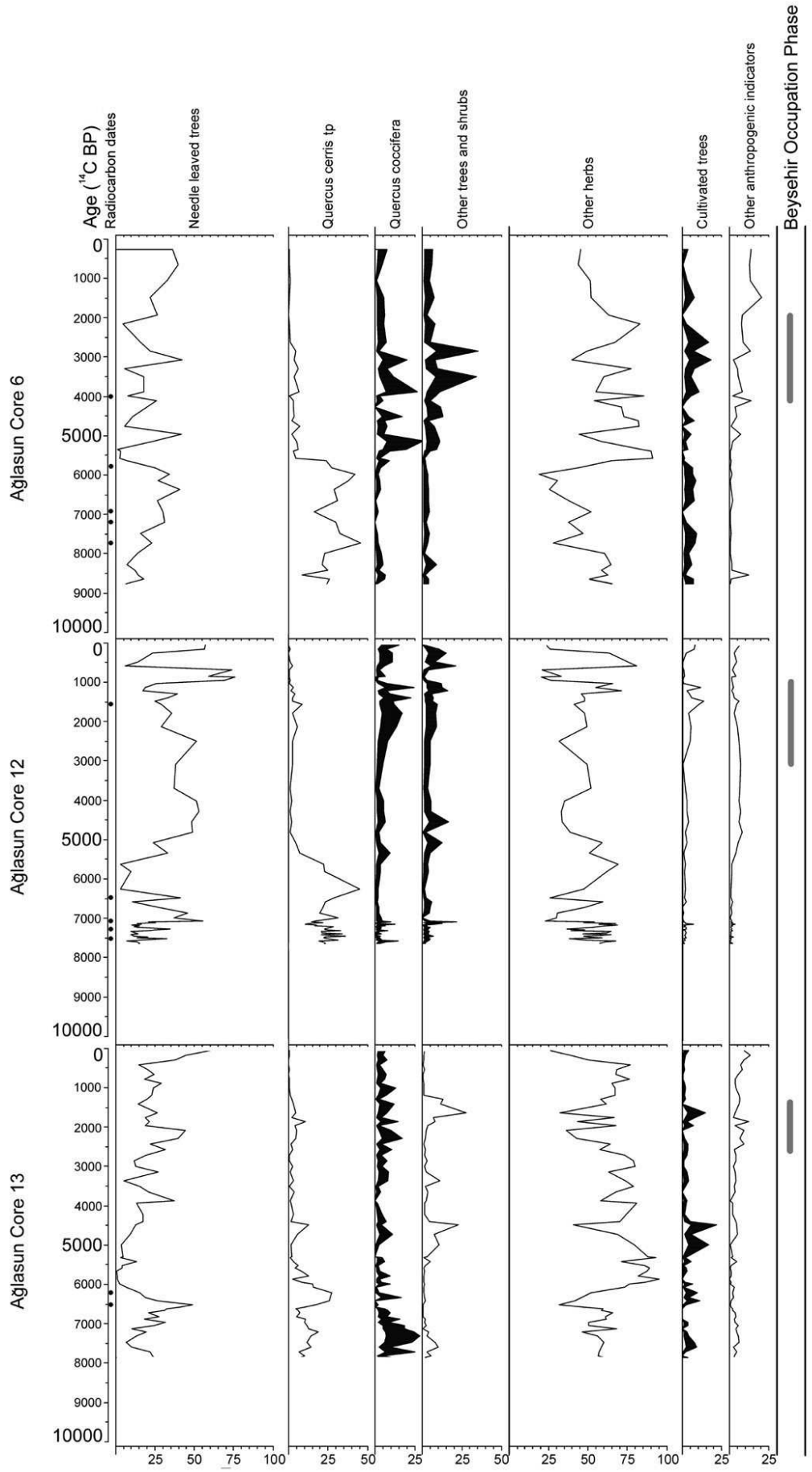


Fig. 2.3. Summery percentage pollen diagrams of the records from Ağlasun, displayed along a time axis (Vermoere et al., 2004). The vertical grey bar indicates the part of the diagram corresponding with the BO-Phase. Black dots along the time axis indicate the radiocarbon dates for that record.

Table 2.2. A list of all AMS 14C ages used in the pollen records discussed in this chapter.

Sample number	Depth	Dated material	Radiocarbon age (^{14}C BP)
Ağlasun core 6 (Vermoere 2004)			
GrN-26341	314	Bulk peat sample	3990 +/- 80
GrN-26342	650	Bulk peat sample	5730 +/- 110
GrN-26343	813	Bulk peat sample	6910 +/- 60
GrN-26344	833	Bulk peat sample	7220 +/- 60
GrN-26345	889	Bulk peat sample	7730 +/- 60
Ağlasun core 12 (Vermoere 2004)			
OS-33145	158	Terrestrial macroremains	1580 +/- 30
OS-33146	422.5-427.5	Bulk peat sample	6530 +/- 45
GrN-26691	474-476.5	Bulk peat sample	7080 +/- 90
GrN-26692	638.5-640	Bulk peat sample	7310 +/- 100
OS-33147	745-746.5	Bulk peat sample	7530 +/- 35
GrN-19428	757	Woody material	7410 +/- 50
Ağlasun core 13 (Vermoere 2004)			
GrN-26346	269-275.5	Bulk peat sample	6330 +/- 60
GrN-26347	594-600.5	Bulk peat sample	6510 +/- 85
Gravgaz G96 (Vermoere et al. 2002a,b)			
GrA-19721	35.5-38	Bulk peat sample	200 +/- 60
GrA-19876	35.5-38	Bulk peat sample	180 +/- 45
GrA-19878	223-226.5	Bulk peat sample	1280 +/- 50
UtC-6738	300	Bulk peat sample	1460 +/- 90
GrA-19892	283-284	Bulk peat sample	2240 +/- 50
UtC-6739	583	Terrestrial macroremains	2495 +/- 40
UtC-6741	770	Terrestrial macroremains	2480 +/- 120
Gravgaz G99 (Vermoere et al. 2002a,b)			
GrA-19895	99.5	Bulk peat sample	1010 +/- 50
OS-25651	161	Terrestrial macroremains	1410 +/- 55
Beta-142070	419-422	Bulk peat sample	2220 +/- 50
Beta-142069	443-446	Bulk peat sample	2270 +/- 50
OS-25652	579	Terrestrial macroremains	2400 +/- 45
OS-25653	752	Terrestrial macroremains	2400 +/- 50
Beta-142073	752-756	Terrestrial macroremains	2520 +/- 40
Bereket BKT 1/2 (Kaniewski et al. 2007a,b)			
Beta-213848	85.5	Terrestrial macroremains	107.6 +/- 0.9 pMC
Beta-213849	103	Terrestrial macroremains	104.7 +/- 0.4 pMC
Beta-223548	157	Terrestrial macroremains	1390 +/- 60
Beta-210929	197.5	Terrestrial macroremains	1580 +/- 40
Beta-210926	203.5	Terrestrial macroremains	1710 +/- 40
Beta-210927	286	Terrestrial macroremains	1870 +/- 40
Beta-193788	470	Terrestrial macroremains	1970 +/- 40
Beta-193789	610	Terrestrial macroremains	2140 +/- 40
Beta-210931	729	Terrestrial macroremains	2370 +/- 40
Beta-213851	783	Terrestrial macroremains	2230 +/- 40
Beta-210930	800	Terrestrial macroremains	3260 +/- 190

This approach was chosen in order to make the text as a whole more readable and to present a chronological historical framework with which the timing of the natural or anthropogenic changes in vegetation can be compared. The start and end dates given for these periods are indicative and should by no means be interpreted as indicating absolute boundaries between distinct phases in vegetation development unless explicitly stated otherwise.

Anthropogenic activity in the pollen record is assessed by studying the primary and secondary anthropogenic indicator species as determined for the region by Bottema and Woldring (1990) and Behre (1990). The primary anthropogenic indicators encountered in the pollen diagrams presented in this dissertation are all cultivated tree species. The most important of these are *Olea europaea* (olive), *Juglans regia* (walnut) and *Castanea sativa* (chestnut). *Fraxinus ornus* (manna ash) is also considered a primary anthropogenic indicator

by van Zeist et al. (1975), as it was probably cultivated in ancient times for the sugary extract from the sap this tree produces. *Vitis vinifera* (grapevine) and *Prunus* are also classic primary anthropogenic indicators, although they are very rare in the pollen spectra analysed for the present dissertation. However, it must be noted that *Vitis* and *Prunus* pollen are not transported over very large distances, and their pollen percentage values remain low, even within a vineyard (Turner and Brown, 2004). Secondary anthropogenic indicators are plant taxa which are not cultivated, but are favoured in one way or another by the presence of human activity.
Examples of secondary anthropogenic indicators are *Plantago lanceolata*, *Rumex acetosella*, *Sanguisorba minor*, *Polygonium aviculare* and *Polygonium cognatum*. The status of *Artemisia* as a secondary anthropogenic indicator (by o.a. Bottema and Woldring, 1990) is debatable. While it frequently occurs as pioneer vegetation in disturbed places or abandoned fields, several species of *Artemisia* are also typical for the steppe vegetation in central Anatolia. Tables 2.3 and 2.4 provide an overview of the most important/indicative pollen taxa encountered in the territory of Sagalassos, and some auto-ecological data for each species.
Establishment of meadow steppe on land previously occupied by forest or agriculture is seen as an indication of pastoralism. The interpretation of Cerealia type pollen percentages requires special attention. While in northern European pollen records, the presence of Cerealia type pollen can be seen as proof of cereal cultivation in the vicinity of a sample site, they need not always represent cereal cultivation when encountered in Middle Eastern pollen records, especially when occurring in very low numbers. A number of wild grasses occurring in the Middle East, for instance *Hordeum spontaneum* and *Aegilops squarrosa* also produce Cerealia type pollen. Some of these species (e.g. *Secale anatolicum*) occur at the borders of cultivated fields and may be considered a secondary anthropogenic indicator (Zohary, 1971), but this is not the case for all such grasses. Furthermore, cereals produce relatively little pollen, which is also not transported over large distances, meaning that an absence of cereal pollen may not indicate an absence of cereal cultivation in the wider area around the site of a pollen core.

2.4. Overview of vegetation change per time period

2.4.1. The Neolithic (c. 9600-6000 BC)

Data on the early Holocene landscape and the first signs of human impact on the vegetation are available from three cores drilled in the Ağlasun Çay valley. Vegetation was already very diverse during the 8th millennium BC, all of the vegetation units currently found in the region being already present at the time, although in different proportions. All cores record very high amounts of deciduous oak pollen while *Pinus* pollen remains consistently high throughout this period. This period is also noted for the presence of low amounts of *Pistacia* pollen.
The more local vegetation indicated by the pollen data, is dependent on the location of each core. The presence of several wetland pollen types such as Cyperaceae, *Typha* and *Dryopteris* indicate wet conditions on the valley bottom. The presence of open *Quercus coccifera* woodland is recorded for the higher areas surrounding the valley floor. *Juniperus* is also well represented during this period, percentage values being highest in cores from the bottom of the valley.
All cores record the presence of Cerealia type pollen but other primary or secondary anthropogenic indicators are very sparse or absent during this period. Low amounts of *Olea europaea* are also recorded in all cores.

2.4.2. The Late Neolithic/Early Chalcolithic until the Late Bronze Age (c. 6000-1200 BC)

The pollen record of Ağlasun Çay valley shows a striking reduction of deciduous oak *and Pistacia* between c. 5300-4300 BC. *Pinu*s pollen remained an important component of the pollen record. The decrease in deciduous oak is immediately followed by an increase in secondary anthropogenic indicators (*Plantago lanceolata, Polygonum aviculare, Polygonum cognatum*). The increase of *Juglans* following the decline in deciduous oak, and the appearance of *Elaeagnus angustifolia* since c. 2500-2600 BC, points towards the introduction of arboriculture. Finally, while Cerealia-type pollen was already present in one of the three cores from the Ağlasun Çay valley, the amount in the other two cores increases rapidly at the time of the deforestation.
Locally, wetland indicators (Cyperaceae, *Sparganium*, *Typha*) lose importance or disappear completely during the 5th millennium BC.

Table 2.3a. An overview of the most important/indicative tree and shrub taxa encountered in the territory of Sagalassos, and some auto-ecological data for each species. Based on table Vermoere (2004), as well as various written sources mentioned in the table.

Pollen type	Species	Present-day altitude preferences	Temperature requirements	Precipitation requirements	Other habitat requirements	Indicative value
Pinus spp.	*Pinus nigra*	1000-1800 m (Davis, 1965-'88)	Demands lower temperatures than Pinus brutia (Zohary, 1973)	Occurs in humid, subhumid, and semi-arid zones	Calcereous rocky slopes (Browicz, 1982-'97; Fontaine et al, 2007)	Can survive surface fires. Will readily and quickly colonize cleared/destroyed spaces when no grazing is present. Will eventually form secondary climax vegetation.
Pinus spp.	*Pinus brutia*	0-1200m (Davis, 1965-'88). Occurs no higher than 1400 m ASL in the territory of Sagalassos (Fontaine et al., 2007)	Can tolerate high temperatures	Drought tolerant (Fontaine et al., 2007)	Calcereous rocky slopes (Browicz, 1982-'97; Fontaine et al, 2007). Light demanding pioneer tree (Fontaine et al., 2007)	Will quickly colonize cleared/destroyed places. Especially quick recolonizer after fires.
Cedrus libani	*Cedrus libani*	1000-1800 m (Davis, 1965-'88)	Min. temp. coldest month = -2℃ (Peyron et al., 1998)	Resistant to dryness (Le Houérou, 1981)	Calcereous soils	Forms part of the secondary climax vegetation in the territory of Sagalassos. Establishes itself in already present *Pinus* forest (Fontaine et al., 2007)
Abies cilicica	*Abies cilicica*	1000-2000 m (Davis, 1965-'88)	Cold resistant (Aussenac, 2002; Fontaine et al., 2007)	Requires a high degree of humidity (Aussenac, 2002)	Requires moist soil (Browicz, 1982-'97)	Forms part of the secondary climax vegetation in the territory of Sagalassos. Establishes itself in already present *Pinus* forest (Fontaine et al., 2007)
Acer	O.a. *Acer sempervirens*	300-1700 m (Browicz, 1982-'97)	No data	Dry tolerant	Occurring on dry, sunny hillsides	Indicator of open deciduous woodland.
Alnus	O.a. *Alnus orientalis*	No data	No data	No data	Humid places, river valleys, stream sides (Browicz, 1982-'97)	Indicator of moist riparian woodlands on the valley floor
Betula	O.a. *Betula pendula*	up to 3050 m (Browicz, 1982-'97)	Mean minimum temperature of the coldest month between -30ºC and 10ºC (Maliouchenko et al., 2007)	Annual precipitation values ranging from 350 to 1800 mm (Maliouchenko et al.,2007)	Can grow on poor soils (Browicz, 1982-'97)	May be an early successional pioneer species. May also appear as part of a deciduous woodland/forest.
Castanea sativa	Castanea sativa	0-1700 m (Browicz, 1982-'97)	Min. temp. coldest month = -2℃ (Peyron et al., 1998)	Over 600 mm (Browicz, 1982-'97)	Fertile, deep and well drained soil (Browicz, 1982-'97)	May be a cultivated species, although it will also occur in the wild, appearing in the pollen spectrum, but reaching only low percentages.
Fraxinus ornus	*Fraxinus ornus*	600-2300 m (Davis, 1965-'88)	Min. temp. coldest month = -2℃ (Peyron et al., 1998)	Drought tolerant (Browicz, 1982-'97)	Rocky limestone slopes (Davis, 1965-'88)	Usually seen as a cultivated due to the sugary extract obtained from the sap of the tree (van Zeist et al., 1975)
Fraxinus tp	O.a. Fraxinus angustifolia	500-2000 m (FRAXIGEN, 2005)	No data	400-800 mm (FRAXIGEN, 2005)	Rocky, moist soils. Associated with lakes and wetlands.	Indicative of riparian woodland on the valley floor. *F. ornus* may be a cultivated tree as its sap could be harvested.
Juglans regia	*Juglans regia*	0-1550 m (Davis, 1965-'88)	Min. temp. coldest month = -2℃ (Peyron et al., 1998)	No data	Rich, moist and deep soils on mountain slopes and in valleys (Browicz, 1982-'97)	May be a cultivated species, although it will also occur in the wild, appearing in the pollen spectrum, but reaching only low percentages.

Table 2.3b. Idem to 2.3a

Pollen type	Species	Present-day altitude preferences	Temperature requirements	Precipitation requirements	Other habitat requirements	Indicative value
Juniperus excelsa/J. oxycedrus	*Juniperus excelsa*	300-2300 m (Davis, 1965-'88)	Cold resistant (Aussenac, 2002; Fontaine et al., 2007). Min. temp. coldest month = -35℃ (Peyron et al., 1998).	Requires a high degree of humidity (Aussenac, 2002)	Sunny, stony slopes (Browicz, 1982-'97)	Often forms the tree line in the Taurus mountains (Davis, 1965-'88). Also often found as a part of the pine forest or as a pure *Juniperus* woodland/forest. (Over)grazing may stimulate the esteblishment of woody shrubs, including Juniper (Asouti and Hather, 2001).
Juniperus excelsa/J. oxycedrus	*Juniperus oxycedrus*	0-1300 m (Davis, 1965-'88)	Dry tolerant. Resistant to warmth. Min. temp. coldest month = -35℃ (Peyron et al., 1998).	Drought tolerant (Browicz, 1982-'97)	Sunny and stony places (Browicz, 1982-'97), maquis, oak shrubland and pine forests (Davis, 1965-'88).	Invasive and weedy tree species in degraded arboreal plant communities (Zohary, 1973). May increase when landscape is subjected to (over)grazing.
Olea europaea	*Olea europaea*	50-750 m (Davis, 1965-'88)	Min. temp. coldest month = 5℃ (Peyron et al., 1998). Sensitive to low temperatures. Winter temperatures below -10℃ may severely damage the tree.	Characteristic for summer-dry regions. Does not tolerate prolonged and fierce drought.	Stony, calcareous soils, dry slopes (Browicz, 1982-'97)	Cultivated species. Indicator of the BO Phase. Finds of Olive pollen at locations above its current range are an indicator of warmer-than-present climatic conditions.
Pistacia	O.a. *Pistacia atlantica*	Variable 0-1500 for *P. vera* (Davis, 1965-'88), and 900-2500 for P. atlantica (Behboodi, 2003).	Can withstand warm summer temperatures	Can withstand very dry conditions (Browicz, 1982-'97)	Light demanding. Calcareous soils (Seigue, 1990; Davis, 1965-'88)	*Pistacia* may be a cultivar, although cultivation is not observed in the present landscape around Sagalassos. *Pistacia* was a common component of the deciduous climax forest vegetation before the onset of human impact in the territory.
Platanus	*Platanus orientalis*	0-1300 m (Browicz, 1982-'97)	No data	No data	Rich, wet soils on river banks, along streams (Browicz, 1982-'97)	Indicative of riparian woodland on the valley floor.
Populus	*Populus alba or Populus nigra*	No data	No data	No data	Deciduous woodland, near rivers (Davis, 1965-'88)	Indicative of riparian woodland on the valley floor. Modern-day *Populus* trees are all recently cultivated species.
Quercus cerris tp	*Quercus cerris*	0-2500 m (Davis, 1965-'88)	Resistant to cold winters (Seigue, 1990)	P = 800 - 1200 mm (Le Houérou, 1981)	Relatively deep calcereous soils (Seigue, 1990)	*Quercus cerris* pollen type may also be indicative of other deciduous oak species, but *Q. cerris* remains the most important of these. Part of the original pre-human impact vegetation of the region. May be an early colonizer after abandonment of the landscape. Prefers moist conditions.
Quercus coccifera	*Quercus coccifera*	0-1500 m (Davis, 1965-'88)	Min. temp. coldest month = 5℃ (Peyron et al., 1998)	P = 400 - 1200 mm (Le Houérou, 1981)	Will grow on unfavourable, calcereous soils (Pons and Quezel, 1985; Le Houérou, 1981).	*Q. coccifera* forests were maintained during Hellenistic times as grazing grounds for pigs. After the BO-Phase they were prone to be grazed by goats and sheep, stunting their growth limiting reproduction. Presence of *Q. coccifera* may be an indicator of grazing. Found generally as a part of a (degraded) maquis vegetation.

Table 2.3c. Idem to 2.3a

Pollen type	Species	Present-day altitude preferences	Temperature requirements	Precipitation requirements	Other habitat requirements	Indicative value
Salix	Multiple species of *Salix*	No data	No data	No data	Generally found in or on the edges of marshes, on streamsides, river banks, and river beds. Light demanding.	Indicative of riparian woodland on the valley floor.
Ulex	*Ulex europaeus*	630-2220 m	No data	No data	Seedlings often found at sites with some bare ground. Following fire seed germination leads to high densities of seedlings. Often found on site of former forests (Gaynor and MacCarter, 1981).	Requires disturbance, such as fire or large grazing herbivores, for establishment. Absent from arable and wetland habitats.
Vitis vinifera	*Vitis vinifera*	No data	Min. temp. coldest month = -2℃ (Peyron et al., 1998)	Tolerates humid conditions (Zohary and Hopf, 1994)	Cultivated and naturalized near arable land among rocks, in shrubland, along river banks and in damp woods (Davis, 1965-'88)	Cultivated species. Poor pollen producer. Finding *Vitis* pollen in a range of samples may indicate wine cultivation near the sample site. Indicator of BO Phase.

Table 2.4. An overview of the most important/indicative herbaceous taxa encountered in the territory of Sagalassos, and some auto-ecological data for each species-level entry. Based on and expanded from Vermoere (2004), as well as various written sources mentioned in the table.

Pollen type	Species	Altitude preferences	Temperature requirements	Precipitation requirements	Other habitat requirements	Indicative value
Artemisia herba-alba	*Artemisia campestris*	0-1500 m (Davis, 1965-'88)	Cold temperatures (Rossignol-Strick, 1993)	150-300 mm (Rossignol-Strick, 1993)	Light demanding hillsides and sandy places (Davis, 1965-'88)	*Artemisia* pollen may be indicative of high-altitude alpine meadows, its appearance in the pollen spectrum indicating a landscape open enough to allow the transport of pollen from the mountains to the valley floor. However, *Artemisia* also occurs as a ruderal species on agricultural land (Bottema and Woldring, 1990).
Cistus	*O.a. Cistus parviflorus*	No data	Min. temp. coldest month = 5°C (Peyron et al., 1998)	No data	Limestone-garigue (Pils, 2006)	Important early post-fire colonisator. Usually indicative of (degraded)maquis.
Erynchium	*Erynchium campestre*	0-1800 m (Davis, 1965-'88)	No data	No data	Open woodland, stony hillsides, disturbed steppe, fallow fields (Davis, 1965-'88)	Part of an open herbaceous steppe. Indicates overgrazing due to its antipastoral characteristics (Zohary, 1973).
Plantago lanceolata	*Plantago lanceolata*	0-3050 m (Davis, 1965-'88)	No data	No data	Meadows, streamsides, maquis, forest, roadsides, waste places (Davis, 1965,'88)	Indicator of pastoralism (Behre, 1990; Bottema and Woldring, 1990)
Polygonum cognatum	*Polygonum cognatum*	720-3000 m (Davis, 1965-'88)	No data	No data	Roadsides, slopes, cultivated land	Indicator of cultivated land (Davis, 1965-'88)
Polygonum aviculare	*Polygonum aviculare, P. convolvulus, P. equisetiforme*	0-700 m (Davis, 1965-'88)	No data	No data	Shrublands and fields (Davis, 1965-'88)	Ruderals. Weedy species connected with farming (Bottema and Woldring, 1984)
Rumex acetosa/R. acetosella	Rumex acetosa, R. acetosella	No data	No data	No data	Roadsides, slopes, cultivated land	Ruderal. Indicator of agriculture and disturbance
Sanguisorba minor	Sanguisorba minor	0-2100 m (Davis, 1965-'88)	No data	No data	Fields, slopes, forests (Davis, 1965-'88)	Ruderal and indicator of grazing pressure (Le Houérou, 1981)
Asteraceae Cichorioideae/Asteroideae	/	/	/	/	/	Part of herbaceous steppe. Also very dominant on abandoned land. Indicator of warm/dry climates. May achieve prominence in pollen diagrams through selective pollen transport under dry climatic circumstances (Bottema and Woldring, 1984).
Apiaceae	/	/	/	/	/	Widespread. May appear in steppe vegetation, as a ruderal, or in mountain forests.
Caryophyllaceae	/	/	/	/	/	Indicator of cold, open steppe vegetation.
Chenopodiaceae	/	/	/	/	/	Indicative of meadow-steppe.
Ericaceae	/	/	/	/	/	Associated with meadow-steppe in Kaniewski et al. (2007b).
Poaceae	/	/	/	/	/	May be indicative of reeds on marshes, grasses on fields and meadows, or herbaceous steppe
Poacae Cerealia	/	/	/	/	/	Indicative of cultivated cereals. However, cereal-type pollen are also produced by wild relatives of cultivated species. As many of such wild species are still ruderals, Cerealia type pollen may still be seen as a secondary anthropogenic indicator.

2.4.3. Early Iron Age to Roman Imperial Period (c. 1000 BC – 300 AD)

In the Ağlasun Çay valley, the period between 3000 and 2500 ^{14}C BP is mainly indicated by increased percentage values for secondary anthropogenic indicator species (*Plantago lanceolata, Polygonum aviculare, P. cognatum*) and Cerealia type pollen. Cultivated tree species (*Olea europaea, Juglans regia*), usually seen as a main indicator of the BO Phase, are present in the pollen spectrum, but they remain relatively rare throughout the BO-Phase. The pollen data also records an increase in deciduous and evergreen oak pollen.
Around c. 800-500 BC, a short time after the increase in secondary indicator species in the Ağlasun Çay valley, the pollen spectra of Gravgaz indicate a distinct decrease in pine forest, followed by a gradual increase of *Olea*. Such a phenomenon is not recorded for Bereket due to a hiatus in the sediment record (Kaniewski et al. 2007b).
In Gravgaz, the distinct increase in primary and secondary anthropogenic indicators (*Olea europaea, Juglans regia, Fraxinus ornus, Castanea sativa* and *Vitis finifera*), is estimated to have occurred in Gravgaz between 400 and 260 BC. The estimated start of the BO-Phase for Bereket is c. 280 BC. In Bereket, the high resolution record also shows the development of a human-induced shrub-steppe, following a period of intense fire activity.
The pollen records from Ağlasun, Bereket and Gravgaz show an extra increase in anthropogenic indicators during the first century BC, contemporaneous with the start of the Roman Imperial Period in the study area.
Local wetland indicators (*Carex, Apium/Berula* type, *Sparganium*/*Typha angustifolia*) show increased values in all cores during this period. The local pollen signals of Gravgaz reveal wet conditions, in particular high values for *Typha angustifolium/Sparganium* from c. 930-790 BC onwards (Vermoere, 2004). A study of the marsh hydrology using local pollen indicators in the Bereket Basin found evidence of relative dry conditions prior to c. 1520 BC. From 360 BC onward, the basin was subjected to a high sedimentation rate and high moisture availability.

Table 2.5. An overview of the start and end ages of the BO Phase for a selection of pollen records from Turkey.

Location	First published in	Number of radiocarbon dates	Estimated start of BO-Phase (^{14}C BP)	Estimated end of BO-Phase (^{14}C BP)
Beyşehir Gölü I	van Zeist et al., 1975	2	3500	1550
Söğüt Gölü	van Zeist et al., 1975	2	3000	1900
Pinarbaşı	Bottema and Woldring, 1984	2	3000	1100
Köyceğiz Gölü	van Zeist et al., 1975	2	3200	2900
Gölhisar Gölü	Eastwood et al., 1998	8	3000	1300
Ova Gölü	Bottema and Woldring, 1984	2	3538	2672

[a] Early date may be a result of a dating error or of the presence of a hiatus in the pollen record

[b] Date is an estimation. The actual end of the BO Phase was obscured by a hiatus in the pollen record

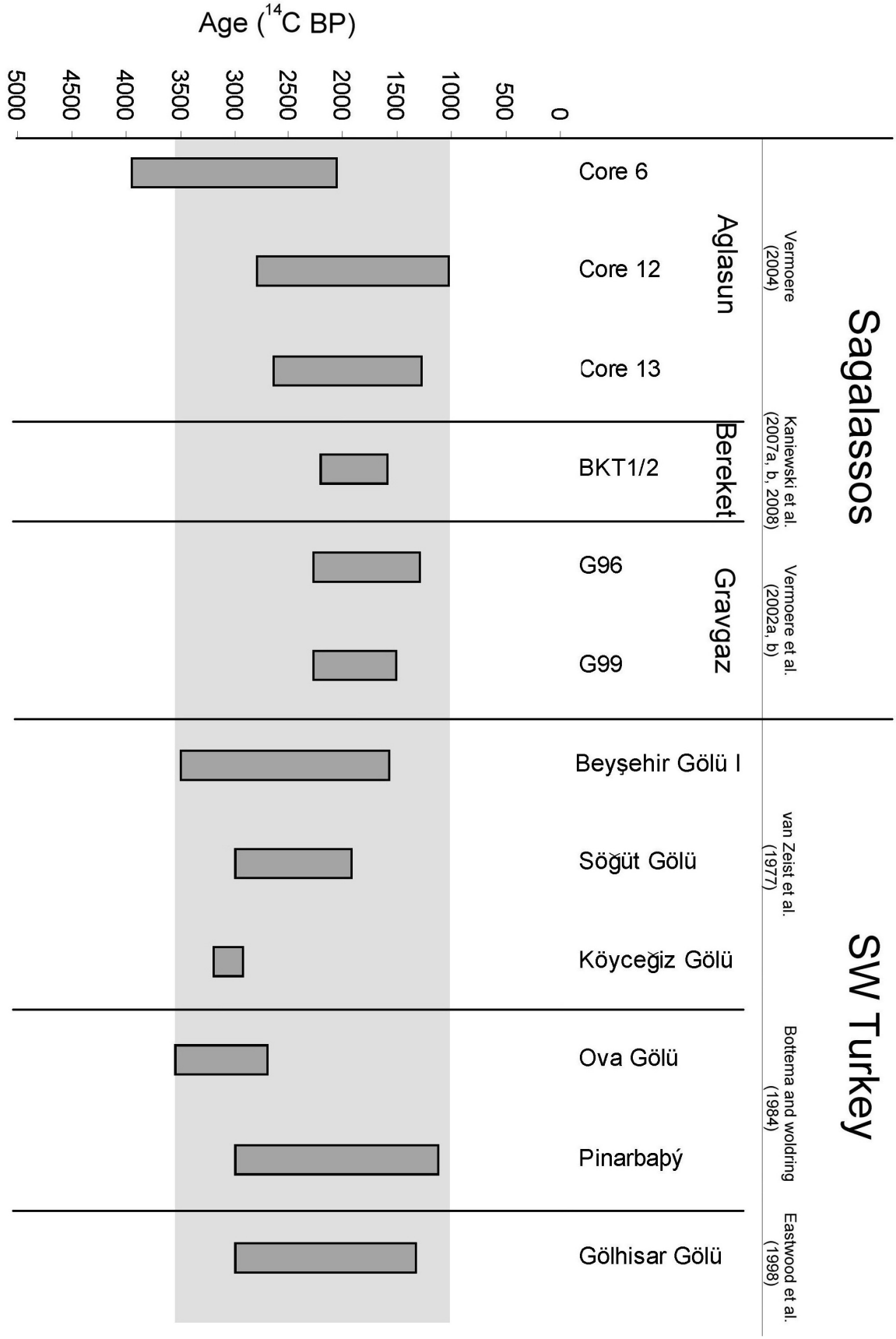


Fig. 2.4. A comparison of the duration of the BO Phase in the various pollen records collected in the territory of Sagalassos (Ağlasun, Bereket, Gravgaz) and elsewhere in SW Turkey. The early start and end of the BO Phase in Ağlasun core 6 is attributed to a dating error. It must also be noted that the chronology of the older cores from the valley of Ağlasun, as well as those of the older cores analyzed by van Zeist et al. (1977) and Bottema and Woldring (1984) are based on a small number of radiocarbon dates. The chronology may therefore be relatively unreliable (see also Tables 2.1 and 2.2).

2.5. Discussion

2.5.1. The Neolithic (c. 9600-6000 BC)

2.5.1.1. Vegetation

Vermoere (2004) asserts that, based on their ecological preferences, coniferous forests most likely occurred on the higher calcareous slopes while extensive deciduous oak woodlands were present on the lower limestone slopes. Evergreen oak and juniper occupied the poor substrates at lower altitudes, where conditions were unfavourable for deciduous oaks. The high values of *Artemisia* may indicate that some residual steppic areas persisted for some time after the end of the Younger Dryas (c. 12800-11500 ^{14}C BP). Deciduous oak/*Pistacia* woodland is thought to have formed the natural climax vegetation in the Ağlasun Çay valley. Deciduous oak/*Pistacia* woodland is an important constituent of the climax vegetation in the Middle East. The rapid rise and subsequent dominance of deciduous oak following the last Ice Age has been reported for Western Anatolia (Knipping et al. 2008; Wille 1995; Jahns 2005; Rossingol-Strick 1999) as well as the wider Middle Eastern region, e.g. Lake Zeribar in western Iran (van Zeist and Bottema 1977), Lake Hula in northern Israel (Baruch and Bottema 1991), lake Xinias in Greece (Bottema 1979) and southwestern Bulgaria (Marinova et al. in press). Yasuda et al. (2000) report the earliest recorded rise of deciduous oak as early as 14,500 years ago in the Ghab valley of Syria.
The most likely constituents for this deciduous oak woodland are Quercus cerris, *Q. ithaburensis* and *Q. infectoria*. Riparian oak groves consisting of these taxa still occur today, restricted to the wetter parts of the region such as Çanakli and Başköy. The combination of deciduous oak and *Pistacia* is observed in Anatolia (van Zeist and Woldring 1978; Roberts et al. 2001; Wick et al. 2003) and throughout the Middle East (e.g. Niklewski and van Zeist 1970; Baruch and Bottema 1991; Bottema 1979). This omnipresence of deciduous oak woodland during the Early Holocene may be explained by the fact that deciduous trees are more tolerant of cold winter temperatures than their evergreen counterparts. During the extremely cold winter conditions that the Middle East experienced during the glacial periods of the Pleistocene, deciduous oak trees would have had a marked advantage over evergreen sclerophylls (Blumler 1991).
Remarkably enough, the only other location where palynological evidence indicates the dominance of deciduous oak woodland in southwest Turkey is Söğüt Gölü (van Zeist et al. 1975), while the Ağlasun Çay valley is the only location in southwest Turkey where the *Pistacia-Quercus* combination is clearly present. This may be a result of the relatively low amount of high resolution palynological records from this region, rather than an actual absence of this type of forest during the Early Holocene.

2.5.1.2. Climate

There is overwhelming evidence of a world-wide Holocene climatic optimum, characterized by increased temperatures, is overwhelming (e.g. Rossignol-Strick 1999; Arz et al. 2003; Davis et al. 2003; Lamy et al 2006; Mächtle et al. 2010; Schmidt et al. 2000). However there is considerable debate concerning whether the climatic regime in the Middle East was relatively wet or dry during the Early Holocene (e.g. Roberts 1983; Roberts and Wright 1993).
The presence of juniper, evergreen oak and olive in the Ağlasun Çay valley indicates mild winter and spring temperatures. While these species are known to be resistant to summer drought, the presence of deciduous oak/pistacia woodlands indicate ample moisture availability throughout the year (Rossignol-Strick 1999). The abundance of Poaceae and wetland pollen types in the Ağlasun Çay valley indicates that the valley floor was relatively moist. Analysis of two short travertine sections in the Ağlasun Çay valley 2 km upstream from the core locations, also indicates travertine formation in a moist environment during the early Holocene (Vermoere 2004).

Unfortunately no other record from the territory of Sagalassos contains data dating back to the early Holocene. It is therefore not possible to study to what extent the exact vegetation, hydrology and topography of the landscape influenced local moisture availability during this period. Moist conditions on the valley floor may be a result of an increase in the number of springs in the proximity of the pollen cores. Even today the total flow of the springs around the site of Sagalassos reaches more than 5 million litres per day (Steegen et al. 2000). Moisture availability may also have been positively influenced by the presence of widespread deciduous woodland (Thompson 1980; Dümenil Gates and Liess 2001; Bonan 2008; Anav et al. 2010).

2.5.1.3. Human occupation

Despite the presence of archaeological sites in the Burdur valley (see chapter 1 and Fig. 1.6), Palynological indications of Neolithic agriculture in the Ağlasun Çay valley are weak. The cores from the Ağlasun Çay valley do record small amounts of Cerealia-type, but it must be noted that in the Eastern Mediterranean, some types of wild grasses, e.g. *Glyceria* and ancestors of cultivated cereals also have Cerealia type pollen (Bottema 1995, see above). Zohary (1971) explains that several wild species of Poaceae which produce Cerealia-type pollen occur frequently on roadsides, (abandoned) fields and cleared maquis and that Cerealia pollen type might therefore still be considered a secondary anthropogenic indicator. Nevertheless, the amounts of classic anthropogenic indicator species remain low, and signs of deforestation are absent. Furthermore, archaeological remains from this period have also not been found in the vicinity of the valley. This indicates that the Cerealia type pollen observed in the core most likely originated from grasses that naturally occur in forest and steppe habitats and that there was no anthropogenic activity in the valley. Furthermore, the presence of peat and detritic travertines in the early Holocene sediments of the Ağlasun Çay valley (Six 2004) may indicate that the valley bottoms were too wet for sustaining agricultural practices. As stated in chapter 1, archaeological finds dating from this period are extremely rare within the study region (Vermeersch et al. 1997, 2000).

2.5.2. The Late Neolithic/Early Chalcolithic until the Late Bronze Age (c. 6000-1200 BC)

2.5.2.1 Vegetation

A decrease or disappearance of the original deciduous oak woodlands occurs in many records throughout the eastern Mediterranean and Middle East, although the estimates for the timing and extent differ between locations by the order of several centuries to over a millennium. In some cases the estimate may be less precise due to a poor chronological framework (e.g. van Zeist et al. 1975). However, this variation in the timing of the deforestation of the deciduous oak woodlands is also present among more recent, better dated records (Eastwood 1999; Fontugne et al 1999; Yasuda et al. 2000; Roberts et al. 2001; Wick et al. 2003; Neumann et al. 2007b; Knipping et al. 2008). In other records, deciduous oak pollen percentage values have remained high until the present day, e.g. Lake Van, Turkey (van Zeist and Woldring 1977), Greece (Willis 1992) and western Iran (van Zeist and Bottema 1977). Because of this, it is unlikely that a single event such as a change in the regional climate, as proposed by Wick et al. (2003), has caused the decrease in deciduous oak. The sedimentological record of the Ağlasun Çay valley indicates that the wetlands on the valley floor had shrunk to a small area around the riverbed between c. 4000 and c. 2500 BC. The notion of a desiccation of the valley floor is supported by the pollen data, indicating that drier local conditions were established during this period. While a link between climate change and the deforestation of the deciduous oak woodlands seems unlikely, the establishment of dry conditions some time afterwards may have hampered the return of the deciduous oak woodlands.

2.5.2.2. Climate

Dry conditions during this period are recorded for the Ağlasun Çay valley as well as Gravgaz marsh (Six 2004; Six et al. 2008b), indicating the presence of a region-wide dry trend. The sedimentological evidence supporting dry conditions may have been an indirect result of the deforestation event, rather than reflecting climatic change. Removal of the deciduous oak woodland from the lower slopes may have resulted in the rapid acceleration of erosion, desiccation of the valley floor and the cessation of peat deposition recorded in the Ağlasun Çay valley (Six 2004). Unfortunately, pollen data for this period from the territory of Sagalassos

is not abundant enough to complement the sedimentological evidence. There is widespread evidence for the occurrence of a period of relative drought following the Holocene climatic optimum (Weiss 1982). The precise start and end dates of this period differ per record. In Gölhisar, also located in the SW Taurus Mountains, a switch from warm and wet to cold and dry climatic conditions occurs at roughly the same time as in the Ağlasun Çay valley; c. 3300 BC (Eastwood et al. 2007). Other records from the Middle East and the Eastern Mediterranean report that this climatic shift occurred earlier. Roberts et al. (2001) show a shift towards a drier hydroclimatic regime between c. 4900 and 4100 BC. Reihl and Marinova (2008) show a distinct hiatus in the settlement pattern in their study area during the same period. Other authors report that a distinct aridification of the region occurred later, around 2000 BC (e.g. Bar-Matthews et al. 1999; von Rad et al. 1999; Stephens et al. 2001; Wick et al. 2003; Triantaphyllou et al. 2009). Additionally, data from the nearby Elmalý basin (Galicki and Doerner 2010) indicates a period of increased moisture availability from c. 4000 to c. 1000 BC, contrasting with the data from Sagalassos and Gölhisar. This difference in timing might be caused by differences in local conditions at the sample sites such as hydrology and topography. It is important to further study this time period in order to properly understand the environmental changes in the territory of Sagalassos and its origins. None of the available records showed any trend that could be linked to the 4.2 and 3.2 Ka BP dry periods (Mayewski et al. 2004).

2.5.2.3. Human occupation

As stated in chapter 1, this period is characterized by an increase in the number of settlements, which also started to appear in the more interior parts of the study site from the late Chalcolithic and Early Bronze Age I periods onwards. Increased human presence in the Ağlasun Çay valley since the 5th millennium BC is supported by an increase in secondary anthropogenic indicators and the introduction and increase of cultivated trees. Although it is not wise to interpret an isolated increase of Cerealia type pollen as a sign of anthropogenic activity, the rise observed during this period coincides with a general rise in anthropogenic activity and may therefore indicate the presence of cereal cultivation in the valley. This increase in anthropogenic activity in the pollen record is also contemporaneous with an increase in settlements in the study area (Chapter 1; Waelkens and Poblome 2011). Even though no archaeological site has been found in the Ağlasun Çay valley dating from this period (Chapter 1, Fig. 1.6), the pollen records indicate that sedentary agriculture was already practiced here. The increase in *Juglans* and secondary anthropogenic indicators in the Ağlasun Çay valley records is unusual as it occurs very early compared to other locations in the Pisidian Lake District (van Zeist et al. 1975; Bottema and Woldring 1984). The abandonment phase observed throughout Anatolia during the early third millennium BC is not visible in the records from the Ağlasun Çay valley, with the exception of a decrease or temporary absence of *Juglans*. This apparent continuation of human impact is in accordance with the very recent discoveries of sites in the study area which remained occupied after the Bronze Age collapse (Poblome pers. comm.; Waelkens pers. comm.).

2.5.3. Early Iron Age to Roman Imperial Period (c. 1000 BC – 300 AD)

The Beyşehir Occupation phase (BO-Phase) is a distinct Late Holocene period of anthropogenic activity which took place throughout the Eastern Mediterranean, roughly between 1500 BC and AD 800 (Chapter 1, Fig. 2.4, Table 2.3). The BO-Phase occurs in all records from the territory of Sagalassos (Figs. 2.2 and 2.3). The start of the BO-Phase as calculated for the Ağlasun Çay valley, at c. 1000-800 BC, is comparable to other records in SW Turkey, such as the well dated Gölhisar record (Eastwood et al. 1998), where the BO Phase starts c. 1250 BC. The start of the BO Phase in the Ağlasun Çay valley is also comparable with the general estimate for the start of the BO Phase in Turkey and Greece, the late second millennium BC (Bottema 1993; Eastwood et al. 1998). One core from the Ağlasun Çay valley gives an estimate of 2480-2350 BC. As this estimate is so old compared to the other estimates from the Ağlasun Çay valley, it is assumed to be the result of a dating error or of the presence of a hiatus in the pollen record after this dated level.
The BO-Phase proper manifests itself later in Bereket and Gravgaz than in Ağlasun. The chronologies of all cores from Ağlasun are based on a small number of radiocarbon dates, mostly from the lower Early Holocene parts of the core. Only one radiocarbon date gives an age that falls within the BO-Phase (Fig. 1.21). While the estimates of the start and end times of the BO-Phase must therefore be treated with caution, the differences between the estimates for Ağlasun and Bereket and Gravgaz are of such a magnitude (approximately half a millennium) that it remains likely that the BO-Phase started earlier in the Ağlasun Çay valley.

2.5.3.1. Vegetation

Although discernable in the pollen spectrum, palynological signs of the BO-Phase are less clear for the Ağlasun Çay valley than for Gravgaz and Bereket, despite being located much closer to the city of Sagalassos itself. Evidence for the presence of the BO-Phase in Ağlasun is based on increased amounts of secondary anthropogenic indicators and the expansion/recovery of oak woodlands, presumably used as grazing grounds for pigs (Vermoere 2004).
A short time after the onset of the BO Phase in the Ağlasun Çay valley, a distinct deforestation event occurred in Gravgaz marsh. This deforestation is estimated to have occurred c. 800-500 BC, and which was followed by a gradual increase in anthropogenic indicators. When the BO Phase manifests itself in Bereket and Gravgaz, it takes the form of a marked increase in multiple important cultivated plant taxa, most notably olive and cereals.

2.5.3.2. Climate

The onset of the BO-Phase in the Eastern Mediterranean has been linked to a change in the climate towards warmer and more humid conditions (van Zeist et al. 1975; Bottema et al. 1986, 1993). More recent palaeoenvironmental research supports this (e.g. Bar-Matthews et al. 1999; von Rad et al. 1999; Schillmann et al. 2002; Lamy et al. 2006; Triantaphyllou et al. 2009).
An increase in moisture availability, coinciding with the perceived start of the BO-Phase in the Eastern Mediterranean was recorded for the Ağlasun Çay valley. The sedimentological data of Gravgaz Marsh reveal that that basin became wetter at approximately the same time, while that period is also characterized by very high sedimentation rates. Six (2004) reports the deposition of ~4.5 metres of pure mineral detritus during a period of no more than 170 years, estimated to occur between the early 10th and mid 8th century BC.
A link between the onset of the BO Phase and the Santorini volcanic eruption during the 16th century BC has also been proposed. The mechanism by which the eruption would influence human activity would be volcanically induced climatic change, and/or indirectly through socio-economic change and resulting population migrations (e.g. Bottema 1993; Eastwood et al. 1998). A tephra layer deposited after the Santorini eruption has been found in a sediment core in Gravgaz (Six 2004; Six et al. 2008 a). However, Six et al (2008a) have found no direct impact of the deposition of the Santorini tephra on the vegetation at Gravgaz. Furthermore, the difference between the estimated date of the Santorini eruption and the start of the BO Phase in the Ağlasun Çay valley as researched by Vermoere (2004) is approximately half a millennium. It is therefore highly unlikely that there is any link between the Santorini eruption and the onset of the BO Phase in the territory of Sagalassos.

2.5.3.3. Human occupation

The differences in estimated start dates of the BO Phase in the various sites within the study area may in part be caused by the imprecise chronology of some of the older records but this notion does not explain all differences between sites. The onset of the BO-Phase in the Ağlasun Çay valley coincides with a wet climatic trend. The deforestation phase observed in Gravgaz may be related to the development of Kapez Kalesi, an important proto-urban site located to the north-east of the marsh. The start of the BO Phase in Gravgaz and Bereket, which occurs slightly later than in Gravgaz, is more likely linked to an increase in anthropogenic activity in the territory of the city of Sagalassos during the Hellenistic period and the development of the city into an influential regional centre.
All palaeoenvironmental records from the territory of Sagalassos show that the increase in human activity that resulted in the BO-Phase pollen signal, also had a major impact on surface processes, the records showing a sharp increase in deposition rates (Six 2004; Kaniewski et al. 2007b; Dusar et al. in press). The charcoal record of Bereket shows a direct link between the occurrence of fires and increases in the sedimentation rate (Kaniewski et al. 2008). While fires could have a natural cause, they could also be anthropogenic in origin, indicating land clearance (Pederson et al. 2005; Power et al. 2006). Turner et al. (2008) concluded that for the Eastern Mediterranean, regional fire activity was mostly controlled by climatically-induced variations in biomass. When the environment was relatively humid, more biomass would be able to accumulate, providing more fuel for fires. Despite increasing human presence during the Holocene, a shift from a climatic- to a

human-driven fire regime would have occurred very recently. The fact that fire activity in Bereket coincided with historical and palynological evidence for a drastic increase in human activity in the region indicates that the situation in Bereket differs from that described by Turner et al. (2008).
All records from the territory of Sagalassos show an additional increase in anthropogenic activity at the start of the Roman Imperial period, which commenced in 25 BC. This period is considered to be the 'golden age' for the region (Vanhaverbeke and Waelkens 2003) and agricultural production intensified throughout the wider region at this time (Donners et al. 2000; Mitchell 2007). The record from Bereket shows intense fire activity at the start of and during the Roman era.

2.6. Conclusions

An overview of the main changes in the vegetation and environmental conditions in the territory of Sagalassos, the main historical periods, and the main climatic periods, supported by records from the Northern Atlantic (Bond et al. 2001), Asia (Gupta et al. 2003), the atmospheric radiocarbon record (Reimer et al. 2004) and the Middle East (Schilman et al. 2001, 2002), is given in Figure 2.5.
The ongoing palaeoenvironmental studies undertaken in the territory of the classical city of Sagalassos have resulted in a detailed overview of vegetation change from the early Holocene to the present. The studies undertaken have resulted in a number of new understandings of the relationship between vegetation, climate and man.
Despite the presence of people in the territory of Sagalassos throughout the Early Holocene, no evidence for agriculture during this time is found in the Ağlasun Çay valley. This may be caused by the fact that the valley floor became too wet for agriculture after the onset of the Holocene climatic optimum. Signs of arboriculture only appeared during the Middle Holocene/Chalcolithic period. A shift in the climate towards drier conditions sometime during the 4th millennium BC may have caused the wetlands in the Ağlasun Çay valley to shrink in size, allowing the land to be used for agriculture and perhaps further drained by man.
The pollen records from Gravgaz and Bereket show that while climatic change as may be a plausible explanation for the onset of the BO Phase at individual locations (such as Ağlasun), but the onset of the BO Phase in general can not be attributed to one single event. The start of the BO Phase in the Ağlasun Çay valley, and the first main increase in anthropogenic activity in Gravgaz are contemporaneous with a shift towards a wetter climate, the start of the BO Phase proper in Bereket and Gravgaz, are not. At these locations, the start of the BO Phase occurs at a later date and is more likely directly connected to the expansion of human activity following the start of the Hellenistic period in the region in the 4th century BC. The start of the Roman Imperial period signals an additional intensification of agriculture.
The fire history of the Bereket basin challenges the notion that man became the driving force behind the fire regime only very late in the Holocene as fires have been mostly anthropogenicaly influenced in Bereket since Hellenistic times.

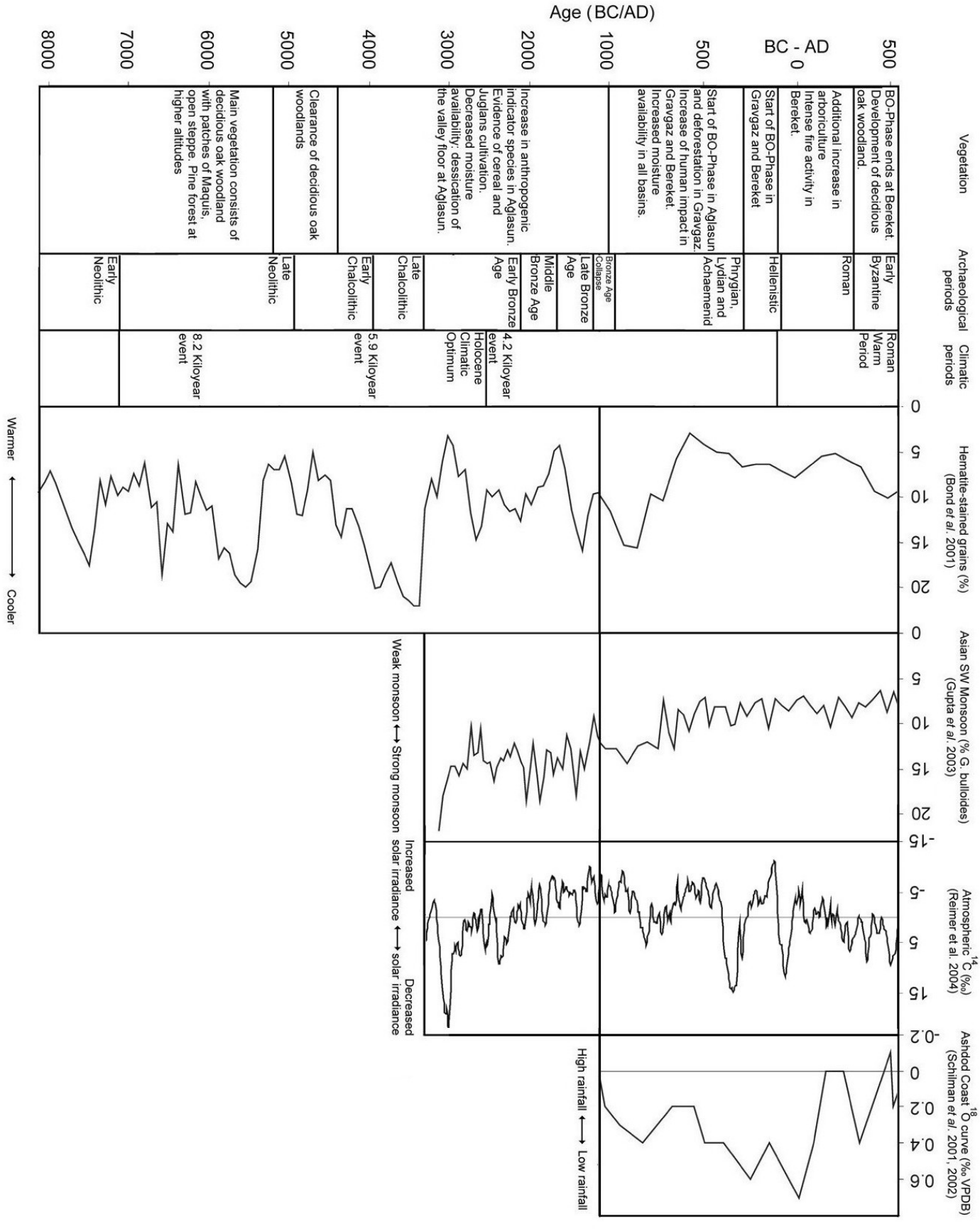


Fig. 2.5. An overview of the main changes in the vegetation and environmental conditions in the territory of Sagalassos, the main historical periods, and the main climatic periods in records from the Northern Atlantic (Bond et al. 2001), Asia (Gupta et al. 2003), the detrended atmospheric radiocarbon record (Reimer et al. 2004) and the Middle East (Schilman et al. 2001, 2002).

Part II: Vegetation, Climate, People, and Fire: New insights into Late Classical and Post-Beysehir Occupation Phase Vegetation Dynamics in the Eastern Mediterranean

Chapter 3

Vegetation change in the territory of Sagalassos (SW Turkey) from the late Roman Imperial period (AD 300) until the present

This chapter is based on/adapted from:

Bakker J, Paulissen E, Kaniewski D, Poblome J, de Laet V, Verstraeten G, Waelkens M (in prep) Climate, People, Fire and Vegetation: New insights into Late Classical and Post-Beysehir Occupation Phase Vegetation Dynamics in the Eastern Mediterranean.

3.1. Introduction

A growing number of studies is available which assess the environmental impact of the rise various major civilisations in the Eastern Mediterranean region, the way the landscape recovered after their demise, and the way changes in the environment such as shifts in precipitation and temperature may have influenced the welfare of a civilisation (van Zeist et al. 1975; Kaniewski et al. 2007b; Neumann et al. 2007a; England et al. 2008; Knipping et al. 2008; Leroy 2010). Such studies may reveal previously unknown episodes of anthropogenic impact on the landscape or reveal new information concerning the occurrence, extent, and impact of climatic change. Palynology is an important tool for revealing which important landscape changes are the results of increased or decreased anthropogenic impact and which are the result of natural environmental change. Research can also reveal how changes in the vegetation may have influenced human presence in a region as well as revealing the way human impact influenced the environment, by observing the occurrence and nature of changes in the vegetation through time. In combination with geomorphic and geological studies, palynology enables the study of the full extent of landscape change caused by anthropogenic or natural environmental change.

However, at present palynological studies in the Eastern Mediterranean mostly focus on important, long-term trends and the main classical civilisations. Relatively little palynological studies cover changes in the landscape which occurred between the end of the High/Mid Roman Imperial period (AD 300) and the present in any detail (e.g. England et al. 2008). Furthermore, the complex cultural history and high ecological diversity in the mountainous regions of the Eastern Mediterranean present a challenge to palaeoecological researchers who work in this region (Bottema and Woldring, 1990; Kaniewski, 2007a; Riehl and Marinova, 2008), and necessitates the availability of data from many different locations in order to compile a reliable reconstruction of vegetation, climatic and anthropogenic change for the Eastern Mediterranean region as a whole. High resolution, well dated palaeoenvironmental records that include a detailed overview of post BO-Phase period vegetation dynamics are still very rare for the Eastern Mediterranean (Schwab et al., 2004; England et al., 2008; Neumann et al., 2007, Kaniewski et al., 2011a, b). For the region of southwest Turkey, such records are completely absent.

This chapter aims to provide the first relatively detailed and precisely dated overview of local and regional vegetation change in SW Turkey during the post-BO Phase period, providing an overview of periods of human impact and abandonment. By studying local pollen and NPP's in addition to changes in sediment characteristics, this chapter aims to reveal the way changes in the regional environment have altered the local environment. Furthermore, a reliable record of local environmental changes, in combination with a critical assessment of changes in pollen concentration and pollen preservation, enables a more reliable interpretation of the pollen signal. The use of multiple pollen records from different locations within the study area, Gravgaz marsh and the Bereket basin, enables a proper distinction between local and regional trends in vegetation change. Both basins are located within a distinctly different physical environment (basin size and shape, altitude, potential climax vegetation, etc.) and have a different history of human occupation (Vanhaverbeke

and Waelkens, 2003; Vanhaverbeke, 2008; Kaptijn et al. submitted). The two records are supported by a chronological framework of 10 and 17 radiocarbon dates for Gravgaz and Bereket respectively, providing a relatively accurate estimate of the age of the pollen samples and sedimentation rates.
This overview will serve as a source of data upon which the numerical analyses of the subsequent chapters are based. The final interpretation of the pollen data and the assessment of the precise roles of both climate and human impact upon the vegetation and of all three of these forces upon one another shall be discussed once all this information is presented. As such, the current chapter will primarily focus on the timing, extent and expression of multi-decennial to multi-centennial changes in vegetation and the local physical environment.

3.2. General description of the study areas

The locations of Gravgaz marsh and the Bereket basin are indicated in Figure 3.1. Both sites have been the subject of earlier palynological investigations (see chapter 2), and a sufficiently thick layer of sediments deposited after the end of the BO Phase was proven to exist on both locations. Unfortunately the geology of the territory of Sagalassos and the requirements for pollen preservation limit the amount of suitable sites for palynological research. The 2008-2011 fieldwork campaigns have not yielded any additional locations which contained useable sediments dating from the post-BO Phase period. At all locations visited during the fieldwork campaigns, sediments either contained no pollen, no datable material, or the sediments deposited during the post-BO Phase period had a thickness of less than 1 m.

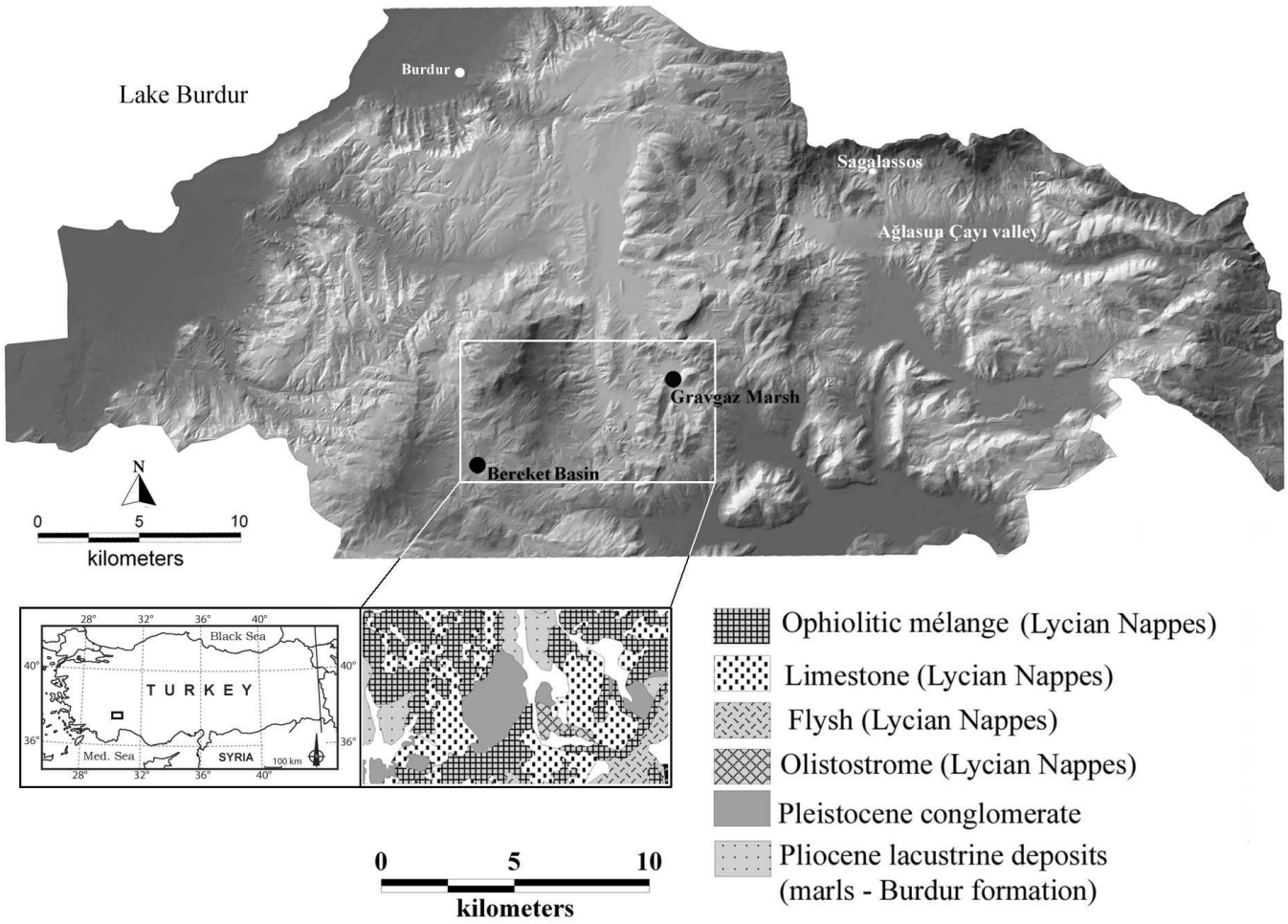


Fig. 3.1. A map of the territory of Sagalassos and the position of the locations of the drill sites in Gravgaz Marsh and the Bereket basin within the territory and Turkey.

3.2.1. Gravgaz Marsh

3.2.1.1. Physical setting

Gravgaz Marsh is located in an intramontane valley at an altitude of 1215m above sea level, 25 km Southwest of Sagalassos. The valley itself can be described as a small-scale endorheic catchment, measuring 11.4 km^2, and lacking external drainage. The topography of the basin is dominated by a wide valley, filled by extensive colluvial deposits (17% of the total catchment area). The area is surrounded by limestone hills. At several locations on the lower slopes, limestone-derived conglomerate (12%) and ophiolite (10.5%) are present (Dusar, 2011).
The marsh itself measures approximately 800 by 350 meters. It is fed by water sources to the west of the marsh. Water flows through the marsh via two streamlets, disappearing in a karstic outflow (Turkish: düden) east of the marsh. Despite the presence of this karstic outflow, sediment export from the basin is assumed to be insignificant. Water levels fluctuate seasonally but have dropped in recent years. While the marsh has been studied previously by Six (2004), Six et al. (2008b) and Vermoere et al. (2000, 2002a, 2002b) but no detailed study of vegetation dynamics during the post BO-Phase period had been attempted. A detailed description of the physical setting of Gravgaz marsh is available in Six (2004).

3.2.1.2. Vegetation

The vegetation on the hills surrounding the marsh is dominated by shrubs of Quercus *coccifera* and to a lesser degree by *Juniperus excelsa* and *J. oxycedrus*. A pine forest is located on the hillsides south-east of the marsh. The land around the marsh is used for the cultivation of cereals and chick peas. Land not used for crop cultivation is grazed by cattle (mainly goats).
The marsh itself is well vegetated and features a patchy vegetation pattern, dominated by *Scirpus lacustris*, in both wetter and dryer parts. The streamlets feature *Carex riparia*, *Typha latifolia* and *Sparganium erectum*. The transitional zone between the fields and the marshlands is characterized by *Alisma plantago/aquatica, A. lanceolata, Butomus umbellatus, Lythrum salicaria, Plantago major, Cirsium arvense* and *Agrostis gigantea.* The other edges are characterized by grasses such as *Lolium perenne* and *Hordeum murinum* (see Figs. 3.2, 3.3).

3.2.1.3. Occupation history

The area around Gravgaz marsh has as of yet never been subjected to an intensive archaeological survey. Nevertheless, an extensive archaeological survey that did include the area around the marsh revealed the presence of a number of sites that were occupied during the late roman and/or Byzantine period (Table 3.1). Descriptions of these sites are given in Waelkens et al. (1997), who asserted that the fertile area around Gravgaz marsh and the nearby Kuzköy district may have been one of the most continuously and densely populated parts of the territory of Sagalassos, from prehistoric to early Byzantine times. Most of the sites located in the vicinity of the marsh contained Roman pottery. A number of the recorded sites (Yüksek Yurt, Haci Hüseyinin Vurulduğu Yeri, Bel Çeşmesi, Elmadabi Mevkii) are assumed to have been involved in agricultural practices in the basin where Gravgaz marsh is located, or in nearby basins. An olive press was found at the nearby site of Kepez Kalesi, which was once the location of a wealthy and sizable, yet still unnamed proto-urban site, nowadays still notable because of its massive fortifications. This find bears testimony to the intensive arboriculture that took place in and near the basin containing Gravgaz marsh during the height of the BO-Phase. The site of Asar Tepesi, assumed to be a sanctuary of some sort, but having also had an industrial function, is considered to date from the late Roman and early Byzantine period. Archaeological remains dating from after the Early Byzantine period have not been recorded, although this may also have been a result of the lack of intensive field surveys in this part of the territory (Fig. 3.4).



Fig. 3.2. A view of Gravgaz marsh from the west. 1: Locations of springs feeding the marsh. 2: The location of the karstic outflow, or Düden. 3: Location of the pollen core. 4: Grain fields. 5: Transition zone between the marsh and agricultural land. 6: Marsh. 7: *Quercus coccifera* shrubland. 8: (location of) open Juniper wood/shrubland.

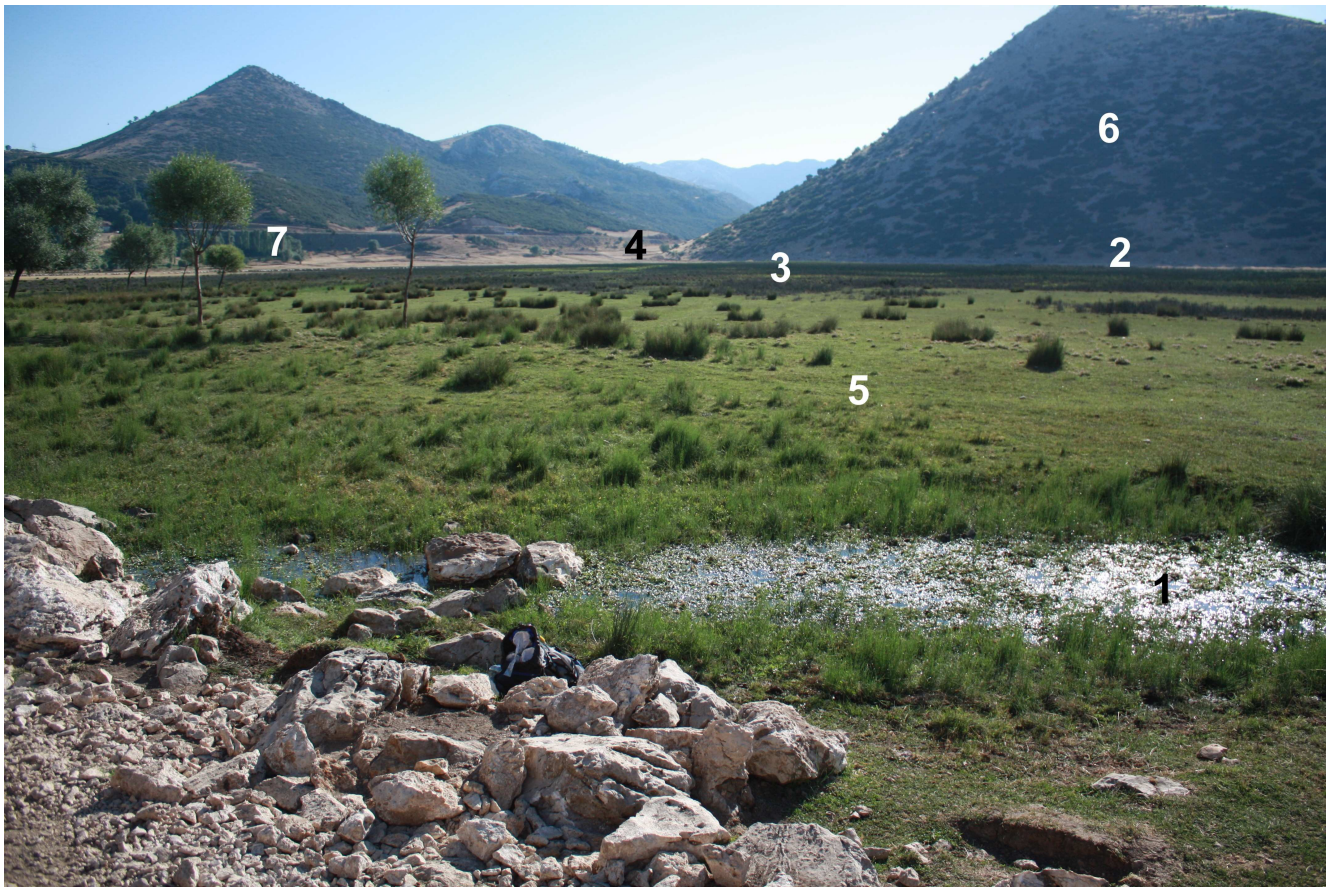


Fig. 3.3. A view of Gravgaz marsh from the south. 1: Locations of springs feeding the marsh. 2: The location of the karstic outflow, or Düden. 3: Marsh 4: Grain fields. 5: Transition zone. 6: *Quercus coccifera* shrubland. 7: Farm and *Populus* plantation



Fig. 3.4. A map of the basin containing Gravgaz marsh, with the sample site indicated (black dot) and an overview of the archaeological sites in the vicinity of Gravgaz marsh (stars).

Table 3.1. An overview of the various archaeological sites in the vicinity of the drill sites in Gravgaz marsh and the Bereket basin.

Near Gravgaz

Archaeological site	Name	Type of site	Occupation period
KAA2	Haci Hüseyin Vurulduğu Yeri	Village site, perhaps involved in farming activities on the valley floor	Late Roman
KAA3	Inönü Taşı	Rock cut tombs	Early-mid Roman
KAA6	Şırşırpınarları	Hillside sanctuary	Late Hellenistic-mid Roman
KAA7	Bel Çeşmesi	Site on strategic location with agricultural function	Late Roman-early Byzantine
KAR1	Asar Tepesi	Sanctuary/industrial function	Late Roman-early Byzantine
KAR2	Kartalpınar	Unknown	Roman
KAR3	Kapez Kalesi	Unnamed sizable proto-urban site	Prehistoric, Hellenistic, early Roman, Ottoman periods
BES1	Yüksek Yurt	Site with possible agricultural function	Chalcolithic-Roman

Near Bereket

Archaeological site	Name	Type of site	Occupation period
Bereket Hüyük	Bereket Hüyük	Hüyük	Early Bronze Age
Kale (not on map. 4.5 km north of drill site)	Kale	Fortified hilltop settlement	Classical/Hellenistic
Kirselik I	Kirselik I	Habitational site	Roman to Early Byzantine (Habitation may have persisted until 12th century)
Kirselik II	Kirselik II	Habitational site	Roman to Early Byzantine
Kavaklik	Kavaklik	Habitational site	Roman to Early Byzantine

3.2.2. Bereket Basin

3.2.2.1. Physical setting

The intramontane Bereket Basin is located at 1410-1430m a.s.l., about 200 m higher and at a distance of c. 11 km SW from Gravgaz marsh. The site is located 300 m downstream of the source of the Aykirdak Deresi, nowadays a canalized river. The basin is surrounded by two mountain ridges. Towards the west lies the Kokayanık Tepe and towards the east lies the Beşparmak Dağları. The affluent valley drains a basin of 6.3 km^2, of which 13% belongs to the flat valley bottom. The slopes are characterized by Lithosols developed on different substrates. 9% developed on old coarse fans (gravels and granules), 5% on marls on basal gravels (Pliocene), 46% on limestone and 27% on ophiolitic melange, containing large amounts of clays (Kaniewski et al., 2007b). The presence of a colluvial fan accumulated in the mouth of the main valley, blocked the drainage in the main valley, and caused the formation of a large marsh in the lowest parts of the bottom of the main valley. This marsh, about 35 ha in size, acted as a depocenter until it was drained in the 1960's.

3.2.2.2. Vegetation

Nowadays the valley floor is mainly used for the cultivation of cereals and chick peas. Other cultivars include *Castanea sativa, Prunus persica, Prunus avium, Beta vulgaris and Juglans regia. Vitis vinifera* occurs sporadically. The overgrazed hillsides are covered by degraded *Juniperus excelsa* woodland in the south-east area, or partially degraded *J. excelsa-Cedrus libani* woodland in the northwest area. Other constituents of these degraded or partially degraded woodlands are *Quercus coccifera* shrubs and *Juniperus oxycedrus*. In the last remaining marshes *Carex riparia, Scirpus lacustris, Typha angustifolia, Sparganium spp.* and *Butomus umbellatus* occur. A low amount of *Salix spp*. and *Fraxinus angustifolia* occurs along the borders of the remaining marshlands, while limited *Populus nigra* cultivation occurs at the southern end. (Figs. 3.5, 3.6). Although this basin has been previously studied by Kaniewski et al. (2007a, 2007b, 2008), the limitations of the chronology for their core BKT1/2 made it impossible to study the vegetation and sediment history from the 7th century onwards in any detail.

3.2.2.3. Occupation history

The Bereket basin was first subjected to an archaeological survey during the 1996 and 1997 survey campaigns (Waelkens et al. 2000a). A more intensive archaeological survey of the basin was conducted in 2008 (Vanhaverbeke et al. 2011b; Kaptijn et al. in prep). The surveys revealed the presence of a hüyuk site in the centre of the basin, indicating that the basin was occupied at the latest from the Early Bronze Age onwards. As with most of the valleys within the study area, the Early Iron Age saw the development of a fortified hilltop settlement, which in this case lay at Kale, c. 4.5 kilometres to the north of the Bereket basin drill site.
Waelkens et al. (2000a) identified the location of a village known as Moatra, which lay on a low hill known as Kirselik and with an excellent view on the main valley bottom to the north. The site is situated south of the modern small village of Bereket. concluded that, based on the artefacts found on and around the site, Moatra must have been a site of some importance that had been occupied from the beginning of the early Imperial period at the latest, until early Byzantine times. This more detailed survey revealed the presence of several sites during the Roman period: Kirselik I, Kirselik II and Kavaklik (Table 3.1). Most likely these were all habitation sites. During the late Roman period, the nature of the relationship between the village sites in the Bereket basin and the city of Sagalassos changed. While the pottery found at the sites in Bereket originated almost exclusively from the Potters' Quarter in the city of Sagalassos, the amount of Sagalassian red slip wares decreased, more and more pottery having been produced in another, as yet unknown, location. This ceramological shift cannot be directly dated by means of absolute dating techniques, only by analogy with pottery from excavated sites. However, the ceramological chronology of Sagalassos that formed the basis of most comparisons is well established and fixed by many radiocarbon dates. Although no specific dates can be given, the shift in dominance between SRSW and RSW will probably have occurred somewhere in the Late Roman period, i.e. 4th or early 5th century AD (Kaptijn et al., submitted).Human presence in the Bereket basin persisted throughout the late Roman Imperial and Early Byzantine period, but only on the location known as Kirselik I. A limited permanent human presence is assumed to have persisted in the basin until the 12th century, based on the tentative dating of several individual pieces of pottery (Fig. 3.7).



Fig. 3.5. A view of the southern end of the Bereket basin, showing the last remaining marshlands. 1: (the location of the) Aykirdak Deresi. 2: *Populus nigra* plantation on the wettest part of the marsh. 3: Modern drainage ditch. 4: The location of the sample site. 5: Mixed *Juniperus/Pinus* forest.



Fig. 3.6. A view of the secondary valley of the Bereket basin from hills south of the main basin, looking towards the north-east. 1: (the location of) the alluvial fan, closing of the valley. 2: Mixed *Juniperus/Pinus* forest. 3: Open *Juniperus oxycedrus* woodland. 4: The Beşparmak Dağları mountain range.

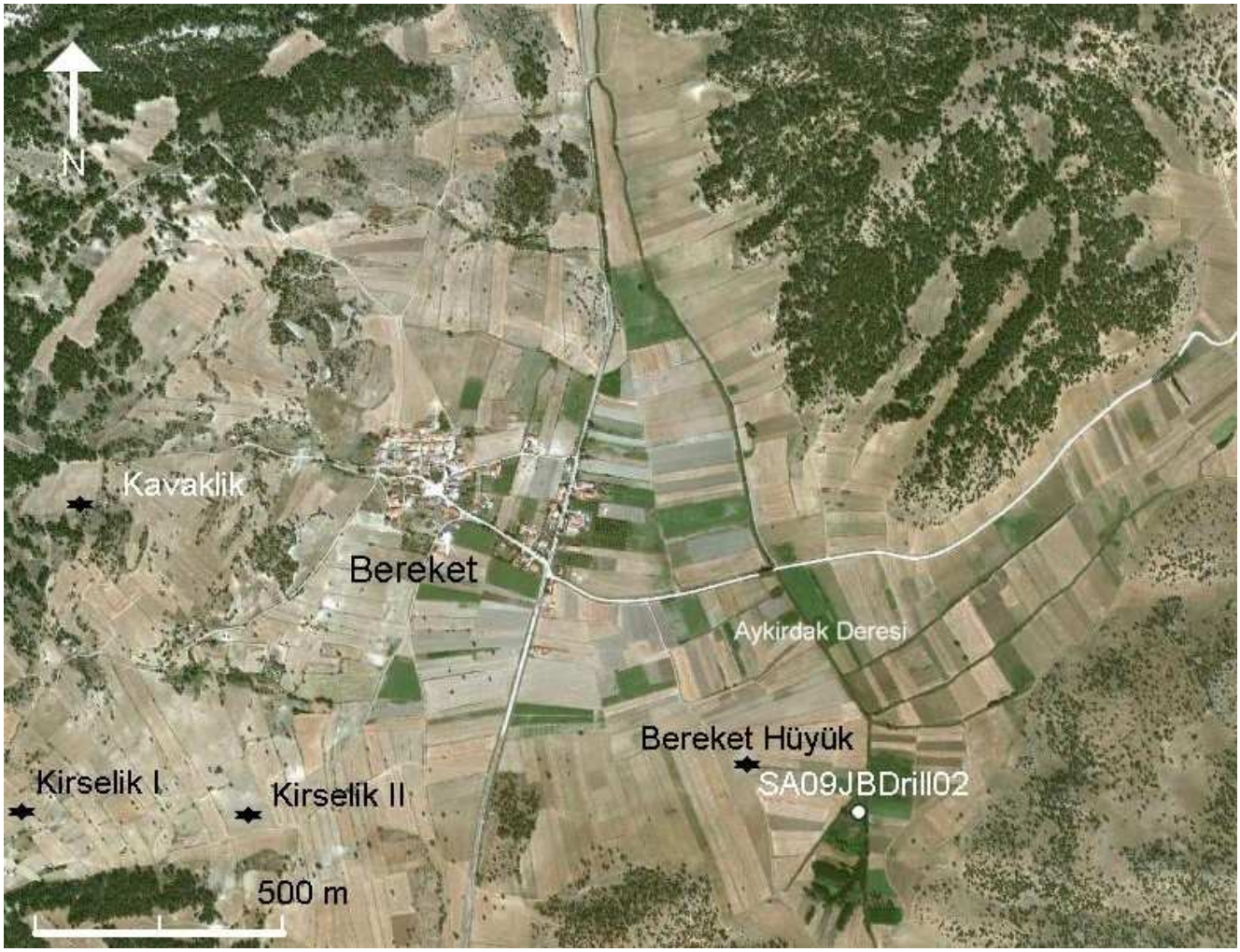


Fig. 3.7. A map of the Bereket basin, with the sample site indicated (black dot) and an overview of the archaeological sites in the vicinity (stars). The fortified Hilltop settlement at Kale is not pictured here.

3.3. Methods

3.3.1. Data collection

The pollen data from Gravgaz marsh originates from the top 3 meters of an 8 meter sediment core (SA06EP1) drilled in 2006 by E. Paulissen and D. Kaniewski, using a Dachnowsky sampler. The sediment core was drilled in the middle of the marsh, where erosion is expected to be minimal (Fig. 3.4). This core is located at 30.403578° E, 37.584248° N. The core had previously been divided into subsamples at regular intervals of 2 cm. These were then placed into Minigrip® bags and stored dry.
The pollen data from Bereket originates from a six meter long sediment core (SA09JBDrill02) drilled in 2009 by J. Bakker, D. Kaniewski, and P. Muchez. The drill site is located near the south bank of the Aykirdak Deresi, a canalized river at the southern border of the former marsh (Fig. 3.7). An Eijkelkamp percussion drill, containing a core sampler with a one meter long PVC sample tube, was used for the collection of the sediment core. This core is located at 30.293076° E, 37.541241° N. The one meter long tubes, as well as the 10 cm long samples originating from the detachable head of the samples, had been stored in a freezer at a temperature of -12 degrees Celsius upon arrival in Belgium. The core was subsequently subdivided into one centimetre thick slices, which were stored refrigerated in Minigrip® bags until they were used for pollen extraction. A portion of the subsamples from core SA09JBDrill02 was used for sediment analysis.

3.3.2. Chronology

The age-depth model for the Gravgaz core is based on ten AMS ^{14}C ages. Seven radiocarbon ages were attained by radiocarbon dating material from the pollencore SA06EP1. Three additional dates were attained by re-calibrating additional radiocarbon dates of core SA00EP03, drilled at the same location and studied by Six (2004) and Six et al. (2008b). The age-depth model for the Bereket core is based on 17 AMS ^{14}C ages.
The ages were calibrated with the IntCal09 calibration curve (Reimer *et al*., 2009), using the BCal calibration program (Buck *et al*. 1999; http://bcal.sheffield.ac.uk). BCal uses Bayesian statistics allowing for the implementation of *a priori* knowledge into the age-depth model, e.g. that ages higher in the core are younger than ages lower in the core. When ages with overlapping calibrated probability distributions occur, BCal produces posterior probability distributions with non-overlapping modes, essentially wiggle-matching the ages to the calibration curve. The Bcal software also provides the option to perform an analysis of possible outliers.
The material used for radiocarbon datings consisted of macroscopic charcoal fragments and terrestrial plant seeds, collected using a 200µm sieve. The material used for the radiocarbon datings on core S100EP3 consisted of soil organics. All ages in the text are given as cal BC/AD and rounded to a decadal level.

3.3.3. Pollen Diagrams

Fossil pollen and NPP's were extracted using an adaptation of the method developed and used by Annemarie Philip of the University of Amsterdam. The exact laboratory techniques are described in appendix 1.
Slides containing the palynomorphs were studied under a 400X and 1250X magnification (using oil immersion) under a Leitz microscope. Identifications of pollen types were performed using Beug (2004), Moore et al. (1991) and Reille (1992). Identifications of NPP's were performed using Kuhry (1997), Pals et al. (1980), van Geel et al. (1981), van Geel et al. (1983), van Geel et al. (1989) and van der Wiel (1983).
The complete pollen and NPP count data are printed in Appendix 2. In order to gain a good overview of vegetation dynamics through time, a minimum amount of 300 - 500 pollen was counted per slide. Pollen and NPP's encountered three times or less, or which obtained a maximum percentage value of 1% are not used in the analysis of vegetation change and not displayed in the pollen diagrams.
Pollen conservation was assessed by summing corroded, degraded, broken and crumpled pollen in a "deterioration assemblage" (Cushing, 1967).
The inability to reach the minimum pollen count can, depending on additional factors, be used as an indicator of poor pollen preservation, or very fast sedimentation rates. Additionally, abrupt changes in pollen concentrations may indicate problems with pollen conservation or indicate changes in the sedimentation rate or the presence of a hiatus in the pollen record. Pollen concentration is expressed in pollen/gram, rather than pollen/cm^3 as the Gravgaz soil samples were kept dry. As a result it was therefore impossible to consistently take sub-samples of a certain volume as most samples first needed to be crushed with a hammer (see also appendix 1).
Percentage diagrams were constructed using TILIA and TGVIEW software (Grimm, 1991). Pollen data were expressed as relative frequencies (%) of the pollen sum, which includes herbaceous land plants, trees and shrubs. The notion of Dusar (2011) that most erodable sediments had been deposited in the basin well before the onset of the BO Phase, supports this notion as it implies that the rocky, grassless slopes around the marsh had this form for most of the time period included in the present study.
Fieldwork during the 2008-11 survey seasons confirmed the notion of Vermoere (2004) that wild Poaceae only occur on the marsh at Gravgaz, while being mostly absent on the surrounding hill slopes. The pollen dispersal capabilities of Poaceae appear to be limited for the research area (see chapter 6), and the relevant source area of Poaceae pollen resembles that of other smaller herbaceous taxa. However, the limited occurrence of Poa on the hill slopes surrounding the marsh indicates that a background pollen signal would be absent or at least limited, prompting the decision to treat Poaceae as a local plant taxa for Gravgaz marsh.
There were no indications to assume that Poaceae only occurred on the sample site in the Bereket basin, Poaceae being more abundant on the low and smooth hills immediately surrounding the sample site in Bereket, than on the steeper, rocky slopes surrounding Gravgaz marsh.

3.3.4. Sediment analysis

Sediment data for core SA06EP1, from Gravgaz marsh, is available in the PhD dissertation of Simon Six (2004), who provides a detailed analysis of sediment core SA00EP3, located within 1 meter from the location of core SA06EPB1. The sediment analysis of core SA09JBDrill02, from the Bereket basin, was performed by E. Paulissen, who also greatly aided the interpretation of the sediment data.
The sedimentological parameters discussed in the present study are: Organic matter content (OM), calcium carbonate content (CC), other detritic matter content, and average grain size. All parameters are expressed as weight percentages. OM content is calculated using weight loss after oxidation with H_2O_2. CC content was calculates using weight loss after treating the samples with HCl 10%. The remaining matter is deemed "other detritic matter".
The chronological framework of both cores is used to calculate non-density connected sedimentation rates, assuming unchanging deposition rates between two AMS dates.

3.4. Results

3.4.1. Chronology

The results of the AMS radiocarbon datings and the calibration with BCal are displayed in Table 3.2, and incorporated in two age-depth curves, displayed in Fig. 3.8. The age-depth curve for Gravgaz marsh is only displayed for the depth-range of core SA06EP1, as pollen data are only available from that core. Ages of individual pollen samples were estimated using an interpolation/extrapolation assuming constant sedimentation rates between two individual calibrated radiocarbon dates. All dates are given as cal. BC/AD and rounded to the decadal level.

3.4.1.1. Gravgaz marsh

For Gravgaz, nine out of ten ages from core SA06EP1 and SA00EP03, ranging between cal. 20 BC at 386 cm and AD 1800 at 39 cm, are in chronological order. One age was determined to be an outlier using the Outlier Analysis of BCal and is subsequently not used in the age-depth model (Fig. 3.8, Table 3.2). The age of the base of the core at 339 cm is calculated at AD 90.
The not density-corrected accumulation rates implied by this chronology are displayed in Table 3.3.

3.4.1.2. Bereket basin

The seventeen AMS ages for core SA09JBDrill02 range between cal 610 BC at 582 cm, and AD 1580 at 43 cm (Fig. 3.8, Table 3.2). The oldest age at depth 582 cm is in chronological order, but its validity is questionable taken into account the age-depth curve of the well dated cores BKT2 and BKT1 (Kaniewski et al., 2007a), which are situated in the fan deposits forming the valley bottom at respectively 440 m and 420 m upstream from core SA09JBDrill01 (Table 3.3). The oldest AMS age is therefore omitted as input in the Outlier Analysis of BCal. Three other ages were determined to be outliers using the Outlier Analysis of BCal and are not used in the age-depth model (Table 3.2). The extrapolated age of the core bottom at 622 cm is BC 420.
Core SA09JBDrill02 is situated in a depression which acted as a swale, enabling peat growth and peat conservation. Additional cores have showed that the area of peat growth is elongated in an east-west direction and is closely connected to the position of the headwaters of the Aykirdak Deresi River which flows at the toe of a large fan dipping to the south.
The not density-corrected accumulation rates for the Bereket core are displayed in Table 3.4. The chronological data imply that two detritic calcium carbonate dominated layers that intersperse a peat deposit, are deposited very rapidly, perhaps instantly (see Fig. 3.8). Deposition of older, reworked sediments within this rapidly deposited layer may have resulted in the occurrence of the out-of-sequence date at 391 cm, which was recognized as faulty during the outlier analysis. Both cores include sediments deposited from the Roman period until the present.

Table 3.2. List of AMS 14C ages from charcoal samples from core SA06EP1 and the top four ages from core SA00EP03 (both Gravgaz Marsh) and core SA09JBDrill02 (Bereket Basin). Ages are calibrated using the IntCal09 calibration curve. Calibrated ages are given as 1 sigma and 2 sigma probabilities, using the BCal online software package (Buck et al. 1999).

Gravgaz: Core SA06EP01

Depth cm	Sample Type	Lab codes	δ13C(‰PDB)	Measured age	conventional age	95% lower	95% upper	69% lower	69% upper
39	Charred material	Beta-257413	n/a*	n/a	100 +/- 40 BP	1680	1940	1690	1920
88	Seeds	Beta-257414	-24.9	370 +/- 40 BP	370 +/- 40 BP	1450	1640	1460	1630
133	Charred material	Beta-263584	-23.2	860 +/- 40 BP	890 +/- 40 BP	1030	1210	1040	1190
140	Charred material	Beta-257420	-24.3	1010 +/- 40 BP	1020 +/- 40 BP	970	1150	990	1040
147	Charred material	Beta-263585	-24.7	1160 +/- 40 BP	1160 +/- 40 BP	860	1010	920	980
222	Charred material	Beta-257421	-21	1030 +/- 40 BP	1100 +/- 40 BP	800	990	890	960
277	Charred material	Beta-257422	-22.5	1700 +/- 40 BP	1740 +/- 40 BP	210	410	240	340

Gravgaz: Core SA00EP03

282	Bulk soil sample	GrA-19896	n/a	n/a	1760 +/- 50 BP	130	350	180	300
233	Bulk soil sample	GrN-26339	n/a	n/a	1760 +/- 60 BP	204	424	277	387
386	Bulk soil sample	GrA-19898	n/a	n/a	2020 +/- 50 BP	-160	80	-60	60

Bereket: Core S109JBDrill01

43	Plant remains	Beta-287853	-27.8	360 +/- 40 BP	310 +/- 40 BP	1480	1660	1520	1650
170	Plant remains	Beta-287855	-25.9	770 +/- 40 BP	760 +/- 40 BP	1210	1300	1230	1280
207	Charred material	Beta-287854	-29	1020 +/- 40 BP	950 +/- 40 BP	1020	1170	1030	1160
234	Charred material	Beta-295432	n/a*	n/a	1190 +/- 30 BP	780	900	820	890
238	Charred material	Beta-280822	-27.4	1230 +/- 40 BP	1190 +/- 40 BP	770	890	800	860
270	Plant remains	Beta-295434	n/a*	n/a	1220 +/- 30 BP	720	870	770	830
283	Charred material	Beta-295433	-23	1180 +/- 30 BP	1210 +/ 30 BP	690	830	720	800
305	Charred material	Beta-287856	-25.1	1420 +/- 40 BP	1420 +/- 40 BP	Posterior probability of sample being an outlier: 85%			
319	Charred material	Beta-280821	-27.2	1460 +/- 40 BP	1420 +/- 40 BP	Posterior probability of sample being an outlier: 67%			
331	Charred material	Beta-274769	n/a*	n/a	1350 +/- 40 BP	650	770	660	700
361	Charred material	Beta-274770	-24.7	1380 +/- 40 BP	1380 +/- 40 BP	620	690	640	670
391	Charred material	Beta-295435	-25	1740 +/- 30 BP	1740 +/- 30 BP	Posterior probability of sample being an outlier: 100%			
463	Uncharred wood	Beta-280824	-24	1390 +/- 40 BP	1410 +/- 40 BP	600	670	620	660
493	Charred material	Beta-295437	n/a*	n/a	1500 +/- 30 BP	440	620	540	600
507	Plant remains	Beta-280823	-25.9	1620 +/- 40 BP	1610 +/- 40 BP	380	550	410	530
525	Plant remains	Beta-295436	-25	1740 +/- 30 BP	1740 +/- 30 BP	250	390	290	390
582	Charred material	Beta-287857	-25.8	2450 +/- 40 BP	2440 +/- 40 BP	-780	-410	-760	-490

*Sample was too small for a seperate 13C/12C ratio and AMS analysis.

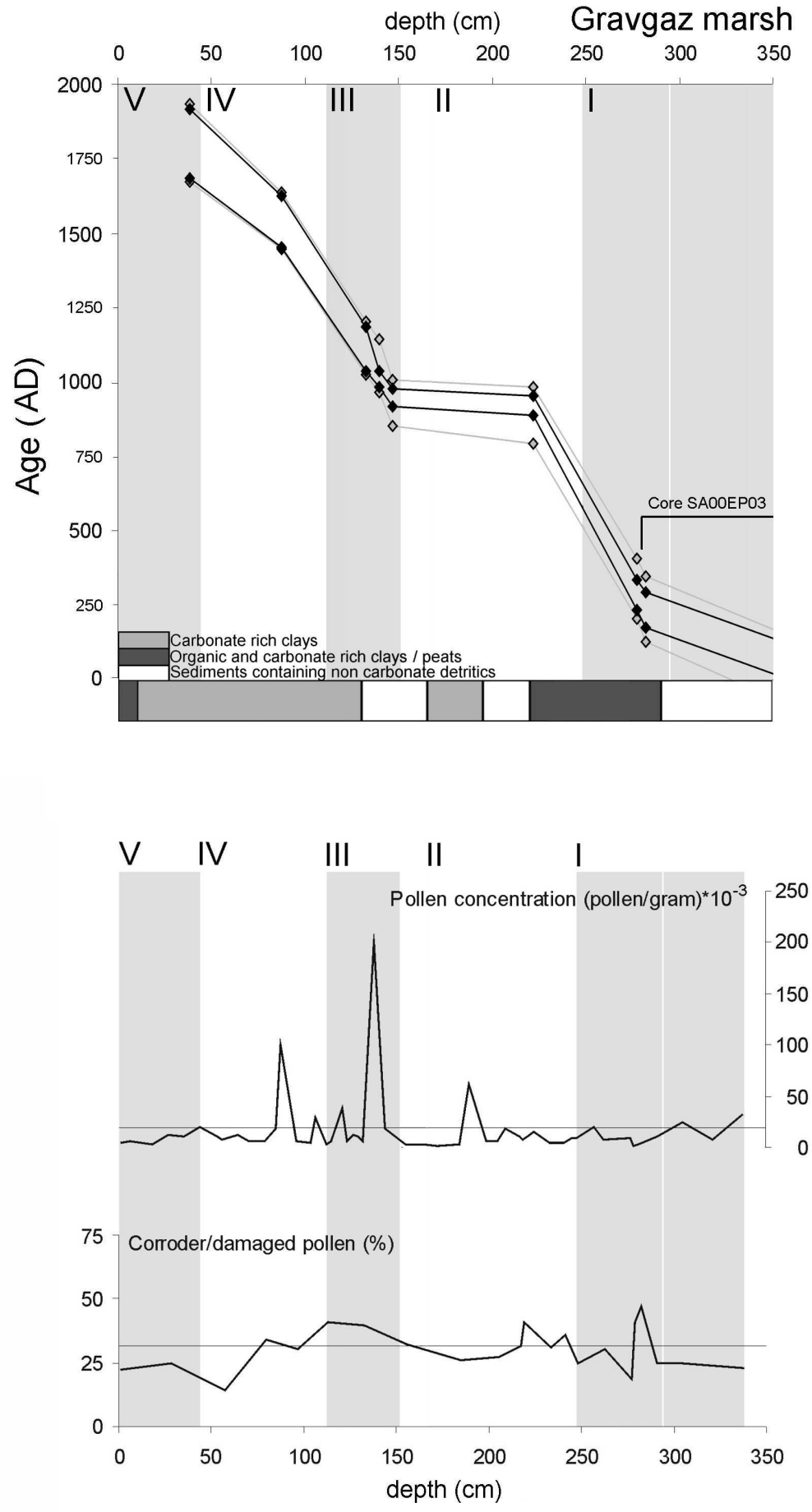


Fig. 3.8a. The age-depth curve, lithology, pollen concentration, and pollen preservation for core SA06EP1 (left), and SA09JBDrill02 (right). The white and grey bands numbered I to IV correspond with the periods into which the pollen record is subdivided.

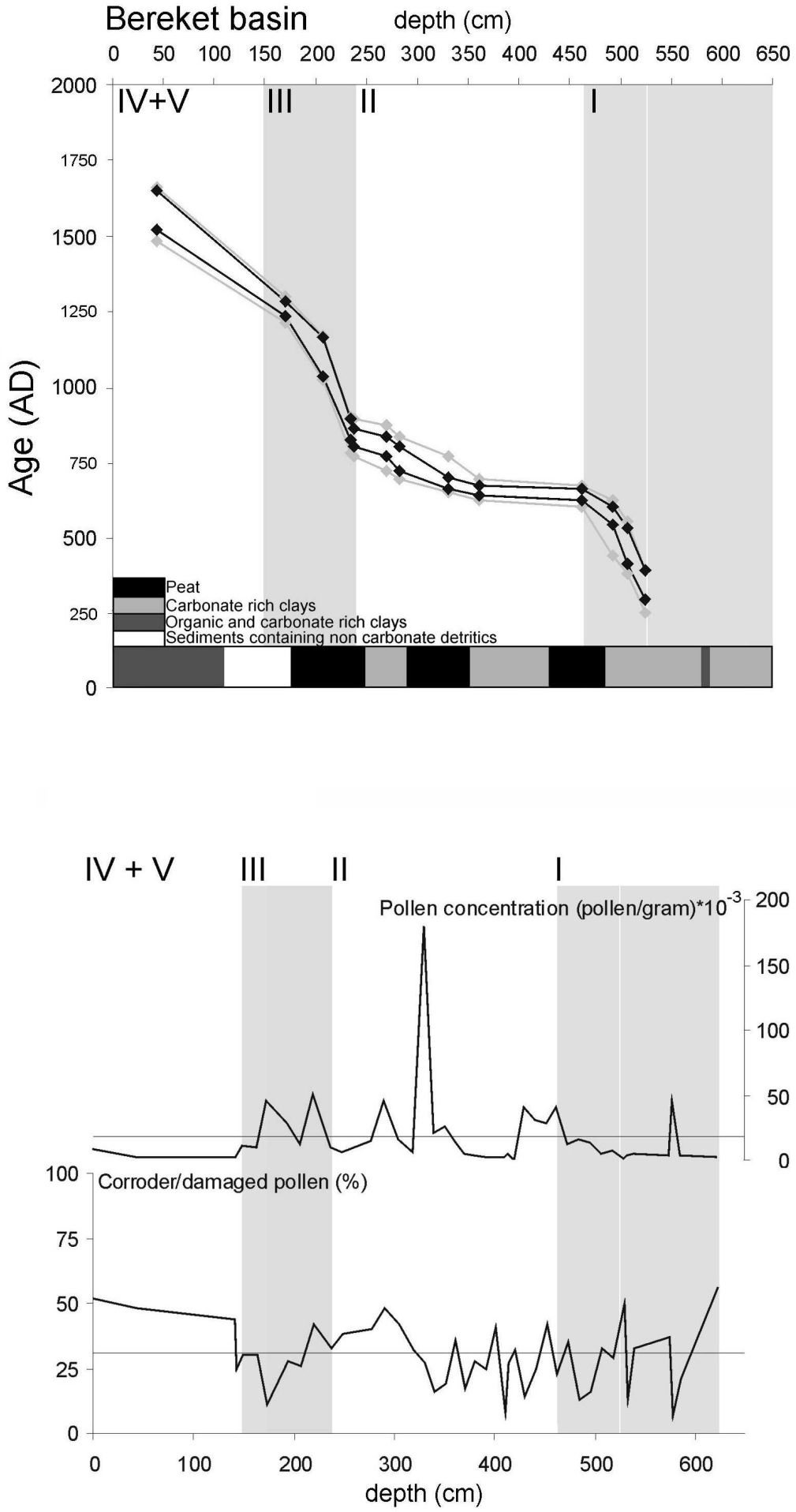


Fig. 3.8b. Same as 3.8a.

Table 3.3. An overview of the not density-corrected accumulation rates for the Gravgaz marsh (left) and Bereket basin (right) sediment cores.

Gravgaz marsh		Bereket Basin	
Depth range (cm)	Not density-corrected accumulation rate (mmyr-1)	Depth range (cm)	Not density-corrected accumulation rate (mmyr-1)
339-282	4	622-507	1.4
282-222	1	507-463	2.6
222-147	25	463-361	> 100
147-88	1	361-283	7.4
88-39	1.9	283-238	6.4
		238-170	1.6
		170-43	4.2

Table 3.4. A comparison of the chronological data of core SA09JBDrill02 and BKT1/2 for the time period of AD 700 BC – AD 2000.

Core SA09JBDrill01			Cores BKT1/2		
Code	Age (cal BP)	Depth (cm)	Code	Age (cal BP)	Depth (cm)
Beta-287853	310+/-40 BP	43			
Beta-287855	760+/-40 BP	170			
Beta-287854	950+/-40 BP	207			
Beta-295432	1190+/-30 BP	234			
Beta-280822	1190+/-40 BP	238			
Beta-295434	1220+/-30 BP	270			
Beta-295433	1210+/-30 BP	283			
Beta-274769	1350+/-40 BP	331			
Beta-274770	1380+/-40 BP	361	Beta-223548	1390+/-60 BP	157 Depth incision at 1380+/-40 BP: 204 cm
Beta-280824	1410+/-40 BP	463			
Beta-295437	1500+/-30 BP	493			
Beta-280823	1610+/-40 BP	507	Beta-210929	1580+/-40 BP	197.5 Depth incision at 1600+/-40 BP: 309.5 cm
Beta-295436	1740+/-30 BP	525	Beta-210926	1710+/-40 BP	203.5 Depth incision at 1730+/-30 BP: 321.5 cm
			Beta-210927	1870+/-40	286
			Beta-193788	1970+/-40 BP	470
			Beta-193789	2140+/-40 BP	610
			Beta-210931	2370+/-40 BP	729
			Beta-213851	2230+/-40 BP	783
Beta-287857	2440+/-40 BP	582			
			Beta-210930	3260+/-190 BP	800

3.4.2. Sedimentology and Lithology

An overview of the lithology, organic matter, calcium carbonate and non-carbonate detritic matter content in both cores for the sediments from Gravgaz marsh and the Bereket basin are given in Fig. 3.9.

3.4.2.1. The lithology of core SA06EP1/SA00EP3

The lithological sequence is composed of seven units: two units of CC rich clays, two units dominated by non-carbonate detritics, and two units characterized by organic clays. The age of the base of the core at 339 cm is calculated at AD 90.
The chronology implies the following not density-corrected accumulation rates: 4.0 mm/yr for the 339-282 cm interval, c. 1 mm/yr for the 282-222 cm interval, c. 25 mm/yr for the 222-147 cm interval, c. 1 mm/yr for the 147-88 cm interval, and 1.9 mm/yr for the 88-39 cm interval. The lithological column, mainly clays and fine silts, is composed of 74 wt% non-carbonate detritics, followed by 16 wt% CC and 10 wt% OM. There is a statistically insignificant positive cross correlation (CC: 0.31) between OM and CC content, and a strong negative cross correlation (CC: -0.81) between OM and non-carbonate detritic matter (Fig. 2, A1). The new detailed chronology of core SA06EP1 provides new information on changes in sedimentation rates through time. Because of this, the grouping of the lithological units differs somewhat in this dissertation, compared to the grouping supplied in Six (2004).

The core can be subdivided into the following six lithological units based on the organic matter content (see Table 3.5).

-Gv-a (339 - 289 cm, AD 90-200): This unit is characterized by detritic clays with a low organic and calcium carbonate content. Organics start to increase from AD 170 onwards.

-Gv-b (289 – 226 cm, AD 200-870): During c. 6.5 centuries, an organic/peaty clay is deposited, with organic and calcium carbonate contents always above the average and forming three distinct peaks at AD 210, 400, and 700. The waxing phase of the final peak followed by a continued decrease in OM content for the remainder of this zone.

-Gv-c (226 – 123 cm, AD 820-1220): At the end of the Ninth Century, organic and calcium carbonate content decrease, organic matter content remaining below the mean. There is a single peak in calcium carbonate content around 189 cm, coinciding with a peak in pollen concentration and an increase of the silt fraction, and falls within a part of the core marked by fast accumulation rates which occurs between 222 and 147 cm (c. AD 910-940). Above 133 cm, the influx of sand causes a strong increase in grain size (see Six, 2004).

-Gv-d (123 – 99 cm, AD 1220-1450): This unit is characterized by extremely low organic and high calcium carbonate content. Grain size increases, with more than 50% in the sand fraction. Microscopic analyses show an important part of the coarser fraction is composed of finer particles bonded by calcium carbonates.

-Gv-e (99 – 19 cm, AD 1450-1900): The organic content is fluctuating around the overall mean. The calcium carbonate content is generally above average, mainly due to individual peak values. The lower section of this unit (100-90 cm) shows notably higher calcium carbonate and lower organic content than the rest of this unit.

-Gv-f (19 – 0 cm, recently deposited sediments): This recently deposited layer is very rich in organic matter and calcium carbonates, giving the highest values for the entire core. They confirm the marsh environment that has been observed during the 1990’s.

3.4.2.2. The lithology of core SA09JBDrill02

The lithological sequence is composed of seven lithological units. The texture of all detritic units are clays and fine silts with varying amounts of calcium carbonate and organic matter with occasional peaty layers. Sand and silt are conspicuously absent from the sediments. However, various layers within sediments can be distinguished by their specific organic matter and calcium carbonate content, both of which can vary strongly. The chronology implies the following not density-corrected accumulation rates: 1.4 mmyr-1 for the 622-463 cm interval, > 100 mmyr-1 for the 463-361 cm interval, 7 mmyr-1 for the 283-238 cm interval, and 4.2 mmyr-1 for the 170-43 cm interval. The top 150 cm of the sediment core, distinguished by a dark brown colour, is currently located above the present water table as water levels dropped after the marsh was drained in the 1960's. The lithological column is composed of 47 wt% CC, 30 wt% OM, and 23 wt% non-carbonate detritics. Sediments with high OM content are concentrated in the peat deposits between c. 500 and 170 cm. There is a strong negative correlation between OM and CC content. No significant correlation exists between OM and non-carbonate detritic matter content (Figs. 3.9, 3.10).

The core can be subdivided into the following seven lithological units based on the organic matter content (see Table 3.5).

-Br-a (622 – 501 cm, cal 420 BC-AD500): The organic matter content shows a pronounced peak at 585 cm. Organic content increases continuously from c. 530 cm (c. AD 290) onward. The composition of detritics is dominated by calcium carbonate material, and starts to decrease dramatically at a depth 517 cm. The rejected AMS-sample Beta-287857 was sampled in this unit.

-Br-b (501 – 430 cm, AD 500-640): This clayey peat unit was built up during circa one century. Due to an important increase of the non calcium carbonates, the composition of the detritics is significantly different from that of Unit Br-a.

-Br-c (430 – 356 cm, AD 640-660): This unit consists of a 1.3 m thick layer of detritic sediments, deposited during a very short period of time. The organics amount to 14% and the calcium carbonates largely dominate the detritics, which are devoid of decayed organic matter, but contain numerous well-preserved rhizomes of Poaceae (cf. *Phragmites*; van Geel, pers com). The downward infiltration of rhizomes of Poaceae may have increased the thickness of this layer.

-Br-d (356 – 285 cm, AD 660-760): Clayey peat unit built up during less than a century. Compared with the lower clayey peat unit, it is richer in organics while the composition of the detritics remains identical.

-Br-e (285 – 253 cm, AD 760-820): As unit Ber-c, this 0.8 m thick detritic deposit has been deposited during a very short time period. The organic content is similar, but the non calcium carbonate detritics are more important than within unit Br-c.

-Br-f (253 – 169 cm, AD 820-1260): The upper clayey peat unit covers more than four centuries. The composition is identical to that of unit Ber d.

-Br-g (169 – 0 cm, AD 1260-present): The lowest part of this unit (until 143 cm, AD 1330) contains a very high percentage of non-calcium carbonate detritics. The rest of this unit, distinguished by a dark brown colour, is situated above the water table. The organic content shows little variation with a mean of 17%. The chronology implies that nearly no sediment has been deposited during the last five centuries (0.3 mm/yr-1).

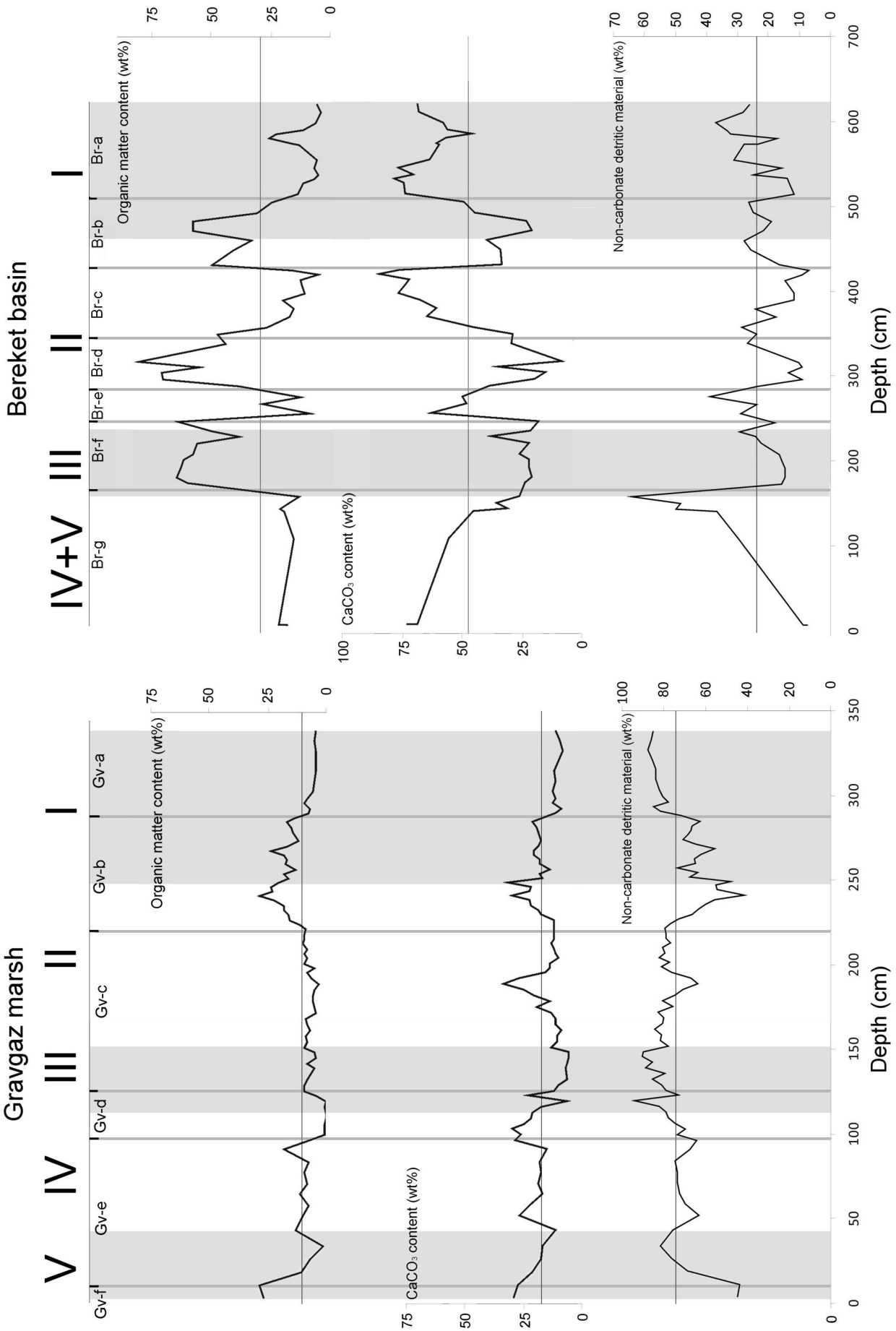


Fig. 3.9. An overview of the OM content (weight percentage), CC (weight percentage), and other detritic matter (weight percentage) for core SA06EP1 (left) and SA09JBDrill02 (right). The white and grey bands numbered I to IV correspond with the periods into which the pollen record is subdivided. The codes Gv-a to Gv-f and Br-a to Br-g mark the different units distinguished in the sediment record.

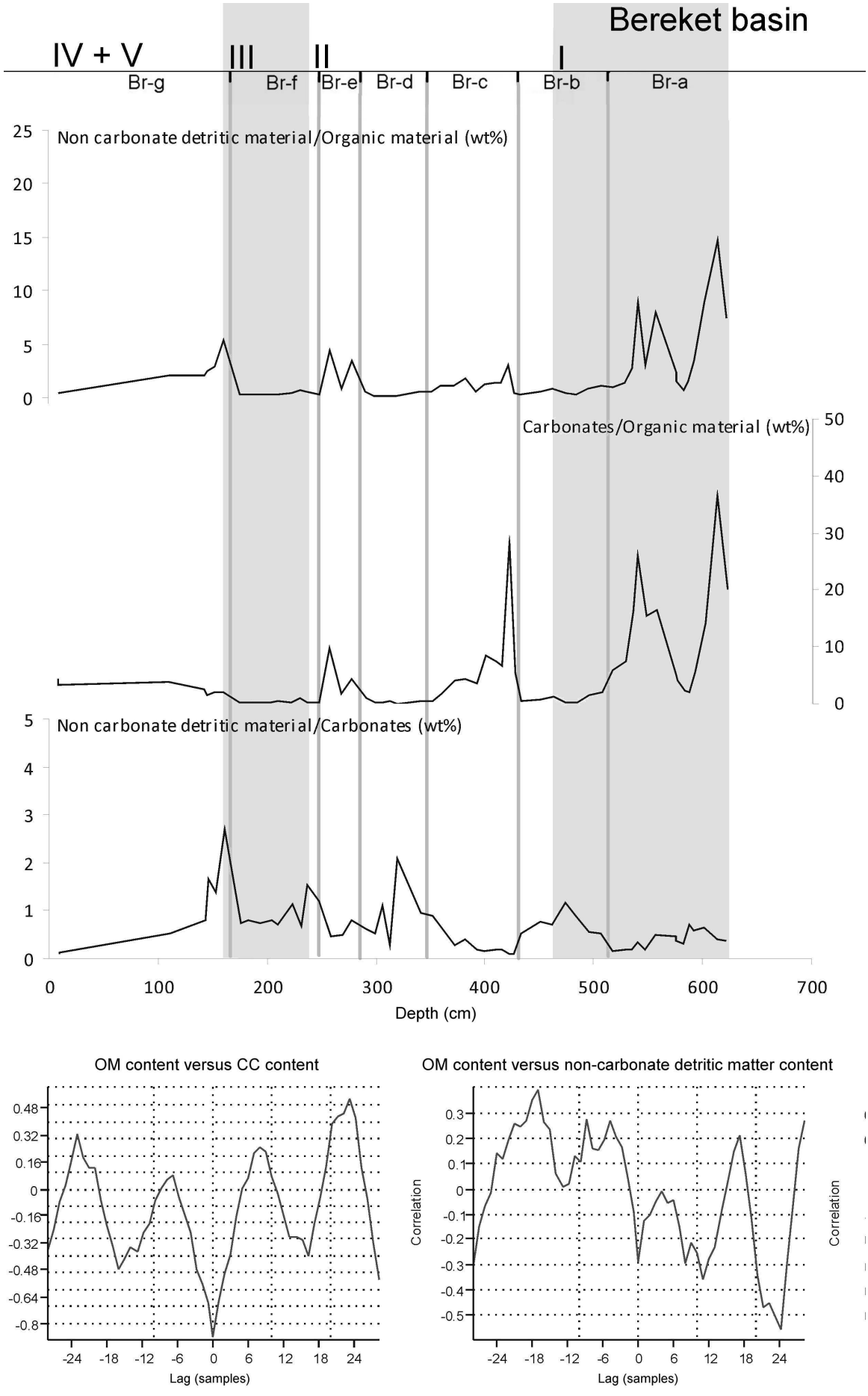


Fig. 3.10a. Top: The relationship between organic matter content and detritic matter content, and carbonate and non-carbonate detritic matter content. Bottom: Correlograms displaying the correlation between organic matter content of the sediments versus carbonate content, and non-carbonate detritic matter content. The white and grey bands numbered I to IV correspond with the periods into which the pollen record is subdivided.

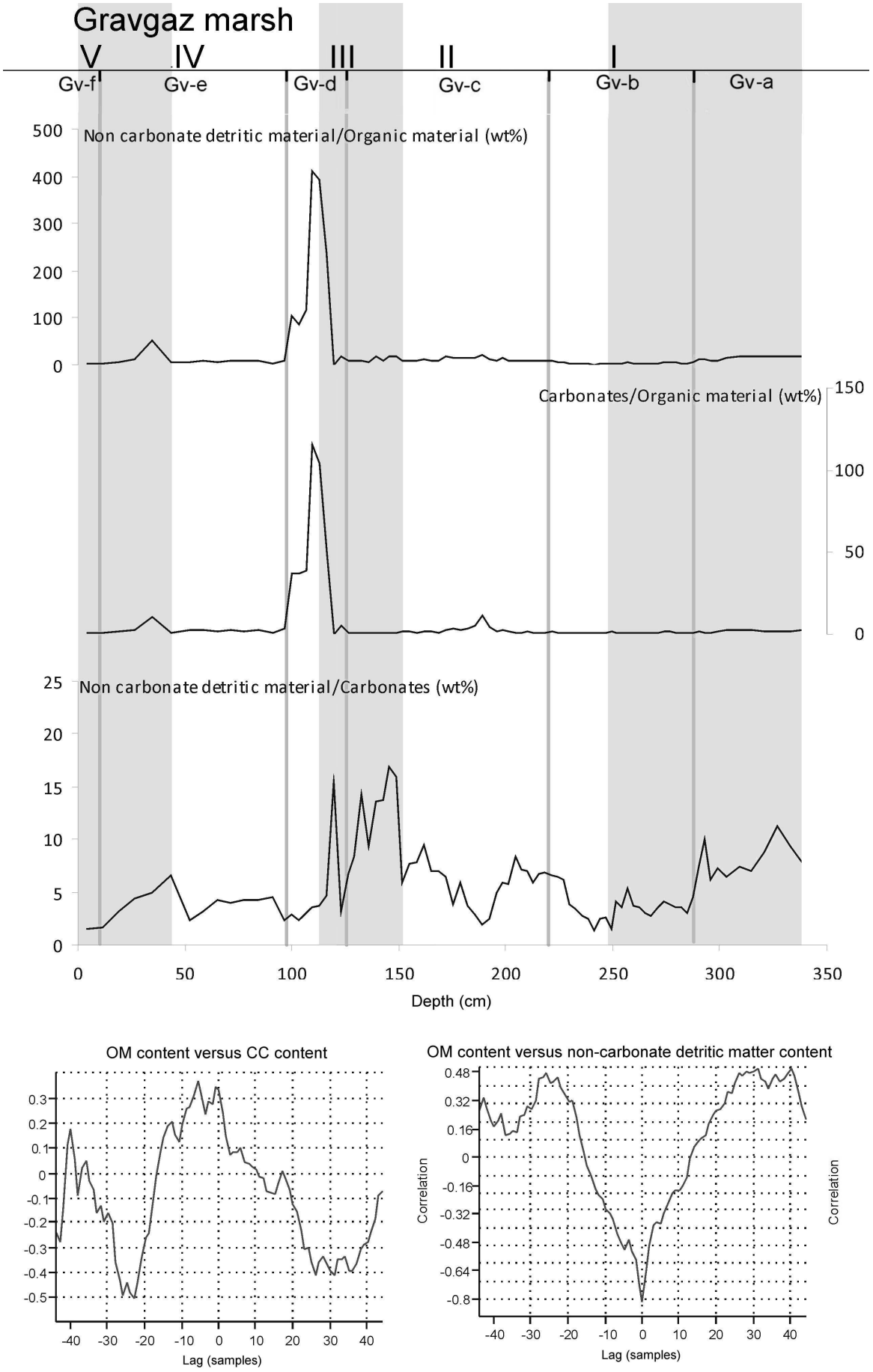


Fig. 3.10b. Same as 3.10a.

Table 3.5. A list showing the different lithological units distinguished for core SA06EP1 and core SA09JBDrill02.

Gravgaz marsh

						Detritics = 100%	
Depth (cm)	Unit	Age (cal AD)	OM (%)	Carbonates (%)	Other detritic material (%)	Carbonates (%)	Other detritic material (%)
19 - 0	Gr-f	modern	27.5	28.2	44.3	39	61
99 - 19	Gr-e	1450 - 1900	9.2	19.1	71.7	21	79
123 - 99	Gf-d	1220 - 1450	0.4	21	78.6	21	79
226 - 123	Gr-c	870 - 1220	7.3	13.3	79.4	16	84
289 - 226	Gr-b	200 - 870	17.7	19.6	62.7	24	76
339 - 289	Gr-a	90 - 200	5.9	10.6	83.5	11	89

Bereket basin

						Detritics = 100%	
Depth (cm)	Unit	Age (cal AD)	OM (%)	Carbonates (%)	Other detritic material (%)	Carbonates (%)	Other detritic material (%)
169 - 0	Br-g	1260 - present	17	48	35	57	42
253 - 169	Br-f	820 - 1260	59	22	19	53	47
285 - 253	Br-e	760 - 820	15	54	31	64	36
356 - 285	Br-d	660 - 760	58	24	18	57	43
430 - 356	Br-c	640 - 660	14	71	15	84	16
501 - 430	Br-b	500 - 640	46	31	23	57	43
622 - 501	Br-a	-420 - 500	10	65	24	73	27

3.4.3. Taphonomy

Pollen concentrations and preservation for both cores are displayed in Fig. 3.8. Pollen preservation is high, with an average of 70 % of the pollen undamaged in both cores. Indeterminable pollen grain percentages are low throughout (max. 12% in Gravgaz and 18% in Bereket). In general, there is no relation between the percentages of corroded/damaged pollen on the one hand and the sediment types and sedimentation rate on the other hand.

The average pollen concentration for both cores is high, 17010 pollen/gram in the Gravgaz core and 18400 pollen/gram in the Bereket core. Pollen concentrations are generally stable with the exception of a single peak value in both cores, indicating a short-term disturbance in the sedimentation of unknown origin. As these single peaks have no influence on the larger scale vegetation and sedimentation trends, they are of no relevance for the present study.

For Gravgaz, other than an individual peak value in pollen concentrations, no distinct deviations in indeterminable, damaged, or corroded pollen occur, indicating that there are no further instances of disturbances of the sediment. The top meter of the Bereket basin core shows clear signs of disturbance; poor pollen preservation, low pollen concentration, while OM content of the sediment was low. Levels of *Glomus* are high. This fungus occurs as a parasite on terrestrial plants and does not occur in marshes and lakes. Elevated levels of Glomus in a peat core may be indicative of relatively dry local environmental conditions, or the deposition of sediment into the basin, in which case they occur as reworked material (see Table 3.7).

3.4.4. Pollen Diagrams

The pollen diagrams for both cores are displayed in Figs. 3.11 and 3.12. Summary data are displayed in Figs. 3.13 and 3.14. The zonation in the pollen diagrams displays the different time periods distinguished using the numerical analyses described in chapter 4. As their significance and meaning is also explained in chapter 4, they have been given temporary, neutral names in the present chapter (Zone I to Zone V). An overview of the main characteristics of the pollen signal per zone is provided in Table 3.6.

The pollen counts indicate that the Cerealia type pollen curve for the Gravgaz marsh core can be interpreted as indicators of human impact. However, in the case of the Bereket basin, the average percentage value for Cerealia type pollen is as low as 1.6%. Cerealia pollen is therefore not interpreted as an anthropogenic indicator species for the Bereket basin.

Non-pollen palynomorphs may be indicative of specific local environmental conditions, providing valuable additional information concerning the conditions on and around the sample site. The conditions indicated by the NPP's found in the Gravgaz marsh and Bereket basin records, and which occurred in three or more pollen samples, are displayed in Table 3.7.

3.4.4.1. Gravgaz marsh: core SA06EP1

3.4.4.1.1. Zone I (338-248 cm, c. AD 90-640)

Cereal cultivation and arboriculture (*Castanea, Juglans, Olea*) remain present throughout this period. However, between the mid 3rd and mid 7th century AD, cereal and olive cultivation gradually decline in favour of moist deciduous woodland (e.g. *Populus, Platanus, Alnus*), meadows (e.g. *Sanguisorba, Plantago, Artemisia*), and pine forest. Locally, the late 3rd century decline in agriculture co-occurs with relatively high values for *Typha* and Cyperaceae, while Poaceae percentages markedly drop. This characteristic vegetation shift coincides with the beginning of the deposition of organic/peaty clay on the sample site.

3.4.4.1.2. Zone II (248-147 cm, c. AD 640-940)

Olive and cereal cultivation stops at c. AD 640. Subsequently, an open, dry shrub-steppe and maquis landscape appears, containing e.g. Caryophyllaceae, *Cistus* and increased values of Asteraceae (Fig. 3.11). The latter occasionally shows values of over 40 %. Pine pollen percentages fluctuate, a result of the occasional high percentage values for Asteraceae and fluctuating pollen production of deciduous trees, but remain important until the beginning of the 10th century AD. This zone is also characterized by a relatively high calcium carbonate content of the sediments, notably the occurrence of a peak in calcium carbonate content around 189 cm. The high sedimentation rate calculated for this layer of sediment, as well as the results of the sediment analysis point towards the notion that the top part of this zone was deposited instantly and the sediments may have become mixed in the process. The pollen data does not show signs of a disturbance in the form of decreased pollen preservation. There is a small increase in pollen percentage values for taxa representative of dry herbaceous steppe, at the cost of *Pinus* pollen percentages mainly.

3.4.4.1.3. Zone III (147-113 cm, c. AD 940-1300)

In Gravgaz, this zone is initially characterized by a resurgence in both primary and secondary anthropogenic indicators (*Plantago lanceolata, Sanguisorba minor, Castanea sativa, Fraxinus ornus*), and indicators of grazing (*Quercus coccifera*), and a decrease of dry steppe species (Apiaceae, Caryophyllaceae, Ericaceae, See Fig. 3.11). Cerealia type pollen has been present since the early 10th century, but increases within this zone. However, the low percentage value makes it difficult to determine whether these pollen represent actual cereal cultivation, or the limited presence of wild grasses which also produce Cerealia type pollen. A notable shift to wet local conditions is indicated by the increased presence of *Myriophyllum* and *Spirogyra*. The disappearance of coprophilous fungi (Sordariaceae, *Podospora*) may indicate that the sample site, located in the middle of the marsh, had become too wet for animals to reach. After c. AD 1150, Pine forests strongly increase as signs of anthropogenic activity decrease.

3.4.4.1.4. Zone IV (113-45 cm, c. AD 1300-1700)

Cerealia type pollen disappears at the start of this zone. The pollen spectrum is dominated by Pine, although percentages generally decrease towards the top of this zone. The land not covered by pine forest is covered by open meadow/steppe vegetation. *Quercus coccifera*, *Juniperus, Artemisia* and Lamiaceae show increased percentage values from a depth of c. 80-36 cm (Fig 3.11), continuing into the lower part of the next zone. Locally this zone is characterized by relatively high calcium carbonate content of the sediments, while the non-pollen data indicates dry local conditions and clayey, rather than organic soils, although the continued presence of Alismataceae in the pollen spectrum indicates the presence of water on the sample site. The start of this zone coincides with the occurrence of a layer of sediments largely devoid of organic matter (Gv-d).

Table 3.6. Summary of the palynological characteristics of the regional pollen zones in each core from Gravgaz marsh and the Bereket basin (depth, age range and pollen characteristics).

Gravgaz core SA06EP1

Zone	Depth (cm)	Age range (AD)	Main characteristics
I	*338-248*	80-640 AD	Anthropogenic indicators well presented, but decreasing after AD 300, coinciding with a climatic shift towards wetter environmental conditions. Pine forest gradually becomes more important as human impact diminishes
II	*248-147*	640-940 AD	Increase in taxa characteristic for herbaceous steppe, followed by an increase in pine forest to percentage values encountered in modern pollen samples. *Olea* pollen disappears. Cerealia type pollen disappear temporarily at the start of this zone.
III	*147-113*	940-1310 AD	Cultivated species show a small increase at the start of this zone, but decrease again, being replaced by pine forest from the 12th century onwards.
IV	*113-45*	1310-1710 AD	Continued dominance of pine forest. Herbaceous steppe increases in importance slightly, and there is a distinct increase in maquis/shrub-steppe, driven by high percentage values for Juniper.
V	*45-0*	1710 AD -present	Juniper-dominated shrub/woodland remains important at the start of this zone. During the most recent years, pine forest returns while pollen indicating maquis, herbaceous steppe and deciduous trees disappear.

Bereket core SA09JBDrill02

Zone	Depth (cm)	Age range (BC/AD)	Main characteristics
I	*639-463*	420 BC-640 AD	Open herbaceous steppe and arboriculture (notably *Olea*) until AD 300. After this date, arboriculture decreases and *Olea* disappears from the pollen record. Degraded maquis/shrubs remain important while taxa indicative of pastures increase in importance. Shortly after AD 300 the development of a reed marsh causes a disturbance in the pollen signal as the regional Poaceae signal becomes temporarily dominated by pollen originating local reeds.
II	463-224	640-940 AD	The start of this zone shows an abrupt decrease in grasses and increase in pine forest. The middle part of this zone shows a re-opening of the landscape, maquis/shrub steppe taxa becoming more important. Riparian woodland develops on the sample site, indicating the marsh is drying out. Increase in pine forest during the top part of this zone.
III	*224-150*	940-1310 AD	The start of this zone shows a sharp drop in pine forest while degraded maquis, riparian woodland, and cultivated species increase. Dry herbaceous steppe does not. Pine forest increases again from the 12th century onward.
IV-V	150-0	1310 AD -present	The start of this zone shows a continued dominance of pine forest. The top section of this zone was located above the present water table and is not usable for pollen analysis.

Table 3.7. An overview of the non-pollen palynomorphs identified in the pollen record and the specific environmental characteristics their presence may indicate. Data based on the literature mentioned in section 1.10.4.

Type number	Type of organism (if known)	Species or family name (if available)	Description
T2	Fungus	*Gelasinospora* cf. *reticulispora*	Relatively dry conditions. Associated with fire
T14	Fungus	*Meliola* cf. *niessleana*	Relatively dry conditions. Frequently found on *Calluna vulgaris*
T18	Fungus	Unknown	Found on Eriophorum vaginatum (cotton tail sedge)
T25	Fungus	cf. *Clasterosporium caricinum*	Occurs on various sedges growing in marshes and fens subject to periodic flooding
T55A/B	Fungus	Sordariaceae	Eu- to mesotrophic environments. Coprophilous (indicator of dung)
T82	Fungus	Unknown	Unknown. Possibly Coprophilous
T113	Fungus	Sporormiella	Coprophilous
T119	Unknown	Unknown	Occurs in lake deposits
T121	Fungus	Unknown	Occurs in lake deposits
T126	Fungus	*Gaeumannomyces* sp.	Occurs on several species of Carex
T130	Algae	*Spirogyra*	Stagnant, shallow water
T140	Fungus	Unknown	Eutrophic wet conditions
T148	Fungus	Unknown	Clayey peat and clay
T170	Cyanobacteria	*Rivulatia* type	Found on submerged parts of water plants such as *Nuphar* (water lilly)
T184	Unknown	Unknown	Found in sandy clay deposits
T200	Fungus	Unknown	Relatively dry conditions. Occurs on helophytes or plant remains in temporary dessicating bottoms of pools
T201	Fungus	Unknown	Same as T200
T207	Fungus	*Glomus* cf. *fasciculatum*	Occurs as parasite on terrestrial plants and is indicative of Dry conditions or of sediment deposition into the sample site
T368	Fungus	*Podospora*	Coprophilous

3.4.4.1.5. Zone V (45-0 cm, c. AD 1700- the present)

In the lower part of this zone, the signal of open steppe, featuring evergreen oak (*Q. coccifera*) and *Juniperus* shrubs remains present. In the topmost samples of the core, above 36 cm, taxa indicating open meadow and steppe vegetation (e.g. Apiaceae, Lamiaceae, *Ulex*, *Artemisia*, See Fig 3.11) decrease in favour of indicators of increased moisture availability (*Q. cerris* type, Urticaceae and *Abies*), followed by another increase in *Pinus* pollen percentages. Locally the abrupt increase of coprophilous fungi may indicate an increase in pastoralism on and around the sample site itself. A pollen spectrum representative of the current vegetation only occurs in the topmost sample of this core.

3.4.4.2. Bereket basin: core SA09JBDrill02

3.4.4.2.1. Zone I (639-463 cm, until c. cal 420 BC - AD 640)

Prior to the mid 4th century, the pollen spectrum contains indicators of open and dry vegetation (Apiaceae, Asteraceae, Lamiaceae). The presence of *Olea* and *Castanea* pollen indicate the presence of arboriculture in the vicinity of the sample site. Olive cultivation ends during the first half of the 4th century, while arboriculture on the whole (*Fraxinus*, *Castanea*) diminishes, first giving way to open, herbaceous steppe vegetation (*Artemisia*, Chenopodiaceae, Ericaceae), followed by relatively moist, grass-dominated, vegetation (featuring e.g. Urticaceae and *Plantago*). The top half of this zone is characterized by very high percentages for Poaceae. Considering the limited pollen production and dispersal qualities of Poaceae (see chapter 6), these high values may indicate the presence of dense reed (*Phragmites*) vegetation on and around the sample site. Locally, the switch from agriculture to an open grassy steppe coincides with a distinct increase in Cyperaceae. A drop in the dung indicator Sporormiella, and increased presence of T200, a fungus growing on helophytes, also occurs at this point. The formation of a clayey peat layer on the sample site is indicated by sharply increased organic matter content of the sediments.

3.4.4.2.2. Zone II (463-224 cm, c. AD 640-940)

The transition from zone I to zone II is characterized by an abrupt decrease in Poaceae and an increase in *Pinus*. Apart from the initial dominance of pine forest, the pollen signal within the rapidly deposited 7th century sediment layer indicates the prevalence of open and dry vegetation (Apiaceae, Brassicaceae, Ericaceae, and Asteraceae). As these pollen originate from a layer of sediments deposited during a very short period of time, likely one or two individual events, it is reasonable to assume that some mixing of the sediments may have taken place. However, under the climatic circumstances prevalent in the study area, pollen preservation outside of a wetland/marsh environment is limited and pollen will most likely not survive for longer periods in the topsoil. Therefore it can be assumed that the pollen signal found within this layer represents the pollen produced immediately prior to the sedimentation event.
After c. AD 650, *Pinus* increases in importance, while Poaceae become less important and several species which may indicate early stages of secondary afforestation of the basin (*Quercus cerris, Salix*) increase (Fig. 3.12). From the 8th to the 10th century, *Pinus* pollen increases in importance, reaching pollen percentages of 80% near the top of this zone.
The disappearance of aquatic plant species such as Lemna minor and *Butomus umbellatus*, and the appearance of *Clasterosporium*, a fungus on sedges, indicate continuing desiccation of the sample site.

3.4.4.2.3. Zone III (224-150 cm, c. AD 940-1300)

The transition from zone II to zone III shows increases in secondary anthropogenic indicators (o.a. *Plantago lanceolata, Polygonum*, and *Rumex*), and riparian woodland taxa (*Salix, Quercus cerris type, Populus*) (Figs. 3.12, 3.13). *Pinus* pollen percentages drop sharply. Signs of arboriculture are present in the form of *Castanea sativa* and *Fraxinus ornus*. However, pollen percentages for these taxa remain very low and other cultivated species are absent or near absent. From the mid 12th century onward, the pollen spectrum becomes dominated by *Pinus*. Increased percentage values for aquatic plant taxa (*Myriophyllum*, Alismataceae, *Butomus*) and *Rivularia* (a cyanobacterium living on water plants) indicates relatively wet local conditions.

3.4.4.2.4. IV/V (150-0 cm, C. AD 1300- the present)

For Bereket, only the part 143-169 cm, dated AD 1260-1330, remains usable. The sediment is characterized by low pollen concentration, a high percentage of corroded pollen and a very poor diversity of pollen in the pollen spectrum. The combination of all these factors indicates that the top meter of the sediment core in Bereket, encompassing samples dating from the 15th century and later, was located above the present water table during a longer period and is not useful for pollen analyses. The usable part of the sediments dated to the LIA is very short and seems to indicate a continued dominance of pine forests while signs of crop cultivation are absent.

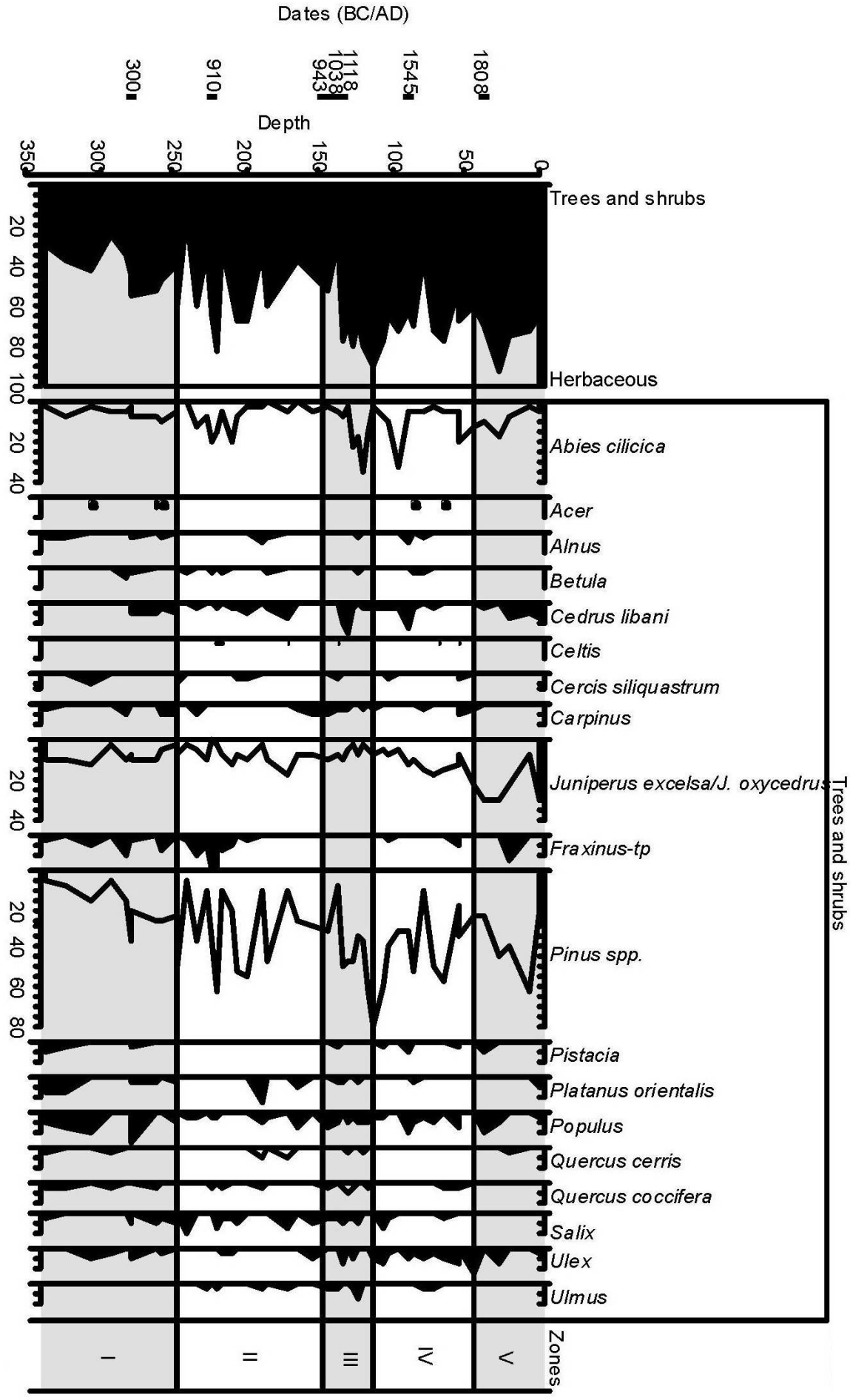


Fig. 3.11a. Percentage pollen diagram of core SA06EP1 (Gravgaz marsh). Only the species used in the numerical analyses are shown. The black curves indicate a 4-fold exaggeration of the pollen signal.

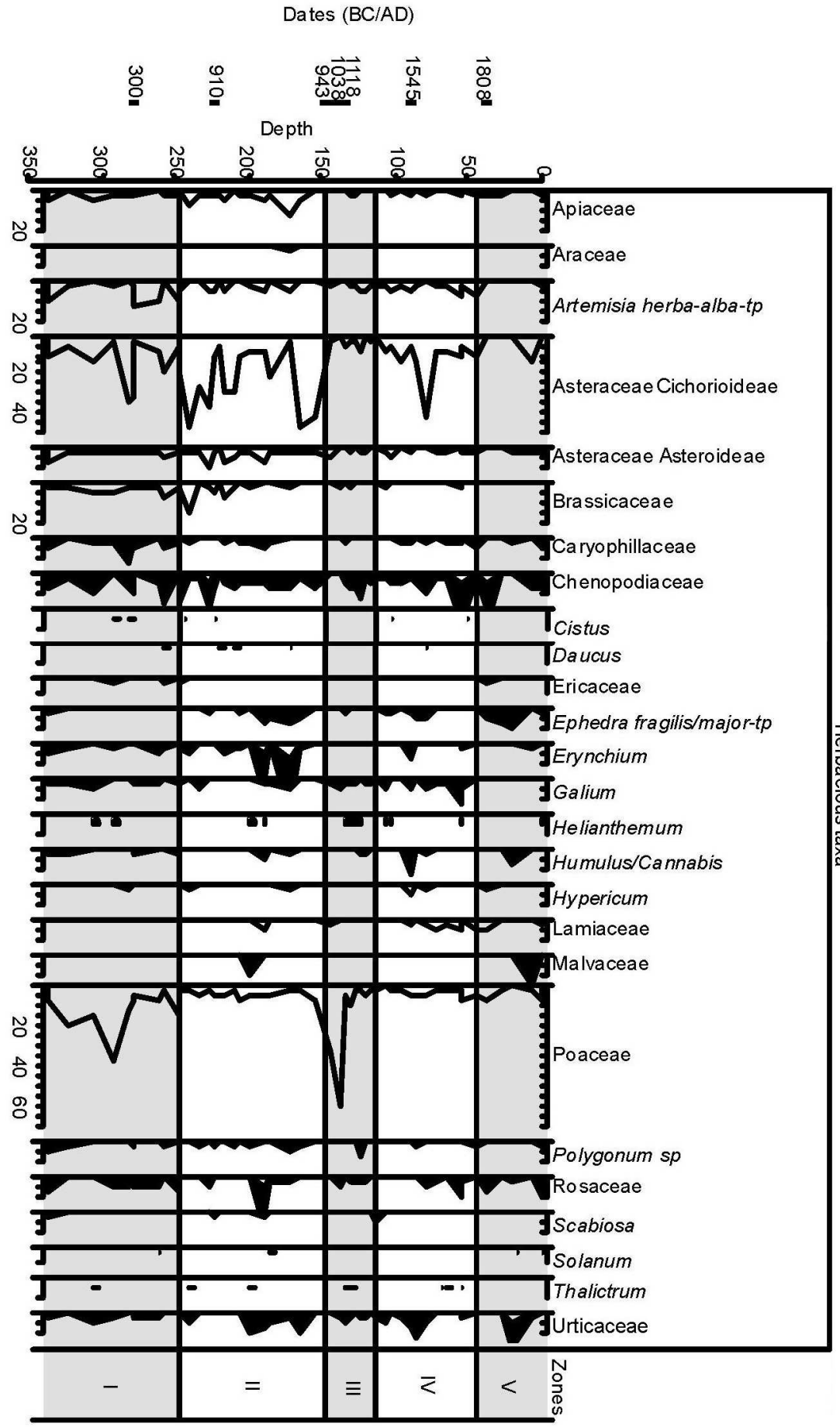


Fig. 3.11b. Same as 3.11a

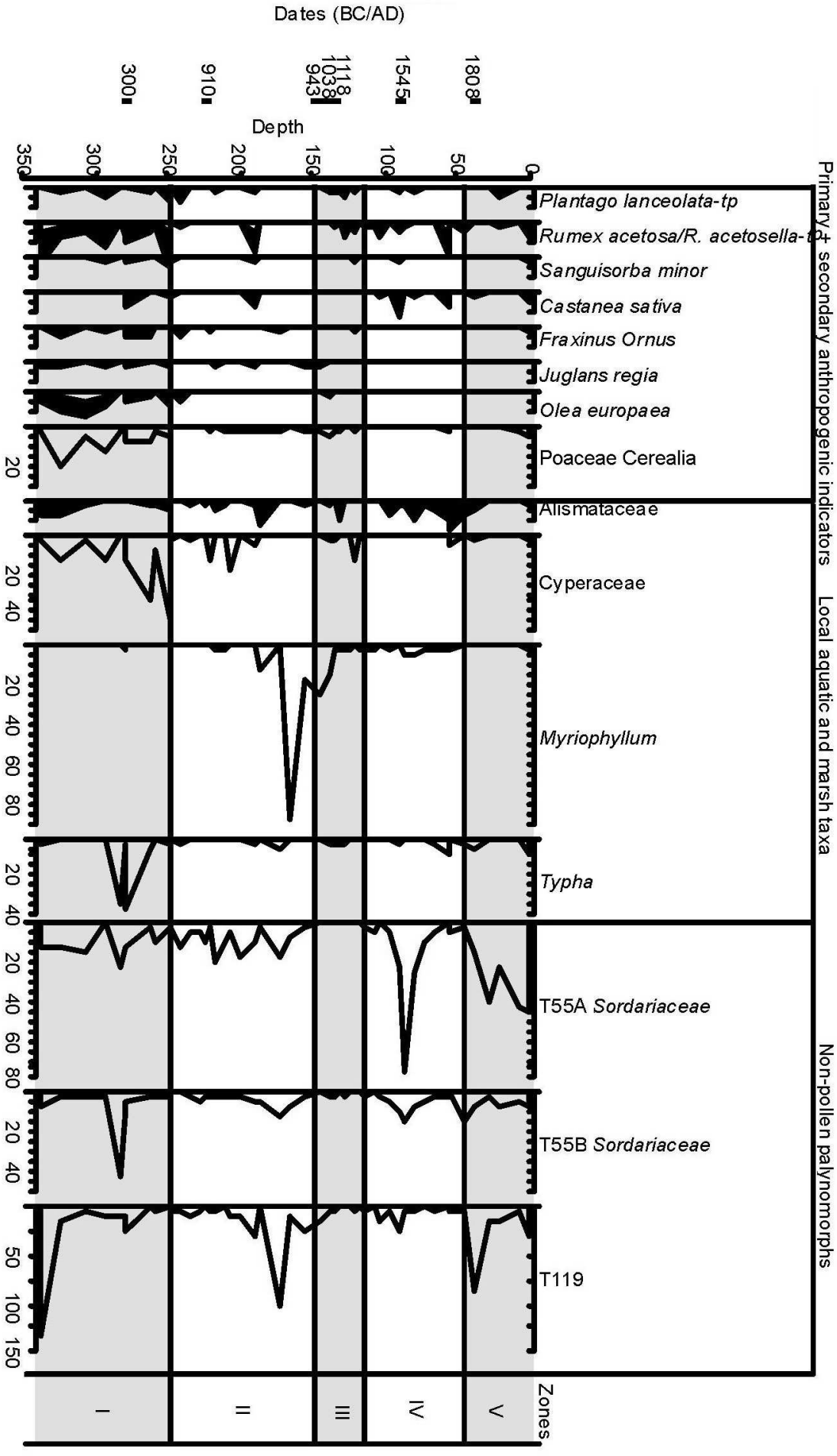


Fig. 3.11c. Same as 3.11a

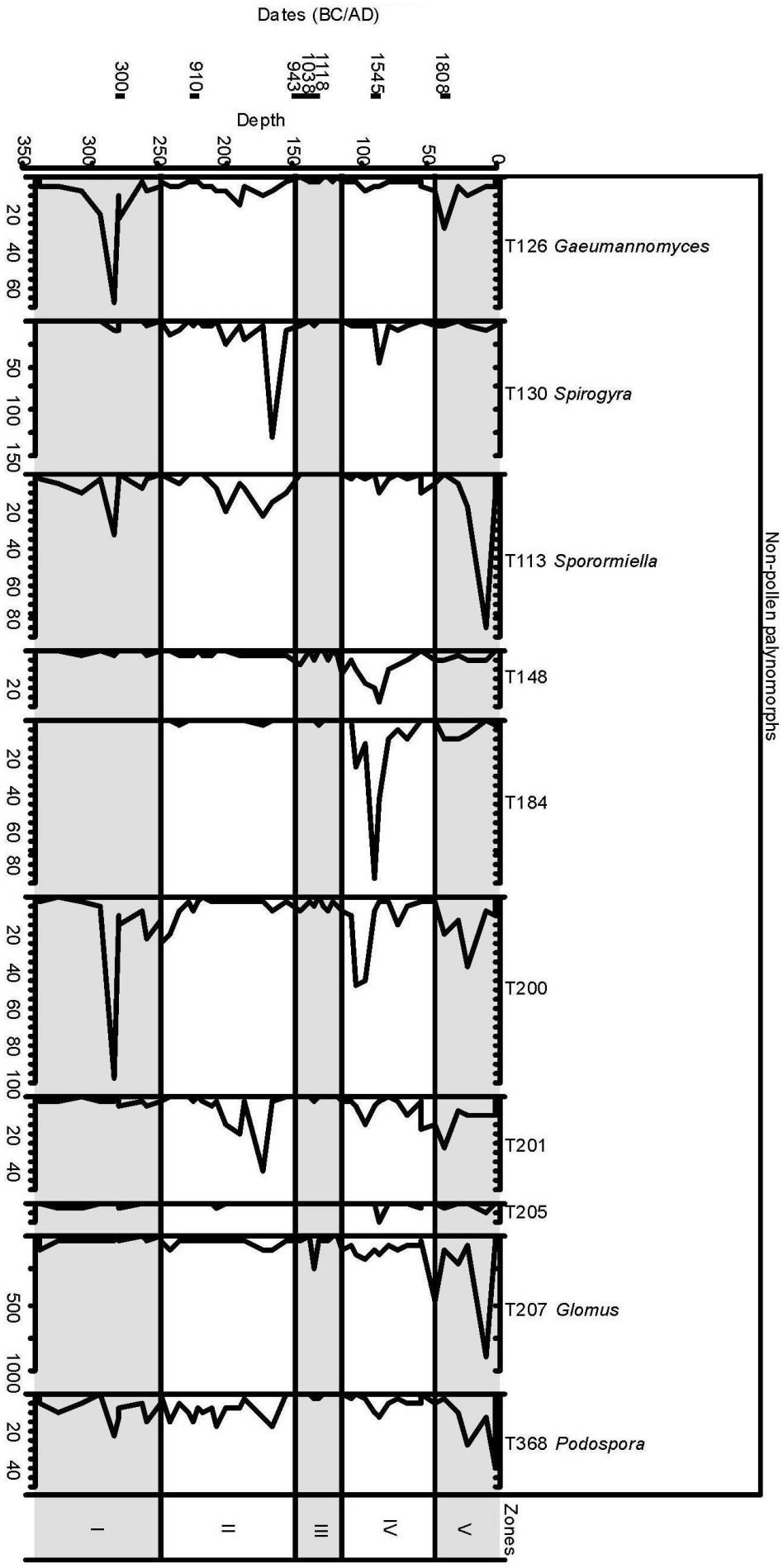


Fig. 3.11d. Same as 3.11a

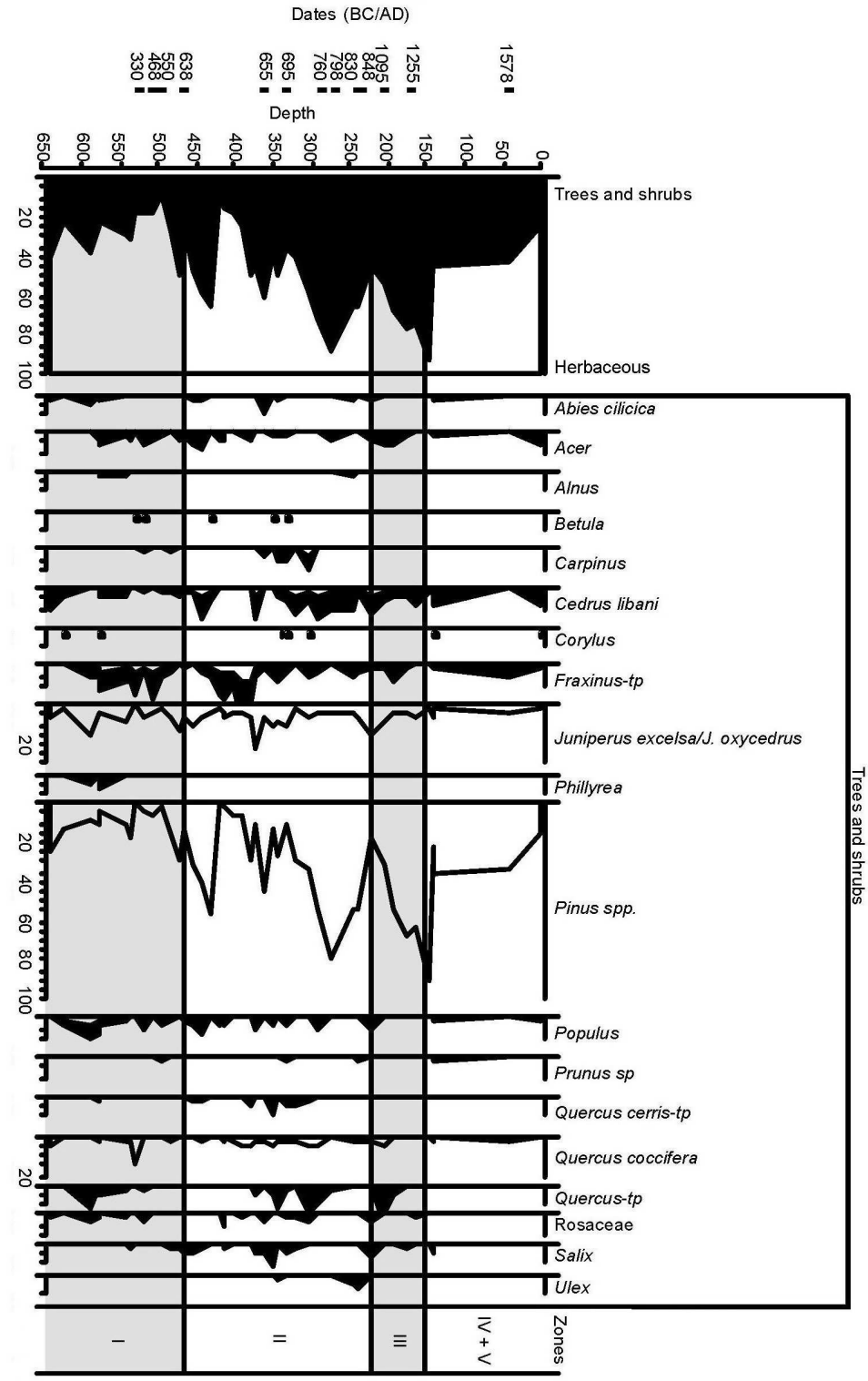


Fig. 3.12a. Percentage pollen diagram of core SA09JBDrill02 (Bereket Basin). Only the species used in the numerical analyses are shown. The black curves indicate a 4-fold exaggeration of the pollen signal. Poaceae Cerealia are grouped with the herbaceous taxa, rather than with the anthropogenic indicator species as the low abundance of this taxon is an indication that these Cerealia mostly originate from wild plants, rather than cultivated species.

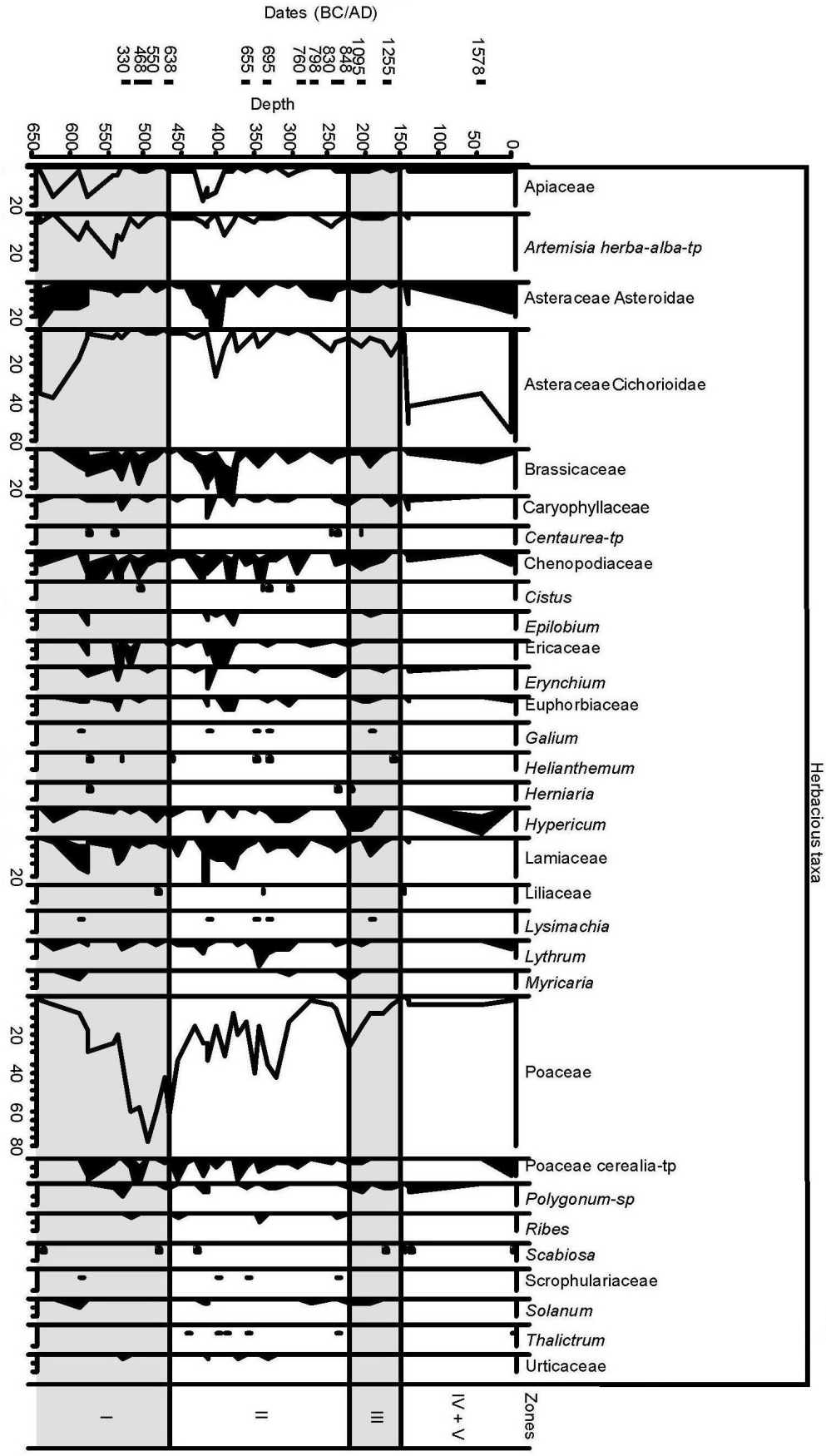


Fig. 3.12b. Same as 3.12a

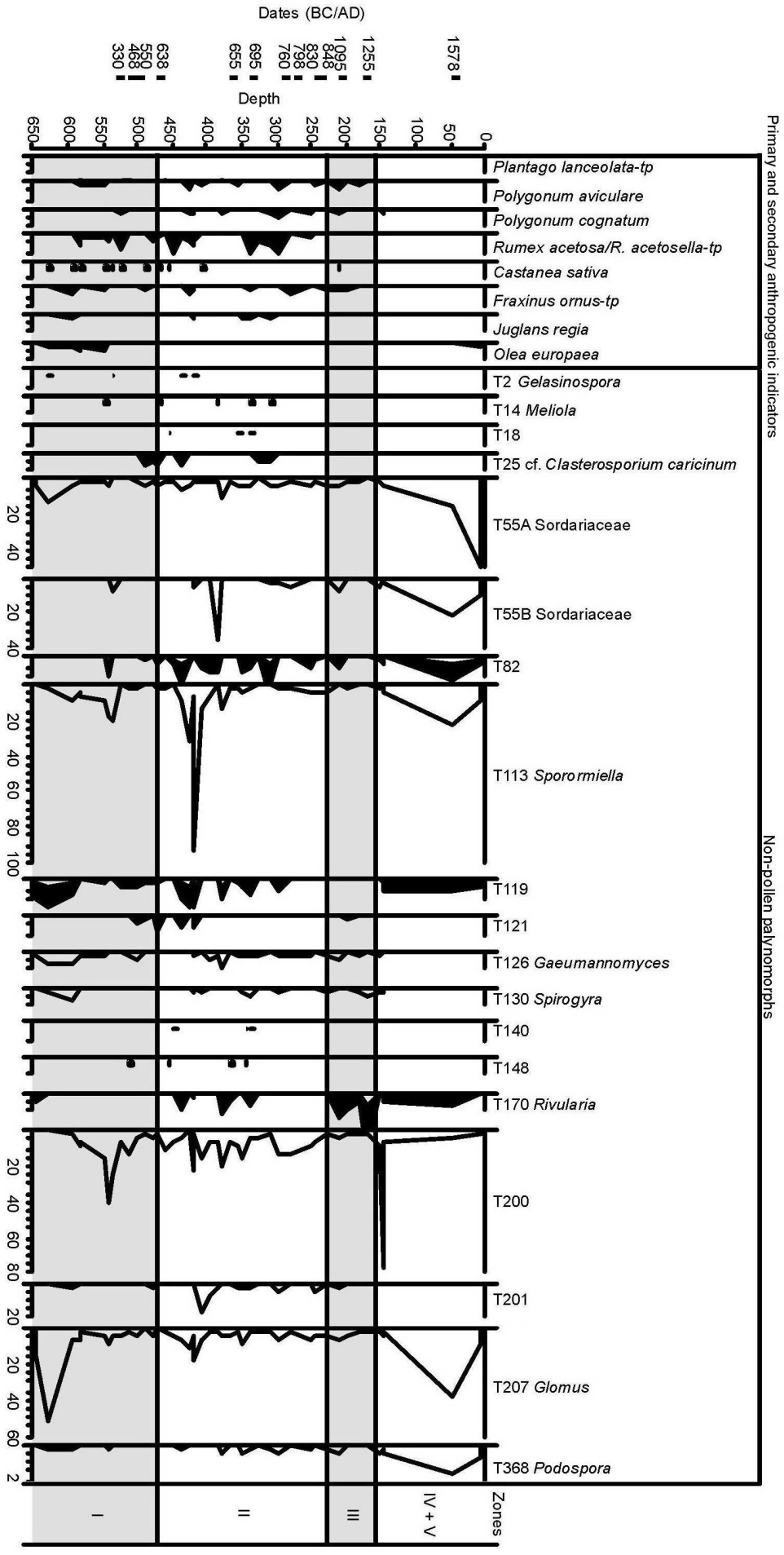


Fig. 3.12c. Same as 3.12a

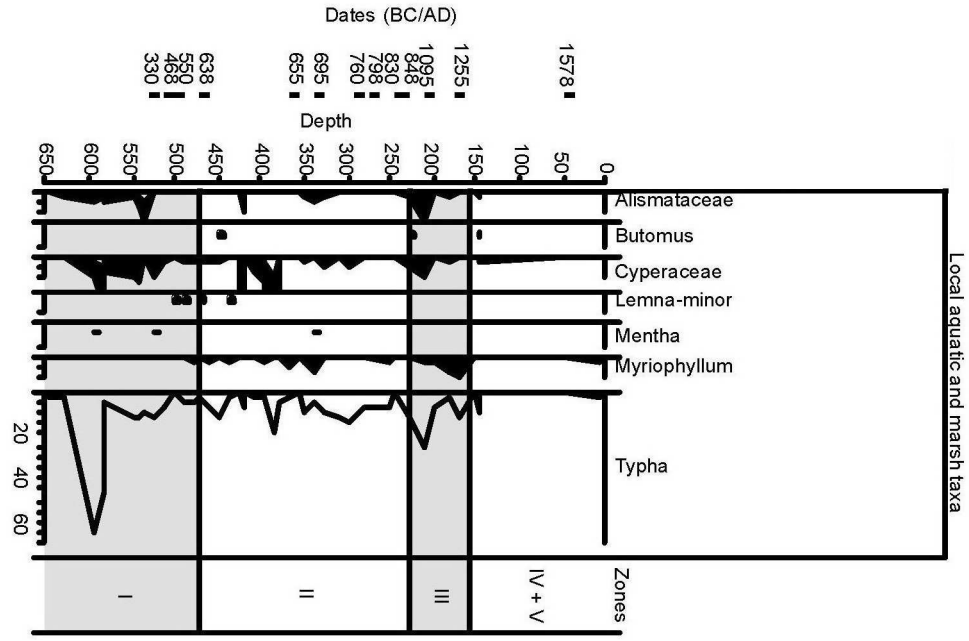


Fig. 3.12d. Same as 3.12a

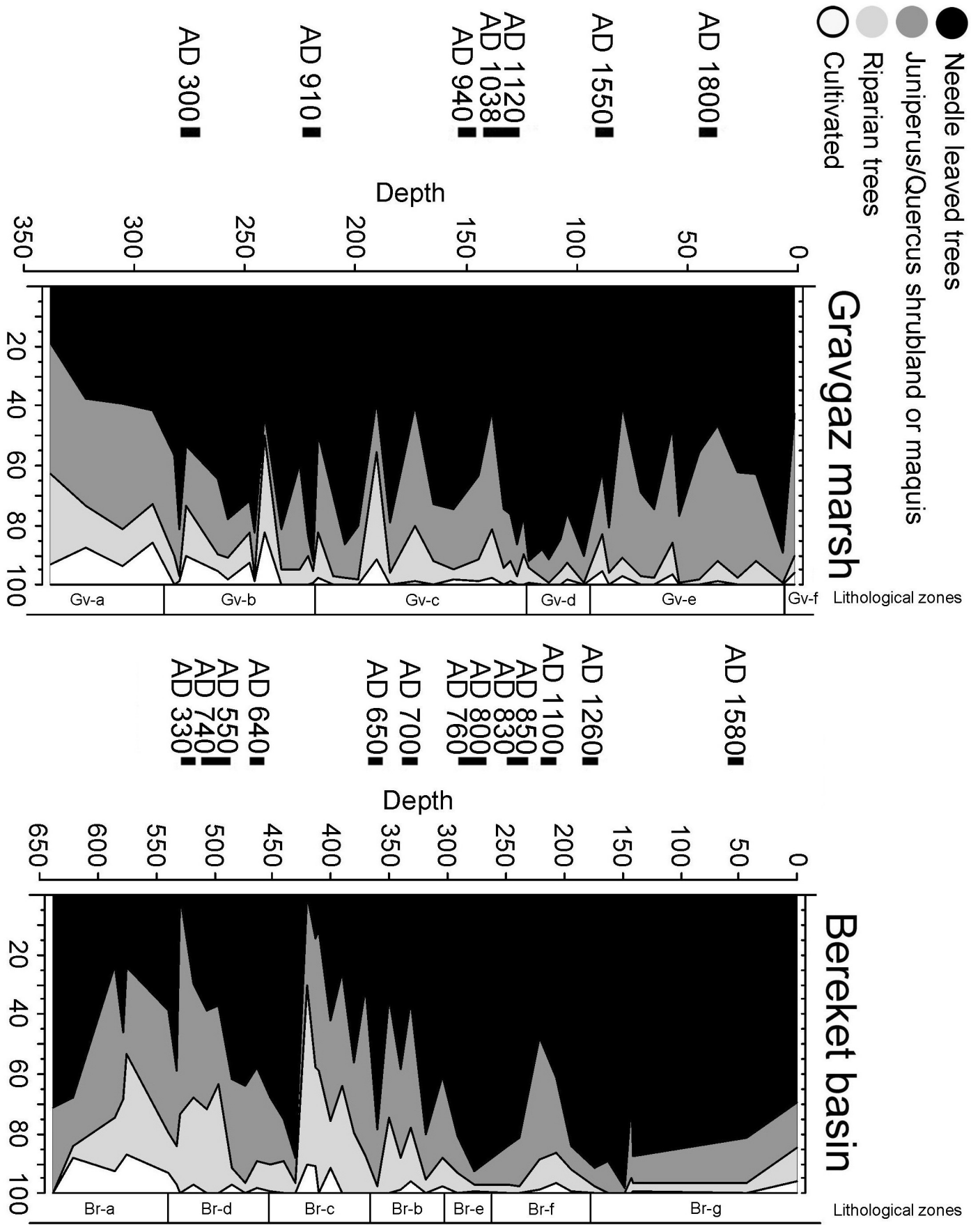


Fig. 3.13. Summary percentage pollen diagram, displaying the relative contribution of the most important tree and shrub species to the total tree and shrub pollen count for core SA06EP1 (Gravgaz Marsh) and SA09JBDrill02 (Bereket basin).

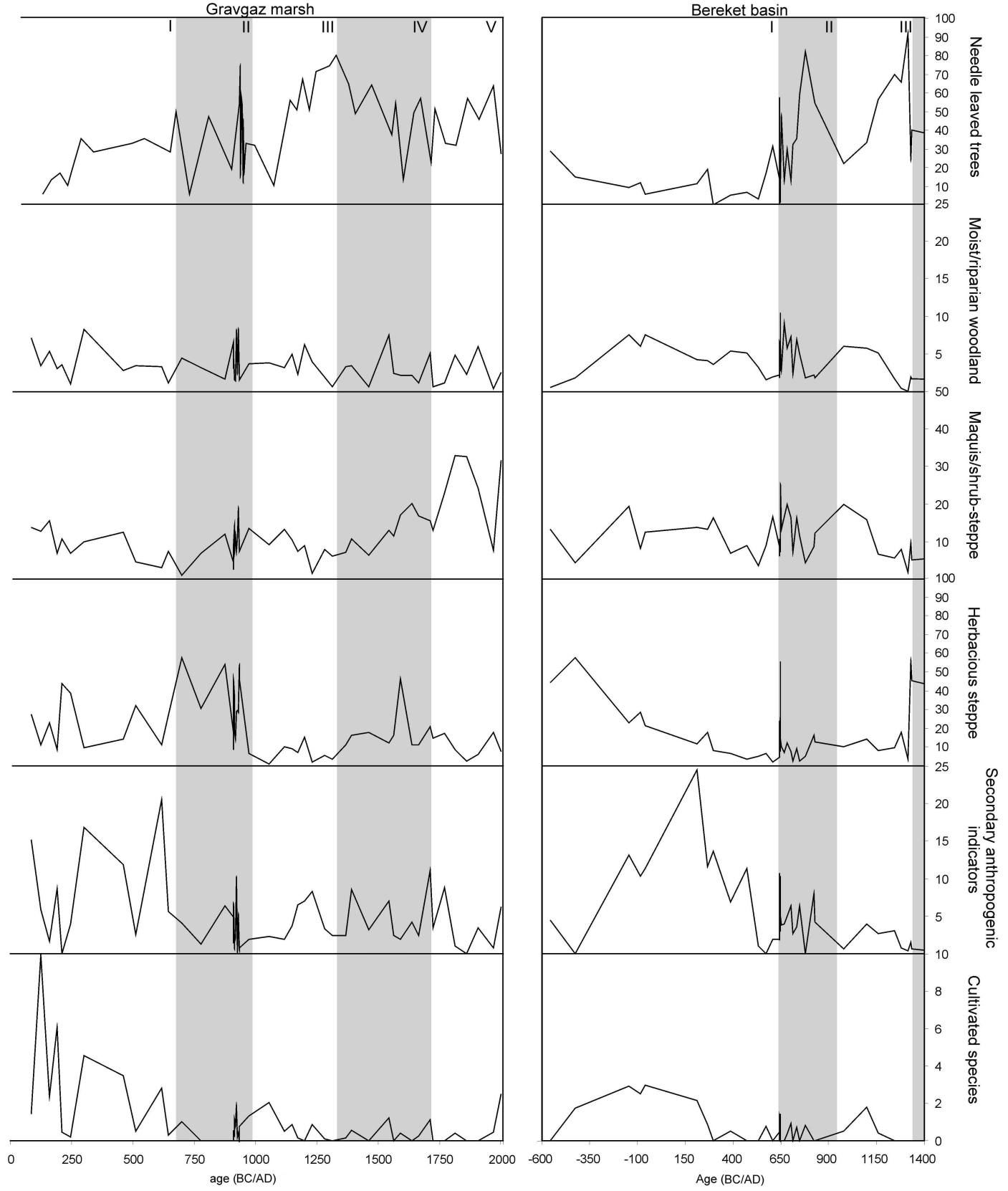


Fig. 3.14. Summery percentage pollen diagrams of the records from Gravgaz and Bereket displayed along a time axis, showing curves for groups of pollen taxa determined to be indicative of various specific environments, based on the literature referenced in Tables 1.2 and 1.3. The Bereket diagram omits the top, uninformative section of the pollen record.

3.5. Discussion

3.5.1. Sediment dynamics

The mean values of the OM (Bereket: 30% versus Gravgaz: 10%), as well as the composition of the detritics are very different on both sites, suggesting a different local environment. CC and non-carbonates account for respectively 65% and 35% for Bereket and 18% and 82% for Gravgaz (Table 3.5). The differences in composition are mainly caused by differences in sediment provenance. For both sites ophiolithic mélange, limestones and older colluvial deposits, all with different surface areas (Fig.3.1), deliver mainly non carbonates, but also calcium carbonates. These detritic CC are estimated below 10% for Gravgaz and below 20% for Bereket. The latter figure is based on data by Kaniewski et al. (2007) for the northern valley which drains nearly exclusively these substrates. Six (2004) revealed that the isotopic composition of oxygen and carbon of the CC present in the sediments of the central part of the Gravgaz marsh has a meteoric water signature, and precipitated from spring waters dominantly influenced by soil-CO_2 and/or CO_2 released during decomposition of plants and did not originate from physical erosion of the limestone mountains. The spatial distribution of CC in the sediments at the present surface supports the notion that CC may partially originate from the precipitation from source waters fed by an aquifer situated in the limestone substrate. The combination of above the mean values for both organics and CC in some lithological units at Gravgaz (Figs. 3.9 and Table 3.5) may be interpreted as the signature of evaporation processes in a local wetter environment where conservation of organics was possible. At Bereket, the combination between OM and CC content is strongly negative, as periods of peat formation alternate with periods of influx of CC dominated detritics. High CC contents of the detritic deposits in Bereket, very obvious in units Br-a and Br-c are likely due to the influx of the eroded marl substrate from the western slopes. The sediment fingerprinting studies of D'Haen (2012) revealed that the sediment in one sample from these deposits is also characterized by a large amount of ophiolithic mélange, which is present to the south of the drill site. However, the high CC content throughout these deposits makes it more realistic that they originated from Marl deposits. In any case, the inverse relationship between OM and CC content may be indicative of an open or absent vegetation on locations some distance away from the sample site, causing an increase in erosion. The possible role of autigenic CC at Bereket is unknown.

Local sediment dynamics may be primarily influenced by purely local environmental changes and need not be related to regional environmental changes in any way. However, when a certain change in the local environment occurs simultaneously at multiple locations, it may be that this phenomenon does represent a local response to a regional change in the environment. In Bereket and Gravgaz, two such simultaneous shifts, implying regional environmental change, occur.

A shift towards a moister environment occurs in both records during the late 3rd century AD.

At Gravgaz, the organic clay Unit Gv-b, indicates simultaneous high values for OM and CC (Fig. 3.9), indicative of increased moisture availability at the sample site. At Bereket, an organic rich clay layer starts to develop at this time, eventually grading into a clayey peat deposit during the early 6th century.

The second simultaneous change in sediment dynamics occurs during the late 13th century AD. At Gravgaz, a local drying trend occurs during the mid 13th century. At Bereket, the accumulation of clayey peat ends abruptly at the close of unit Br-f dated c. AD 1260, indicating a drastic change in local hydrology.

During the intermediate period, the Bereket record shows no response to changes in the regional environment indicated by the pollen data. The accumulation of clayey peat continues more or less uninterrupted until the second half of the 13th century, only interspersed by two short term sedimentation periods at AD 640-660 (unit Br-c) and at AD 760-820 (unit Br-e), indicative of changing environmental conditions elsewhere in the basin. It may be that the activity of nearby springs provided enough water to overpower any climatic influence or local environmental change on OM content.

The Gravgaz record seems to have been more sensitive to environmental change. The local humid trend in Gravgaz, occurring since the late 3rd century AD, is reversed during the second half of the 7th century AD, which may suggest a decrease of the precipitation-evaporation balance. The notable peak in CC, occurring in the first quarter of the 10th century is not reflected in the regional pollen signal and is more likely a short-term local change in the flow of the brooklets feeding the marsh with spring waters.

After AD 1330 the CC content of unit Br-g seemingly increases, although the low number of samples from this unit makes it impossible to determine whether this is a continuous trend reflecting an increasing openness of the environment on the slopes on marl.
Although reliable sedimentological data are only available from the Gravgaz record for the period from the 14th century AD onwards, changes in OM and CC content do show a remarkable correspondence with a tree-ring based reconstructed record of May-June precipitation in SW Anatolia for the altitudinal range 1700-2020 m a.s.l., covering a time interval of AD 1097-2000 (Touchan et al., 2007).
Two of their three driest 70-year periods, dated AD 1195-1264 (the driest) and AD 1434-1503, are mainly situated within the time frame calculated for unit Gv-d. This layer is depleted of organic material. This may result from the oxidation of organic matter under dry circumstances. The peak of calcium carbonate matter coinciding with the top part of this Unit may be indicative of the forming of a soil on the dry former marsh surface, calcium carbonates precipitating downward.
These dry periods in the data of Touchan et al. (2007), are separated by a notably wet interval dated AD 1285-1360. This interval does not stand out in the sediment data. The AD 1434-1503 May-June dry period is succeeded by a pronounced increase in humidity dated from AD 1470 onwards. This part of the tree ring based climatic proxy corresponds with an increase in local humidity recorded in Gravgaz marsh at the start of sediment unit Gr-e, dated at c. AD 1440 – 1520. The period of AD 1518-1587 is considered the most humid May-June period during the last 900 years by Touchan et al. (2007). Only one sample in the sediment record of Gravgaz corresponds with this time interval. However, this sample does indicate the highest OM content for the last 600 years.

3.5.2. Chronology

While the relatively high number of radiocarbon dates available for the Gravgaz and Bereket cores do create a more trustworthy chronological framework compared to earlier palynological records from the region, the exact ages of the pollen samples located between two carbon dates remain unknown and have been estimated using extrapolation and interpolation under the assumption that sedimentation rates were constant between two radiocarbon dates. Although this is a relatively reasonable assumption to make when dealing with peat bogs, it is more likely to be wrong that right in the context of a mountain valley filled with colluvial deposits. Even though there are remarkable similarities between the sediment record of Gravgaz Marsh and the tree-ring data of Touchan et al. (2007) for the last 1000 years (the timing of the wet and dry periods identified in both records are never more than 50 years out of step with one another), this need not be the case for the remainder of the core, nor for the Bereket core. Nevertheless, when a researcher is watchful and pays attention to signs of increased sedimentation the chronological framework may be strengthened. Signs such as low pollen concentration, increased abundance of damaged/corroded pollen, changes in OM and detritic matter weight percentage, etcetera, may indicate which parts of the record represent most of the time interval between two radiocarbon dates.

3.5.3. Vegetation Dynamics

3.5.3.1. Indicators of livestock herding in the pollen spectrum

When occurring in dry and degraded vegetation, livestock herding (e.g. pastoralism) may not be indicated by secondary anthropogenic indicators. In such circumstances, grazing may be detected by increased values of coprophilous fungi and the development of open herbaceous vegetation. (Over)grazing by goats and sheep may drive the development of degraded *Quercus coccifera* dominated woodland. However, while evergreen oak can withstand intensive grazing, grazing pressure can stunt growth (Fontaine et al., 2007) and limit pollen production (Bottema and Woldring, 1995). During the BO Phase, high abundance of evergreen oak was associated with the herding of pigs (De Cupere, 1998), and other economical activities. Oak woodlands were therefore actively maintained by the local populace. However, no signs of this activity, in the form of unusually high *Q. coccifera* percentages have been found in the pollen records. Periods that show slightly raised percentages for *Q. coccifera* are interpreted as being indicative of grazing.

3.5.3.2. Selective transportation of pollen

Asteraceae percentages occasionally show peaks, reaching up to 40%. These peaks do not coincide with higher percentages of damaged pollen or indications of abnormal sediment disposition, apart from in the top part of the Bereket basin record. The notion that such values are caused by differential pollen preservation in other parts of the cores is rejected on these grounds. High Asteraceae percentages occur frequently in cores from Turkey and occur in cores from Ağlasun, near Sagalassos (Vermoere, 2004). According to Bottema and Woldring (1984; 1990), heating effects in the summer may cause upward wind flows which transport and concentrate Asteraceae pollen, precipitating them in relatively cool locations such as lakes and valleys. This process would require a relatively open landscape and low levels of cloud cover and precipitation. High levels of Asteraceae can therefore be a sign of dry climatic conditions in an open landscape. Earlier records from Gravgaz have not recorded any such peaks as their lower resolution may have missed them, while the high Asteraceae peaks found in the lowest part of the Bereket basin core are found in sediments not present in the cores analyzed by Kaniewski et al (2007a, b). The sample site of core SA06EP1 is located in the middle of the Gravgaz swamp, which is a more ideal place for the deposition of Asteraceae pollen compared to previously studied sample sites (Six, 2004; Six et al., 2008b; Vermoere, 2004; Vermoere et al., 2000; 2002a; 2002b), nearer to the edge of the basin. Core SA0EPdrill02 is also located in the centre of the valley of the Aykirdak Deresi.

3.5.3.3. The relation between vegetation cover and moisture availability

The relationship between vegetation and climate works both ways. While a change in the climate may result in a change in the vegetation, a shift in vegetation cover over a larger area may result in the change in climate. It is a well known phenomenon that a decrease in the amount of forest may lower the amount of evaporation of moisture. Such a decrease in evaporation would then lead to a decrease in cloud formation and eventually precipitation (O' Brien, 1995; Pielke, 2001, Anav et al. 2010). Avissar and Liu (1996) indicated that rainfall patterns may be influenced by fragmentation of the landscape, land surface changes on the order of 10 km^2 being able to cause changes in the local rainfall pattern.
The pollen data from Bereket and Gravgaz indicates that this process is of little or no importance in the territory of Sagalassos. Both present records, as well as previous records analysed by Vermoere et al. (2002a, b) and Kaniewski et al. (2007a, b) indicate how the landscape was continuously relatively open for centuries while the pollen records indicated a succession of relatively wet and relatively dry periods. Relatively open vegetation persisted throughout the relatively wet period that occurred at c. AD 250-640. In fact, the pollen data indicates that, during times of relative drought, the amount of forest actually increased, in the form of dry-tolerant pine forest on the hills surrounding the basins. The Bereket core indicates how the marsh in the centre of the basin dried out, allowing for the establishment of a riparian woodland on and near the previously submerged sample site.
Another important way that vegetation change might influence climate is the extraction of water from the soil by needle leaved trees (Qureshi et al., 1964). It is generally known that needle-leaved trees such as pine are able to extract sizable amounts of water from the soil, the establishment of pine forest around a basin eventually leading to drier conditions within that basin (Sun et al., 2000; Waterloo et al., 1993). If this process was important within the territory of Sagalassos, the relationship between local dryness and a relatively cold climate, indicated in chapter 3 of this dissertation, would not exist, the establishment of pine forests in absence of crop cultivation and pastoralism being the cause of local climate change, rather than the result.
However, in the Gravgaz marsh record, it is clear that the establishment of dry conditions preceded the establishment of pine forests by decades, if not centuries. The amount of pine pollen fluctuated during the dry phase in Gravgaz marsh, but showed an increasing trend. However, pine pollen percentages the start of this dry period were comparable to those observed for the preceding wet period, and were comparable to percentages found at the top of the pollen core.

When, after the 10th century deforestation in Gravgaz and Bereket, the pine forest regenerates from the 12th century onwards, taxa indicative of relatively moist pastures, fields and meadows (Chenopodiaceae, Rosaceae, *Platanus,* and *Plantago* in Gravgaz. Decidious oak, *Polygonum aviculare, Polygonum cognatum,* Brassicaceae, and Chenopodiaceae in Bereket) remain present until the early 14th century. Furthermore, the statistical analysis discussed in chapter 4 of this dissertation indicates that, while pine forest is seen as an indicator of drought, based on the timing and associations of taxa recognized by the analyses, its importance as a drought indicator is very limited. This indicates that changes in the amount of pine forest in the region have only a limited influence on local changes in hydrology and that it is climate change that drives vegetation change (together with changes in anthropogenic impact), and not the other way around.

3.5.3.4. Zone I (until c. AD 640)

The focus of the palynological record is on the period post-dating the 7th century AD, although the late Roman period is also included in the data. Olive cultivation disappeared altogether in the Bereket basin during the second half of the 3rd century AD, while it continued to be present until the mid 7th century around Gravgaz marsh. The estimates for the ending of the BO-Phase given for Gravgaz is more or less contemporaneous with estimates given for other records in SW Turkey, which lie between c. AD 400 and 900 (van Zeist et al. 1975; Bottema and Woldring 1984; Eastwood et al. 1998 (See chapter 1 and Chapter 2). Not only is the estimation for Bereket unusually early, it is also unusual to find such a large time difference (second half of the 3rd century for the Bereket Basin, mid 7th century for Gravgaz) in two well dated records located within a relatively small distance from one another.
Despite the differences in the timing of the end of the BO Phase proper in Gravgaz and Bereket, the pollen data reveal that the end of the BO Phase in Bereket coincides with a gradual decrease in human impact around Gravgaz, indicating that the phenomenon which ended the BO Phase pollen signal in Bereket had an influence over a wider area and was not a small scale change in anthropogenic activity or environmental conditions restricted to a single basin.
The sedimentological and regional pollen data from both locations imply that the late 3rd- early 7th century AD period is characterized by relatively moist conditions, eventually beneficial to intensive agriculture in the region. A similar moist trend is observed throughout the Eastern Mediterranean and the Middle East (von Rad *et al.,* 1999; Hirschfeld, 2004; England *et al*., 2008; Jones *et al*., 2006; Sorell *et al*., 2007; Neumann *et al*., 2007a,). It may be that the amount of arable land on the valley floors had shrunk as the marshes and wetlands on the valley floors encroached upon it. While an increase in precipitation in the relatively dry region of SW Turkey may be seen as amelioration, the current study implies that local effects may actually be detrimental to human activities in areas which were already relatively wet, such as the marshlands at the bottom of the Bereket and Gravgaz basins.
Detailed records of vegetation change during this particular period are rare for southwest Turkey. Earlier records may not have recorded this phenomenon due to limitations in chronology and/or sampling resolution. This new phenomenon may well be evidence of socio-economical or environmental changes that occurred throughout the wider region. This moist trend and its possible impact on agriculture and vegetation are discussed in more detail in chapter 7 of this dissertation.

3.5.3.5. Zone II (c. AD 640-940)

The mid 7th century marks a turning point in the vegetation history within the territory of Sagalassos, as well as in the wider Eastern Mediterranean region as anthropogenic impact in the form of intense cereal cultivation and arboriculture shows a marked decrease (Enzel et al., 2003; Leroy, 2010; Neumann et al., 2010). The limited pollen production and dispersal capabilities of Cerealia type pollen are well known. Therefore one cannot conclude that the disappearance of Cerealia type pollen from one single pollen core indicates However, the fact that Cerealia type pollen disappear completely and remain absent for a sizable part of this zone in the Gravgaz pollen record indicates that Cerealia pollen also did not form part of the background pollen signal at that location. Additionally, a similar absolute disappearance is also observed in the earlier Gravgaz pollen records of Vermoere et al. (2002a, b), which were collected at different locations within the marsh.

Most plant taxa indicating dry, open steppe vegetation are small herbaceous species with limited pollen production and dispersal capabilities (see chapter 6). Increased pollen percentages above the modern day background pollen signal, not including those taxa which are subjected to selective pollen transportation, indicate an increased abundance of these species in the wider region, suggesting an overall increased abundance in dry open steppe, rather than merely in the close vicinity of the sample sites.
The pollen data indicate that the decrease in crop cultivation and arboriculture, and switch to pastoralism seen in the Gravgaz marsh pollen data, and the further increase in pastoralism observed in the Bereket basin coincides with the establishment of distinctly dry and open vegetation. The sediment data shows that in Gravgaz, the high organic matter content of the sediments, which had been increasing since the second half of the 3rd century, started to decrease shortly after the start of this period, and continued to gradually decrease until the early 10th century, suggesting a continued local aridification of the valley floor throughout most of this period.
The decrease or disappearance of anthropogenic indicators is immediately followed by a distinct increase in *Pinus* pollen in many records from SW Turkey (van Zeist et al. 1975; Bottema and Woldring 1984; Roberts 1990; Eastwood et al. 1998) and beyond (Heim et al. 1997; Neumann et al. 2007a, 2010; England et al. 2008). The sudden increase in *Pinus* in many Middle Eastern records is also subject to ongoing debate. Some attribute this to fast reforestation by pine dominated woods after a decrease in population (Neumann et al. 2007b; Kaniewski at al. 2007b; England et al. 2008). Pines are early pioneers of abandoned farmland and can cope with dry environments (Zohary 1995; Ne'eman et al. 2004; Neumann et al. 2007a). Another hypothesis proposes that the high pine pollen percentages originate in a distinctly open, overgrazed landscape. In this case the pollen production of the open vegetation is incapable of overpowering the pollen signal of the pine forests on the higher mountain slopes (Bottema and Woldring 1995; Vermoere et al. 2002a, b; Knipping at al. 2008). There are several high resolution pollen diagrams available that indicate that the sudden increase of pine forest has indeed taken place in some locations (Neumann et al. 2007a, 2010).
The new pollen data from SW Turkey indicates that, after the disappearance of intensive crop cultivation, human impact remained present, but the focus shifted towards pastoralism, resulting in a dry, open steppe and/or maquis vegetation. Near Bereket, the establishment of such an overgrazed, degraded vegetation resulted in the erosion of the marl deposits and the deposition of these sediments in the marsh. As human impact continued to dwindle the, a secondary pine forest gradually developed in the Bereket basin from the 8th century AD onwards. Such a slower process could have taken place elsewhere, but may have been missed in some of the older cores due to low sampling resolution. In any case, the establishment of an open, overgrazed landscape did not cause an immediate rise of pine pollen in the Gravgaz pollen core. This new information has a profound impact on previous interpretations of vegetation change after the end of the BO Phase.
It is an undeniable fact that pines, as well as other needle leaved trees such as *Abies*, are very copious pollen producers, their vesiculate pollen grains are able to travel large distances. Richardson (1998) indicates that *Pinus* pollen has been found in large quantities at distances of up to 58 kilometres from the nearest pine forest. However, within well preserved modern pollen samples from southwest Turkey, there is still a notable difference in pine pollen percentages between samples collected within or very near to a pine forest, and samples collected in open, herbaceous vegetation at a greater distance from a pine forest. A collection of 64 modern pollen samples, collected by Vermoere, and submitted to the European Modern Pollen Database (EMPD) project (see also Fig. 3.15 and Table 3.8), revealed how pine pollen percentages in samples collected in open herbaceous vegetation had an average pine pollen percentage of 47.5%. By comparison, the samples from pollen core SA06EP1, collected from the centre of Gravgaz marsh, and dating from the beginning of the 20th century until 2006, displayed an average pine pollen percentage of 36.9%. Pollen samples collected within a pine forest had an average pine pollen percentage of 85.4%. High *Pinus* pollen percentages are also encountered in samples on extremely exposed locations, such as the sparse herbaceous vegetation on limestone rocks, located on the clear-cut slopes above the city of Sagalassos. Modern pollen samples collected in the seasonal lake of Canaklı also reach very high pine pollen percentages. This seasonal lake is a vast, flat area, the very sparse vegetation of which is dominated during the summer by Poaceae, which in the samples of Vermoere (2004) reaches surprisingly low percentages. The modern pollen samples collected around the edge of Gravgaz marsh by Vermoere (2004) are unusual, as *Pinus* pollen is remarkably abundant, reaching values of over 80% in some samples. These values surpass *Pinus* pollen percentages found in locations much more exposed and much closer to actual pine forests. Modern pollen samples collected from the herbaceous vegetation surrounding Gravgaz marsh during the 2009 and 2010 fieldwork campaigns revealed an average pine pollen percentage of 14.8%. Modern pollen data collected by Kaniewski et al (2007b) in the Bereket

basin revealed that pine pollen percentages in the samples collected in the central basin did not exceed 25%, despite the presence of mixed *Pinus nigra/Cedrus libani/ Juniperus excelsa forest*, surrounding the basin on the western, northern, and eastern side.
The combination of the data from Kaniewski et al. (2007b), Bakker (this dissertation), and the other 59 samples collected by Vermoere (2004) indicate that, while pine pollen may reach percentage values of up to 60% in the present open landscape, high percentages of 70-90% pine pollen are only reached when a sampling location is either devoid of most vegetation, located on an extremely exposed place, or when a sample site is located near or in a pine forest. Taphonomical problems, resulting from the frequently flooding and drying of a sample site, may also lead to elevated pine pollen percentages. As the modern pollen samples collected by Vermoere (2004) are located at the very edges of the marsh, it may be that these samples had indeed suffered from repeated flooding and drying of the sediments. Unfortunately it is unknown to what extent such environmental circumstances damage the pollen and how long it takes before all pollen except the strongest types remain. Another hypothesis suggests that pine pollen percentages may accumulate at the edges of open water. If there was open water on Gravgaz marsh while the pine trees released their pollen, this may have accumulated at the sample sites of Vermoere (2004). This would not have occurred at the site of SA06EP1 as this core was collected from the centre of the marsh. However, it is impossible to determine to what extent the marsh was inundated (if at all) during springtime over a decade ago and whether this water reached the sample sites of Vermoere (2004). Although it remains unclear what caused the high pollen percentages present in moden pollen samples collected near Gravgaz marsh by Vermoere (2004), they seem by all accounts to abnormally high. The relationship between pollen percentages of a certain taxon, and the presence of that taxon in the landscape is the subject of part III of this dissertation.
The pollen and sediment data of present study supports the theory that a rise in pine pollen signals an increase in pine forest, rather than the presence of an open vegetation type. Not only is there evidence supporting the notion that the background *Pinus* pollen signal is much lower than previously assumed, the recent pollen data also displays a pollen spectrum indicating open herbaceous steppe vegetation separately from a pollen spectrum containing very high *Pinus* pollen percentages.

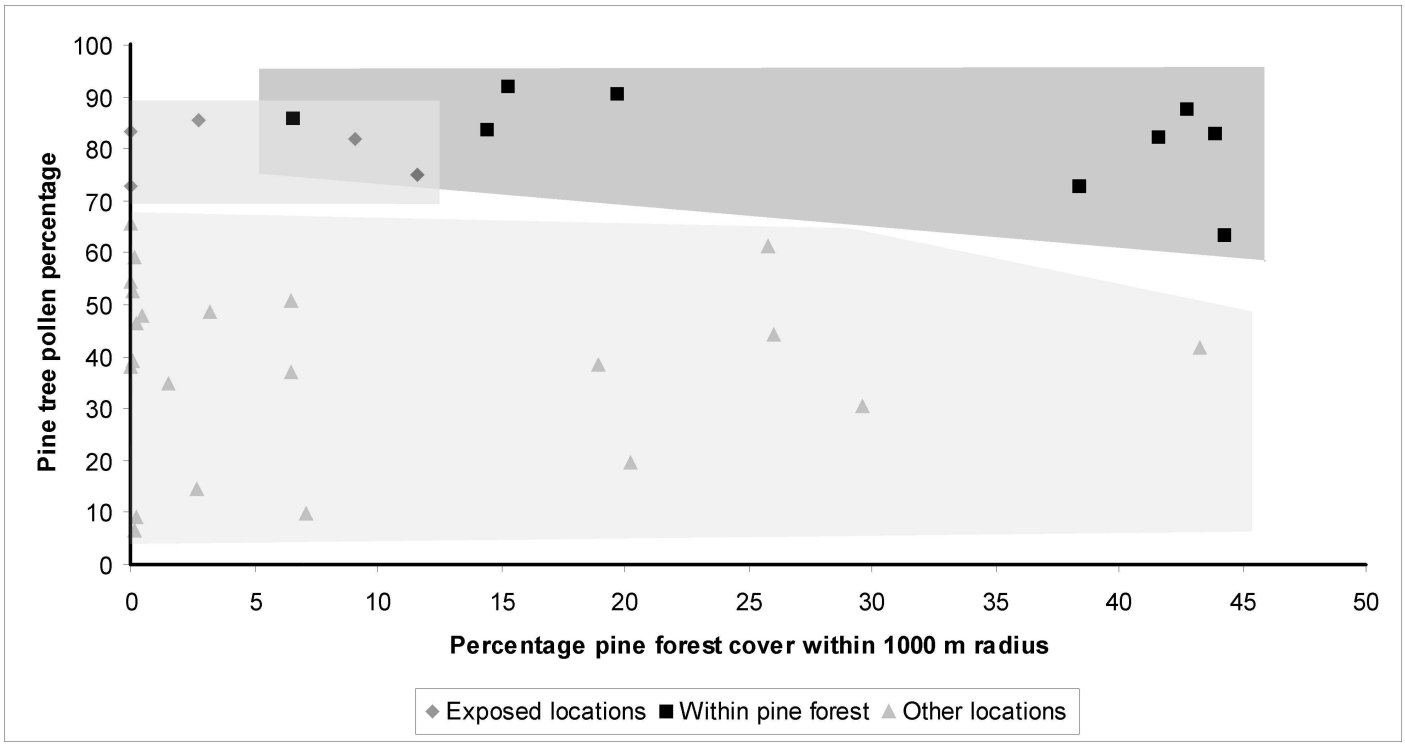


Fig. 3.15. The relation between percentage forest cover within a circle with a diameter of 1000 m around a site of a modern pollen sample and the percentage coniferous pollen (*Pinus, Abies, Cedrus*) found in within that sample, displayed for a selection of modern pollen samples collected within the territory of Sagalassos. Multiple samples with a similar vegetation cover have been averaged and displayed as one point in this graph. Modern pollen samples with a SA number originate from Vermoere (2002). Modern pollen samples with an SA10JB or SA09JB number were collected for use in the present dissertation.

Table 3.8A. The relation between percentage forest cover within a circle with a diameter of 1000 m around a site of a modern pollen sample and the percentage coniferous pollen (*Pinus, Abies, Cedrus*) found within that sample, displayed for a selection of modern pollen samples collected within the territory of Sagalassos. Multiple samples with a similar vegetation cover have been averaged and displayed as one point in this graph.

ID	Northings	Eastings	Pine forest cover %	Pine forest pollen %	Description	Category
SA19	37°40.983	30°31.045	0.00	64.54	Herbaceous alpine vegetation	Exposed
SA18	37°41.105	30°30.824	0.00	66.02	Herbaceous alpine vegetation	Exposed
SA15	37°40.710	30°30.739	0.00	71.61	Herbaceous vegetation on limestone scree	Exposed
SA37	37°35.168	30°33.370	0.00	75.65	Open vegetation on seasonal lake (Canaklı)	Exposed
SA38	37°34.881	30°33.592	0.00	86.74	Open vegetation on seasonal lake (Canaklı)	Exposed
SA39	37°35.413	30°32.803	0.04	83.42	Open vegetation on seasonal lake (Canaklı)	Exposed
SA10JB15	4158928	261512	2.76	85.58	Open steppe with sparse Juniperus vegetation facing the pine/juniper forest across the basin	Exposed
SA10JB14	4159421	261292	9.09	81.73	Open pine/juniper forest on hill slope north of the basin	Exposed
SA17	37°33.655	30°35.683	11.61	75.00	Overgrazed Quercus coccifera maquis	Exposed
Average Pine forest pollen: 76.70		Max: 86.74		SD Min: 64.54		
SA30	37°38.086	30°30.196	6.54	85.80	Pinus forest	Pine forest
SA26	37°33.060	30°34.571	14.45	83.54	*Cedrus* forest	Pine forest
SA27	37°32.949	30°34.701	15.25	92.05	*Cedrus* forest	Pine forest
SA35	37°38.255	30°39.602	19.66	90.69	*Pinus* forest	Pine forest
SA31	37°38.024	30°39.291	38.37	72.78	Herbaceous vegetation among *Pinus* forests	Pine forest
SA29	37°37.637	30°39°398	41.58	82.30	Open Herbaceous vegetation within *Pinus/Abies* forest	Pine forest
SA32	37°37.734	30°39.564	42.78	87.63	*Pinus* forest	Pine forest
SA33	37°37.766	30°39.346	43.90	82.84	*Pinus* forest	Pine forest
SA12	37°37.680	30°33.162	44.27	63.37	Young *Pinus brutia* plantation	Pine forest
Average Pine forest pollen: 82.33		Max: 92.05		SD Min: 63.37		
SA11	37°34.425	30°23.829	0.00	61.55	Open Herbaceous vegetation above *Q. coccifera* shrubland	Other
SA48	37°40.623	30°30.224	0.00	61.60	Herbaceous vegetation among Sagalassos ruins	Other
SA10JB23	4161168	267625	0.00	63.37	Open Herbaceous vegetation surrounded by open *Q. coccifera* shrubs on top of exposed hill	Other
SA20	37°40.531	30°31.677	0.00	63.69	Herbaceous vegetation on limestone	Other
SA08	37°35.050	30°34.869	0.00	77.47	Herbaceous vegetation between degraded *Q. coccifera* shrubs	Other

Table 3.8b. Same as a.

SA10JB06	4162967	270964.2	0.01	6.08	Middle of Gravgaz marsh. Local vegetation characterized by sedges	Other
SA41	37°35.129	30°24.241	0.01	44.55	Herbaceous vegetation near Gravgaz marsh	Other
SA40	37°34.874	30°23.966	0.01	63.93	Herbaceous vegetation near Gravgaz marsh	Other
SA02	37°34.793	30°35.424	0.02	54.32	Heracious vegetation near fields	Other
SA57	37°39.708	30°28.554	0.08	52.69	Herbaceous vegetation near fields	Other
SA10JB09	4163441	269662.8	0.10	39.01	open *Q. coccifera* shrubland near Gravgaz marsh	Other
SA10JB33	4158847	269018.8	0.15	6.62	Southern edge of agricultural fields. Near open *Quercus* shrubs on hillside	Other
SA09	37°33.785	30°24.335	0.17	58.06	Herbaceous vegetation in open *Q. coccifera* and *Juniperus* maquis	Other
SA10	37°33.768	30°24.276	0.17	59.74	Open Herbaceous vegetation above *Q. coccifera* and J*uniperus* maquis	Other
SA25	37°33.963	30°33.616	0.22	9.03	Dense stand of *Q. coccifera* trees	Other
SA01	37°39.601	30°28.438	0.25	46.41	Herbaceous vegetation among fields	Other
SA56	37°39.502	30°29.573	0.45	47.96	Open place in *Q. coccifera* maquis	Other
SA03	37°38.515	30°28.422	1.52	34.78	Herbaceous vegetation between *Q. coccifera* shrubland and grain fields	Other
SA10JB04	4161233	271184	2.64	14.55	In the middle of fallow fields overgrown with Asteraceae, near Gravgaz marsh	Other
SA06	37°38.744	30°29.784	3.21	48.55	Herbacous vegetation on travertine	Other
SA55	37°37.981	30°29.724	6.49	50.86	Open place in *Q. coccifera* maquis	Other
SA21	37°38.175	30°29.970	6.51	36.79	Degraded Herbaceous vegetation	Other
SA10JB30	4160404	290030.9	7.09	9.64	Fields and Herbaceous roadside vegetation. Juniper woodlands to the south. Pine forest to the east	Other
SA63	37°37.302	30°33.875	18.91	38.52	Open vegetation near *Q. cerris* stands	Other
SA64	37°37.230	30°33.848	20.25	19.64	Open vegetation near isolated *Q. cerris* stands	Other
SA62	37°37.155	30°33.671	25.78	61.16	Grazed *Q. coccifera* maquis	Other
SA59	37°37.447	30°33.566	26.04	44.26	*C. coccifera/Juniperus* maquis	Other
SA24	37°37.287	30°33.549	29.64	30.31	*Quercus coccifera/Juniperus* maquis	Other
SA58	37°37.804	30°33.047	43.30	41.73	Open maquis vegetation	Other
Average Pine forest pollen: 43.00		Max: 77.47		Min: 6.08		

3.5.3.6. Zone III (c. AD 940-1300)

The onset of this period was marked in Gravgaz marsh and the Bereket basin increased signs of pastoralism, while at Bereket, the start of this period is marked by a deforestation of the landscape (Bakker et al., 2011a, 2011b, submitted). Furthermore, the resurgence in anthropogenic impact in Gravgaz is also indicated by an increased influx of non-carbonate detritic material into the marsh (Fig. 3.9 and 3.10).

This resurgence is not observed in earlier records from southwest Turkey (van Zeist, 1975; Bottema and Woldring, 1884), likely due to limitations of the sampling resolution and chronology. A similar resurgence in anthropogenic activity has only been recorded in one record from Nar Lake, central Turkey (England et al., 2008; Eastwood et al., 2009), indicating it is a local expression of a wider increase in anthropogenic pressure. The role of human impact in the territory of Sagalassos and in the whole of Byzantium is one of the subjects of chapter 7 of this dissertation.

The presence of cultivated species in the pollen diagram remains much more limited than during the BO-Phase. While Poaceae Cerealia pollen increased slightly, their percentages were too low to determine whether they were a sign of local cereal cultivation, or naturally occurring grasses. Furthermore, it is notable that *Olea* cultivation and arboriculture in general remains absent during the MCA. The focus of anthropogenic activities remained on cattle grazing and possibly limited cereal cultivation, rather than arboriculture. Eastwood et al. (2009) attribute the lack of olive cultivation, in the pollen record of Nar Lake, to the fact that during such unstable times as the Mid-Byzantine, it was not worth the effort to invest in such potentially vulnerable, time-intensive crops.

Human impact on the landscape diminishes during the mid 12th century, secondary mixed spruce/pine forests becoming dominant in the landscape. This decrease in anthropogenic activity may be related to a period of intense drought spanning several centuries. The tree ring data of Touchan et al. (2007) indicate a gradual, minor dry trend since AD 1170, followed by a pronounced aridification phase which starts between AD1200 and 1220, and lasts until c. 1500, roughly corresponding with the deposition of sediment zone Gv-d in Gravgaz. However, the uncertainties inherent in the dating techniques applied to the Bereket pollen core make it impossible to determine whether the climatic change observed in Touchan et al. (2007) coincides with the disappearance of human impact in the pollen record, estimated to occur in c. AD 1150, or with the deposition of a sediment layer devoid of OM, linked to very dry local conditions (zone Gv-d), estimated to occur in c. AD 1220.

3.5.3.7. Zone IV (c. AD 1300-1700)

The pollen data indicate that secondary mixed spruce/pine forest remained important in the territory of Sagalassos during the earlier part of this period. This dominance of pine is in stark contrast with the forest composition that was prevalent prior to the onset of human impact in the region (Bakker et al. 2011a), and which took the form of a mixed deciduous oak (most likely *Quercus cerris*, *Q ithaburensis* and *Q infectoria)* and *Pistacia* forest/woodland (Van Zeist and Woldring 1978; Bottema 1979; Baruch and Bottema 1991; Roberts et al. 2001; Wick et al. 2003; Vermoere, 2004).
The overall dominance of pine, rather than (deciduous) oak, may have been a result of colluviation caused by (over)grazing, which may have further decreased the amount of fertile soils covering the hillsides and slopes. Deciduous oak, which is intolerant of calcareous soils, would be restricted to the fertile deposits on the basin floors, while Pine forests, which are more resistant to calcium rich soils, are able to extend their range (Roberts 1990). However, many of the mountainsides in the study area have always been calcerous and it is impossible to determine how much more of the calcareous substrate in the study area had been exposed since the onset of human impact on the environment in the territory and how much the potential range of deciduous oak had decreased (if at all).
The sediment data imply very dry local conditions at the very start of this period, a continuation of the situation which was established during the late 12th century. The pollen data are in line with this interpretation, *Pinus* pollen percentages reaching a value of 79% at a depth coinciding with the start of this Unit, and dated to c. AD 1220. As discussed earlier, such high values may be achieved when the sample site itself is covered in pine forest, there is a problem with pollen preservation, or when the site is located on a very open and exposed location. Only the first two notions are realistic, although the second option is not supported by anomalous values in pollen concentration and preservation. Both imply very dry local conditions. The dry period observed in the sediment record as unit Gv-d ends during the mid 15th century AD, corresponding with the onset of a short, very wet phase recorded by Touchan et al. (2007). This local shift in moisture availability is not reflected in the regional pollen record, although the pollen data from Gravgaz marsh does indicate that the landscape becomes more open again from this period onward.
While this wet phase may not be represented in the pollen data from the territory of Sagalassos, there is no denying that there is a change in the sediment records, as well as a non-climate related change in the vegetation coinciding with the occurrence of the wet period of Touchan et al. (2007). This leads to the notion that the phenomena observed in the tree ring data, as well as in the current pollen and sediment data, both reflect different responses to the same climatic phenomenon.
The increasing openness of the landscape around Gravgaz marsh from the 16th century onwards indicates that livestock grazing may have been practiced around the marsh, although the lack of coprophilous fungi indicates that grazing did not take place at the sample site of core SA06EP1. The lack of cultivated species during this period, only *Castanea* occurs in the pollen record, indicates that crop cultivation did not take place near the location of the sample site. Cereal cultivation and arboriculture may have taken place elsewhere in the basin, beyond the reasonable distance over which pollen may be expected to travel. Unfortunately, apart from Cerealia type pollen, no data on the pollen production and dispersal capabilities of cultivated species is available for the study area (see chapter 6).

It must be noted that vegetation data from this period is only available from Gravgaz marsh. It is therefore unknown whether this increase in pastoralism was a local phenomenon, or whether there is evidence indicating it occurred throughout the territory. An increase in landscape openness indicated by the increasing CC content of the Bereket core is not considered conclusive evidence as the number of samples is too low and they are located too far apart. However, regardless of whether or not this phenomenon occurred elsewhere as well, the pollen data from Gravgaz are a clear indication of in increase in human activity within the rural landscape of the SW Taurus Mountains.

3.5.3.8. Zone V (c. AD 1700-the present)

The pollen data indicates that livestock grazing continued until the 19th century AD. The decrease of *Pinus* forest around Gravgaz marsh during the 19th century AD may be the result of increased timber export from the port city of Antalya and the consequent deforestation that took place in the Taurus Mountains during this period (de Planhol 1958; Vanhaverbeke and Waelkens, 2003). Although the chronology for core SA06EP1 is relatively detailed compared to most other cores from Anatolia, it is impossible to pinpoint when the increase in pine, observed in the pollen data, took place. Nevertheless, the pollen data indicate that the current landscape has a very recent origin. While it is impossible to estimate the age of the most recent samples of the pollen cores, historical evidence indicates that the present landscape is not much older than c. 100 years. Most of the present day villages in the study area date from the late 19th century. At that time the Ottoman government encouraged the nomadic part of the population to settle at one location. This was mostly done to simplify the process of tax collection (Vanhaverbeke and Waelkens, 2003) and will have resulted in a notable increase in sedentary agriculture. Vermoere (2004) indicates that the adaptation of agricultural machines and the establishment of a dense road network after the Second World War further boosted the expansion of agriculture in the region.

3.6. Conclusions

The two cores, from Gravgaz marsh and the valley bottom of the Aykirdak Deresi River in the Bereket basin, offered a unique opportunity to study the evolution of the vegetation after the end of the BO Phase in a detailed manner, and to properly distinguish between vegetation change caused by local (sedimentation events, local changes in water availability) and regional (climate change, widespread social change) changes in the environment. The chronology constructed for these records from Bereket and Gravgaz are unparalleled in SW Turkey and their accuracy is proven by the similarities observed between specific changes in vegetation and local sediment dynamics in the territory of Sagalassos and the occurrence of climatic trends observed for the last millennium in the data of Touchan et al. (2007).

The results of the pollen analysis of these two cores reveal how the vegetation responded to changes in anthropogenic pressure and provides a more detailed overview of when anthropogenic pressure on the landscape was present after the end of the BO Phase. The anthropogenic impact on the landscape during the 9th to 12th and 16th to 19th centuries AD has not been observed before in SW Turkey. The new data also led to a number of new insights into post BO Phase vegetation dynamics, most notably the notion that increased pine pollen percentages are not necessarily indicative of an open landscape whose vegetation cannot counter the copious pollen production of pine trees. While pine pollen percentages may increase, open, overgrazed vegetation is clearly indicated in the pollen data by the increased presence of herbs typical for dry steppe or meadow vegetation.

The new data shed new light on how and why the BO Phase ended. Most notably it becomes apparent that there is not necessarily one single phenomenon that caused the end of intensive BO Phase crop cultivation, not even within a smaller region such as the territory of Sagalassos. Furthermore, the new data clearly shows that, following the 6th century shift towards pastoralism, the resulting open and degraded landscape did not persist indefinitely, as was previously thought (Vermoere et al. 2002a,b). At times of reduced or no human impact, a secondary pine forest was able to establish itself. Deciduous oak was absent from the natural climax vegetation as soils suitable for the establishment of this tree have eroded away over the course of the BO-Phase.

Although the pollen and NPP data reveals the occurrence of several periods characterized by relatively wet conditions (c. AD 300-640 and during the $10^{th}/11^{th}$ century deforestation event), as well as relatively dry conditions (prior to c. AD 300 and after c. AD 640), it remains difficult to determine the duration of these periods. The following chapter will focus on this problem by creating a bioclimatic proxy of relative moisture availability and testing to what extent this bioclimatic proxy is driven by regional climatic change.

Chapter 4

Numerically derived evidence for late-Holocene climate change in the southwest Taurus Mountains, Turkey

This chapter is based on/adapted from:

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4.1. Introduction

The simultaneous presence of two major forces of influence driving vegetation change and succession; global climatic change, and anthropogenic activity, creates difficulties for the proper interpretation of vegetation change observed in pollen records. Therefore a thorough understanding of the timing and extent of both forces on the vegetation in the region of interest is of crucial importance. As illustrated by the historical overview presented in chapter 1, there is a growing amount of information on the dynamics of human civilisation from the Late Roman Imperial period until the present in what is now The Turkish Republic. However, attaining a good understanding of the patterns of climate change during the period and within the region of interest is more problematic.

4.1.1. Principal weather systems

The principal weather systems in the region mainly originate from the Atlantic Ocean, passing over Europe or the Mediterranean Sea. Relatively cold air leaving Turkey moves in a southern direction, colliding with warmer Saharan air over Cyprus, forming a front along which winter storms may travel eastward, bringing rain and snow into the Middle East (LaFontaine and Bryson 1990). As the region is a climatic transition zone, the Eastern Mediterranean is sensitive to fluctuations in natural environmental parameters, such as rainfall, temperature, vegetation types, the origin and pattern of storm tracks, and the location of the desert boundary (Bar-Matthews et al. 1999). The most dominant source of climate variability in the wider region is the North Atlantic Oscillation (NAO). The NAO accounts for one-third of the total variance in sea-level pressure and 20 to 60% of the December through March temperature and rainfall variability from Greenland and Europe to the Eastern Mediterranean (Luterbacher et al. 2009). Fluctuations in the NAO may result in surface winds and wintertime storms, moving across the north Atlantic from west to east, being stronger or weaker than usual. As a result, winters in the Eastern Mediterranean will be cooler and drier or warmer and wetter respectively. While in Europe, periods of increased yearly precipitation have been disastrous for agriculture, the increased precipitation in the Eastern Mediterranean, connected to a weak NAO, is considered to be an amelioration of the climate. Past changes in climatic conditions over the North Atlantic, such as described by Bond et al. (1997, 2001), may have influenced the NAO and thus the Middle Eastern winter climate (Cullen et al. 2002). On a smaller scale than the NAO, the Mediterranean basin is also subjected to the Mediterranean Oscillation (MO), driven by differences in atmospheric pressure between the Eastern and Western Mediterranean basins. The MO may affect wind and rainfall patterns in the region in a similar way to the NAO.
Furthermore, Anatolia forms a bridge between Europe, Africa and Asia for plants as well as human civilization, but it is not only subjected to the NAO. As the Mediterranean is situated on at the transition between the middle latitudes influenced by the NAO, and the tropical zone, the impact of the NAO varies from location to location. The role of NAO is significant for winter precipitation in the Western Mediterranean but weaker to the east and the south (Jalut et al. 2009). Other modes, which play an important role in shaping the Mediterranean climate are the Eastern Atlantic pattern, the Eastern Atlantic/Western Russia pattern and the Scandinavian pattern (Jalut et al. 2009).The climate in the Eastern Mediterranean is also influenced by changes in the El Niño Southern Oscillation (ENSO), South Asian and African Monsoons (Bolle 2003; Alpert et al. 2006; Jones et al. 2006).
The impact of the ENSO on the climate of extra-tropical regions is as of yet poorly understood (Pozo-Vázquez et al. 2001; Alpert et al. 2006). However, fur the Eastern Mediterranean, studies showed significant connections between ENSO events and winter rainfall in Israel, indicating increased rainfall occurring during

El Niño winters (Yakir et al. 1996; Price et al. 1998). La Niña winters appeared connected to below normal rainfall (Price et al. 1998). Kadioğlu et al. (1999) observed that most of the month-to-month variability in the monthly total precipitation from 1931 to 1990 AD at 108 meteorological stations in Turkey was related to El Niño events, which seemed to produce depressions as well as enhancements in southern and north-western parts of Turkey.
The South Asia Monsoon is a key factor influenceing the climate of the Eastern Mediterranean (Reddaway and Bigg 1996; Alpert et al. 2006), causing high variability in sea level pressure over Arabia and the Middle East, with high pressures in winter and low pressures in summer. Rodwell and Hoskins (1996) indicate how the Asian Summer Monsoon influences the Eastern Mediterranean, pointing out the linkage between the appearance of the semi-permanent subsidence structure over the Eastern Mediterranean and the onset of the monsoon. Liu and Yanai (2001) found a significant positive relation between the June-September All-India Rainfall Index and the June-September tropospheric temperature over the entire Mediterranean.
Both the Asian as well as the African monsoon also appear to be correlated with the Mediterranean Sea Level Pressure Oscillation. This correlation is negative for the Eastern Mediterranean and positive for the Western Mediterranean (Alpert et al. 2006). Indications for a relation between the (West) African Monsoon are also indicated by Rowell (2003), who found a significant correlation between Mediterranean sea surface temperatures and Sahelian precipitation, the latter increasing when the Mediterranean is warmer than average.
This multitude of systems influencing the climate patterns of the Eastern Mediterranean results in regional differences in the timing and magnitude of climatic change. It is therefore unclear which of the driving forces behind climate change will be more prevalent in the southwest Taurus Mountains and therefore the timing, as well as the impact (increased drought or increased precipitation) cannot simply be assumed on the basis of a comparison with the nearest available climatic record.

4.1.2. Climatic change in Europe and the Middle East during the last two millennia

Over the past two millennia Europe and the Middle East have witnessed a number of periods characterized by specific environmental conditions. The following text gives an overview of the extent and effects of these climatic periods in Europe and the Middle East. Much information is available concerning Late Holocene climate change, and quantifications of temperature and precipitation are available on a hemispherical scale, as well on more regional scales (e.g. Luterbacher et al. 2006b). However, as already stated in chapter 1 of this dissertation, it is clear that the magnitude and timing of temperature and precipitation change through time varies from region to region (see also Fig. 4.1 for examples), and quantifications of temperature and precipitation change are not available for all of these regions. Therefore the following section will only provide an overview of the general trends in the climate, and will forgo supplying a detailed report of temperature and precipitation estimates.

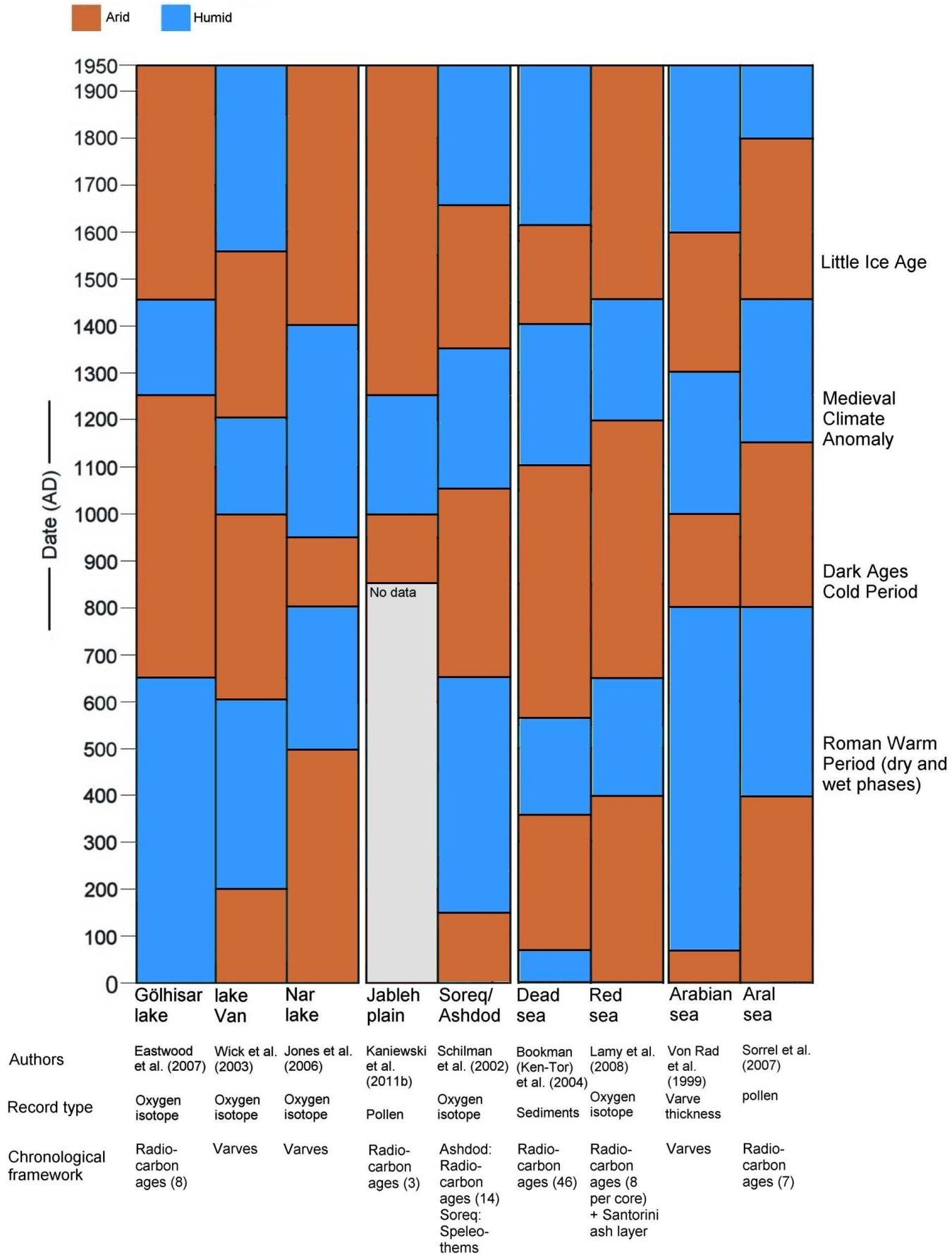

Fig. 4.1. An overview of the estimated timing of the RWP, DACP, MCA, and LIA, in a selection of climatic records from Europe and the near East. The estimations are based on a critical interpretation of the data, and do not necessarily follow the conclusions of the authors of the original publications.

4.1.2.1 Roman Warm Period

The chronological setting of this dissertation focuses on the period after the end of the BO Phase. Therefore the so-called Roman Warm Period (RWP) will be the oldest Late Holocene climatic period that is of our interest.
While its starting age is similar in records from Europe and the Middle East, centring on the 3rd century BC, its end date shows a remarkable discrepancy between northern and western Europe, and the western Mediterranean on one hand and the eastern Mediterranean and the Middle East on the other. While European records seem to indicate the RWP came to an end around the 5th or 6th century AD (Chapman and Shackelton, 2000; Grudd et al., 2002; Desprat et al., 2003), records from the Eastern Mediterranean indicate that the RWP lasted until at least the 7th century AD (Jones et al., 2006; Kaniewski et al., 2010; Leroy, 2010).
It can be described as a period characterized by a relatively warm climate in the North Atlantic (Bianchi and McCave, 1999; Bond et al., 2001), Europe (McDermott et al., 2001; Holzhauser et al., 2005), and the Middle East (Heim et al., 1997). While the RWP was characterized in Europe by relatively dry climatic conditions (Berglund et al., 2003; Holzhauser et al., 2005), moisture availability during the RWP in the Middle East varied through time. While especially the period from the 4th to the 7th century was characterized by increased precipitation (Izdebski, 2011; Hirschfeld, 2004; England *et al*., 2008; Jones *et al*., 2006; Sorell *et al*., 2007), it was preceded by a period of relatively dry conditions (von Rad et al., 1999; Kaniewski et al., 2007a,b; Neumann et al., 2007). It is difficult to quantify how warm the RWP was, but Lambeck et al. (2004) indicate that, based on sea level changes through time, temperatures during the RWP were comparable to those encountered at the beginning of the 20th century AD.
In both regions the changes in temperature and precipitation could, from an anthropogenic perspective, be seen as an important amelioration of the climate. For Europe, the onset of warmer and drier climatic conditions is thought to have aided the expansion of the Roman Empire throughout the continent (Hass, 1995), and the RWP was characterized by a pattern of deforestation accompanied by the expansion of both agriculture and pasture land (Berglund, 2003). Moister conditions in Northern Africa supported a wealthy agricultural economy during pre-Roman and Roman times (Grove, 1972; Reale and Dirmeyer, 2000). The onset of relatively moist conditions in the Eastern Mediterranean has been linked to a further intensification of agriculture during the BO Phase, specifically during the period from c. 300 AD to the mid seventh century (Izdebski, 2011).

4.1.2.2. Dark Ages Cold Period

The Dark Ages Cold Period (DACP) is a period characterized by relatively cold and wet environmental conditions in Northern and Western Europe, from Norway to the Iberian Peninsula, during early medieval times. Tree-ring data indicates that the start of this period was marked by a rapid cooling (Eronen et al., 1999). Throughout Europe, a decrease in agriculture, both crop cultivation, as well as pastoralism, can be observed during this period, which is characterized by the mass migration of Germanic tribes (Schönwiese, 1994). Large areas of central Europe and Scandinavia becoming reforested as agriculture decreased (Andersen and Berglund, 1994). Jones (1998) illustrates how an increase of precipitation of over 10% and a drop in annual temperature of c. 1.5°C would have had disastrous consequences for agriculture in Britain, and linking this climatic deterioration to the eventual downfall of the Roman occupation of Britain. A chironomid-based inference model (Millet et al. 2008) reconstructed a July air temperature decrease of c. 0.7°C for the DACP. Outside of Europe, the climatic changes associated with the start of the DCAP have been linked to the collapse of the Mayan civilisation, which succumbed after a series of prolonged droughts during the DCAP (Hodell et al., 1995).
While the European DACP is characterized, not only by relatively cold conditions, but also by relatively wet conditions (e.g. Berglund et al., 2003); its equivalent in the Middle East was characterized by relatively dry conditions (e.g. Bookman (Ken-Tor) et al. 2004; Neumann et al. 2007b; Sorrel et al. 2007; Lamy et al. 2008). The situation in the Middle East is difficult to interpret, various records showing that the end of the RWP coincided with a sharp decrease in intensive agriculture and a process of reforestation. Unfortunately it remains unclear whether this shift in human impact and vegetation are the result of climatic change, and/or the invasions of Arab forces into the region (Issar and Zohar, 2004; Neumann et al., 2007a, b; Leroy et al., 2010).
Estimates for the start of this period in Europe generally centre on the 5th to 6th century AD. Estimates for the

end date of the DACP in Europe vary from the 9th to the 13th century AD (e.g. Bond et al., 1997; Chapman and Shackelton, 2000; Grudd et al., 2002; Desprat et al., 2003). While the assumed start and end dates of this climatic period do not always coincide in the eastern Mediterranean, even among well dated climatic records (see Fig. 4.1 for examples), the available data shows that this period of drought and cold occurred later than in Europe. An aridification of the environment is visible as a drop in the Dead Sea lake level during the 7th century (Enzel et al., 2003; Leroy, 2010; Neumann et al., 2010). The occurrence of a dry period is noted by Kaniewski et al. (2010) for the coastal region of Syria between c. AD 850 and 1000 and at Nar lake, Central Turkey, c. 360 km east of Gravgaz marsh, between the ninth and the eleventh centuries AD (Jones et al., 2006). A general trend towards dryer conditions is observed for the Ashdod coast (Schillman et al., 2001, 2002) and Soreq Cave (Bar-Matthews et al., 1999; Schillman et al., 2002). A decrease in precipitation is indicated by decreased fluvial inputs in the Arabian Sea from the fifth to the tenth centuries AD (Lückge et al., 2001; Von Rad et al., 1999) and a decrease in the Nile runoffs since the eighth century AD (Jiang et al., 2002). High δ18O values indicate drier conditions for the northern Red Sea between the seventh and the eleventh century AD (Lamy et al., 2006). δ14C values were generally higher than during the BO-Phase, suggesting a decreased solar irradiance (Reimer et al., 2004). Historical data show that winters became colder and the Bosporus frequently froze after the start of the eighth century AD (Yavuz et al., 2007). This late onset of the DACP, compared to European records, is also seen in the eastern Mediterranean sea, Castagnoli et al. (2002) indicating that the DACP generally occurred between the 7th and 10th century AD in the Eastern Mediterranean and wider Middle East.

4.1.2.3. Medieval Climate Anomaly

The appropriately named Dark Ages Cold Period was followed by the Medieval Climate Anomaly (MCA), formerly also known as the Medieval Warm Period. This name was eventually dropped as, while this period is generally characterized by warmer temperatures in Europe and the Middle East, the occurrence of relatively warm temperatures was not a globally occurring phenomenon. While the impact of the MCA varies, relatively warm conditions have been recorded for large parts of Northern Europe and Asia. As with the preceding climatic period, the data show that the impact of climate change on the principal weather differed from place to place. In Europe and the Atlantic the MCA was generally characterized by warm and dry conditions (Schönwiese, 1994; Hass, 1996). Warm conditions are uniformly reported for all parts of Europe. Lamb (1964) reported that a notably warm climate in many parts of the world occurred around A.D. 1000–1200, and was followed by a decline of temperature levels till between 1500 and 1700. Giraudi (2009) indicates higher temperatures than at present during the 11th to 13th centuries in northern Italy, while Andren et al. (2000) found indications of higher water temperatures in the Baltic Sea from the 11th to the start of the 13th century. In Western Europe, Berglund (2003) reported that the climate was relatively dry as well as warm. Mann (2002) indicates how agriculture was possible at higher latitudes (and higher elevations) than is currently possible in many regions, while numerous anecdotal reports mention especially bountiful harvests throughout Europe. Similar to during the RWP, grapes were grown in England several hundred kilometres north of their current limits of growth, while subtropical flora such as fig trees and olive trees grew in regions of Europe (northern Italy and parts of Germany), also well north of their current range. In contrast, the Middle East experienced relatively wet conditions between the eleventh and fourteenth centuries AD (Schillman et al., 2002; Jones et al., 2006; Kaniewski et al., 2010). Information on the influence of climatic change on anthropogenic activity in the Middle East remains sporadic, a situation hopefully remedied in part by the contents of the present dissertation.

In contrast to the DACP, estimations for the start and end times of the MCA generally place it between the start of the 11th century and the start of the 14th century for Europe as well as the Middle East. Asian records show that the MCA, evidenced by changes in the Asian monsoon regime, lagged behind Europe and the Middle East, occurring during the 13th to 15th century (Liu et al., 2009; Grießinger et al., 2011). The δ18O records from Soreq cave and the Ashdod coast show a trend towards wetter conditions since the early twelfth century AD (Bar-Matthews et al., 1999; Schillman et al., 2001, 2002). In coastal Syria (Kaniewski et al., 2010) and the northern Red Sea (Lamy et al., 2006) a wet trend commences at the beginning of the eleventh century AD while the Dead Sea water level rose strongly between the eleventh and thirteenth centuries AD (Enzel et al., 2003). At Nar Lake (England et al., 2008; Jones et al., 2006), a phase characterized by lower summer evaporation and increased winter rainfall occurred between the eleventh and fourteenth centuries AD. Gupta et al. (2003) note a strong Asian SW Monsoon from the tenth to the thirteenth centuries AD. Fluvial inputs in the Arabian Sea off Pakistan increase between c. AD 950-1100 and remain relatively high until the beginning of the thirteenth century AD (Lückge et al., 2001; Von Rad et al., 1999).

4.1.2.4. Little Ice Age

Evidence shows that the occurrence of the Little Ice Age (LIA), a period of relatively cool temperatures, punctuated by several short periods characterized by severe cold (Grove 1988; Luterbacher 2006b; Touchan et al. 2007). Its occurrence was more widespread than the MCA. While the extent and extremes of the LIA vary, they do occur within roughly the same timeframe, between the fourteenth and the nineteenth centuries AD (Bradley and Jones, 1992; Briffa, 2000; Büntgen et al., 2005). Pfister (1992) reveals that in central Europe, this period was characterized by increased summer precipitation as well as colder climatic conditions. Nesje et al. (2001) and Chapron et al. (2005) report increased flood activity in Norway and the French Alps respectively. A notable feature of the LIA is the apparent world-wide glacier advance (e.g. Le Roy Ladurie 1983; Röthlisberger 1985; Luckman 1995; Nesje et al. 2008; Espizua and Pitte 2009). Records from the eastern Mediterranean (e.g. Camaron, 1993; Lamb, 1982; Pope and Van Andel, 1984) reveal a period characterized by relatively dry conditions and cooler summer temperatures which generally coincides with the European LIA. A similar trend is found in records from the Soreq cave and the Ashdod coast, Israel (Bar-Matthews et al., 1999; Schillman et al., 2001, 2002). The Red Sea planktonic δ18O record (Lamy et al., 2006) shows a dry trend from c. AD 1200 to 1550. Interestingly, records from Nar Lake (England et al., 2008; Jones et al., 2006) and the Dead Sea (Neumann et al., 2010) show a shift towards dryer conditions around the beginning of the 15th century AD, somewhat later than elsewhere in the Middle East. Greece, however, shows a pattern that is a combination between the Northern European and the Middle Eastern situation. Records indicate that the LIA was characterized in Greece by heavy summer rains, as well winter and spring drought. However, the occurrence of summer rain seems to have been more pronounced in the western and central Mediterranean, than in the Eastern Mediterranean (Grove and Conterio, 1995). Tree ring data collected by Touchan et al. (2007) provides a reconstructed record of May-June precipitation in SW turkey, covering the entirety of the Little Ice Age. Luterbacher and Xoplaki (2003) indicate how the mean winter temperatures oscillated throughout the LIA in the eastern Mediterranean. E.g. while the average long term (AD 1500-1900) mean winter temperature is c. 6.7 °C, it dropped by about 1 °C at the end of the 17th century AD, while during the 18th century AD, temperatures are near the long term mean. The LIA ended during the mid 19th century, as evidenced by increasing January temperatures throughout Europe and a notable glacial retreat (Le Roy Ladurie 1983; Röthlisberger 1985).
Historical records show that the onset of the Little Ice Age had a profound influence on mankind in Europe, epidemics and food shortage resulting from the increased rain and lower temperatures of the LIA (Appleby, 1980). As with the MCA, knowledge of the impact of the LIA on anthropogenic activity in the Middle East remains scarce and anecdotal.

4.1.3. Pollen-based climate reconstructions

Over the past decades, a number of methods have been developed which use pollen data to create a proxy for climatic variables such as temperature or precipitation. Guiot (1986) introduced a method based on best analogs estimation and multiple regression, calculating the relationship between climate (monthly temperature and precipitation) and modern pollen spectra from a large number of sites. The next step would be to use a combination of canonical correlation and principal components analyses to compare the modern data with fossil pollen sequences in order to produce a so-called "paleobioclimate".
The problem with this and other "modern analogue" techniques is that they require the presence of areas of vegetation that are similar to the various types of vegetation indicated by the fossil pollen data. Unfortunately the modern landscape encountered in the Taurus Mountains today, characterized by its combination of extensive cereal cultivation, widespread overgrazed *Quercus* and *Juniperus* maquis, and secondary pine forest, is almost entirely modern in origin. This was proven by the numerical analyses performed by Vermoere (2004), who found that there was no adequate modern analogue of any of the fossil pollen assemblages researched for that thesis.
Another method is using biome models (e.g. Prentice et al, 1996). This method uses the concept of the plant functional types (PFT). PFT's are broad classes of plant taxa, which are defined hierarchically by growth form (herb, shrub, tree), physiological adaptation to the climate (deciduous, evergreen), and further climatic adaptations and limitations in its range (boreal, tropical). These PFT's are then combined to form biomes, which is defined as a vegetation association (or grouping of different plant taxa/PFT's) which occur within a reasonably uniform bioclimatic range. Calculating the biome with which a fossil pollen spectrum has the greatest affinity, and researching the climatic ranges within which this biome currently occurs will reveal valuable information about the climatic conditions prevalent at the time of deposition of that fossil pollen spectrum.
The problem that there are very few natural landscapes left in the SW Taurus Mountains would in this case be solved by the fact that these biomes would be generalisations based on modern pollen data from a larger region. Kaniewski et al. (2008b) have successfully implemented this method in their effort to reconstruct the response of the vegetation to abrupt climate changes in Syria, using PFT's constructed for the Mediterranean and Kazakhstan regions by Tarasov et al. (1998).
Unfortunately one of the principal strengths of the biomisation method is actually its weakness when implemented in the territory of Sagalassos. As PFT's may occur in various different biomes, and in turn, plant taxa may occur in various PFT's, the dominance of one specific taxon in the pollen data may result in the situation where many PFT's are also completely dominated by that same taxon, greatly reducing their usefulness. This was the case for the current study, where the importance of *Pinus* throughout the pollen records of Gravgaz and Bereket inhibited the proper assignment of pollen samples to biomes.
Apart from Modern Analogue Vegetation Type techniques, recent studies have also shown that it is possible to reconstruct environmental variables based on pollen data by quantifying the climatic requirements (temperature or moisture availability) of a fossil flora by means of the climatic requirements of the present-day nearest living relatives of the fossil plant taxa (Klotz, 1999; Klotz and Pross, 1999; Pross et al., 2000; Klotz et al., 2004). Unfortunately the amount of useful taxa for this type of analysis is limited in the Sagalassos pollen records. Furthermore, detailed information on the present-day potential distribution areas, and therefore the climatic requirements of these taxa, are only available for part of the taxa included in the pollen records from the study area. Finally, Probability Mutual Climatic Spheres techniques are based on the presence or absence of these plants from the pollen diagram. But in this case, not only are many of the taxa found in the two pollen records present throughout the core, climatic forcing only influencing their abundance rather than their occurrence, the presence or absence of taxa may also be influenced by other factors such as changes in human impact.

4.1.4. Research objectives

While, as the preceding texts illustrate, there is a wealth of information available on the timing and impact of climate change on the environment during the last two millennia for Europe in particular and for the Middle East in general, Anatolia seems to be a blind spot. Only a very small number of climatic records are available for this region. A high resolution oxygen isotope record from a varved lake sequence is available from Nar Lake, central Anatolia (Jones et al., 2006; England et al., 2008). A mineralogical and sediment analysis is available for Tecer Lake, in the Eastern Anatolian Highlands (Kuzucuoğlu et al., 2011). Finally, a high-resolution record of pollen, charcoal, isotopic and geochemical data from laminated sediments of Lake Van, southeast Turkey has been published by Wick et al. (2003).

Obtaining a more local record of climate change is of the utmost importance as the position of the area of interest for this dissertation is located in a region characterized by a different climate (Oro-Mediterranean), than that of the two available and usable records from Nar Lake and Tecer Lake (which are subjected to a more continental climatic regime) and the relative importance of the different weather systems in SW Turkey may differ from elsewhere in the Eastern Mediterranean, or even from central or eastern Anatolia. This is illustrated in Fig. 4.1, which shows the start and end dates of the main climatic periods which occurred during the last two millennia, as observed in various well dated climatic records from the Middle East. While the occurrence of various climatic periods occur around the same time period, estimates given for the start and end ages of these periods differ strongly from location to location.

The present chapter aims to reveal the timing and extent of climatic change in southwest Turkey during the last two millennia, thus enabling the disentanglement of anthropogenic and climatic influences on vegetation change in that region of Anatolia. Estimating temperature change based on pollen data, is extremely tricky in general, and impossible for the study area as the temperature ranges of the dominant plant taxa encountered in the pollen records overlap too much. However, a conventional pollen analysis can reveal whether a certain area around a sample site was subjected to relatively moist or dry conditions at a given time, thus giving an indication of the relationship between precipitation and evaporation. Unfortunately it is extremely difficult to create a continuous overview of changes in moisture availability through time based on visual inspection of a multitude of pollen percentage data for this region.

Supported by a detailed chronology and relatively high-resolution pollen data, pollen, NPP and sedimentological data are analysed using newly developed numerical methods in order to create one clear pollen-based bioclimatic record of relative moisture availability. This bioclimatic proxy will be based on both the herbaceous, as well as the arboreal pollen signal, ensuring that the signal reflects moisture availability throughout the basin, rather than only local moisture availability. Additionally, pollen and sediment data of Gravgaz marsh and the Bereket basin will be compared to one another in order to ascertain whether the pollen-derived bioclimatic proxy is applicable to only one single basin, or to the wider area. Finally, a comparison with independent climatic proxies (summarized in section 4.1.2) will determine whether the moist/dry bioclimatic signal found in the pollen data can be interpreted as a climatic signal applicable to the larger area of SW Turkey, or at least those parts that are subjected to a similar Oro-Mediterranean climate. Comparing the pollen-derived climatic data with independent climatic proxies from the Middle East and Europe will reveal whether climate change in southwest Turkey was driven by the North Atlantic, African or Asiatic climatic phenomena. The results of this study will provide new insight into past climate change, human presence and vegetation dynamics in the Near East. These newly developed analyses circumvent the problems in the data that prevent the creation of a climatic reconstruction using modern analogue, biome-based, or Probability Mutual Climatic Spheres techniques.

4.2. Numerical analyses

Individual pollen types were grouped with a cluster analysis (CA). Cluster Analysis is a method for combining similar objects into groups or clusters, which can be visually displayed in a tree-like diagram (Quinn and Keough, 2002). When implementing a CA, the data are grouped in such a way that the degree of association between two taxa is maximal when they have similar occurrences and minimal when they are dissimilar (Baxter, 1994; Kaniewski et al., 2007a). The resulting clusters are termed Pollen Derived Vegetation Patterns (PDVP). Each PDVP contains taxa that may originate from different vegetation types, but which thrive under similar environmental conditions. This situation does not apply in the Bereket basin pollen record apart from the possible single, short-lived occurrence of a reed marsh. The ecological significance of each PDVP can be assessed by studying the most important taxa in each PDVP and the vegetation types they are associated with. For subsequent analyses, the primary anthropogenic indicator species (as determined by Bottema and Woldring, 1990) were removed from the PDVP to which they were originally assigned. An additional CA was performed on a data set excluding cultivated plant species in order to test whether the occurrence of crop cultivation influenced the clustering of pollen types and whether the cultivated species could be removed from the data set without compromising the numerical analyses. A final CA was performed on the most important NPP's to generate clusters which represent local environmental conditions. The algorithm used was Paired Group and the similarity measure was Correlation.

To assess the way climate, vegetation and human presence have influenced one another, it is vital to understand which of the PDVPs are directly influenced by the presence of human activities. To test this, each PDVP was cross-correlated with the primary anthropogenic indicator species (P=0.05). A linear detrended Cross-Correlation concerns the time alignment of two time series by means of the correlation coefficient and is graphically presented in a correlogram (Kaniewski et al., 2008a, 2009). A strong positive correlation at Lag0 between a PDVP and the anthropogenic indicators most likely reflects an anthropogenic influence on that PDVP. If there is no correlation, then the PDVP is influenced by another (most likely environmental) factor. A negative correlation indicates that the taxa in a PDVP thrive when anthropogenic influence is absent. Significant positive or negative correlations at certain lag, indicate that a certain PDVP becomes important (or decrease in importance) a short time after an increase (or decrease) in cultivated species in the pollen spectrum. The unit of the lag in the correlograms can be interpreted as the average difference in age between two samples. When the lag is very small, there may still be a direct link between the occurrence of a PDVP and the cultivated species. When a significant correlation occurs at a bigger lag, this correlation may still be interesting in light of studying the succession of the vegetation in the territory (which will be assessed in a different way in chapter 4).

Additional CA's were performed on the NPP data. The resulting PDVP's were named GVZ-NP1 to GVZ-NP5 for Gravgaz marsh and BKT-NP1 to BKT-NP4 for the Bereket basin. These PDVP's have not been included in the subsequent analyses. Important changes in these non-pollen PDVP's will be assessed in the Results and Discussion parts of the present chapter.

It should be noted that this method does not recognize human activities that do not stimulate the increase of primary and secondary anthropogenic indicator species; e.g. intense wood clearance without the development of agriculture on the cleared terrain.

Principal Component Analysis (PCA) was performed in order to reveal in what way each PDVP represents various (climatic and/or anthropogenic) environmental conditions. PCA is a linear method that can provide a two-dimensional representation of high-dimensional data. The scores of PCA-Axis1 and 2 provide numerically derived proxies that explain most of the total variance encountered in the original data set. A Detrended Correspondence Analysis (DCA) was also performed and the first axis scores of the PCA and DCA were compared to check whether the PCA results suffered from Horseshoe effect. The Horseshoe effect is caused by the unimodal distribution of species along gradients (Goodall, 1954). In this case the second PCA axis would be curved and twisted relative to the first, and does not represent a true secondary gradient. The location of the various datapoints along the second PCA Axis would have no real biological meaning.

DCA is an extension of correspondence analysis (CA) designed to cope with a unimodal relationship between two sets of scores derived by CA (Hill and Gauch, 1980). If the results from the DCA and PCA do not match, then this indicates that the PCA results are affected by the Horseshoe effect and a PCA analysis is not useful in the statistical analysis of the data.

These numerical analyses are implemented on two separate pollen cores, located at different locations within the territory of Sagalassos, in order to properly distinguish between local and regional trends in the climatic signal. Notable changes in pollen percentages which occur only in one pollen spectrum, but not in the other, may be indicative of local environmental changes, while changes that occur in multiple records, may be indicative of a phenomena that affects the wider region.
Huntley (2012) states that, when reconstructing palaeoclimates from biological proxies, one must be careful with the interpretation of data if that reconstruction is based on only one single proxy. In most cases the occurrence and dynamics of an organism is dominated by multiple variables. The method described here solves this problem by revealing which variables are the most important in determining local and regional vegetation change, and in what way each of these variables influences the vegetation. All numerical analyses were performed using the computer program PAST (http://folk.uio.no/ohammer/past/).

4.3. Results

4.3.1. Numerical analyses

4.3.1.1. Gravgaz core SA06EP1

Based on the CA results, the pollen data were subdivided into six PDVP's, named GVZ-A (top) to GVZ-F (bottom). Removing the cultivated species did not alter the clustering of pollen types by the CA. The choice to interpret Poaceae as a local pollen type in Gravgaz was tested by running an additional CA on a dataset which included Poaceae as well. Poaceae was grouped with *Olea europea*, *Fraxinus ornus*, and Poaceae Cerealia, the latter's occurrence being more closely similar to that of *Fraxinus ornus*, than to that of Poaceae. The general grouping of the pollen taxa did not change, indicating that the removal of Poaceae did not influence the validity of the numerical analyses. The most abundant and/or ecologically indicative plant species in each PDVP and the vegetation types to which they belong were studied to acquire an idea of the environmental conditions represented by each PDVP. The CA tree diagram of the Gravgaz marsh pollen data is displayed in Fig. 4.2. The CA performed on the NPP's resulted in a subdivision into five groups representing specific local conditions, displayed in Fig. 4.3. A table of the landscape types indicated by each PDVP, and the important taxa indicative of these landscape types within each PDVP, is displayed in Table 4.1.
The Cross Correlations of the PDVP's versus the primary cultivated species reveal that only PDVP GVZ-D is positively correlated with the cultivated plant species. The first CA added all cultivated species to this PDVP and it contains all secondary anthropogenic indicators. There is a strong negative correlation between PDVP A, dominated by *Pinus*, and cultivated species, indicating how pine forests apparently increase when anthropogenic pressure diminishes. None of the other PDVPs, regardless of the ecological preferences of their dominant plant taxa show any correlation, suggesting that PCA-Axis 1 and 2 are not primarily controlled by the presence/absence of crop cultivation but were directly or indirectly driven by external forces (e.g. climate). The correlograms displaying the Cross Correlation results for Gravgaz are displayed in Fig. 4.4.
PCA-Axis 1 scores were similar to those of the DCA, a Cross Correlation indicating that the correlation at lag=0 was as high as 0.91 (Fig. 4.5). These results indicate that the horseshoe effect does not occur in the data from Gravgaz marsh. The PCA scatter plot and the loadings of the different pollen-derived vegetation types are detailed in Fig. 4.6. PCA-axis 1 and 2 account for 73.1% of the cumulative variance, Axis 1 accounting for 50.3% and Axis 2 accounting for 22.8%.
The PCA-Axis 1 loadings assign positive scores to GVZ-A (+0.87) and F (+0.06). Negative scores are assigned to GVZ-B (-0.33), GVZ-D (-0.30), GVZ-E (-0.14) the cultivated species (-0.11) and GVZ-C (-0.04). The PCA-Axis 2 loadings assign positive scores to GVZ-B (+0.85) and GVZ-A (+0.15). Negative scores are assigned to GVZ-D (-0.36), GVZ-C (-0.24), the cultivated species (-0.21), GVZ-E (-0.11) and GVZ-F (-0.08). The PCA-Axis 1 and PCA-Axis 2 scores and local vegetation and NPP dynamics are presented in Fig. 4.7.

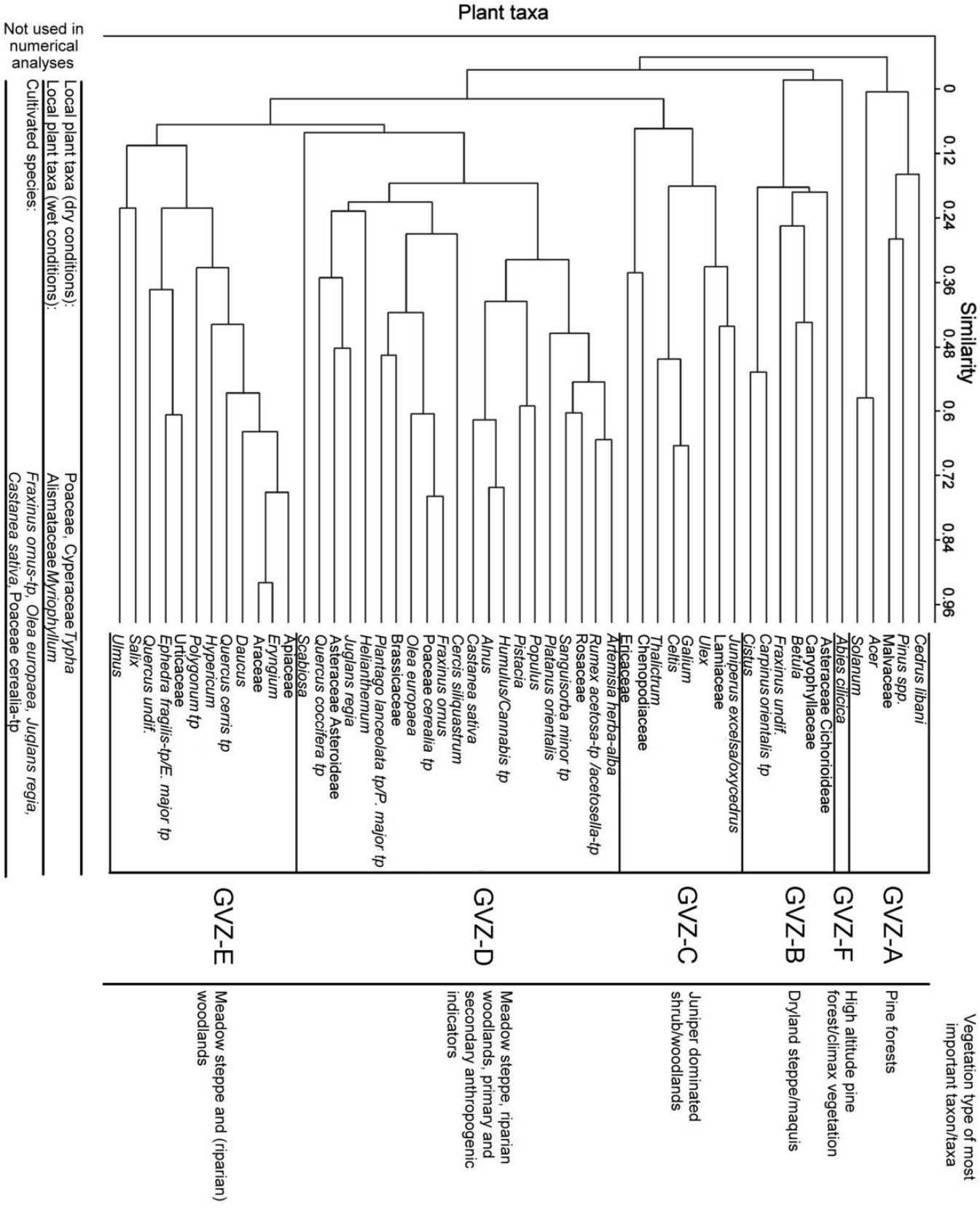

Fig. 4.2. The Cluster Analysis tree diagram displaying the six different pollen derived vegetation patterns (PDVP) for core SA06EP1 (Gravgaz marsh). Each PDVP (named GVZ-A to GVZ-E) contains taxa that may originate from different vegetation types, but which thrive under similar environmental conditions. The vegetation types associated with the most important pollen taxa in each PDVP are based on van Zeist et al. (1975), Bottema and Woldring (1990) Fontaine et al. (2007) and Kaniewski (2007a).

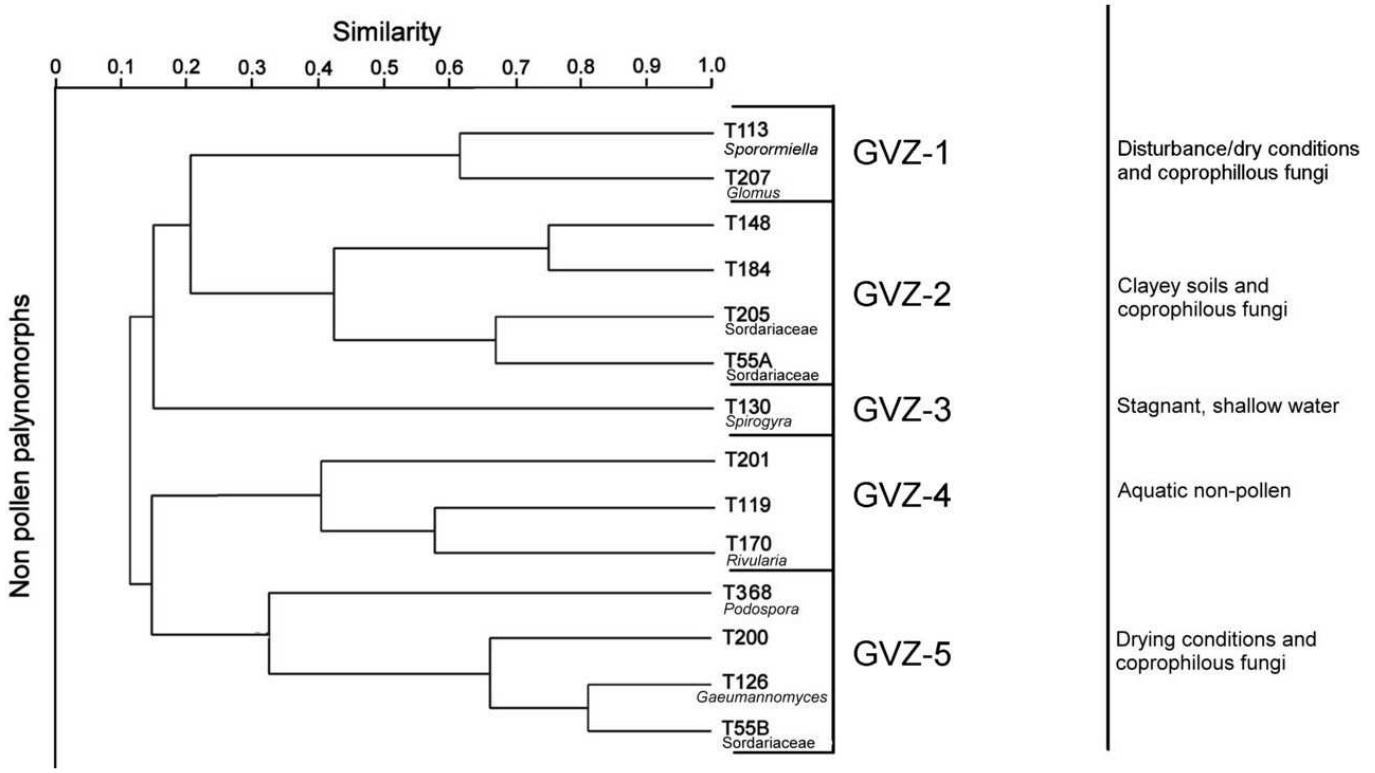

Fig. 4.3. The six different CA-derived groups of non-pollen palynomorphs for core SA06EP1 (Gravgaz marsh), each group indicating a specific set of local conditions.

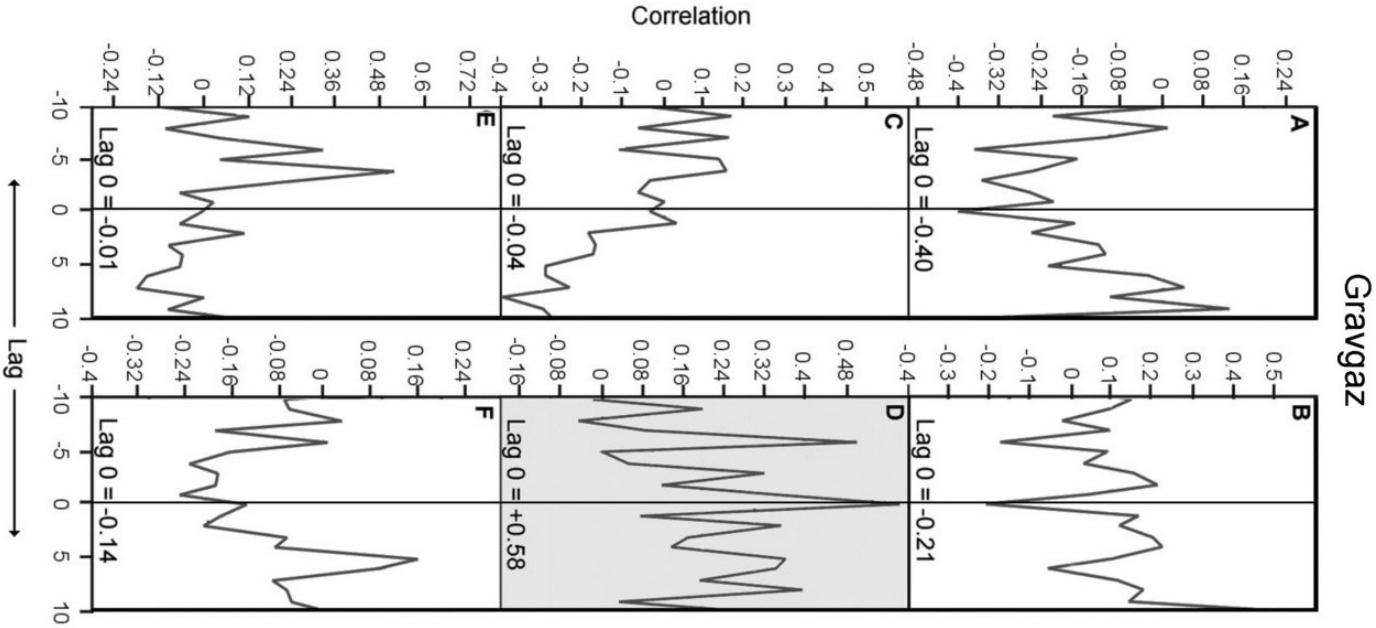

Fig. 4.4. Correlograms of the cultivated species versus the PDVP's for Gravgaz marsh. The vertical axes show the correlation coefficients. The significance level is P=0.05. The correlogram highlighted in grey displays the positive correlation between the cultivated species and GVZ-D, containing secondary anthropogenic indicators.

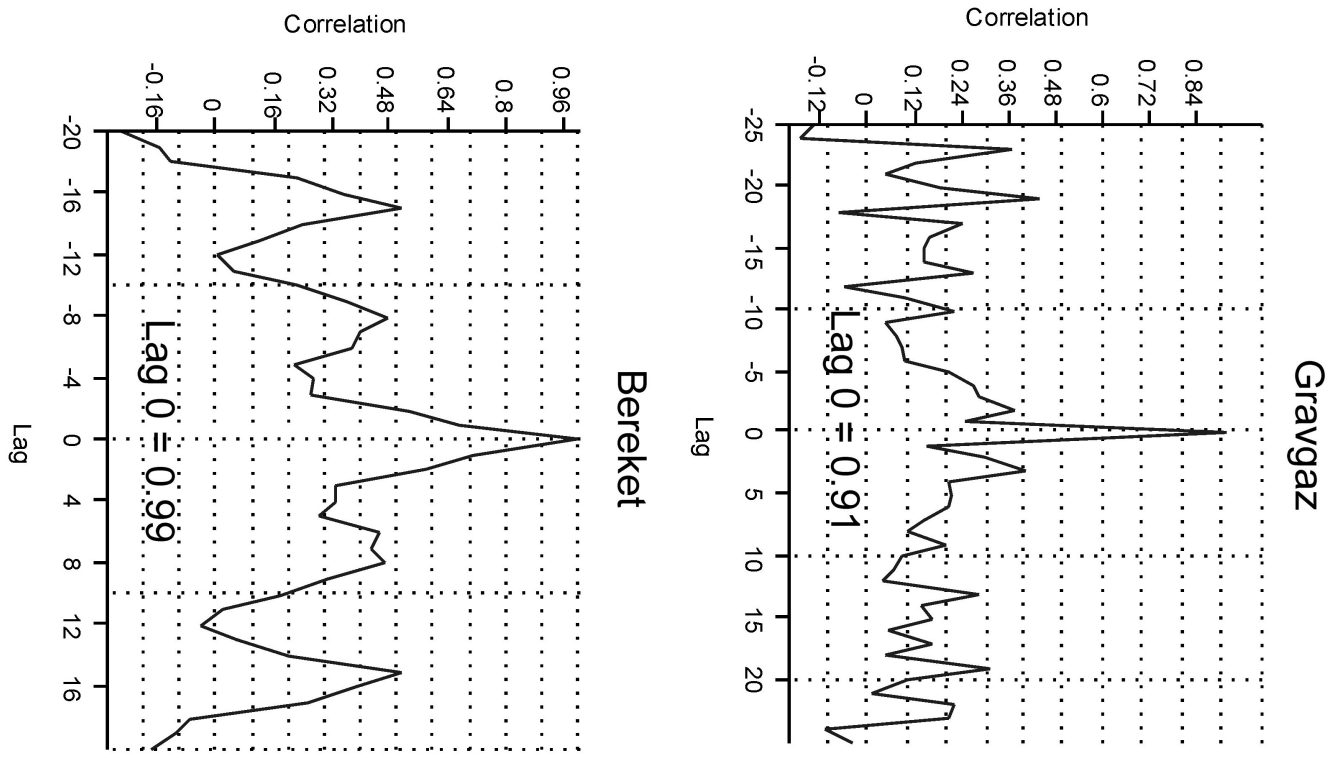

Fig. 4.5. Cross-correlogram showing the correlation between the first axis scores of the PCA and the DCA performed on the Gravgaz marsh (top) and Bereket basin (bottom) datasets.

The loadings for PCA-Axis 1 order the different PDVPs according to landscape openness, based on the most important vegetation types represented by each PDVP. GVZ-A receives the highest positive loading and contains *Pinus* as its most important component. GVZ-B receives the highest negative loading and contains Asteraceae Cichorioideae as its dominant pollen type, which in combination with Caryophyllaceae, may indicate open mountain steppe. *Betula* may occur as a remnant of mountain forests, its pollen signal no longer drowned out by copious pollen production of *Pinus*. *Cistus* and *Carpinus* pollen types indicate Maquis type vegetation.

The loadings of the PDVPs along PCA-Axis 2 indicate relative moisture availability. Taxa indicative of a moist environment (e.g. *Platanus, Populus, Celtis, Salix, Ulmus*) are encompassed in the PDVPs GVZ-D and -E. *Juniperus* is the most important pollen type in GVZ-C. The humid-dependant *J. excelsa* is an important species above 1200 m (a.s.l.). GVZ-F contains only *Abies*, which requires a high degree of humidity (Aussenac, 2002; Fontaine et al., 2007). PDVP A received a positive loading and contains *Pinus* as its dominant pollen type. *Pinus nigra*, an important component of mountain pine forests in the region, is drought tolerant and known to occur in drier environments in Turkey. The light/heat demanding *Pinus brutia* becomes scarce above 1200 meters a.s.l. and does not occur above 1400 meters a.s.l. but may contribute to the regional pollen signal. Apart from being drought-tolerant, pine is also a fast colonizer of abandoned farmlands and pastures. As such, it may also be that the presence of *Pinus* may also be influenced by the absence of human impact as well as dry environmental conditions. The presence of *Cedrus libani* in GVZ-A, while *Abies* is put into its own PDVP, indicates that this PDVP indeed indicates relatively dry environmental conditions. *Abies cilicica* and *Cedrus libani* are both part of the climax vegetation, thriving in already established pine forests. However, while *Abies* requires a high degree of humidity, *Cedrus* is drought tolerant (Boydak, 2003). GVZ-B, indicative of dry steppe and maquis vegetation, is given the highest positive loading. It seems that, while open and more densely forested landscapes are indicated by PDVPs with positive as well as negative loadings, the PDVPs with high positive loadings are indicative of moister landscapes than those with lower loadings along the second PCA-Axis. PCA axis 1 and 2 scores are provided in Appendix 4.

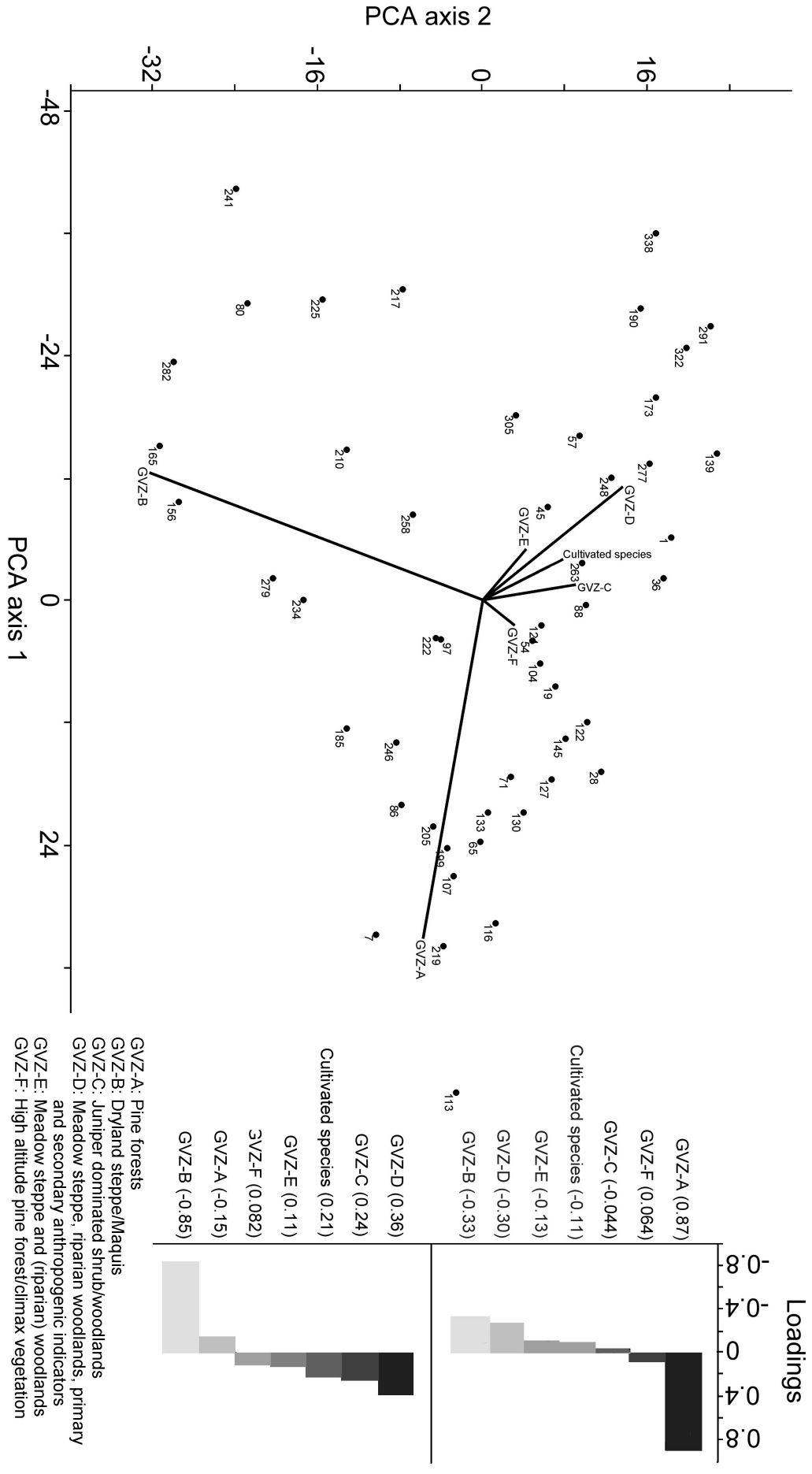

Fig. 4.6. Top: Principal components analysis biplot of the samples from Gravgaz marsh. PCA axes 1 (50.3% of total variance) and 2 (22.8% of total variance) account for 73.1% of the cumulative variance. Bottom: the loadings for each PDVP along PCA axis 1 and 2.

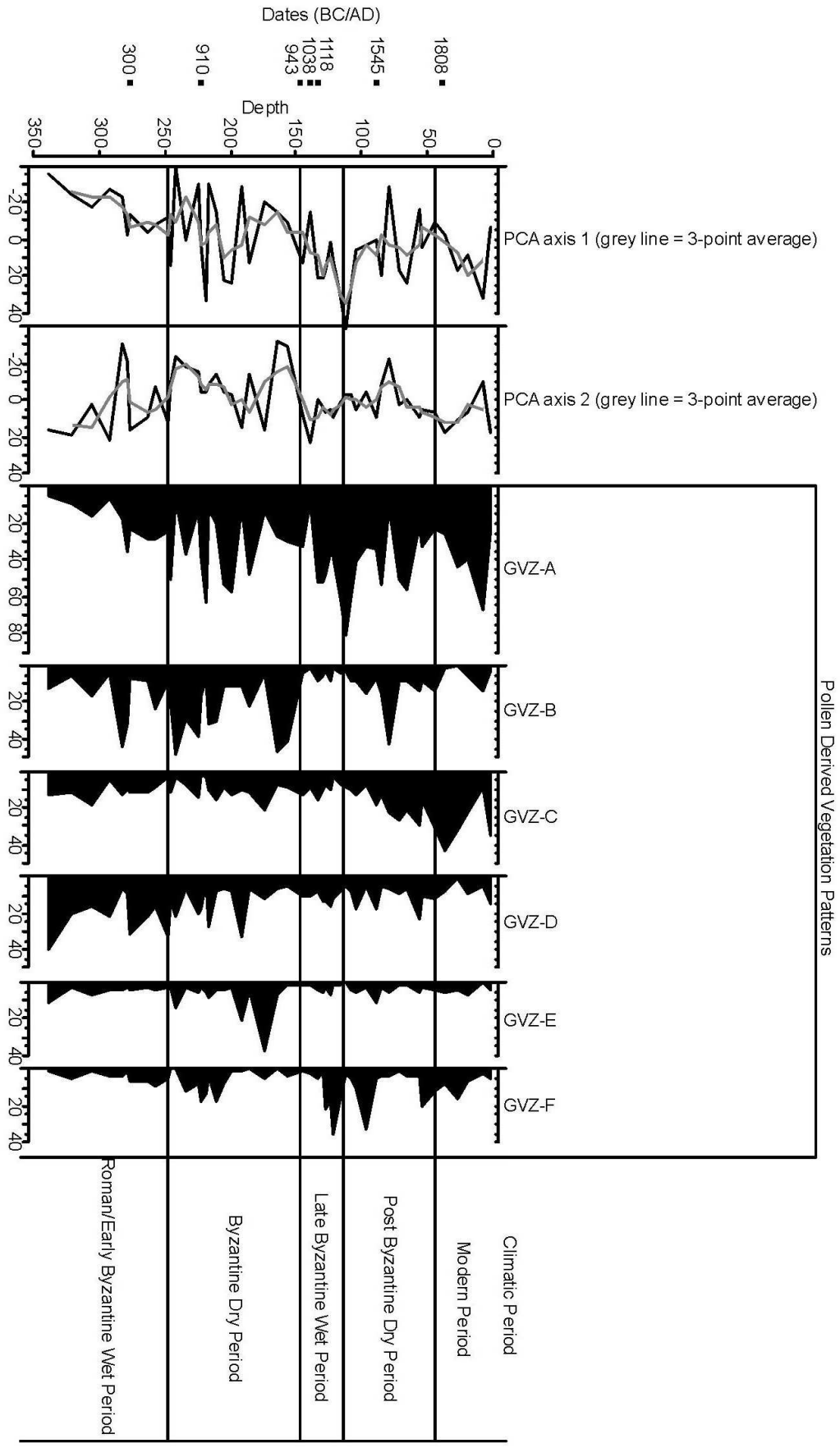

Fig. 4.7a. PCA-Axis 1 scores, PCA-Axis 2 scores, PDVP percentage values for pollen (GVZ-A to F) and non-pollen palynomorphs (GVZ-1 to 5) for core SA06EP1 (Gravgaz marsh). The grey lines in the PCA-Axis 1 and 2 graphs show the three point moving averages for the axis scores. The curve named "Cultivated species" contains the primary anthropogenic indicator species (as determined by Bottema and Woldring, 1990) as a cumulative percentage diagram featuring cereal pollen (white) and cultivated trees (black).

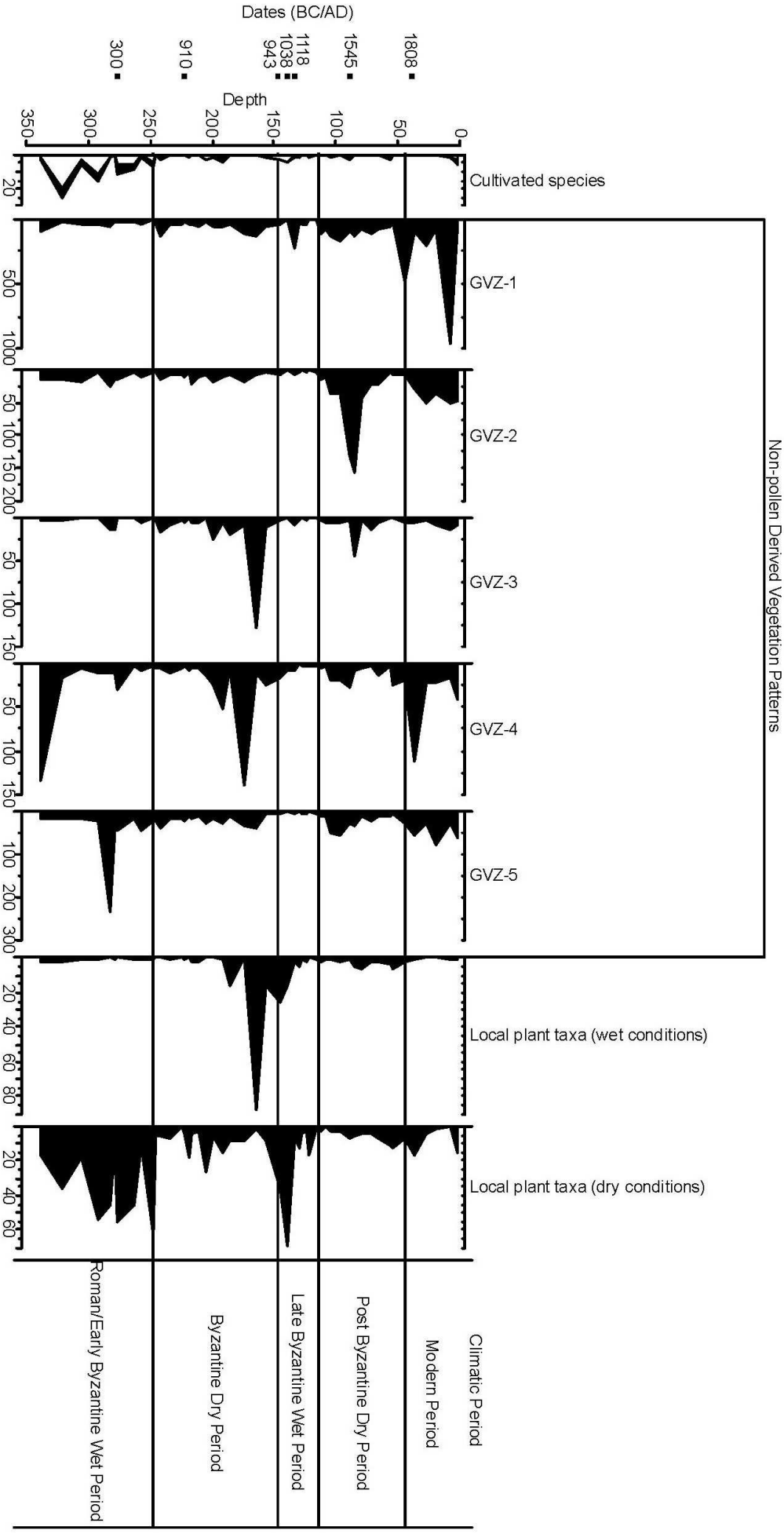

Fig. 4.7b. Same as 4.7a.

Table 4.1. A table of the landscape types indicated by each PDVP, and the important (in amount or indicative value) taxa indicating these landscape types within each PDVP for core SA06EP1 and SA09JBDrill02.

Core SA06EP1

PDVP	Landscape type	Indicated by the following taxa	Notes
GVZ-A	Pine forest	*Pinus, Cedrus libani*	
GVZ-B	Open, dry steppe/maquis	Asteraceae Cichorioideae, Caryophyllaceae, *Carpinus, Cistus*	
GVZ-C	Juniper dominated wood/shrublands	*Juniperus excelsa/J. oxycedrus*	The appearance of Chenopodiaceae, Ericaceae and Lamiaceae indicate the presence of open steppe vegetation. Juniper pollen does not preserve very well and juniper may be more important in the landscape than indicated by the pollen data. Such shrub/steppe vegetation may result from (over)grazing.
GVZ-D	Meadow steppe, riparian woodlands, primary and secondary anthropogenic indicators	*Rumex acetosa/R. acetosella, Populus, Platanus, Plantago lanceolata, Artemisia herba-alba, Sanguisorba minor.* Cultivated species: *Olea europaea*, Poaceae Cerealia, *Juglans regia, Fraxinus ornus, Castanea sativa*	Artemisia may appear as a ruderal plant, but may also be characteristic of open, alpine vegetation. Its co-occurrence with multiple ruderals, and anthropogenic indicators, implies that the *Artemisia* pollen signal is indicative of pastures and anthropogenic activity. The occurrence of cultivated species is at its maximum during the BO-Phase, but they may also occur at later times.
GVZ-E	Meadow steppe and decidious/riparian woodlands	Apiaceae, *Erynchium, Ephedra fragilis/E. major, Salix, Ulmus*, Urticaceae	some taxa may be indicative of the early stages of succession after abandonment.
GVZ-F	High altitude pine forest/climax vegetation	*Abies cilicica*	

Core SA09JBDrill02

PDVP	Landscape type	Indicated by the following taxa	Notes
BKT-A	Steppe/ruderals	*Centaurea* tp, *Polygonum aviculare*	This PDVP contains three relatively unimportant species whose occurrence nominally follows that of BKT-B and BKT-C. *Centaurea* and *P. aviculare* may indicate steppe vegetation or may occur as ruderals.
BKT-B	Open Dry steppe and BO Phase arboriculture	*Artemisia herba-alba, Phillyrea*, Apiaceae, Asteraceae cichorioideae, Asteraceae asteroideae. Cultivated species: *Olea europaea, Castanea sativa*	Cultivated tree species occur either only, or are at their most abundant, prior to c. AD 300
BKT-C	Dry steppe and degraded shrublands	Brassicaceae, Lamiaceae, Ericaceae, Erynchium, Chenopodiaceae	Abundance of herb species and the association of *Q. coccifera* with this PDVP, may indicate (over)grazing
BKT-D	Pastures and degraded shrublands	*Cistus, Polygonum cognatum, Rumex acetosa/R. acetosella,* Poaceae, *Plantago lanceolata*	Poaceae cerealia only reaches very low percentage values and may only be indicative of wild, ruderal grasses, rather than cereal cultivation. High Poaceae percentages may result from the local occurrence of a reed marsh. Less local species are indicative of maquis/shrubland. Combination of ruderals and maquis shrub species may indicate grazing. *Cistus* is a known Mediterranean fire-prone shrub
BKT-E	Local riparian woodlands and *Juniperus* wood/shrublands	*Juniperus excelsa/J. oxycedrus, Salix, Quercus cerris, Populus*	
BKT-F	Pine forests	*Pinus, Cedrus libani*	

4.3.1.2. Bereket core SA09JBDrill02

The sediment type, pollen and non-pollen content, and bad preservation of the pollen content, all indicate that the top four samples from the Bereket core have been damaged and/or reworked. They are therefore not included in the numerical analyses. Based on the CA results, the pollen data was subdivided into six PDVP's, named BKT-A to BKT-F. As the local physical conditions of the landscape (basin size, shape, altitude, etc.), as well as the occupation history of Bereket differs from those of Gravgaz (see chapter 3), the results of the CA clustering of the pollen and non pollen taxa will also differ. These differences provide extra information concerning the local impact of man and climate on the landscape and will help to separate the influence of local conditions from the important regional trends. A table of the landscape types indicated by each PDVP, and the important taxa indicative of these landscape types within each PDVP, is displayed in Table 4.1.

As explained in chapter 1, Cerealia type pollen need not always represent cereal cultivation. Especially when occurring in very low numbers. In the case of Bereket, Cerealia type only reaches a maximum percentage value of 4.4%, while the average percentage value is as low as 1.6%. Furthermore, the results of the CA that includes cultivated taxa, indicates that the presence of Cerealia type pollen very closely follows that of the smaller Poaceae pollen. It is therefore assumed that Cerealia type pollen in the record from Bereket basin are representative of naturally occurring grasses, which may be indicative of pastoralism, but not of cereal cultivation. Cerealia pollen type was therefore not removed from the dataset for the second CA.

It is of note that not all cultivated trees were grouped in the same PDVP, as was the case for Gravgaz. *Castanea* and *Olea*, which are especially characteristic for BO Phase agriculture, were added to BKT-B, along with indicators of open and dry vegetation (e.g. Asteraceae, Apiaceae). *Juglans* and *Fraxinus ornus* were added to BKT-E, indicative of moist pastures and woodlands (e.g. *Quercus cerris* tp, *Populus, Salix*, and Urticaceae). This results from the fact that *Olea* only occurred during the dry period preceding the mid 3rd century AD climatic change, while *Castanea* only occurs sporadically afterwards. *Juglans* and *F. ornus* also occurred at a later time, perhaps because they were cultivated or occurred in the wild at later times.

Removing the cultivated tree species had no influence on the composition of the clusters apart from the placement of *Artemisia* and *Phillyrea*. Both taxa reach their maximum percentages in the lower part of the pollen core, alongside *Olea* and *Castanea* (see chapter 1). Lacking the presence of these two cultivated species, their occurrences most closely match those of the taxa grouped in PDVP BKT-C, containing taxa representative of open, dry vegetation (e.g. Lamiaceae, Ericaceae, Caryophyllaceae, *Erynchium*).

The CA tree diagram of the Bereket basin pollen data is displayed in Fig. 4.8. The CA performed on the NPP's resulted in a subdivision into 4 groups representing specific local circumstances, displayed in Fig. 4.9.

The results of the Cross Correlations reveal that the highest correlation between the cultivated trees and one of the PDVP's at lag=0 occurs with BKT-B, showing a positive correlation of 0.42. Cultivated trees are significantly correlated with PDVP's BKT-B and BKT-C at a lag of -1 and 1 respectively. A lag this small still indicates that there is a direct link between the occurrence of cultivated trees and the importance of these PDVP's, both of which indicative of open and dry vegetation types. The second highest correlation is with pine forest, which shows a much stronger increase after the end of the BO Phase here, than around Gravgaz (see chapter 3). There is no significant correlation between the cultivated trees and PDVP BKT-E, which originally contained *Juglans* and *Fraxinus ornus*. This may be a result of the relatively limited importance of these two trees in the pollen spectrum.

None of the other PDVPs, regardless of the ecological preferences of their dominant plant taxa show any correlation, suggesting that PCA-Axis 1 and 2 are not primarily controlled by the presence/absence of crop cultivation but were directly or indirectly driven by external forces (e.g. climate). The correlograms displaying the Cross Correlation results for Bereket are displayed in Fig. 4.10.

PCA-Axis 1 scores were similar to those of the DCA, a Cross Correlation indicating that the correlation at lag=0 was as high as 0.99 (Figure 4.5). These results indicate that the horseshoe effect also does not occur in the data from the Bereket basin. The PCA scatter plot and the loadings of the different pollen-derived vegetation types are detailed in Fig. 4.11. PCA-Axis 1 and 2 account for 86.1% of the cumulative variance, Axis 1 accounting for 61.0% and Axis 2 accounting for 25.1%.

The PCA-Axis 1 loadings assign positive scores to BKT-F (+0.82), and BKT-A (+0.002). Negative scores are assigned to the cultivated trees (-0.0077), BKT-B (-0.023), BKT-E (-0.039), BKT-C (-0.18) and BKT-E (-0.54). The PCA-Axis 2 loadings assign positive scores to BKT-D (+0.65), BKT-F (+0.34), and BKT-E (+0.0060). Negative scores are assigned to, BKT-A (-0.003), the cultivated trees (-0.021), BKT-C (-0.32) and BKT-B (-0.60). The PCA-Axis 1 and PCA-Axis 2 scores, and local vegetation and NPP dynamics since AD 300 are presented in Fig. 4.12.

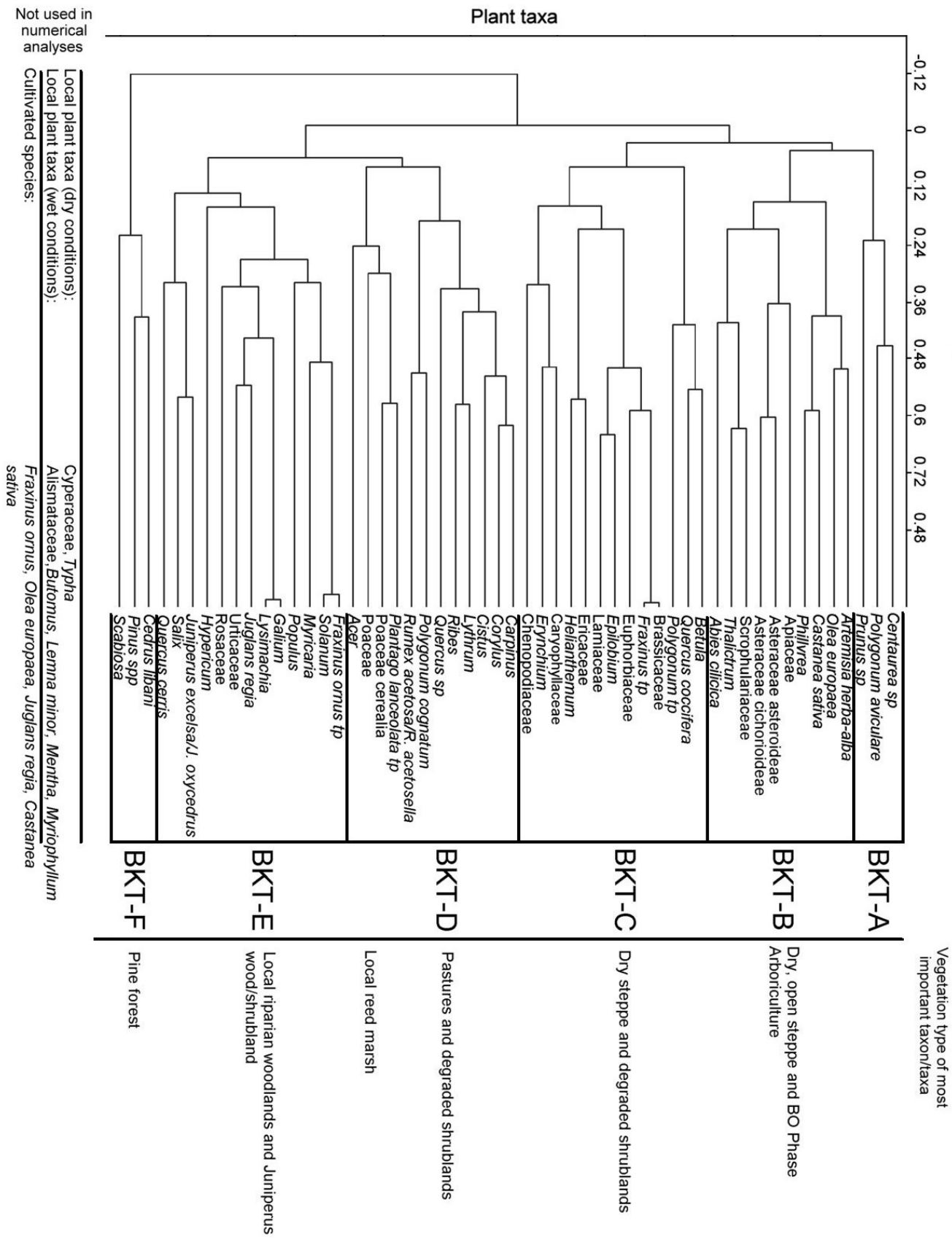

Fig. 4.8. The Cluster Analysis tree diagram displaying the six different pollen derived vegetation patterns (PDVP) for core SA09JBDrill02 (Bereket Basin). Each PDVP (named BKT-A to GVZ-F) contains taxa that may originate from different vegetation types, but which thrive under similar environmental conditions. The vegetation types associated with the most important pollen taxa in each PDVP are based on van Zeist et al. (1975), Bottema and Woldring (1990) Fontaine et al. (2007) and Kaniewski (2007a).

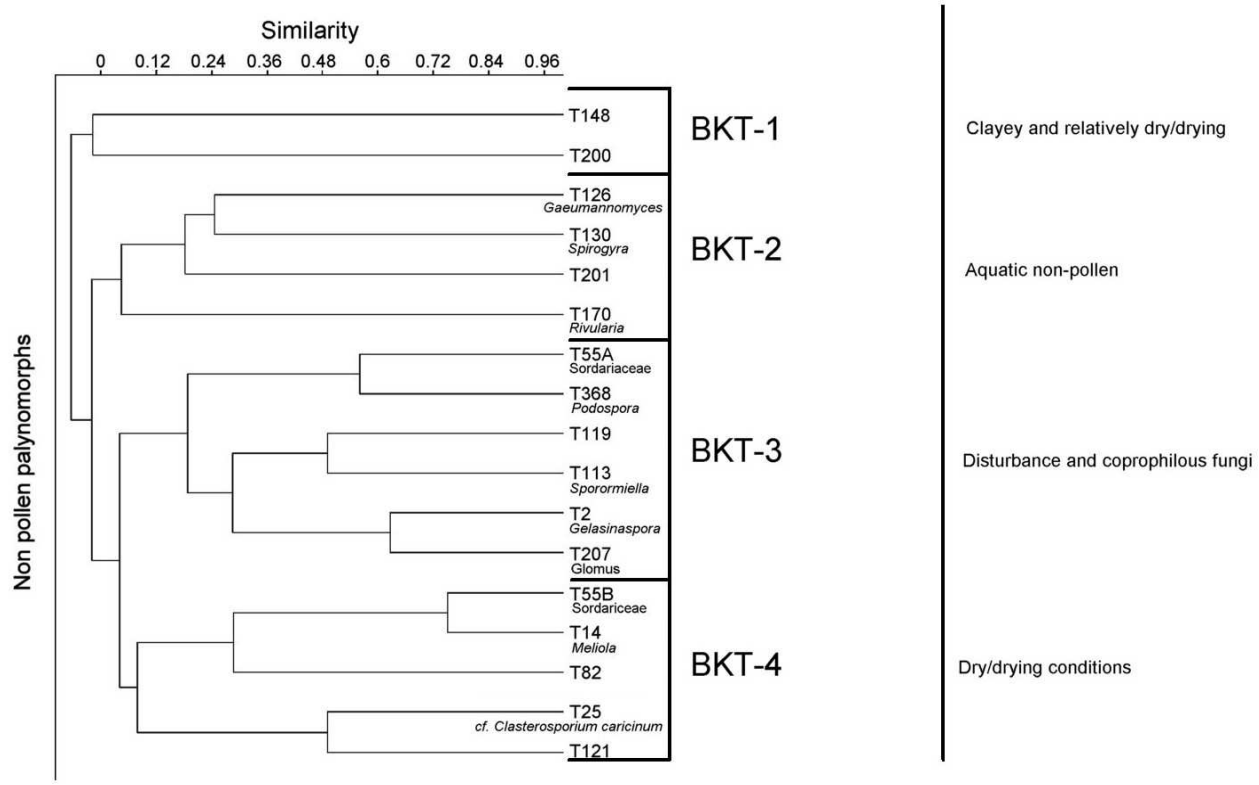

Fig. 4.9. The four different CA-derived groups of non-pollen palynomorphs for SA09JBDrill02 (Bereket Basin), each group indicating a specific set of local conditions.

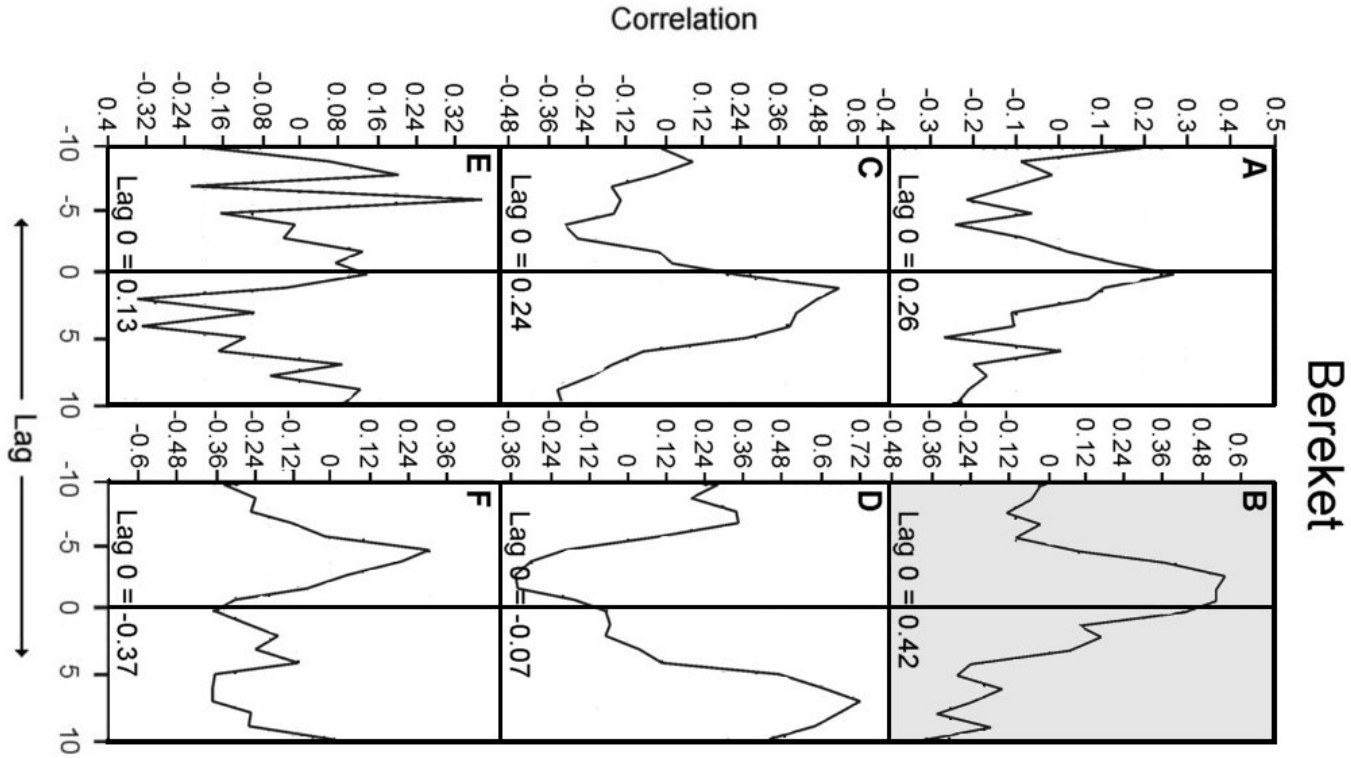

Fig. 4.10. Correlograms of the cultivated species versus the pollen-derived PDVP's for the Bereket basin. The vertical axes show the correlation coefficients. The significance level is P=0.05. The correlogram highlighted in grey displays the near-significant positive correlation between the cultivated species and BKT-B, containing dryland steppe taxa, and the cultivated species themselves in the CA ordination.

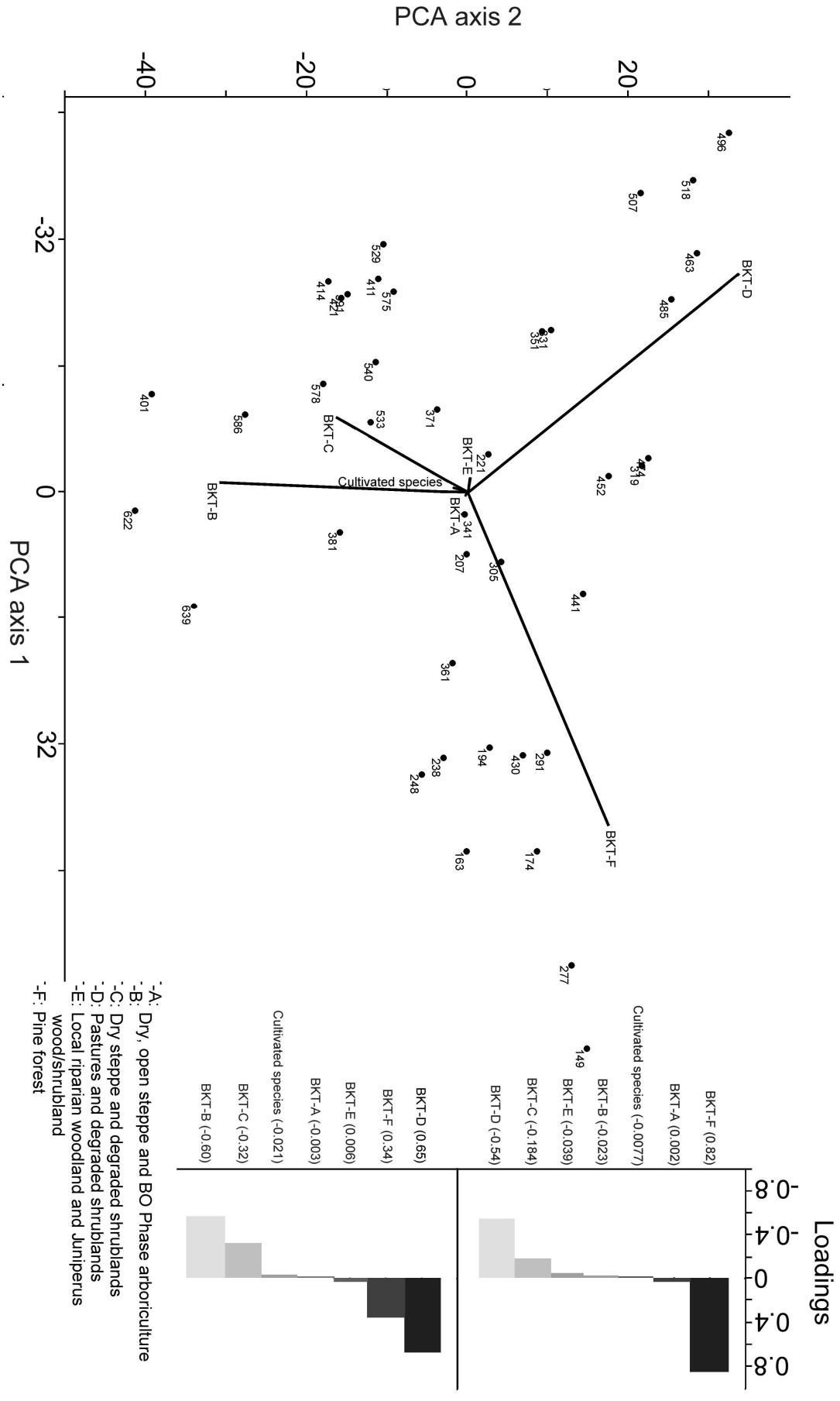

Fig. 4.11. Top: Principal components analysis biplot of the samples for the Bereket basin. PCA axes 1 (60.0% of total variance) and 2 (25.1% of total variance) account for 86.1% of the cumulative variance. Bottom: the loadings for each PDVP along PCA axis 1 and 2.

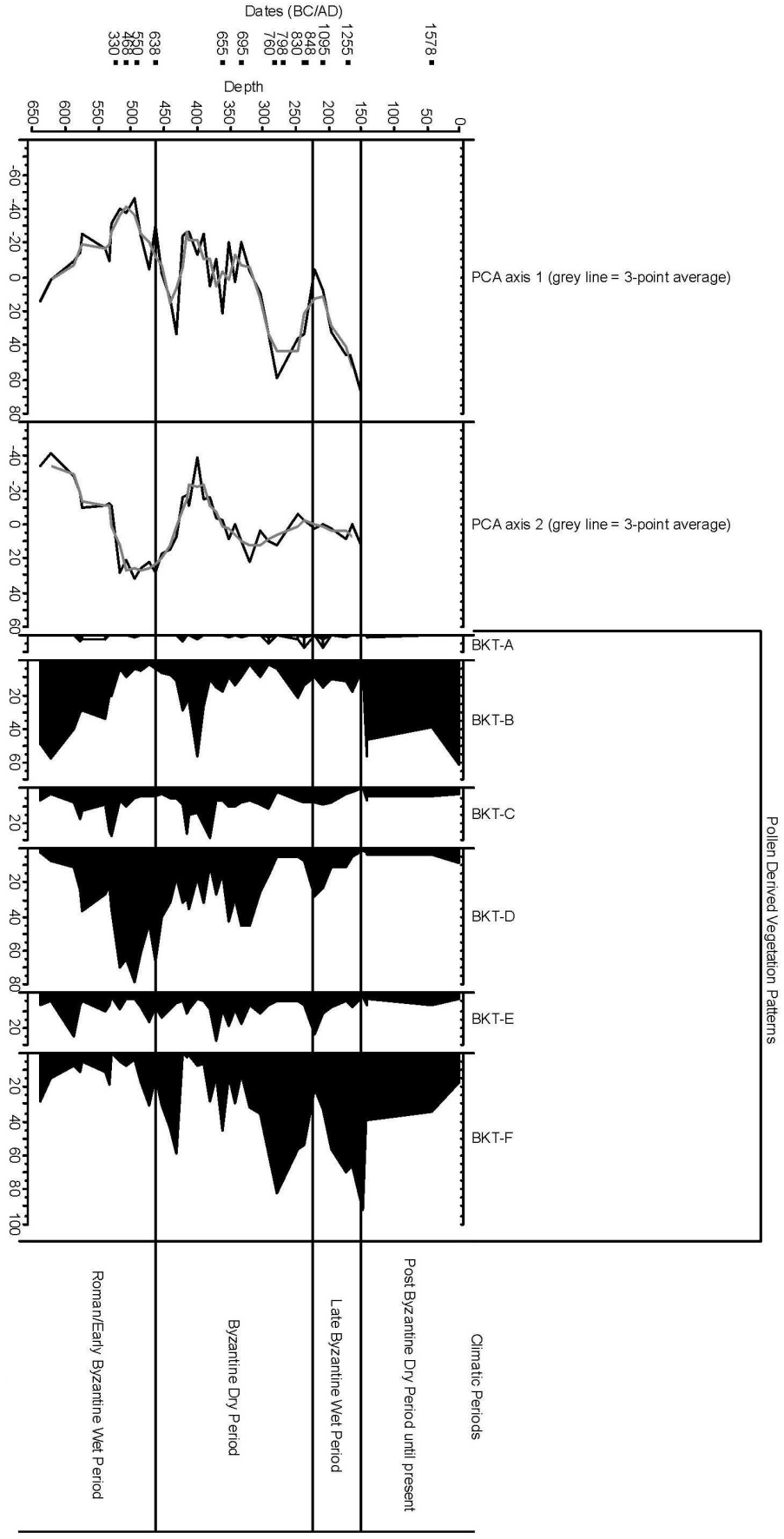

Fig. 4.12a. PCA-Axis 1 scores, PCA-Axis 2 scores, PDVP percentage values for pollen (BKT-A to F) and non-pollen palynomorphs (BKT-1 to 4) for core SA09JBDrill02 (Bereket basin). The grey lines in the PCA-Axis 1 and 2 graphs show the three point moving averages for the axis scores. The curve named "Cultivated species" only contains the cultivated tree species encountered in the pollen data. Cerealia type pollen was considered too rare to be indicative of cereal cultivation (see chapter 2). The subdivision in climatic periods corresponds with the periods distinguished in the Gravgaz marsh PCA scores. A graph displaying individual pollen taxa is given in Appendix 7.

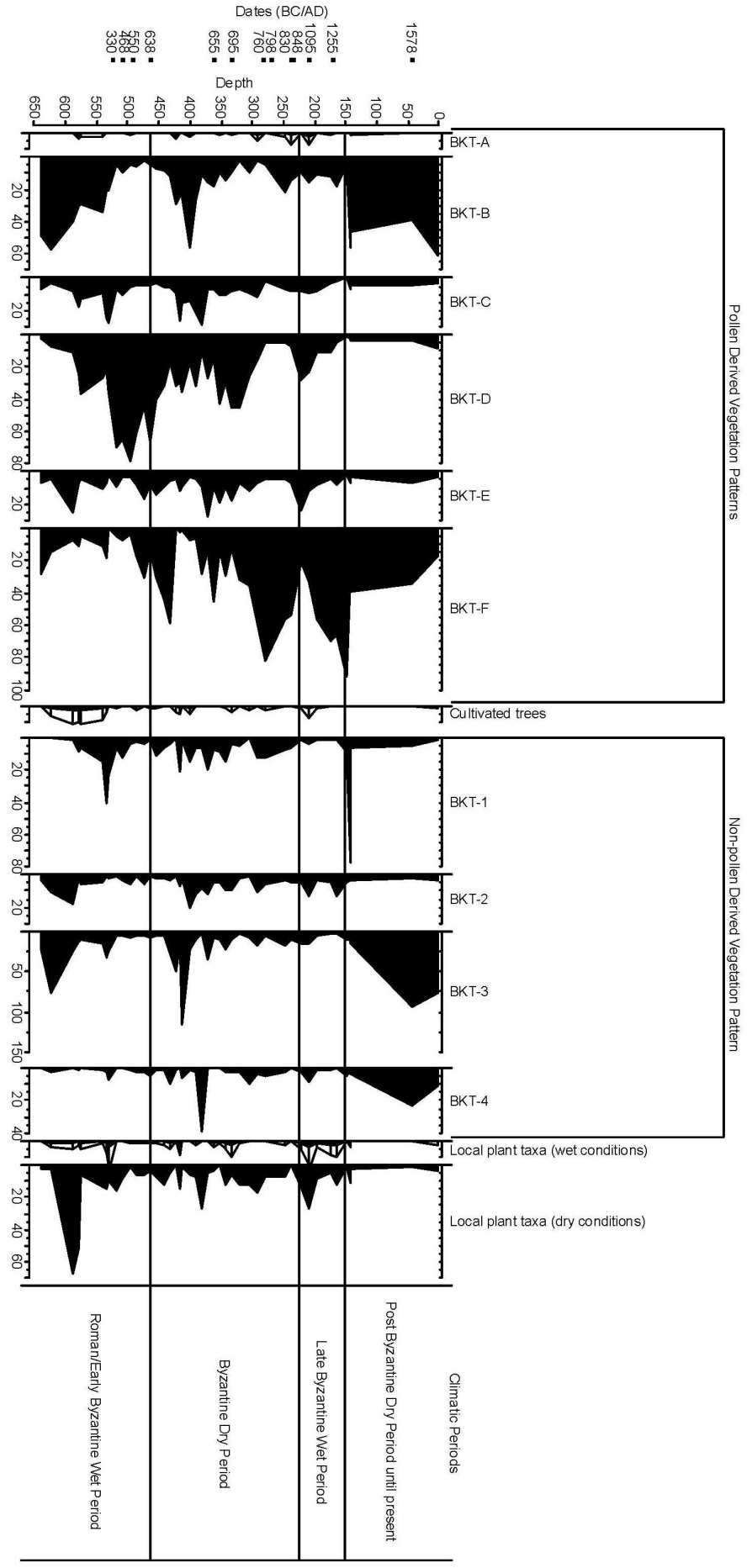

Fig. 4.12b. Same as 4.12a.

The PCA biplot shows that three PDVP's (BKT-B, BKT-D and BKT-F) account for most of the variance in the data. All three of these PDVP's contain one species which may reach relatively high percentage values in the pollen spectrum. BKT-F is indicative of pine forest (*Cedrus, Pinus*), especially *Pinus* reaching very high percentage values, indicating the establishment of a pine forest in absence of human impact in the form of crop cultivation or pastoralism. BKT-B is dominated by occasionally large percentages of Asteraceae Cichorioideae, indicative of open and dry vegetation, expecially high percentage values being the result of selective pollen transportation under very dry climatic conditions. BKT-D is primarily characterized by taxa indicative of pastures (*Plantago, Rumex, Polygonum aviculare, Polygonum cognatum*). However, it also contains Poaceae, which reaches very high values in connection with the establishment of a marsh on the sample site following the end of the BO Phase (see chapter 2), the especially high percentage values being indicative of locally occurring reeds (see also chapter 5).
The loadings for PCA-Axis 1 and 2 do not order the different PDVPs according to any environmental trend. The variance in the data is driven by the relative importance of these three PDVP's. The scores of the samples along the first PCA axis indicate, if anything, the presence or absence of pine forests, while the scores along the second PCA axis seem to indicate presence or absence of human impact in the basin, specifically BO-Phase arboriculture. Using a log transformation in order to counter the large influence of these three PDVP's on the total variance of the data did not provide a solution as these three PDVP's remained the most important causes of variance in the data. The timing and nature of vegetation change in the Bereket core can therefore not be used as proof of climate change. However, studying the timing and nature of vegetation change in the Bereket basin, specifically when and why we see an increase or decrease in pine forest or arboriculture may reveal more information on how and to what extent climate change influenced the evolution of vegetation in the landscape throughout the territory. Comparing the Bereket basin pollen record with that of Gravgaz will help disentangle the influence of the local topography on the vegetation from that of regional changes in the environment caused by the climatic shifts recorded in the Gravgaz pollen data. PCA axis 1 and 2 scores are provided in Appendix 4.

4.3.2. Regional and local environmental change

Given the notion that the PCA-Axis 2 scores from the Gravgaz marsh pollen record indicate relative moisture availability, five distinct bioclimatic periods, characterized by relatively dry and relatively wet environmental conditions can be distinguished. The five periods have been named after their relative moisture availability (wet or dry) and the time period during which they occur (e.g. Roman, or Byzantine). The occurrence of these periods through time has been indicated in Figs. 4.7 and 4.12. In order to illustrate which taxa are the most important in driving each individual PDVP, percentage pollen and NPP diagrams for both cores, showing the taxa used for the numerical analyses grouped per PDVP, are given in appendix 7.
Short-term fluctuations in the percentage values and PCA scores may be caused by the yearly variations in pollen production found in many deciduous tree species. The amount of pollen produced is strongly dependent on the weather during the flowering season, while a multitude of other factors, such as disease or consumption by insects, may also play a role. Therefore it can be expected that pollen production varies from year to year. Furthermore, individual peak values may be caused by isolated events such as a fire, and are not directly related to the prevailing moisture availability. Therefore this study focuses on long-term (multi-centennial) trends in moisture availability. The use of a single numerically derived proxy, rather than pollen types, helps neutralize the obscuring influence of such fluctuations. While the following section will also describe some of the more distinct peak values in PCA scores and PDVP percentage values, the interpretation of the data and the resulting conclusions are based only on the main, long-term trends, which are more likely a result of changes that occur in the wider region. The start and end ages of these zones are extrapolations based on the available radiocarbon dates for this record. All ages in years BC/AD given in the present study are rounded to the decadal level.

4.3.2.1. Gravgaz marsh: core SA06EP1

4.3.2.1.1. Mid 3rd century – mid 7th century AD Wet Period (338-248 cm)

This period corresponds to the latter half of pollenzone I in chapter 3. It is characterized by strong negative scores for both of the PCA axes, indicating moist environmental conditions and a relatively open landscape. These negative scores are primarily driven by high percentage values for PDVP GVZ-D and the cultivated species. The increasing dominance of *Pinus* pollen displayed in chapter 2 is reflected here in increasing percentage values for GVZ-A, as well as rising scores for PCA axis 1. Locally the area around the sample site is characterized by marshy vegetation throughout this zone.

4.3.2.1.2. Mid 7th century – mid 10th century AD dry period (248-156 cm)

The start of this period, which coincides with the disappearance of *Olea* and cereal cultivation around Gravgaz marsh, coincides with a sharp rise in PCA axis 2 scores. These scores remain predominantly positive throughout this zone. These high scores are primarily caused by increased pollen percentages for Asteraceae Cichorioideae, but chapter 2 revealed that other plants indicative of dry, open vegetation types increase as well. PCA axis 1 scores fluctuate, but the three point average shows a gradual increase after an initial drop. This pattern is primarily driven by increasing *Pinus* pollen percentages, which primarily increase at the cost of Asteraceae Cichorioidae. Locally this zone is characterized by a sudden drop in marsh plant taxa (Cyperaceae, *Typha*). Only GVZ-NP1 seems to show a very marginal increase in percentages, mostly driven by an increase in *Sporormiella* (T113). *Rivularia* (T170) percentages show a peak at a depth of 241 cm. However, since this is only one sample, this peak is not interpreted as being indicative of a major change in the environment.

4.3.2.1.3. Mid 10th century – late 13th century AD Wet Period (156-113 cm)

This zone is characterized by a positive trend in PCA-Axis 1 and negative values for PCA-Axis 2. High PCA-Axis 1 scores are driven by high percentages for GVZ-A, which increases throughout this zone, and GVZ-F. GVZ-C (indicating Juniper shrub and woodlands) decreases throughout this zone. Negative scores for PCA-Axis 2 are driven by high percentages for GVZ-C and GVZ-D at the start of this zone. During the top half of this zone, the negative trend in PCA axis 2 scores continues, driven by high pollen percentages of *Abies* (GVZ-F). Locally the start of this zone coincides with increased percentages for Marsh and aquatic plant taxa.

4.3.2.1.4. Late 13th century – early 18th century AD Dry Period (113-45 cm)

PCA-Axis 1 shows a negative trend while PCA-Axis 2 scores are generally higher than within the preceding zone and predominantly positive. This zone is characterized by high GVZ-B values and a strong positive trend for GVZ-C. Locally this zone shows increased values for all NPP groups, although the biggest increase can be seen in those NPP's that indicate dry conditions (T148, T184, T200, *Gaeumannomyces*) and dung (Sordariaceae, *Podospora*).

4.3.2.1.5. Modern Period (45-0 cm)

The negative trend in PCA-Axis 1 is reversed with scores continuously increasing, only dropping in the uppermost pollen samples. The positive trend is mostly driven by increasing *Pinus* pollen percentages (driving GVZ-A), although *Abies* pollen (GVZ-F) also remains important during this zone. PCA-Axis 2 scores are predominantly negative and generally marked by high values for GVZ-C, indicating the importance of Juniper shrubs and trees.

Locally this zone is characterized by increasing percentage values for GVZ-NP1, GVZ-NP4 and GVZ-NP5. These patterns are mostly caused by increases in coprophilous NPP's, indicating the presence of dung (Sordariaceae, *Sporormiella, Podospora*), and aquatic NPP's (*Gaeumannomyces, Rivularia).* The most notable NPP is *Glomus*. The indicative value of this NPP is ambivalent. It occurs as a parasite on terrestrial plants (e.g. *Betula*). Its occurrence may therefore be indicative of dry local conditions. *Glomus* may also be found in marsh and lake sediment when sediments containing *Glomus* are redeposited into these locations from elsewhere. *Glomus* may therefore be indicative of erosion as well.

4.3.2.2 Bereket basin: Core SA09JBDrill02

The Bereket basin pollen data itself was not suited for the creation of a climatic proxy (see section 4.3.1.2). Comparing the pollen data with local NPP and sediment data from the same basin aids the interpretation of the nature of the observed vegetation changes and may give an indication for changing environmental conditions within the Bereket basin. The data shows that a number of the major shifts in the PDVP's coincide with the perceived changes in moisture availability observed in the Gravgaz data.

4.3.2.2.1. Mid 3rd century – mid 7th century AD Wet Period (639-463 cm)

This zone can be subdivided into two different parts, the border of which lies at a depth of 525 cm. This depth corresponds with a radiocarbon date of c. AD 330 and coincides with the start of local peat formation, as described in chapter 2. In the lower part of this zone, the PDVP diagram shows a strong decrease in BKT-B, containing taxa indicative of dry, open steppe (Apiaceae, Asteraceae Cichorioideae, Asteraceae Asteroideae). This decrease coincides with an increase in BKT-C, containing further taxa indicative of dry, open steppe (Lamiaceae, Caryophyllaceae, *Artemisia*) and pastoralism (*Quercus coccifera*), as well as an increase in BKT-D, containing Poaceae as its most important taxa, but also other indicators of moist fields and pastures (*Rumex, Plantago, Polygonum cognatum*). Cultivated trees diminish and *Olea* cultivation stops at 533 cm. The second half of this zone, from 525 to 463 cm is also present in the Gravgaz core. During this zone BKT-D is driven by high values of Poaceae, which reaches pollen percentages of up to 80 percent. BKT-F, indicative of pine forest, starts to increase at the top of this zone. Locally the shift in the PDVP's at 525 cm coincides with a decrease in most NPP groups and local taxa.

4.3.2.2.2. Mid 7th century – mid 10th century AD Dry Period (463-224 cm)

Dominance of BKT-D decreases strongly at the start of this zone. The pollen signal within the rapidly deposited layer between 425 and 350 cm indicates that PDVP's BKT-B and BKT-C (both related to open and dry steppe vegetation) were relatively important prior to the deposition of this layer on the sample site. The sediments located between 350 and 300 cm show that BKT-D (Poaceae) remained relatively important, but BKT-B and BKT-C decrease in importance while BKT-E (taxa representative of relatively locally occurring riparian trees and pastures) and BKT-F (pine forest, dominated by *Pinus* pollen) percentages show a small increase. Above 300 cm, BKT-F becomes the dominant PDVP. Locally all NPP groups increase slightly. No strong response to the fast deposition of sediment can be observed in the NPP data, apart from individual peak values. Such individual peaks are not considered informative for the purpose of the present chapter as they indicate local, short term variations in the local environment, rather than regional long-term trends.

4.3.2.2.3. Mid 10th century – late 13th century AD Wet Period (224-150 cm)

The start of this zone is characterized by a strong decrease in BKT-F. This PDVP is mainly replaced by BKT-D and BKT-E, both indicating relatively moist conditions, both locally and regionally. However, both PDVP's degrease gradually throughout this period as BKT-F once more becomes the dominant PDVP. Locally this zone is characterized by an increased presence of aquatic taxa. The local NPP groups do not show any distinctive trends within this zone, only *Rivularia* (T170), a Cyanophyceae found on submerged leaves and stems of plants (e.g. *Nuphar*).

4.3.2.2.4. Late 13th century AD until present (150-0 cm)

For Bereket, only a small part of the record above 150 cm remains usable. The largest part of the sediment above this depth is located above the present water table, which had dropped due to the draining of the marsh in the 1960's and is not useful for pollen analyses. The sediment is characterized by low organic matter content, low pollen concentration, a high percentage of corroded pollen and a very poor diversity of pollen in the pollen spectrum. The usable part of the sediments is very small and seems to indicate a continued dominance of pine forests while BKT-B and BKT-C increase.

4.4. Discussion

The ecological preferences of the dominant species in each PDVP indicate that PCA-Axis 2 scores are an indication of moisture availability. The following section describes the observed vegetation changes in the light of this assumption. Firstly, the shifts in moisture availability observed in Gravgaz will be compared with the pollen and sediment data from Bereket in order to ascertain to what extent the Gravgaz bioclimatic proxy is applicable to the wider area. Secondly, the timing and apparent nature of the natural environment (relatively dry or relatively wet) will be compared to a series of independent climatic proxies from the Middle East and North-west Europe.

There is no exact match between the start and end dates of the wet and dry periods distinguished in the Gravgaz marsh pollen data and those of any of the Middle Eastern climatic proxies named in this dissertation. Differences in timing may be a result of the limitations of the chronology available for some of these records. Furthermore, the nature of a climatic proxy may result a delay in its response to a change in the climate. E.g. an oxygen isotope record from varved lake sediments would show a faster response to climate change than pollen data.

As postulated in section 4.2.1., the impact of the various driving forces of climate change varies from location to location, also resulting in regional differences in the effects, intensity, and timing of climatic change. While the assumed start and end dates of these climatic periods do not always coincide, their occurrences do generally overlap.

This discussion will focus on a comparison of the Gravgaz pollen-derived climatic proxy with other climatic proxies. There is substantial historical data available concerning the weather in Byzantine times. These records do point towards increasingly cold and dry conditions between the 7th and the 10th century and from the 14th century onward (Wagstaff, 1985; Telelis, 2000), as well as warmer, more friendly climatic conditions during the 11th-12th century (Telelis, 2000; 2005). However, such records remain collections of individual observations of varying accuracy, and biased towards individual extreme meteorological events, rather than long-term climatic changes. Therefore such records should not be used as proof of the accuracy of a climatic proxy such as this one.

Unfortunately, the aforementioned dominance of individual pollen types (e.g. *Pinus*), and recent origins of the current vegetation throughout the wider region, make it impossible to quantify the observed changes in moisture availability using modern analogue techniques.

4.4.1. Mid 3rd century – mid 7th century AD Wet Period (Roman Warm Period)

The pollen-based bioclimatic proxy, derived from the Gravgaz marsh pollen record, indicates that the period estimated to last from c. AD 300 to 650 was characterized by relatively high moisture availability. The PDVP data, as well as the individual pollen and NPP data from the Bereket basin indicate a similar trend towards increased moisture availability. This relatively wet period corresponds roughly with the last part of the RWP, and is observed throughout the Eastern Mediterranean and the Middle East (Hirschfeld, 2004; Izdebski, 2011).

As discussed in the Introduction section of this chapter, the mid 7th century estimation for the end of this relatively wet period coincides with estimations given in climatic proxies from the Middle East and the Eastern Mediterranean (von Rad et al., 1999; Schilman et al., 2001; Hirschfeld, 2004; England et al., 2008; Jones et al., 2006; Sorell et al., 2007; Neumann et al., 2007a,).

The dry peak observed in the Gravgaz record during the mid-late 3rd century is, based on its duration, most likely the result of a short-term local phenomenon. However, it coincides with a dry event observed in the Bereket basin by Kaniewski et al. (2007a, 2007b), as well as the occurrence of relatively dry conditions in the

2009 Bereket basin pollen core prior to the early 4th century (chapter 2; Bakker et al., in press). Dry conditions during the RWP prior to the 4th century are also recorded for the Dead Sea (Neumann et al., 2007) and the NE Arabian Sea (von Rad et al., 1999). Schilman et al. (2001) show that dry conditions end much earlier (mid 2nd century AD) in a record from the SE Mediterranean sea. However, a further amelioration of the climate towards increased humidity occurred between the second half of the 3rd century and the mid 5th century.

4.4.2. Mid 7th century – mid 10th century AD dry period (Dark Ages Cold Period)

The abrupt shift from relatively wet to relatively dry environmental conditions during the mid 7th century coincides with an increase in importance of dry, open steppe taxa in the Bereket basin, as well as around Gravgaz marsh. This data indicates that the shift in moisture availability, as well as its impact on the human population is caused by climate change, rather than a local shift in moisture availability, e.g. due to changes in the spring discharges supplying the marsh. The sediment records of Gravgaz indicate that local moisture availability remains relatively high for some time, decreasing gradually from the 8th century AD onwards (see chapter 2). However, based on the current evidence, it is impossible to tell whether this is a delayed response to a decrease in precipitation, or a purely local phenomenon. The timing of this dry period coincides with the timing postulated for the Dark Ages Cold Period (DACP) in the Middle East, as given in section 4.1.2.2. of this chapter.
When comparing the climatic data from Gravgaz marsh with other climatic records from Turkey, certain notable discrepancies come to light. While the combined oxygen isotope and pollen record from Lake Gölhisar (Eastwood et al., 2007), the only other climatic proxy from SW Turkey, contains little information concerning the period from c AD 500 to the present, it does indicate a strong aridification of the region during the 7th century. The detailed oxygen isotope record from Nar lake, central Anatolia (Jones et al., 2006), also shows a period characterized by dry environmental conditions, corresponding with the DACP. However, at Nar Lake, this period starts during the mid 8th century. A similar delay is also visible in the record from Lake Van, eastern Anatolia (Lemcke and Sturm, 1997; Wick et al., 2003), as well as other records from the more eastern part of the Middle East, such as the Aral Sea basin (Oberhänsli et al, 2007; Sorrel et al., 2007).
This time difference is difficult to explain with the uncertainties inherent in the carbon dating method used for the chronology of the Gravgaz record, as these are relatively precise. The notion that vegetation responds slower to climatic change than an oxygen isotope record is not a proper explanation either, as such a delay would be in the order of several years, rather than a century. A more probable explanation is that the more eastern, inland locations such as Nar Lake and Lake Van are more influenced by the Indian monsoon, whereas in SW Turkey, the influence of the Mediterranean Westerlies, influenced by the NAO, is larger (see also Luterbacher et al. 2009).

4.4.3. Mid 10th century – late 13th century AD Wet Period (Medieval Climate Anomaly)

Throughout this period, moisture availability in Gravgaz marsh was relatively high, locally as well as regionally. Due to the fact that human presence on the landscape was more limited in the Bereket basin than around Gravgaz marsh, pine forest was able to develop more strongly in the former location. This dominance of pine obscures any climatic signal in the pollen data. However, the pine forest in Bereket is cleared during the mid 10th century, coinciding with the start of the wet trend recorded in the Gravgaz pollen data. The resulting open vegetation present in the pollen record between the 10th and the 12th century is characteristic of relatively moist environmental conditions. Furthermore, local pollen data indicate that the marsh present in the Bereket basin was relatively wet throughout this climatic period, while no dry or wet trend could be observed in the sediment record of Gravgaz. The timing of this moist period coincides with the MCA. This climatic period was characterized by relatively warm conditions in Europe and the Middle East, while the environment in the latter region was also relatively wet.
Compared to the regional differences in the starting date of the previous climatic period, the start of the MCA is relatively uniform throughout Western Europe, the Eastern Mediterranean and the Middle East (see section 4.1.2.3.). The onset of the MCA in Nar Lake (Jones et al., 2006) and Lake Van (Lemcke and Sturm, 1997; Wick et al., 2003) occurs later than in Gravgaz marsh, but the difference is small, in the order of 50 years. The height of the MCA in Gravgaz marsh coincides precisely with a drop in hematite-stained grain percentages in the North Atlantic (Bond et al., 2001), linked with a pervasive positive phase of the NAO. The MCA also coincided with an increase in the strength of the Asian SW Monsoon (Gupta et al., 2003). The co-occurrence

of these two phenomena may have caused the fact that the MCA occurs nearly simultaneously from NW Europe to the Middle East (see also Fig. 4.13). The end of the wet period recorded in the Gravgaz pollen record shows a marked discrepancy with the available sediment records from Gravgaz and Bereket. Both records indicate a distinct dry trend, estimated to start in c. AD 1220 and 1260 respectively. These shifts coincide with a distinct dry period recorded in Anatolian tree ring data (Touchan et al. 2007). Unlike during the other climatic shifts, the vegetation was now dominated by pine forest, which forms the natural secondary climax vegetation in this region, and is able to withstand severe drought. The relatively wet conditions indicated by the climatic proxy are the result of the relative abundance of *Abies*, which is seen as an indicator of moist conditions (Ermolli and di Pasquale 2002; Fontaine et al. 2007). This delay in the response of the pollen record to an aridification may be related to the time it takes for the forest composition to change after such a climatic shift, a problem not present during the earlier climatic changes observed in the pollen record, as the mid 7th century and the mid 10th century changes in moisture availability were indicated by changes in herbaceous plant taxa and the particular composition of the vegetation after a deforestation phase respectively.

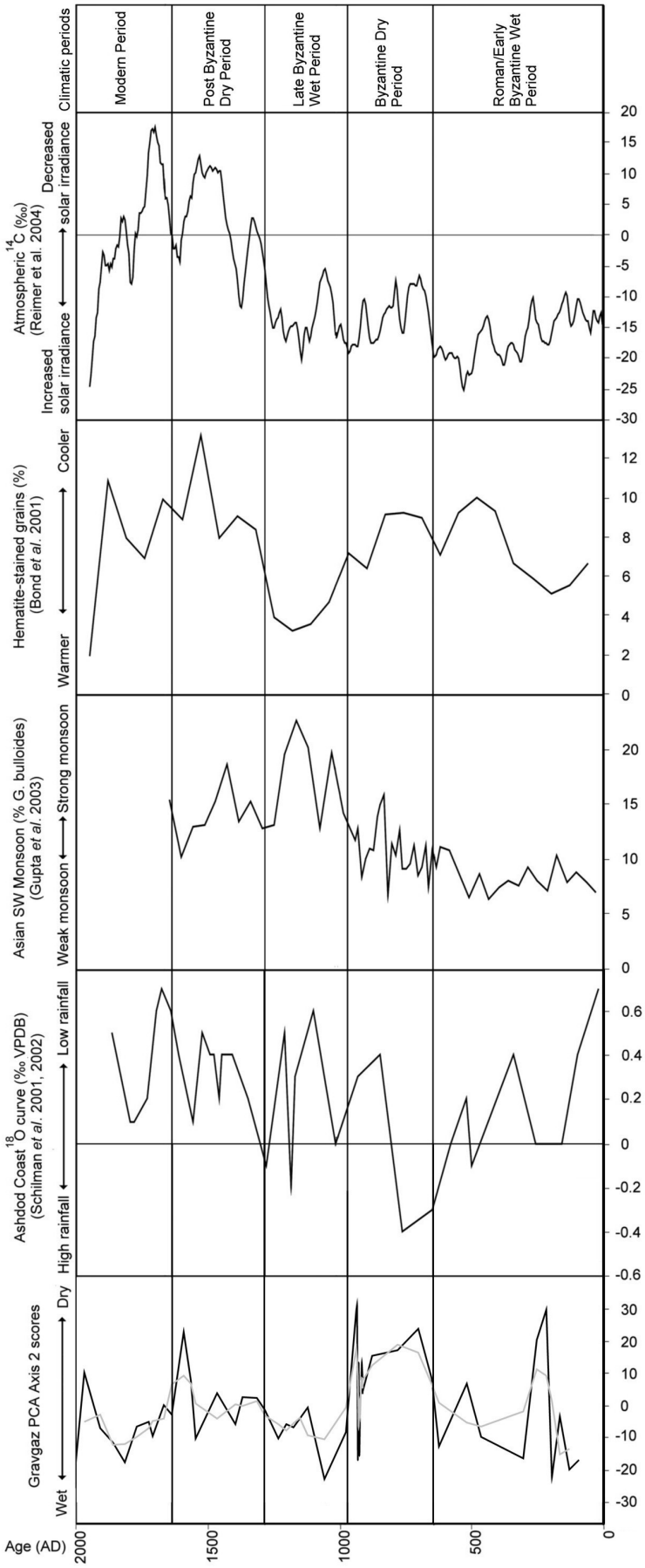

Fig. 4.13. An overview of the main bioclimatic (wet/dry) phases in the territory of Sagalassos, as distinguished by the numerical analyses, and a comparison of the occurrence of humid and dry trends from 0 to 2000 AD in climate records from the Northern Atlantic (Bond et al., 2001), Asia (Gupta et al., 2003), the atmospheric radiocarbon record (Reimer et al., 2004) and the territory of Sagalassos (Bakker et al., 2011a). The data are displayed along a time axis. The subdivision in climatic periods along this axis is based upon the combined chronology of cores SA06EP1 and SA00EP03.

4.4.4. Late 13th century – early 18th century AD Dry Period (Little Ice Age)

Although the shift in environmental conditions is less pronounced than that seen during the RWP-DACP shift, the climatic proxy indicates that environmental conditions generally become drier after c. AD 1300. Conditions remained relatively dry throughout this period, during which the remaining signs of human impact decrease even further.
A similar dry trend is found in other records from the Middle East, although here the timing of this climatic shift differs quite strongly among records. Bar-Matthews et al. (2002) report how moist conditions persist until the mid 14th century in Soreq cave, Israel, although a dry trend can be observed since the early 13th century. A similar early starting date for the aridification of the climate can be seen in the Red Sea planktonic $\delta^{18}O$ record (Lamy et al., 2006), which shows a dry trend from c. AD 1200 to 1550. A dry period in the northern Red Sea region is also estimated to start during the early 13th century (Lamy et al., 2006). At more inland locations, such as the Dead Sea (Neumann et al., 2010) and Nar Lake in central Anatolia (England et al., 2008; Jones et al., 2006), records show that a shift towards dryer conditions only occurred at c. AD 1400. In general, the available data show that the climatic deterioration, corresponding with the onset of the LIA, occurred throughout the Middle East between AD 1200 and 1400.
Both the timing of the start of the dry period in Gravgaz pollen record at c. AD 1300, as well as the perhaps more realistic estimate of AD 1250-1300, based on the sediment data, falls comfortably within these estimates. Furthermore, the estimate for the Gravgaz core coincides with a distinct rise in hematite-stained grain percentages (Bond et al., 2001) and a rise in atmospheric radiocarbon (Reimer et al., 2004), suggesting that changes in moisture availability at this time were connected to the changes in solar activity. The various drier and wetter periods within the LIA, recorded by Touchan et al. (2007), do not clearly show up in the pollen data. However, the climatic proxy does indicate the occurrence of a short, very dry period during the late 16th/early 17th century AD, which coincides with the onset of one of the driest periods recorded in the tree ring data of Touchan et al. (2007), as well as the Maunder minimum in solar activity (Eddy 1976).

4.4.5. Post 18th century AD moist trend (Modern Warm Period)

PCA axis 2 scores indicate a moist trend starting since the early 18th century, and culminating during the mid 19th century. Although the apparent onset of moist conditions coincides with the end of the Maunder minimum in AD 1714, and the start of a relatively wet interval of the LIA in AD 1743 (Touchan et al., 2007), this signal may also be partially caused by the deforestation of the region. Logging activities may have caused the removal of pine from the area, resulting in lower percentage values for PDVP GVZ-A. The onset of moist climatic conditions at the end of the 18th century in Gravgaz is rather early compared to other records that mention this time period in any detail. The end of the LIA is generally placed at the end of the 19th century, or even the beginning of the 20th century in Europe, the Middle East and beyond (Ogilvie and Jónsson, 2001; Hendy et al., 2002; Jones et al., 2006). However, the PDVP's that replaced GVZ-A (GVZ-C, GVZ-F, and to a lesser extent GVZ-E) are all considered to be indicative of relatively moist environmental conditions. Despite the presence of a dry interval during the 19th or 20th century, the climatic proxy indicates a persistent trend towards moister environmental conditions since the 17th century. The most recent part of the climate proxy indicates that the current bioclimate is comparable to that of the wettest period of the MCA.

4.5. Conclusions

The conventional pollen analysis discussed in chapter 3 already revealed how certain important shifts in the vegetation and sediment dynamics, and/or human impact coincided with shifts in moisture availability. The newly developed numerical analyses performed on the pollen data reveal the exact timing and duration of these periods. The vegetation dynamics in the Bereket basin and Gravgaz marsh pollen data indicate that the changes in moisture availability detected in the Gravgaz marsh pollen-derived bioclimatic proxy occurred over a larger area and were not limited to one single basin. This notion is supported by the sediment data of Gravgaz and Bereket analyzed in chapter 3, and which showed important similarities with each other, with the pollen data, and with the tree ring data of Touchan et al. (2007).

The analyses revealed the presence of five regionally occurring periods characterized by relatively dry or wet environmental conditions. A critical comparison of the pollen-derived bioclimatic proxy with a number of independent climatic proxies from various locations within the Middle East revealed that the timing of these periods coincided with that of well-known, large-scale periods of climate change. The pollen derived bioclimatic proxy from the territory of Sagalassos encompasses the SW Turkish manifestations of the DCAP, MCA and LIA, providing new insights concerning past climate change in the Eastern Mediterranean.

The last part of the RWP, starting c. AD 300, is characterized by relatively moist conditions in SW Turkey. This trend in accordance with data from elsewhere in the Eastern Mediterranean and further supports the notion that the decrease in anthropogenic pressure observed in the pollen data is not related to a climatic deterioration in the territory of Sagalassos.

The RWP ends during the mid 7th century (estimated c. AD 640) and is followed by a relatively dry period, coinciding with the onset of the DACP in the Eastern Mediterranean region, while in Europe, the DACP is recorded to start during the late 5th or 6th century. The timing of this climatic shift in SW Turkey is quite early compared to the nearest available climatic proxy from Turkey; the Nar Lake oxygen isotope record. This difference of c. 200 years may partially be caused by the fact that Nar Lake is located about 350 km to the East in central Anatolia and therefore subjected to a more continental climate, rather than the Oro-Mediterranean climate found in the territory of Sagalassos. Furthermore, the more eastern location of Nar Lake may result in the fact that the Asian Monsoon eventually has a bigger influence on the climate at Nar Lake, than at Sagalassos. Anthropogenic activity decreased and switched from crop cultivation to pastoral activities after the 7th century climatic deterioration.

A wetter phase occurred between the first half of the 10th century and the early 14th century AD, coinciding with the height of the warm MCA in Europe, Asia and the Eastern Mediterranean. From the mid 13th century to the early 18th century AD, a dryer phase occurs. The timing of the onset of this phase coincides with a decrease in solar irradiance and falls within estimations for the start of the LIA in Europe and the Eastern Mediterranean. The most recent period is characterized by abundant juniper woodlands, perhaps caused by logging activities in the region during the nineteenth century. These logging activities may have disrupted the climatic signal within the pollen data. The current landscape is a result of an intensification of agriculture since the mid-twentieth century.

The timing of the various climatic periods recorded for SW Turkey, revealed how the onset of dry and cold conditions was connected to a decrease in solar irradiance, while the MCA, as recorded for SW Turkey, coincided with a strong negative NAO.

Generally, the post BO-Phase vegetation was characterized by meadow-steppe, riparian woodlands and abundant *Juniperus* during periods with relatively high moisture availability. Dryer periods were characterized by dryland steppe and maquis type vegetation while pine forests became abundant when grazing pressure was low.

The data reveals for the first time an overview of climate change in SW Turkey from the late Roman period until the present. This information allows for the proper disentangling of anthropogenic and climatic driven vegetation change in the pollen data, resulting in an increased understanding of the interactions between man, climate and vegetation change, which will be further discussed in chapter 7 of this dissertation.

Chapter 5

Fire impact and post disturbance succession in the SW Taurus Mountains from the late Roman period until the present

This chapter is based on/adapted from:

Bakker J, Paulissen E, Kaniewski D, Poblome J, de Laet V, Verstraeten G, Waelkens M (in prep) Climate, People, Fire and Vegetation: New insights into Late Classical and Post-Beysehir Occupation Phase Vegetation Dynamics in the Eastern Mediterranean.

5.1. Introduction

Fire activity is seen as a major ecological factor, shaping the Mediterranean landscape with its mosaic-like pattern of regeneration and degradation stages (Walter, 1968; Naveh, 1975; Spanos et al., 2000; Gracia et al., 2002; Buhk et al., 2006). Fires can be seen as a natural part of the ecosystem in the Mediterranean basin and have occurred for millennia (Pausas et al., 2008). Fire activity has driven de development and evolution of the Mediterranean vegetation, the present vegetation found in many Mediterranean landscapes being adapted to survive single fires, as well as prolonged fire episodes (Lavorel, 1999; Verdú and Pausas, 2007). Apart from being able to withstand fire damage, Mediterranean species may also be adapted to quickly regenerate after a fire due to their capacity to form a seed bank (Keeley and Fotheringham, 2000). Fire may also form the trigger mechanism for the germination of seeds, breaking seed dormancy or triggering seed release by causing cones to open (Naveh 1975; Keeley 1991, 1998; Pausas 1999; Pausas et al., 2004)

Furthermore, the occurrence of fires also plays an important role in sediment dynamics by destroying the vegetation cover. Vegetation density is one of the key factors affecting soil erodibility (Skakesby et al., 1998), a fact also discussed in chapter 3 of this dissertation, where this was illustrated by the observation that CC content in the sediments collected in the Bereket core was positively correlated with landscape openness.

Despite the long standing awareness of the importance of fire on Mediterranean vegetation and landscape dynamics, and the existence of a number of important papers discussing the importance of fire and its relation with human impact and climate (e.g. Carrión et al., 2003; Colombaroli et al., 2007; Caroli and Caldara, 2007), very little data are available on this topic for the Late Holocene in Anatolia. Turner et al. (2008) reconstructed the regional fire history from two crater lake basins in central Turkey, finding that since the onset of the BO Phase the frequency of fire events seems to have become decoupled from climate and linked instead to human-induced land cover changes and fuel load availability. However, the situation in Eastern Anatolia differs strongly from that in SW Turkey, both in terms of climate, the timing of climate change, and vegetation (Jones et al., 2006; chapter 3 of this dissertation), as well as in terms of human impact (Haldon, 2007; England et al., 2008; Bakker et al., 2011a; chapters 2 and 3 of this dissertation).

Fire and fire impact on Late Holocene vegetation development in SW Turkey has previously been researched by Kaniewski et al. (2008), who found a succession of phases of local and extra-local fire activity in the Bereket basin, occurring between the 4th century BC and the 2nd century AD, coinciding with the BO-Phase. For Bereket, the occurrence of fires during the BO Phase is thought to be linked to changing climatic conditions to some extent, but ultimately driven by local anthropogenic processes. Unfortunately, the chronological data of the cores analyzed by Kaniewski et al. (2007a, b, 2008) indicates the presence of a hiatus of unknown duration in the record between the 7th century and the present. As a result, no previous knowledge exists on fire activity and impact in SW Turkey after the end of the BO Phase.

Chapter 4 of this dissertation revealed the presence and timing of several late Holocene periods of climate change in southwest Turkey since c. AD 300, including the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA), enabling for the first time the disentangling of the influence of climate and human impact on historical records of vegetation change in the Eastern Mediterranean. Fire severity and the size of the surface damaged by fire are climatically driven (Pausas, 2004; Keeley et al., 2006) and Turner et al. (2008) link an increase in fire activity to the occurrence of wetter climatic phases. In a humid environment, more biomass would accumulate, providing fuel for fires. The occurrence of periods of relatively dry and wet climatic conditions, such as the MCA and LIA, may have an influence on the fire regime in SW Turkey. Although anthropogenic pressure on the landscape has been an important ecological factor, influencing landscape

openness and actively starting fires, Vannière et al. (2008) suggest that climatic conditions were important for fire occurrence even under strongly humanised ecosystem conditions. Even though Kaniewski et al. (2008a) indicated that human impact was a more important factor driving the fire regime in the region during the BO Phase, this relationship may have changed after the end of the BO Phase, when human impact shifts in character and ultimately diminishes.

5.1.1. Research objectives

The current chapter presents an in-depth study of two combined sediment, pollen, and charcoal records from Gravgaz marsh and the Bereket basin, SW Taurus Mountains, Turkey. The available data provides an overview of fire activity in SW Turkey and the responses of the oro-Mediterranean vegetation to disturbances from the Late Roman Imperial period (AD 300) until the present. This is the very first record of fire impact and post-disturbance succession in SW turkey which covers the period from c. AD 650 until the present.
Comparing the severity and timing of fire events with the climatic and archaeological record will reveal the most important driving factors behind fire activity in the territory. The numerical analyses used in this chapter will also assess the vegetation with which fire activity is mostly associated. This information will enable the assessment of the applicability of the notions of Vannière et al. (2008) and Turner et al. (2008) on the post BO landscape in SW Turkey.
Secondly the numerical analyses implemented in this chapter will provide an overview of post-disturbance succession, not only mapping vegetation change, as was done in chapter 3, but assessing why the vegetation responded the way it did.

5.2. Methods

In order to detect the occurrence of fires, pollen slide charcoal particles (50-200µm) and larger charcoal remains (>200µm) were counted. Macroscopic charcoal remains were collected from the material left behind after sieving the sediment samples using a 200µm sieve.

5.2.1. Charcoal data, CHARs, and the identification of fire events

High-resolution charcoal records are frequently used to estimate the timing of fires and fire episodes, using peaks in charcoal accumulation and concentration as a proxy. Unfortunately the detection of fires is complicated by the fact that charcoal records are complex and non-stationary, their mean and variance changing over time (Clark et al., 1996; Clark and patterson, 1997; Higuera et al., 2010). Higuera et al. (2007, 2010) suggest that the two most important processes that cause non-stationarity in charcoal records are changes in the fire regime and changes in the efficiency of charcoal delivery. The former process may be caused by changes in the rate of burning, the intensity of fires and the type of vegetation that is burned. The latter is described in Higuera et al. (2010) as "*changes in the efficiency of charcoal delivery to the lake centre due to changing rates of slope wash and/or within-lake redeposition*". The pollen records studied in this dissertation originate from marshes filled with peat and colluvial deposits, not from lake deposits. However, the processes described by Higuera et al. (2010) may also lead to changes in sediment accumulation rates in these environments, which may cause long term trends in charcoal records unrelated to changes in the fire regime. This phenomenon also occurs at Bereket and Gravgaz as sediment accumulation rates on the sample sites vary according to landscape openness, land use and other variables determining erosion rates.
A statistical approach is used aiming to isolate the signals related to local and regional fire activity, and to distinguish between truly anomalous charcoal concentrations in the sediment and peaks in charcoal concentration that are the result of changes in sedimentation rates. Pollen slide charcoal particles (50-200µm) and larger charcoal remains (200-2000µm) were counted and summed. Very few charcoal particles bigger than 2000µm were encountered in the samples. Charcoal accumulation rates (CHAR) were computed using the CharAnalysis software, a program for analyzing sediment-charcoal records with the goal of peak-detection to reconstruct fire histories (For more info on CharAnalysis see http://sites.google.com/site/charanalysis/; Higuera et al., 2007; Higuera et al., 2010). The charcoal data were decomposed into a low frequency background component (Cbackground), and a peak component (Cpeak). A locally defined threshold was used to identify fire events. Cbackground was estimated using a moving median, using a 150 year window width,

large enough to ensure a fire event is included within the window. Peak components were obtained by subtracting Cbackground from the interpolated CHAR (Cinterpolated), which corresponded to a re-sampling record of the char series using the median charcoal accumulation rate in years per sample (calculated to 38 years per sample for Gravgaz, 26 years per sample for Bereket, calculated using the chronology established in chapter 3 of this dissertation). A threshold value was calculated using the Zero-Mean Gaussian and Gaussian Mixture Model. Fire events, indicating fires occurring in the landscape around the sample site, were identified when the CHAR of a single sample exceeded the background CHAR by the threshold ratio (Power et al., 2006). When multiple fire events occur in a short time-span, they are referred to as a fire period. Fire frequencies were calculated by summing the total number of fires within a 1000-yr period, and then smoothing this series with a Lowess smoother.
Unfortunately this method, and those using similar programs, such as Charster, does result in an increased risk of not recognizing fire events when they are immediately followed by a sedimentation event. Such processes have been described and discussed around the Adriatic Sea, Romania, Ukraine, and in Bereket itself (Bodnariuc et al. 2002; Oldfield et al. 2003; Huhmann et al. 2004; Kaniewski et al. 2008). In order to check for fire episodes that the numerical analyses might have missed, the untransformed charcoal concentration data are compared with the core chronology and the sedimentological record, in order to check for anomalously high charcoal percentages immediately preceding episodes of rapid sedimentation.

5.2.2. Numerical analyses: Charcoal and vegetation data

In order to investigate short and long-term effect of fires on vegetation, all pollen, and micro and macro charcoal counts were recalculated to concentrations. These were divided by the total regional particle (non-local pollen and micro charcoal particle) concentration in order to counter the obscuring influence of changes in sedimentation rates. Pollen concentrations are presented as pollen per gram.
Charcoal and pollen types were subsequently grouped using a Neighbour Joining (NJ) analysis. The NJ analysis was initially designed as a bottom-up clustering method for reconstructing phylogenetic trees (Saitou and Nei 1987). In this case the NJ technique was used to measure ecological distances between plant taxa (Baxter 1994; Kaniewski et al. 2011b). The length of the branches on the resulting tree can be interpreted as the ecological distances between groups of taxa.
The similarity measure was ‘correlation’ and the root was ‘final branch’. Due to the nature of the analysis, the resulting tree diagrams can be used to investigate which vegetation type is most affected by fire as well as the way the vegetation develops through time. In contrast to cluster analysis, NJ keeps track of nodes on a tree rather than taxa or clusters of taxa. As a consequence, the NJ is less useful for revealing the general relationship between plant taxa and environmental conditions, but gives a better representation of the succession in the vegetation through time. As with the CA analyses performed in chapter 4, the resulting clusters are termed Pollen Derived Vegetation Patterns (PDVP). The ecological significance of each PDVP can be assessed by studying the most important taxa in each PDVP and the vegetation types they are associated with. As was done in chapter 4, the top four samples from the Bereket core were omitted due to the fact that the pollen signal is obviously disturbed in that part of the core. The ordination of the pollen-derived vegetation patterns was further tested using a CA with ‘paired group’, while ‘correlation’ was used as the similarity measure.
Linear detrended cross correlations (p=0.05) were computed in order to study the ecological relationship between each PDVP and the occurrence of fire. Linear detrended cross-correlation concerns the time alignment of two time series by means of the correlation coefficient. Positive and negative correlations (with +0.5 and -0.5 as significant threshold) are considered when the Lag is 0 or realistically small. At lag=0, a significant positive or negative correlation between charcoal and PDVP concentrations may be the direct result of a fire event, while such a relationship at a small lag may be the result of post-fire succession. Null values indicate a complete lack of correlation.

5.3. Results

5.3.1. Charcoal analyses

The fire events determined by the CharAnalysis software are displayed in Figs. 5.1, 5.2, and appendix 7. In the Gravgaz marsh record, fire events have been identified to occur at c. AD 1100, 1170, 1330, and 1590, while a single fire event occurs in recent times, at c. AD 1930. All dates roughly coincide with the latter part of the MCA and the earliest part of the LIA, the duration of which has been demonstrated in chapter 3 and 4 of this dissertation. For Bereket, fire activity is much more limited. Fire events have been identified to occur at c. AD 320, 610, 660, 740, and 790. The AD 320 and 610 fire events occur within the final warm and wet period of the RWP, when crop cultivation had ceased around the sample site in Bereket, while the other three fire events all occur within the period identified as the Dark Ages Cold Period, when a limited human population mainly depended on pastoralism for their subsidence. No signs of local fire damage in the form of burned surfaces in the clayey peat deposits, burned leaves or seeds have been found in the Bereket basin macroremains analysis. As explained in chapter 3, no macroremains could be extracted from the Gravgaz marsh core.

5.3.2. Numerical Analyses

The results of the NJ analyses are displayed in Figs 5.3 and 5.4. Differences in the distribution of taxa between both cores are assumed to be a result of differing local environmental conditions.
For Gravgaz marsh, Six PDVP's were defined by the NJ analysis performed on the pollen and charcoal data. These six PDVP's are drawn to a depth scale in Fig. 5.5. Charcoal concentration is included in GVZ2. This PDVP is associated with taxa indicative of mixed deciduous woodlands and includes several cultivated trees. This PDVP is bracketed by others indicative of cereal cultivation and arboriculture, and the occurrence of secondary anthropogenic indicators. For Bereket, seven PDVP's were defined by the NJ analysis. These seven PDVP's are drawn to a depth scale in Fig. 5.6. Charcoal concentration is included in BKT7, associated with taxa indicative of fires (*Ulex)* and open vegetation (Asteraceae). The PDVP at the smallest ecological distance contains taxa indicative of pine forests (*Pinus*). PDVP's associated with human occupation (BKT1) are located at a larger ecological distance. For both records, Asteraceae Asteroideae are closely associated with charcoal concentration, while Asteraceae Cichorioideae (by far the most important group of Asteraceae) are associated with vegetation which occurs after a disturbance or deforestation event.
The CA results are displayed in Figure 5.7. They show that for the Bereket basin, the hierarchical clustering defined by the NJ analysis remains unaltered. For Gravgaz marsh, the location of charcoal concentration remains primarily linked to the PDVP's indicative of human impact.
The cross-correlograms for charcoal versus the six PDVP's defined for Gravgaz marsh and the seven PDVP's defined for the Bereket core, are displayed in Fig. 5.8. Despite the association of charcoal concentration with certain characteristic PDVP's, the results of the Cross Correlation analyses show that for both Gravgaz and Bereket, no significant correlation (larger than 0.5) existed between the relative charcoal concentration and any of the PDVP's. For the Bereket basin, there is a near-significant positive correlation at Lag=0 of 0.41 for BKT7, indicative of open, herbaceous vegetation in the Bereket basin, also featuring *Ulex*, a notable post-fire pioneer. There is a non-significant positive correlation of 0.37 at a lag of -1 for BKT6, indicative of pine forest. These results mirror the results of the NJ analysis. There is a further non-significant positive correlation of 0.44 at a lag of 1 for BKT4. This suggests a relationship between increased fire activity and the clearing of pine forests, resulting in an increase of juniper wood/shrub on the slopes, while the presence of *Abies*, *Salix*, and *Quercus cerris* hint at relatively moist environmental conditions. Any other correlations nearing the significance threshold of 0.5 in both Gravgaz and Bereket occurred at a lag that was too large to be ecologically informative.

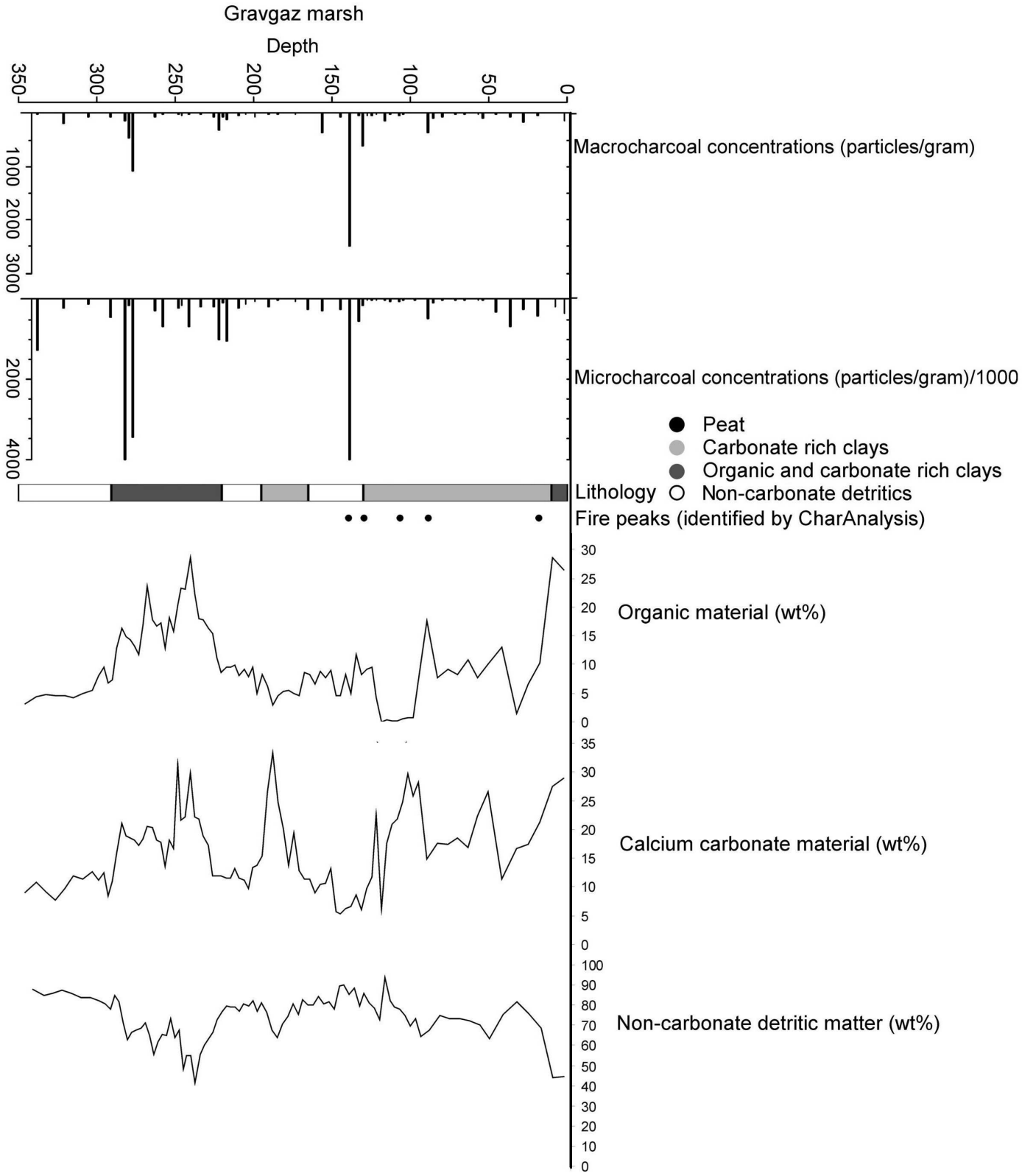

Fig. 5.1a. The charcoal concentrations, lithology, and the organic matter, calcium carbonate and non-carbonate detritic matter weight percentages for core SA09JBDrill02 (a) and core SA06EP1 (b).

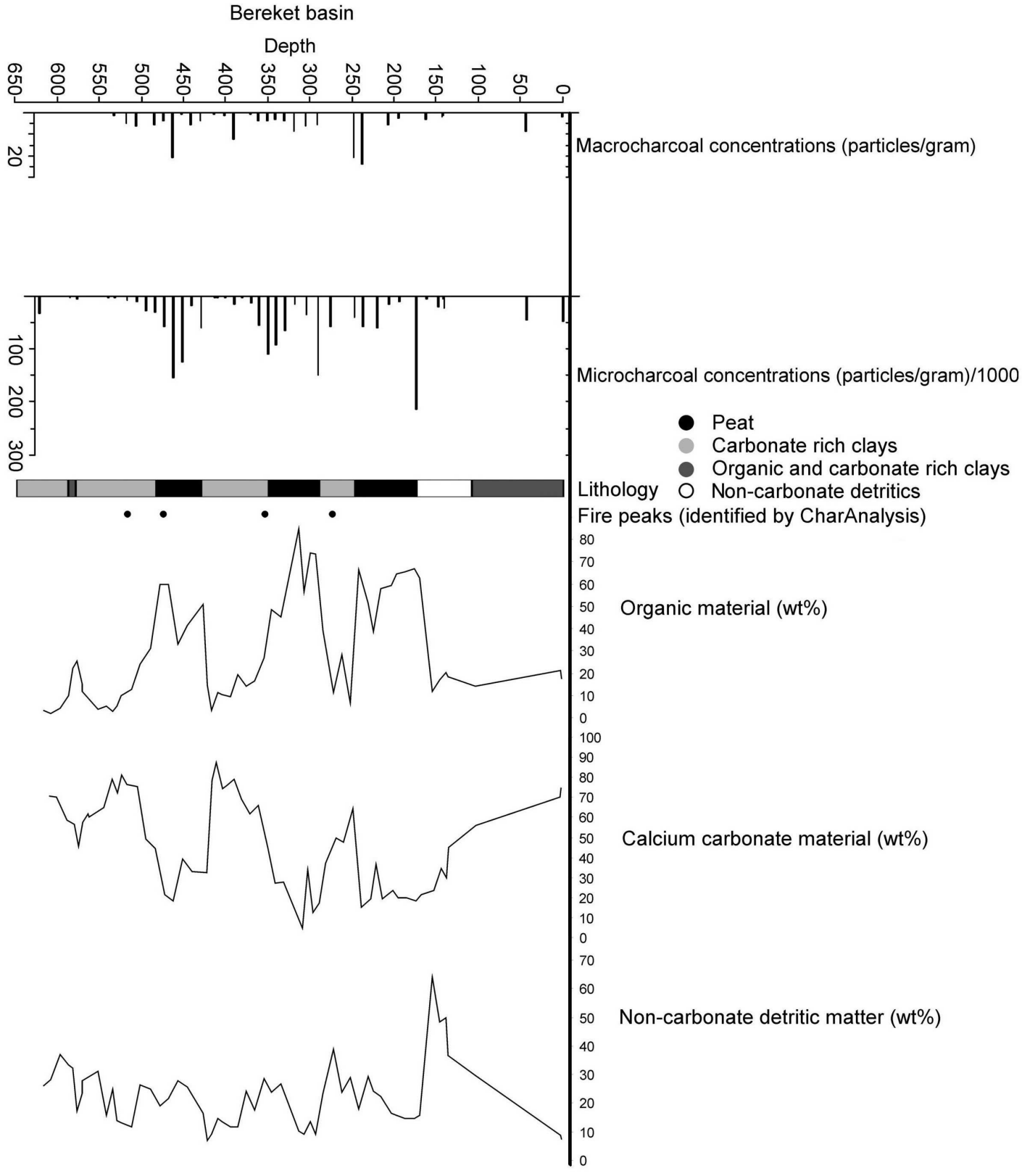

Fig. 5.1b. Same as 5.1a.

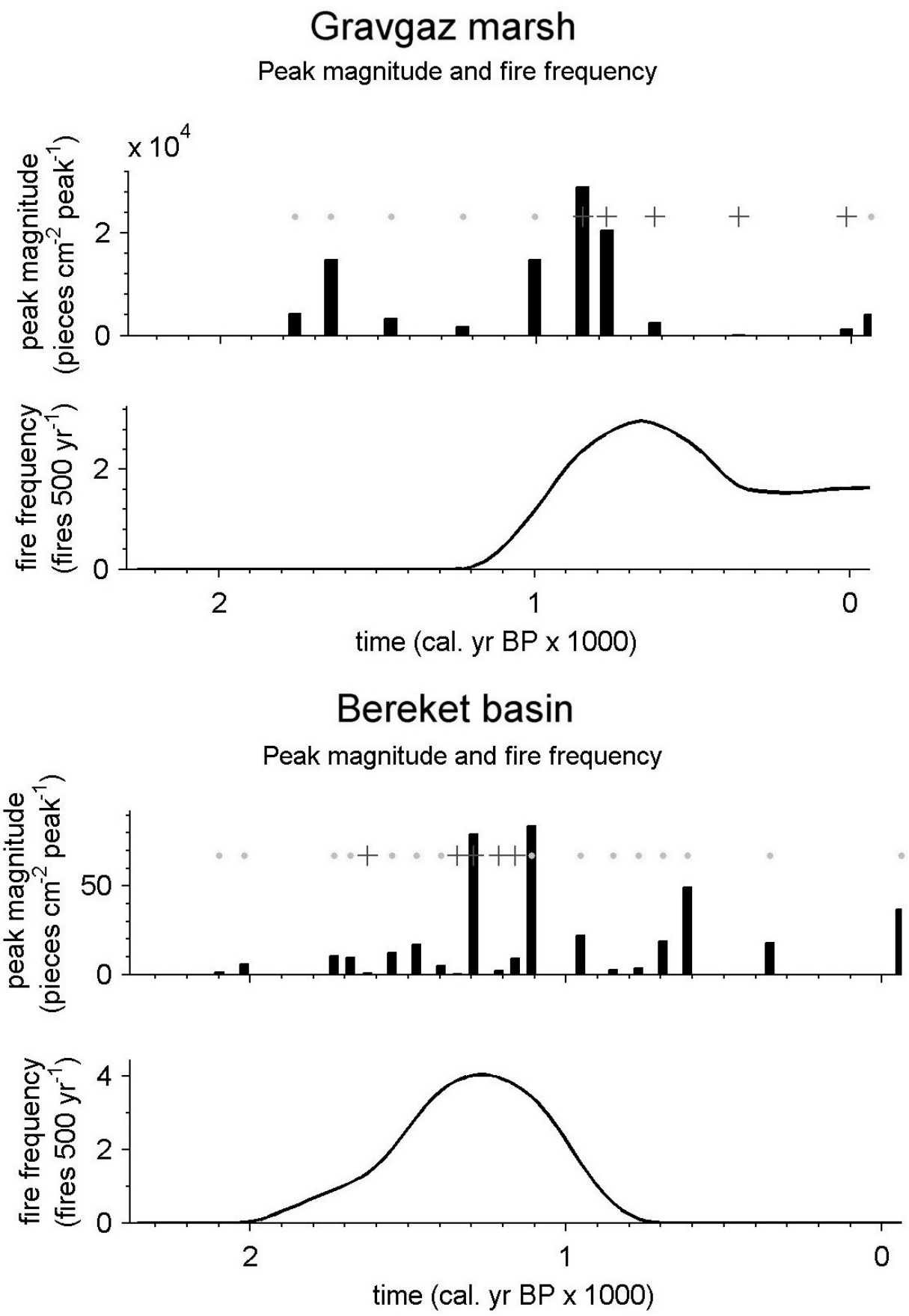

Fig. 5.2. Peak magnitude and fire frequency as determined by CharAnalysis for the Gravgaz core SA06EP1 (top) and the Bereket core SA09JBDrill02 (bottom).

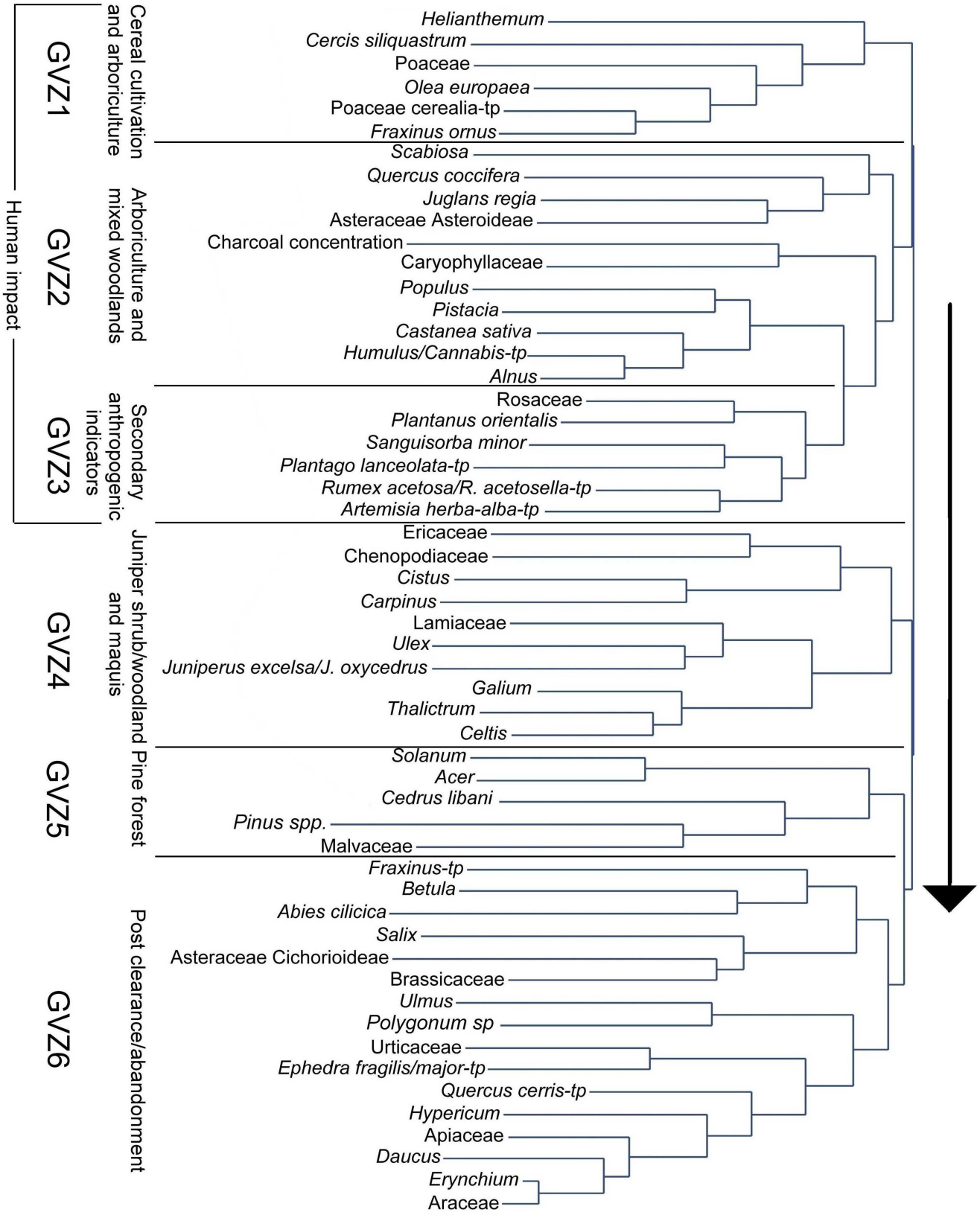

Fig. 5.3. Neighbour Joining tree diagram for the charcoal and pollen concentration data in core SA06EP1 (Gravgaz marsh). Each Pollen derived vegetation pattern (here named GVZ1 to GVZ6), and contains taxa that may originate from different vegetation types, but which thrived roughly at the same time. The vegetation types associated with the most important pollen taxa in each PDVP are based on van Zeist et al. (1975), Bottema and Woldring (1990) Fontaine et al. (2007) and Kaniewski (2007a). The arrow indicates the order in which each PDVP reaches its maximum dominance in the pollen spectrum.

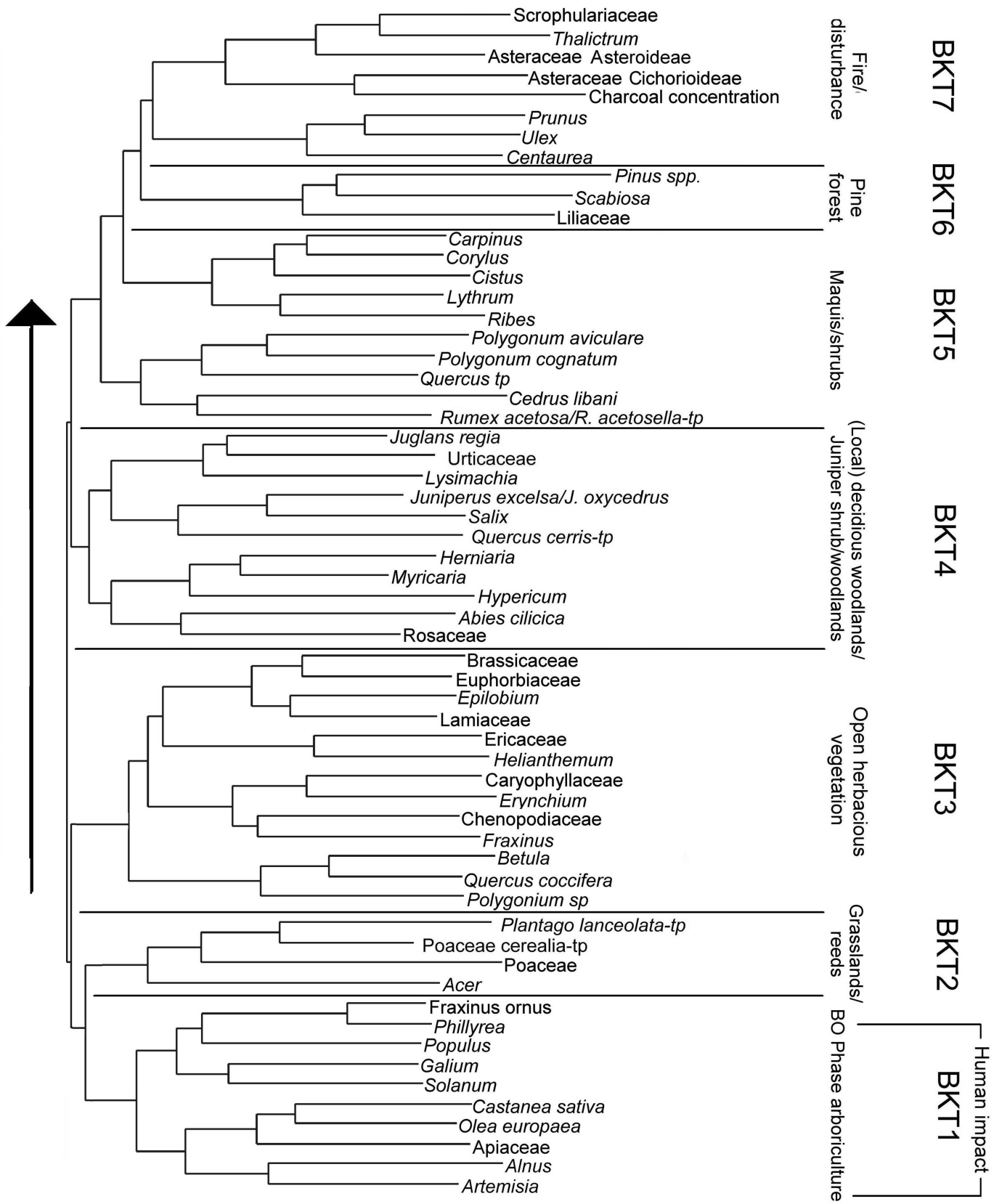

Fig. 5.4. Neighbour Joining tree diagram for the charcoal and pollen concentration data in core SA09JBdrill01 (Bereket basin). Each Pollen derived vegetation pattern (here named BKT1 to BKT7), and contains taxa that may originate from different vegetation types, but which thrived roughly at the same time. The vegetation types associated with the most important pollen taxa in each PDVP are based on van Zeist et al. (1975), Bottema and Woldring (1990) Fontaine et al. (2007) and Kaniewski (2007a). The arrow indicates the order in which each PDVP reaches its maximum dominance in the pollen spectrum.

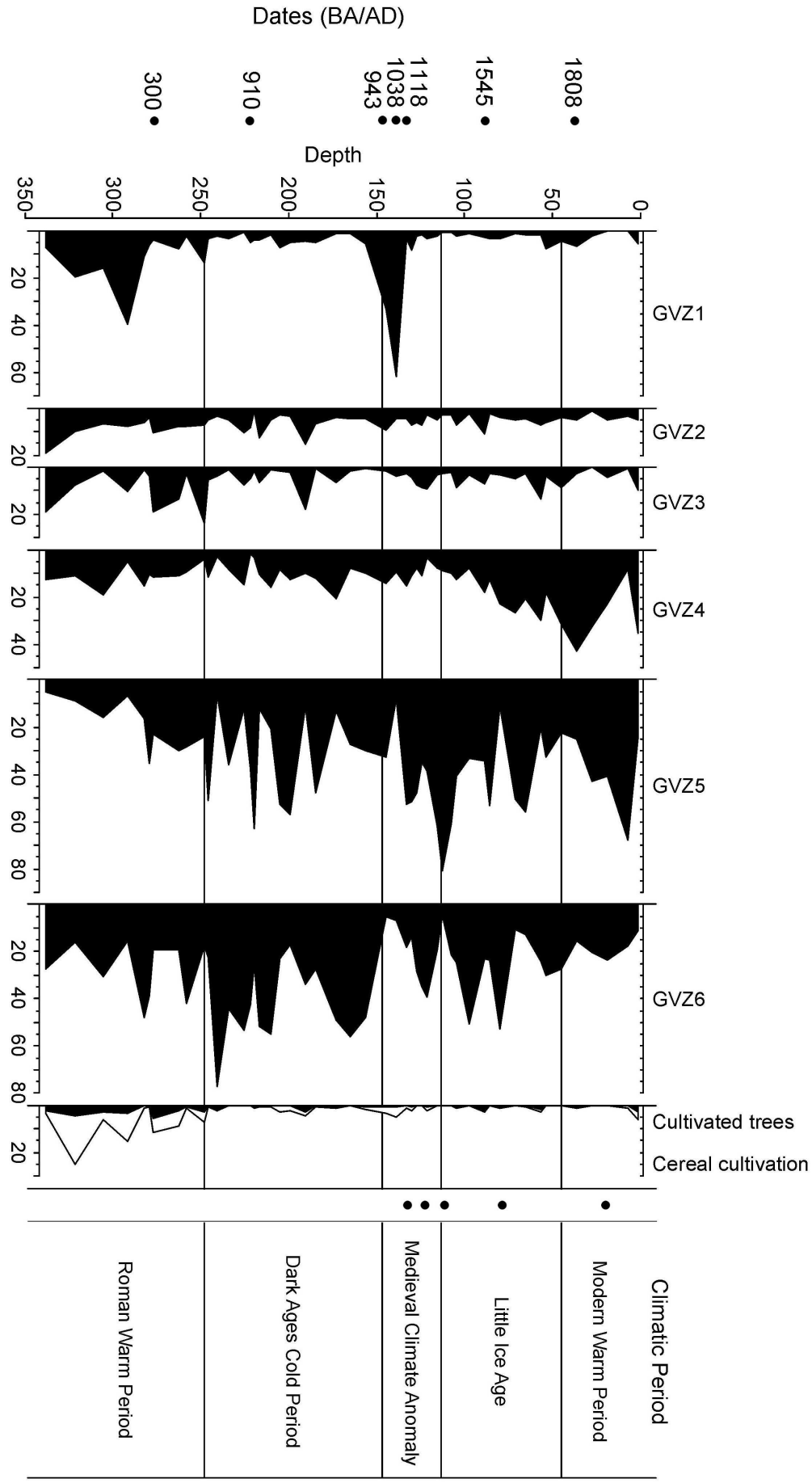

Fig. 5.5. Simplified pollen diagram showing the evolution of the PDVP percentage values for core SA06EP1 (Gravgaz marsh). A diagram depicting curves for all individual pollen taxa used in the analysis, is available in Appendix 7.

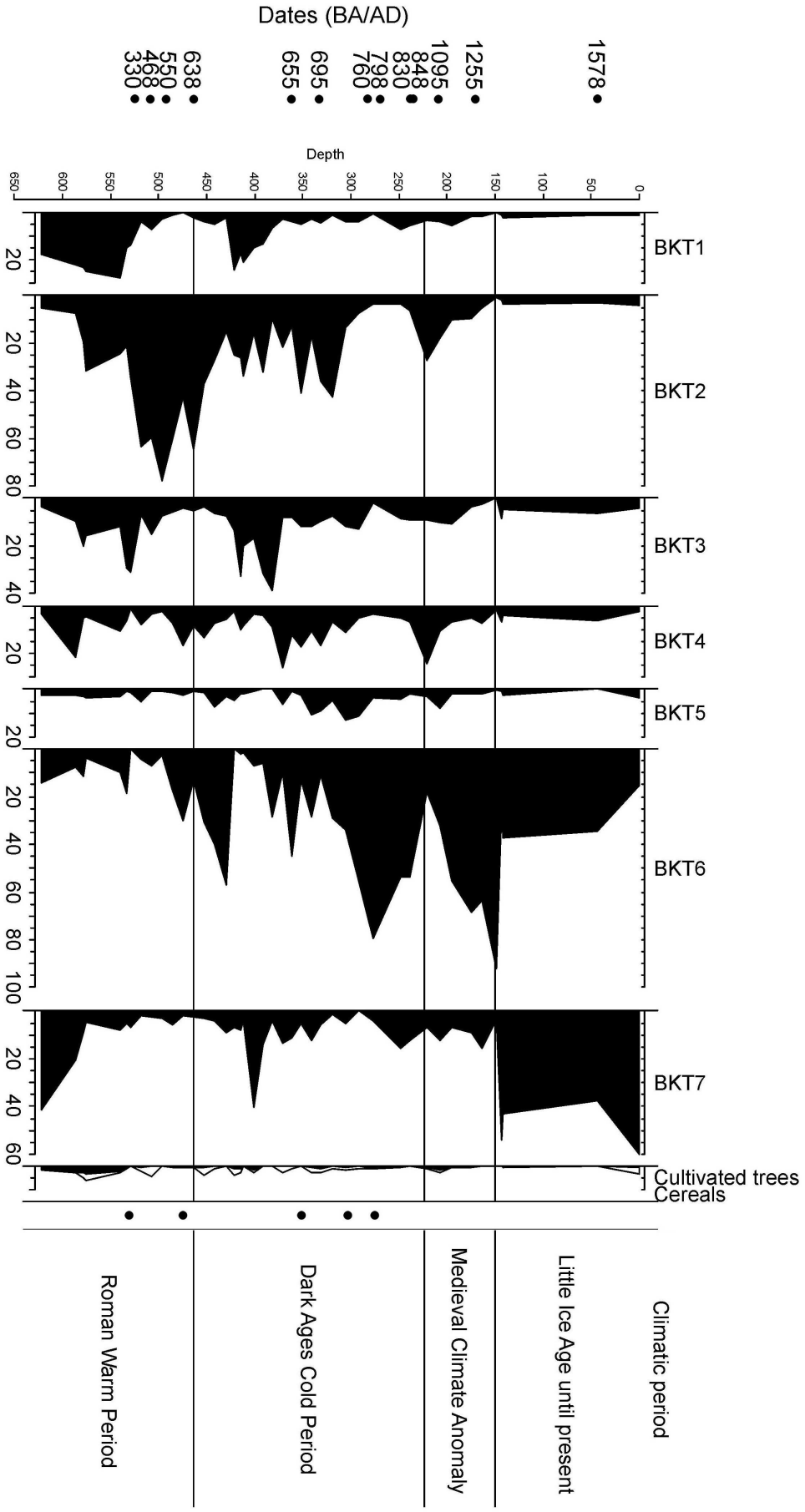

Fig. 5.6. Simplified pollen diagram showing the evolution of the PDVP percentage values for core SA09JBdrill01 (Bereket basin). A diagram depicting curves for all individual pollen taxa used in the analysis, is available in Appendix 7.

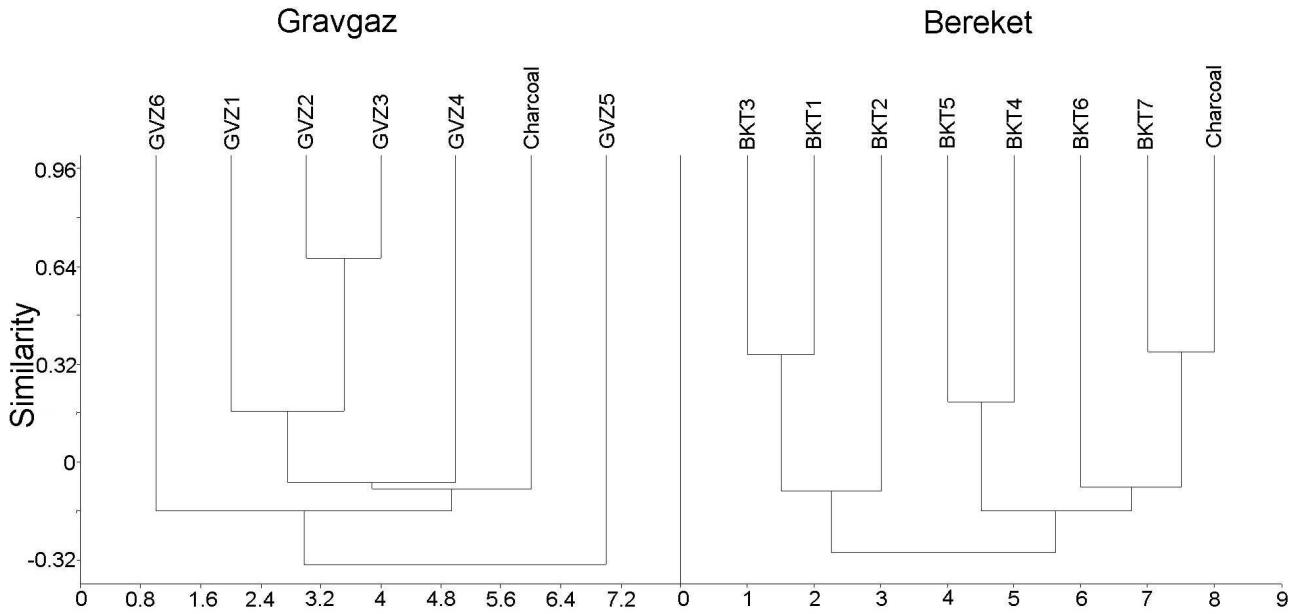

Fig. 5.7. Cluster Analyses performed on the PDVP's distinguished for both cores. The algorithm was 'paired group' and 'correlation' was the similarity measure.

5.3.3. Vegetation dynamics

The numerical analyses presented in chapter 4 created a numerically derived proxy for relative moisture availability and evaluated the serial relationships between that proxy and various independent climatic datasets from the Middle East and Europe. The results revealed for the first time the occurrence of a series of distinct climatic periods in the Western Taurus Mountains. As these subdivisions into climatic periods are applicable in the current study, the following overview of the dynamics in the NJ-derived PDVP's has been subdivided according to these climatic periods. As this chapter concerns the analysis of pollen data collected at two different locations, and sediments deposited at the one time will appear in the two cores at different depths, this chapter will only refer to the pre-established ages of samples, rather than their depths, as is more usual in a Results chapter.
The following sections give an overview of vegetation change through time in light of the results of the NJ analyses. While no direct relationship exists between the fire events recognized by CharAnalysis and the pattern of vegetation dynamics through time, the study of the changes in importance of the NJ-derived PDVP's through time can still reveal valuable information concerning post-disturbance (e.g. human impact) succession of the vegetation.

5.3.3.1. Roman Warm Period (before c. AD 640)

As established in chapter 3, the part of the RWP included in the pollen cores, is divided into two parts. The climate being relatively dry until the beginning of the 4th century AD, while relatively moist conditions prevail until the start of the DACP during the middle of the 7th century. In both records, the PDVP's associated with BO Phase crop cultivation reach their highest percentage values during this zone, but decrease notably after c. AD 300. At Gravgaz marsh, the decrease in cultivated species coincides with an increase in GVZ5, indicating pine forest, although GVZ3, indicating the presence of livestock herding (containing *Rumex, Plantago,* and *Artemisia*) also becomes more important. In the Bereket Basin, the post-AD 300 pollen signal is dominated by high percentage values for BKT2 (driven by high Poaceae percentages), although BKT6 (indicating pine forest) and BKT4 (indicating riparian woodlands and juniper shrubs/trees) also increases.

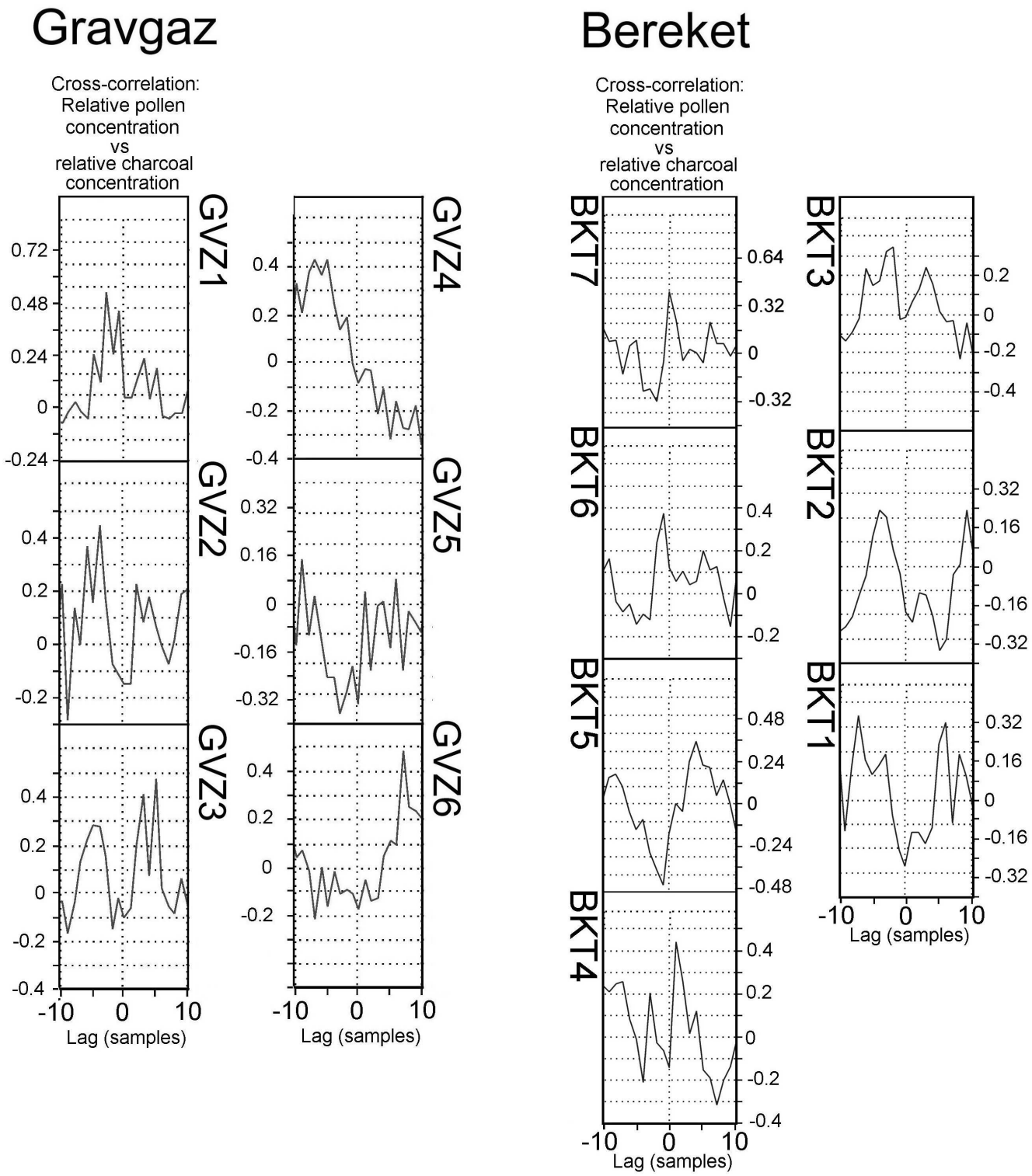

Fig. 5.8. The Cross Correlograms displaying the correlation between each PDVP and relative charcoal concentrations.

5.3.3.2. Dark Ages Cold Period (c. AD 640 – 940)

During the DACP, the Gravgaz marsh core is dominated by GVZ6, indicating open and dry steppe vegetation (Asteraceae Cichorioideae, Apiaceae, *Erynchium*), but also containing taxa characteristic of the early stages of post-disturbance succession (*Quercus cerris, Betula*). While most other PDVP's diminish, GVZ4, containing taxa characteristic of maquis vegetation (*Ulex, Juniperus, Cistus*) remains important in the pollen percentage diagram. Values for GVZ5 (indicating pine forest) vary between 20 and 60%, values similar to those encountered in the modern, relatively deforested landscape. The variations in percentages values throughout this period are most likely related to seasonal variation in pollen production.

The Bereket basin core shows a further increase in BKT6 which is abruptly cut off around AD 640. The period following this abrupt shift in the pollen data shows a succession of PDVP's that show a sudden, short-lived increase. Immediately following the abrupt decrease of BKT6, BKT 1 (generally indicative of BO Phase human impact, but in this case driven by high *Artemisia* percentages), BKT3 (open herbaceous vegetation), and BKT7 (open, disturbed landscapes) show the most notable increase. In all PDVP's, these increases are driven by increases in steppe vegetation (Apiaceae, *Artemisia*, Asteraceae asteroideae, Asteraceae Cichorioideae, Ericaceae, Lamiaceae). This is followed by an increase in BKT4, indicating riparian forest and juniper shrub/woodlands, in turn followed by an increase in BKT5, indicating maquis vegetation (*Cistus, Carpinus*), but also containing secondary anthropogenic indicators (*Polygonum aviculare, Rumex*). From the beginning of the 8th century onwards, BKT6 continues to increase again.

5.3.3.3. Medieval Climate Anomaly (c. AD 940 – 1300)

In the Gravgaz marsh core, this zone is characterized by a sharp drop in GVZ6, and a decrease in GVZ4, while GVZ3 shows a minor increase. The start of this zone also coincides with a notable rise in Poaceae cerealia. Overall, this zone is characterized by relatively high percentage values for GVZ5, which continues to increase throughout this zone.
In the Bereket basin, the start of this zone is very pronounced, being signalled by a deforestation event. As BKT6 percentage values drop, it is mainly BKT4, BKT2 and BKT5 (indicating local riparian forest, grassy meadows and perhaps local reed vegetation, and pastoralism, respectively) percentage values which increase in response. Poaceae cerealia as well as cultivated trees increase during the deforestation event, but the increase is not larger than those observed in the previous zone. The deforestation period is relatively short-lived. *Pinus* pollen percentages reach values comparable to the top of the previous zone in samples dated to no more than c. 200 years after the start of the MCA.

5.3.3.4. Little Ice Age (c. AD 1300 - 1700)

The Gravgaz marsh record is dominated by GVZ5 and GVZ6 throughout this zone, although GVZ4 percentage values increase continuously, mostly driven by an increase in *Juniperus.*
For Bereket, only a small part of the record remains usable. This small portion of the pollen record seems to indicate a continued dominance of BKT6.

5.3.3.5. Modern Warm Period (c. AD 1700 -the present)

Pollen data from this period is only available for the Gravgaz record, which indicates increasing percentage values for GVZ5, percentage values resembling the current situation as evidenced by modern pollen data, only occurring in the topmost sample.

5.4. Discussion

The NJ ordination shows an overview of general vegetation change through time, from the crop cultivation that marked the BO Phase, to periods characterized by a relatively open landscape with an increasing cover of woody maquis species, to a pine forest. This pattern resembles the Clementsian models of post-disturbance succession (Tomascelli, 1977). When human impact decreases or stops, the first stage of secondary succession of the vegetation is characterised by the dominance of herbaceous vegetation in the landscape, which is then replaced by woody species, eventually leading to a dominance of maquis or forest (Tomascelli, 1977). The final PDVP in both NJ tree diagrams represents the vegetation that becomes dominant in the pollen spectrum immediately after the clearing of pine forests.
Fire events, as detected by the CharAnalysis software, seem to occur primarily at times when human impact is absent. However, in the NJ ordination of Gravgaz marsh, charcoal concentration is placed with human impact indicators. This may be a result of the low amount of fire events in each basin. The placement of charcoal in the NJ ordination for Gravgaz is more likely to be driven by variations in the background charcoal influx. In this case it may be that the placement of charcoal concentration in the NJ diagram is driven by changes in the

background charcoal signal, rather than by the occurrence of fire events, essentially recording generally increased fire activity in the wider region while local fire activity remains limited or absent.
The PDVP's associated with charcoal concentrations (and which contain a number of cultivated species) may be indicative of vegetation within a relatively small area around the sample site, but considering the simultaneous increases in human impact at both Gravgaz and Bereket, the association of charcoal concentration with these PDVP's may indicate an increase of fires in the general region around, but not in or near, Gravgaz marsh at times when human impact was present. Fires occurring close enough to the sample site in order to be detected by CharAnalysis occur, as in Bereket, mostly when human impact is absent.
The connection between charcoal concentration and open steppe vegetation (Asteraceae, *Centaurea*), post-fire disturbance indicators (*Ulex*), and pine forest, is in accordance with the link between the occurrence of fire events and increased pine pollen percentages observed in the pollen records.

5.4.1 Fire periods and climate change

As stated in section 5.1, Vannière *et al*. (2008) suggest that climatic conditions were important for fire occurrence even under strongly humanised ecosystem conditions. Turner *et al*. (2008) concluded that Eastern Mediterranean regional fire activity was controlled by climatically-induced variations in biomass. In a humid environment, more biomass would accumulate, providing fuel for fires. These notions do not apply to the situation found around Gravgaz marsh and the Bereket basin. The timing of the main fire episodes in Gravgaz marsh and the Bereket basin are centred on periods characterized by a decreased presence, or even an absence of crop cultivation. In both cases, fire episodes occur in periods characterized by relatively warm and wet environmental conditions (the RWP for Bereket, and the MCA for Gravgaz), as well as periods characterized by cold and dry environmental conditions (the DACP for Bereket, and the LIA for Gravgaz). This indicates that the timing of fire events is most likely not driven by the occurrence of drier-than-normal environmental conditions.

5.4.2. Fire events and the pollen signal

Pine forests form the secondary climax vegetation in the region when human impact is absent. The traditional conceptualisation of succession in Mediterranean landscapes is one where shade-intolerant pines are eventually replaced by shade-tolerant oaks that establish themselves in the pine understory (e.g., Barbero et al., 1990; Zavala et al., 2000). However, in chapter 3 it was shown how the re-establishment of deciduous *Quercus* did not occur in the study area.
Drought tolerant Mediterranean Pine forests are able to thrive during periods characterized by high, as well as low moisture availability (Fontaine *et al*., 2007), providing biomass which serves as fuel for (wild)fires, regardless of the climatic regime. Nevertheless, overall dry conditions would provide better conditions for fires to develop and the numerical analyses presented in chapter 4 indicated that a higher abundance of pine forest is linked to relatively dry environmental conditions. However, the current research results indicate that fire activity is not linked to the presence of dryer than usual environmental conditions. The notion that continuously high or increasing *Pinus* percentage values may be the result of the destruction of the local vegetation, the local pollen signal having become too weak to compensate for the *Pinus* pollen signal originating from the still extant pine forests further away, is rejected. There is no proof of local fire activity in the basins in the form of burned macro remains, (high concentrations of) large pieces of charcoal, or burned earth.
The pollen signal is more likely a result of the quick regeneration of pine forests after a fire. *Pinus nigra* is the most important needle leaved tree in the higher pine forests within the territory of Sagalassos. It is well adapted to cope with fire damage even though it does not regenerate easily after a crown fire, its cones not well adapted to cope with fires (Lanner, 1998; Tapias et al., 2001), and its seeds unable to withstand the high temperatures reached during summer wildfires (Habrouk et al., 1999). *P. nigra* is a long lived tree with a thick bark and it can grow tall with only a few branches on the lower part of the trunk. This makes it very resistant to surface fires (Fulé et al., 2008; Pausas et al., 2008). *Pinus brutia* is a species characterized by a high post-fire resilience (Pausas et al., 2008), its serotinous cones able to protect seeds from fire damage. Thus *Pinus brutia* forests are able to quickly regenerate after fires, although regeneration of *Pinus* may fail if fire episodes occur at a time interval shorter than that which is needed to accumulate a seed bank (Zedler, 1995). Natural stands of *Pinus brutia* are nowadays restricted to the lower parts of the mountains, occurring below 1400 m

a.s.l. However, its range may have extended higher than today during warm climatic phases such as the MCA and RWP. When a large enough area is damaged by fire, the landscape may be characterized by open herbaceous vegetation during short periods directly following a fire event, until the fire-damaged pine forest is able to resprout or regenerate. However, in parts of the pollen record where the temporal resolution is relatively low, such short periods may not have been recorded in the pollen data. Recent models predict the establishment of a pine forest after a fire occurs between 15 and 40 years (Millington et al., 2009). The median sample resolution for Gravgaz marsh and the Bereket basin is 38 and 26 years respectively, making it difficult to record such herbaceous phases.
It is notable that no fire events occurred simultaneously in Bereket and Gravgaz, despite the fact that these basins are located only c. 10 km apart from one another. This is an indication that the scale of the fire events recorded in the data was limited, and while not occurring on the sample site itself, they would have occurred in the vicinity of the basins.
When comparing the charcoal record with the sediment record, it becomes clear that the two most recent fire events recorded for the Bereket basin (occurring during the 8th century AD), immediately precede a detritic deposit, very rich in CC and deposited during a very short period of time. In chapter 3 it was postulated that the CC-rich material originated from the marl deposits to the east of the basin. It may be that in this case, the destruction of the pine forest on these deposits near the basin resulted in the deposition of CC-rich material on the sample site. The rapid sedimentation phase occurring at Gravgaz between c. AD 910 and 940 is preceded by a peak in charcoal; however this peak is not recognized as a fire event by CharAnalysis, as it is not significantly greater than the background charcoal signal.

5.4.3. Fire periods and the presence/absence of human impact

Nearly all fire events are related to an elevated or increasing abundance of pine forest, the pollen signal indicating the amount of pine forest is equal to, or more abundant than in the present landscape. In chapter 6, it is revealed that the pollen signal most likely does not originate from beyond the confines of the basin, this includes pine pollen. However, the general changes in the pollen signal do indicate a decrease in human impact and the establishment of secondary successional vegetation at two different locations within the study area, in line with the notion of a more general decline throughout the study area. Only one fire recorded in the Gravgaz marsh core (c. AD 1590), and one fire recorded in the Bereket basin core (c. AD 320), are associated with a temporary increase in steppe vegetation. In both cases these dates coincide with a change in the pollen data indicating shift in agriculture, from crop cultivation towards animal grazing.
A limited human presence in the region can be assumed to occur throughout the post-BO Phase period, despite the pollen data recording next to no anthropomorphic indicators (see chapter 1). This human presence can be assumed to have been more focussed on livestock grazing, perhaps partially in the form of (semi-nomadic or nomadic) pastoralism (Vanhaverbeke and Waelkens, 2003; Vanhaverbeke et al. 2011a; Fuller et al. submitted ; Bakker et al., submitted). While fires could have been started by herdsmen, looking to enlarge their grazing grounds, one would expect a decrease in pine woodlands over a larger time period. Continuous grazing of the deforested landscape would lead to the encroachment of the opened landscape by shrub species (Asouti and Hather, 2001), while the further development of the landscape, towards a secondary pine forest, would be suspended. This phenomenon is only observed for the AD 1590 fire event in Gravgaz and suspected to occur during the AD 320 fire event in Bereket. Even though the Bereket pollen signal is obscured by high values for Poaceae, the changes in the NJ-derived PDVP's seem to indicate the establishment of open steppe, as well as shrub vegetation, followed by the establishment of pine woodlands during the first half of the 7th century, essentially following the classic pattern of post-disturbance secondary succession (Tomascelli, 1977). The AD 910 charcoal peak observed in Gravgaz may have inadvertently been overlooked by CharAnalysis due to the increased sedimentation rate which occurred immediately following this peak. If this peak is indeed a fire event and not an artefact of the sedimentation rates, correctly overlooked by CharAnalysis, it may be a sign of anthropogenic activity, the forest being burned to make way for agriculture. As it remains uncertain whether or not this charcoal peak represents a fire event, the estimated start of human impact in the basin remains c. AD 940 (see chapter 4). The lack of local and anthropogenic fire activity in Gravgaz and Bereket is in cntrast with the situation during the BO-Phase, for which Kaniewski et al. (2008a) recorded a series of high intensity fire episodes that occurred between the 4th century BC and the 2nd century AD. These fires were linked to a simplification of the vegetation structure, favouring soil erosion, pastures and intensive cultivation in the Bereket basin. No similar research covering the BO Phase period has been performed on sediments from

Gravgaz marsh.
A good example of post-disturbance vegetation succession that is not related to a fire event is observed in the Bereket basin core, where a local sedimentation event deposited about 1 meter of sediments during a very short period of time, possible during one event (Sediment zone Br-e, see chapter 3). The pollen signal within this layer of detritic sediments (Fig. 3.12) indicates an open herbaceous steppe. After the the deposition of this layer, a succession is visible from increased values for maquis and shrublands (*Juniperus, Quercus coccifera, Cistus, Carpinus, Ulex*), to pine forests. Fire activity in the vicinity of the Bereket basin returned as pine forest became more important in the landscape. Abandonment of low-intensity agricultural land has contributed to increased forest cover around the northern rim of the Mediterranean Sea in recent decades (Mazzoleni et al., 2004). Although the pollen signal indicating open herbaceous steppe is detected in the sediments that were deposited onto the sample site, and reworking of the sediments is to be assumed, the pollen signal is interpreted as being an accurate contemporary representation of the pollen rain. In this region, where the climate is characterized by dry summers and cold, wet winters, it can be assumed that pollen will not preserve for longer periods outside of a wetland environment. Although there is no research available quantifying the length of time that pollen are able to survive undamaged in the topsoil outside of the marsh, the good pollen preservation within this layer of sediment does indicate that the pollen were deposited a relatively short time before the sediment was re-deposited into the marsh. A similar process may have occurred after the deforestation and grazing period coinciding with the start of the MCA. However, the temporal resolution is much lower in that part of the record, than in the part corresponding with the DACP. Therefore the post-abandonment succession may only be visible in the two short peak values for maquis vegetation (BKT4 and BKT5), which follow the deforestation event.

5.5. Conclusions

The study of the effects of natural and anthropogenic fire on vegetation dynamics remains an understudied topic for the Eastern Mediterranean and Middle East. Especially for the period after the end of the BO Phase, only limited data are available. No previous studies focussing on this time period, performed on records from Turkey, are available. The detailed study of the role of fire history in two basins located within the SW Taurus Mountains, Turkey, revealed several new insights into the relation between fire activity, climate and vegetation. The occurrence of fire events was not connected to specific climatic (relatively dry or wet) conditions. The fact that no fire events were simultaneously recorded in both sample sites indicates that fires were of a relatively limited scale and, while not located in the basin, they occurred relatively close by to the sample sites. Fire activity was mostly related to fuel availability in the form of pine forests. As most precipitation falls in the autumn and winter in the study area, the summers will be dry enough to facilitate forest fires regardless of the climatic period. Fire events were not predominantly connected to an increased human presence in the region. Only two of the recorded fire events seemed to be connected to the presence of livestock herding in the vicinity of the sample site. One additional potential fire event, occurring during the 10th century in the vicinity of Gravgaz marsh and not recorded by CharAnalysis, may also be related to anthropogenic activity.
Most fire events seemed to occur when human impact was decreasing. The low frequency of fire events and the special adaptations of pine trees to fires allowed for the quick regeneration of the pine forest following a wildfire.
When the temporal resolution of the pollen records were large enough, the pollen data showed how, following a deforestation event or the abandonment of agricultural land, a secondary succession occurred with herbaceous plants initially colonizing the fields, later replaced by woody species, and eventually leading to the establishment of a pine forest. The occurrence of clear peaks in charcoal, directly followed by sedimentation events, indicates the inability of statistical software such as CharAnalysis to provide a 100% reliable overview of the fire history of a certain location. However, when the analyses performed by CharAnalysis are critically reviewed, and attention is given to possible fire events which may not be recorded by the analysis, then the combination of CharAnalysis and a critical manual interpretation of the charcoal record will result in a fire history which is more reliable than one based on a visual interpretation of the charcoal concentrations alone.

Chapter 6

Relative pollen productivity and fall speed estimates for Eastern Mediterranean plant taxa in a mountainous environment

6.1 Introduction

Current palynological techniques enable the creation of a relatively accurate overview of changes in vegetation through time, which supplemented with numerical analyses, and comparisons with external environmental (e.g. climatic), sedimentological, and historical/archaeological records, may result in accurate overviews of natural or anthropogenic environmental change through time. Fossil pollen records also offer great potential for estimating past vegetation composition and abundance in the vicinity of a sample site (Gaillard et al 2007; Sugita et al. 1999). However, the creation of such records has continued to be problematic due to the complex relationship between pollen found at a certain location and the surrounding vegetation which produced that pollen (von Post 1916, 1967; Davis 1963; Jackson 1994). Two major factors controlling the pollen representation of the surrounding vegetation in a sample site (or basin) of a given size (e.g. a lake, bog, moss polster, or surface soil sample) are pollen productivity (PPE) and the dispersal characteristics of pollen (Prentice 1985; Sugita 1994). These factors determine the relevant source area of pollen (RSAP), or the area around a basin/sample site beyond which the correlation between pollen counts at the sample site and vegetation abundance around the sample site does not improve, meaning that little additional information of the linear relationship between pollen and plant abundance will be gained by a vegetation survey beyond that area (Sugita 1994). The differences in plant abundances among sample sites (when of a similar size) represents difference in plant abundance within the RSAP, while there is a constant pollen background signal coming from outside the RSAP (Sugita 1994, 2007b).

When the RSAP and PPE are known for the most dominant taxa of the major vegetation types in the landscape, it becomes possible to make a quantitative estimation of plant abundance in the past based on fossil pollen records, assuming that the present-day dominant vegetation types were also dominant in the past, and that the RSAP and PPE of the analysed plant taxa was not different in the past. Earlier palynological investigations within the study area have provided evidence that vegetation types characteristic of secondary succession and continued grazing pressure, such as Pine forest, and *Quercus coccifera* and/or *Juniperus* shrubland have also been important in the past landscape, at least since the end of the BO Phase (Vermoere 2002; Bakker 2011a, b). However, there is currently no data concerning the validity of the assumption that PPE's remain constant through time (Sugita 2007a, b). Estimates of the RSAP and PPE are dependent on local or regional environmental characteristics which influence pollen productivity and dispersal. It is therefore important to produce a new set of PPE's and RSAP's for each different landscape type where one wishes to create a reconstruction of the historic vegetation. Such reconstruction methods have a great advantage over modern analogue methods in that they do not require a modern analogue of the historical landscape to exist.

The RSAP and PPE of important pollen tree and herb species have been primarily been calculated for important plant taxa in forested, semi open and open landscapes in Europe (e.g. Calcote 1995; Broström et al. 2004; Bunting et al. 2005; Soepboer et al. 2007), especially within the POLLANDCAL (POLlen LANDscape CALibration) network (e.g. Sugita et al. 1999; Broström et al. 2004). A small number of studies also focussed on locations on other continents (Duffin and Bunting 2008; Li et al. 2011). However, no data are available concerning pollen vegetation relationships in the Middle East.

This chapter provides the first contribution to the reconstruction of the historical landscape in the Eastern Mediterranean by providing PPE and RSAP estimates for important plant taxa for the territory of Sagalassos. The study area has been subjected to a strong anthropogenic influence in the form of polyculture, intensive grazing and the deliberate use of fire for millennia. Furthermore, climate change and soil erosion have also resulted in changes of the soil characteristics and vegetation cover (Butzer 2005; Kaniewski et al. 2007b; Bakker et al. 2011b). While palynological analysis indicates that the major vegetation types present in the current landscape have been present since at least the end of the Roman Imperial period (Kaniewski et al. 2007a, b; Bakker et al. 2011a, b, in prep), the present relative abundance of these vegetation types has a very recent origin, having originated not earlier than during the 19th century, but mainly since the mid 20th century (Vermoere 2004; Bakker et al. 2011b, submitted). Because of this, modern analogue methods cannot be used for quantitative vegetation reconstructions, but methods using PPE's and RSAP estimates can be used.

Quantitative reconstruction of past vegetation-cover in this region will eventually provide important data for

understanding the response of the natural environment to anthropogenic and climatic land cover changes, not obtainable through the study of relative changes in importance of pollen taxa through time (Broström et al. 2004). Furthermore, it will also be possible to test hypotheses concerning the relationship between changes in the pollen record and changing actual plant abundance by implementing the pollen production and dispersal data in computer-generated hypothetical landscapes.

6.1.1. Theoretical Background

6.1.1.1. Extended R-value models (ERV) models

A theoretical framework for correlating surface pollen samples and the surrounding vegetation has been developed, using models of pollen dispersal and deposition, computer simulations and empirical studies for both forested landscapes as well as semi-open vegetation types (Parsons and Prentice 1981; Prentice and Parsons 1983; Prentice 1985, Sugita 1993, 1994; Calcote 1995; Soepboer et al. 2007; Broström et al. 2004, 2008; Duffin and Bunting 2008). This framework is based upon the concept of the extended R-value models (ERV). The original R-value is defined as a correction factor for the pollen data to represent vegetation surrounding a sample site (Davis 1963). However, the use of the R-value is problematical due to the lack of a background pollen component, which would account for pollen coming in from outside the surveyed vegetation area. Andersen (1970) solved this problem by introducing a linear model for the relationship between pollen and vegetation abundance, which estimated a pollen representation factor, as well as an estimation of the background pollen component.

This equation can be described as $y_{ik} = \alpha_i x_{ik} + \omega_i$ (1)

Where:

y_{ik}: the pollen loading of species i at site k
x_{ik}: plant abundance of species i
α_i: pollen representation factor for species i (species constant). This variable also represents the PPE of an individual taxon when the plant abundance (x_{ik}) is properly measured.
ω_i: background pollen loading for species i (species constant). This variable also represents the pollen loading coming from beyond the area in which plant abundance is measured.

While improving the understanding of pollen vegetation relationships, it could only work with absolute or quasi-absolute pollen influx data, whereas pollen data are usually only available as percentage data (Soepboer et al. 2007). Unfortunately the implementation of pollen percentage data would cause the relationship between plant abundance and pollen abundance at a sample site to become non-linear. The Extended R-value models (ERV) of Parsons and Prentice (1981) and Prentice and Parsons (1983) expanded and generalized Andersen's model to allow the use of percentage data. They devised two approaches to obtain maximum likelihood estimates of R-values, and representation coefficients and "background" coefficients in a model that attempts to allow for long-distance transport.
Prentice and Webb (1986) further enhanced the existing models by introducing the notion that vegetation abundance data should be distance weighted, as the representation of a pollen type in a sample site also depends on the distance of a certain pollen producing plant from that sample site and the distance over which a pollen grain of that plant can be transported. Finally Prentice (1985) and Sugita (1993) adapted the model to simulate pollen deposition at a point in the centre of a circular basin and pollen deposition over the entire surface of a circular basin respectively.
At the moment three main ERV models have been designed which estimate α_i in equation 1 for individual taxa when only pollen percentage data are available (Parsons and Prentice 1981; Prentice and Parsons 1983; Sugita 1994). One taxon is set as the "reference taxon" and receives a pollen production estimate of α=1 and the PPE's of the other taxa are calculated relative to this reference taxon. The reference taxon is preferably a relatively common monospecific taxon with intermediate pollen productivity. Despite the preference for a monospecific taxon, Poaceae are commonly used. The RSAP of a taxon can also be calculated using the ERV models. Sugita (1994) defines the RSAP as the area of vegetation sampling beyond which the correlation between pollen deposition and distance weighted plant abundance do not improve. Any larger area is recorded

by pollen in sediments as a homogeneous background. Therefore, the relevant pollen source area represents the scale at which pollen is recording local variations of vegetation (Sugita 1994; Calcote 1995).

ERV model 1 is described as $P_{ik} = \alpha_i v_{ik} f_k + z_i$ (2)

Where:

P_{ik}: the pollen percentage of taxon i at site k
α_i: same as equation 1
v_{ik}: percent abundance of taxon i at site k
z_i: analogous to ω_i in equation 1
f_k: site specific term expressed as $(1/\Sigma\alpha_i v_{ik})(1 - \Sigma z_i)$ (3)

In ERV model 1, the background component represents the proportion of the pollen loading coming from beyond the area from which vegetation data are compiled, relative to the total pollen loading for each taxon (Parsons and Prentice 1981).

ERV model 2 is descrived as $P_{ik} = (\alpha_i v_{ik} z_i) f_k$ (4)

Where:

$f_k = 1/\Sigma(\alpha_i v_{ik} + z_i)$ (5)

In ERV model 2, the background component represents the ratio of pollen loading which comes from beyond the area from which vegetation data are compiled, to the total sum of plant abundance within the area from which vegetation data are compiled.

Simply put, The ERV models 1 and 2 attempt to find a linear relationship between relative plant abundance and relative pollen abundance for a taxon. The slope of this relationship is the PPE, while the intercept with the pollen abundance axis represents the predicted pollen percentage when plant abundance within the RSAP is zero. This is the z score, or background pollen loading. ERV model 3 (Sugita 1994) is used when pollen data are available as percentage data, but vegetation data are available in absolute rather than relative values and are therefore not used here. The basic principles of ERV models 1 and 2 are graphically displayed in Fig. 6.1.
By calibrating these models using distance-weighted modern plant abundance and pollen data, it becomes possible to create estimates for the relevant source area of pollen (RSAP) and the relative pollen production estimates (PPE) of the most important plant taxa in the landscape. The RSAP and PPEn in combination with fossil pollen data, can then be used as input parameters of the Landscape Reconstruction Algorithm (LRA), which is in essence a reversal of the ERV models which uses these parameters in order to reconstruct past vegetation cover (Sugita 2007a, b).

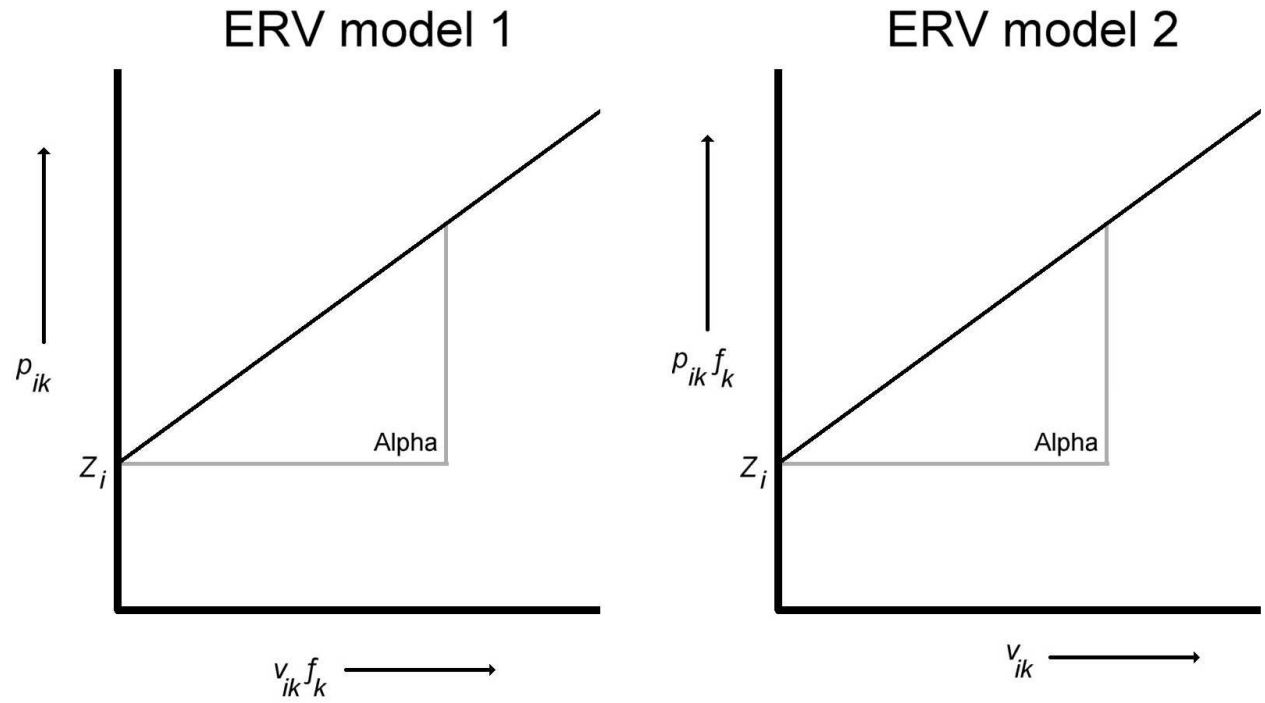

Fig. 6.1. Left: a schematic overview of ERV model 1. The x-axis indicates the adjusted proportional (percentage) vegetation abundance while the y-axis indicates the proportional (percentage) pollen abundance. Right: a schematic overview of ERV model 2. The x-axis indicates the proportional (percentage) vegetation abundance while the Y-axis indicates the adjusted proportional (percentage) pollen abundance. The slope (α) indicates the pollen production estimate (PPE), while the intercept indicates the background pollen loading.

6.1.1.2. Distance weighting

As plants located at a further distance from a sample site contribute less pollen to the total pollen yield of that site, than plants located at a shorter distance (Calcote 1995), it is vital to apply some form of distance weighting to the plant abundance data in order to properly estimate realistic values for the RSAP and PPE. Several models have been proposed to do this. Currently, three types of distance weighting are regularly used (e.g. Soepboer et al. 2007; Duffin and Bunting 2008; Broström et al. 2004): 1/d, where d = distance from the edge of a basin, which in this case would have a surface of 1 m^2 (Prentice and Webb 1986), $1/d^2$ (Calcote 1995; Webb et al. 1981), and taxon specific distance weighting (Prentice 1985; Sugita 1994). The latter model takes into account not only the distance between the plant and the pollen sampling point, but also the transportability of the pollen grain specific to each taxon by requiring data on the fall speed of each pollen type, as well as atmospheric parameters such as average wind speed and air turbulence.

6.2. Methods

Two different reconstructions at two different spatial scales were performed. The first objective of these analyses is to facilitate the general reconstruction of landscape openness in the past in the wider area around the locations of fossil pollen records, and to help answer research questions concerning plant taxa which produce large amounts of pollen and/or pollen capable of being transported over long distances (e.g. *Pinus*). This is done on a large spatial scale using low resolution vegetation data. The second objective is to refine the research results by focussing on a single basin, for which high resolution vegetation data are available. The aim of this analysis is the creation of more realistic PPE's for vegetation types that produce pollen with more limited dispersion capabilities.

6.2.1. Taxa selection

In order to be able to create relatively accurate reconstructions of the vegetation using the results presented in this chapter, it is vital that the taxa selected for the analyses are the dominant plant taxa in the most important vegetation types in the present, as well as in the past. Due to time constraints, it has at present not been possible to collect pollen and plant abundance data for *Olea*, limiting the scope of reconstructions to the time period after the end of the BO Phase until the present. The most important vegetation types in the present landscape and in the past landscape after the end of the BO Phase were determined using:

1: present-day vegetation maps (Vermoere 2004) and fossil pollen records covering the post BO-Phase time interval in the study area (Chapter 3).

2: the ecological preferences of the most important plant taxa found in the present and fossil pollen records (Davis 1965-1988; Fontaine et al. 2007; Kaniewski et al. 2007b).

3: the abundance of taxa in the present landscape around the sample sites used for these analyses

4: the abundance of their pollen in the modern pollen samples selected at these sample sites.

The selected plant taxa are displayed in Table 6.1 and 6.2. Plant and pollen taxonomy were harmonized in such a way that each pollen taxon is correlated to all plant taxa that belong to that specific morphological taxon.
For the analysis on a large spatial scale, the abundance and pollen production of ten taxa; the arboreal taxa *Pinus*, *Quercus coccifera* and *Juniperus*, and the herbaceous taxa Asteraceae, Poaceae, Poaceae Cerealia, *Plantago*, Chenopodiaceae, Apiaceaeae, and Caryophyllaceae were studied. Many smaller herbaceous species are less dominant in the landscape, are insect pollinated species (producing relatively little pollen), or have a much more limited maximum distance over which their pollen can be distributed. In these cases the resolution of the vegetation map is expected to be too low to find a reasonable relationship between plant abundance and pollen percentages. The inclusion of these herbaceous taxa serves to verify these assumptions. While secondary anthropogenic indicator taxa such as *Rumex*, *Artemisia* and *Sanguisorba minor* are important species for the interpretation of fossil pollen data, they are not included in the analyses because they were too rare in the modern pollen data and/or vegetation around the sample sites.
For the analysis on a smaller spatial scale, only vegetation data and pollen data obtained from Gravgaz Marsh were used. Here the data at our disposal may allow for a better estimate of the PPE values of several herbaceous taxa with a limited pollen production and/or pollen distribution distance. Because of the pollen production and dispersal capabilities of *Pinus*, this pollen taxon was excluded from the analyses performed on the high resolution map. A consequence of the nature of the ERV models is that the RSAP calculated for a certain collection of taxa equals the relevant source area of pollen of the taxon with the best pollen distribution capabilities.

6.2.2. Collecting plant abundance data

Two vegetation maps displaying the spatial distribution of the selected vegetation types were prepared by Drs. Hanne de Brue. Classification of land cover in the study area was done using multispectral remotely sensed images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Quickbird-2 satellites. The ASTER images were acquired on June 28, 9.08 am GMT and October 18, 9.03 am GMT in 2001. The Quickbird-2 image used here was acquired on September 19, 8.34 am GMT in 2003. ASTER images were orthorectified and georeferenced using 30 ground control points (GCP's) gathered on the field and in Google Earth. Furthermore, a large set (ca. 1000) of small ASTER training polygons was collected on the field and in Google Earth for all representative land cover classes. Geometric corrections had already been applied to the Quickbird-2 image by V. De Laet (2006). Training polygons for the Quickbird-2 image (ca. 450) were collected directly in ArcGIS, since the spatial resolution of this image is sufficiently large. A cross tabulation validation analysis, based on another ca. 400 (ASTER) and 225 (Quickbird-2) reference polygons collected in the same way as the training data, showed that the overall classification accuracies were reasonably high. Circa 75% of the pixels within the reference polygons were assigned to the

correct vegetation class. Visual validation (comparison with Google Earth and Quickbird-2 high resolution images) and field-based knowledge also indicated that the constructed vegetation map represents the actual land cover quite well. Unfortunately it was not possible to use the vegetation map available in De Laet (2006), as this map does not distinguish between *Quercus* and *Juniperus* shrub/woodlands.The resulting maps are a low resolution map of the entire study area, having a resolution of approximately 16 m/pixel and covering an area of 68.8 x 31.4 km (Fig. 6.2), and a high resolution map of Gravgaz marsh and its surroundings having resolution of approximately 1 m/pixel and covering an area of 6.8 x 7.8 km. The latter map was superimposed upon a portion of the low-resolution map, increasing the amount of land included (Fig. 6.3).

It was impossible to distinguish between fallow fields, and harvested and un-harvested cereal fields in the vegetation maps. Therefore, both were classified as "Brown Fields" in the low resolution map. The average relative abundances of both field types constituting the Brown Fields vegetation type was calculated, and used to calculate a general estimate of plant abundance within these Brown Fields.

In order to facilitate the distance weighting of plant abundance data, it is common to record the vegetation in a series of concentric circles around each modern pollen sample site at varying spatial resolutions (Broström et al. 2004). Because of the minimal distance over which herbaceous species are distributed, precise vegetation data are required from the close vicinity of the sample site. This is usually obtained by recording relative vegetation abundance in a set of 10 concentric circles around the sample site, each having a width of 1 meter. Within this 10 meter radius around the sample site, the abundance of each individual taxa is recorded, rather than that of the vegetation types. Beyond that, the ring width may increase and vegetation abundance may be recorded in a less precise way, e.g. using satellite data or estimating vegetation along transects in the field, and estimating the abundance of vegetation types, rather than individual taxa (Broström et al. 2004).

The vegetation within a 10 meter radius of the sample site was mapped in the field. These maps were used to acquire a more detailed estimate of plant abundance close to the sample sites. For the low-resolution map, it was deemed sufficient to base the innermost two rings around the sample site, each with a width of 5 meters, on field data. The vegetation around sample sites intended to be used with the high-resolution vegetation map, has been recorded in 2m wide concentric circles up to a distance of 10 meters around the sample site. The vegetation data obtained for the modern pollen sites taken from Vermoere (2002) could not be used as this was recorded only in 10 x 10 m relevés and vegetation abundance was estimated using a Braun-Blanquet scale, rather than percentage cover. For these sample sites, the abundance of shrubs and trees was estimated using high-resolution satellite data, while for the herbaceous vegetation, it was assumed that the composition of the locally present vegetation types was as uniform as that observed at all sample sites for which field data were available. Beyond a 10 meter radius around each sample site, vegetation abundance was calculated by estimating the percentage cover of vegetation types only.

The relative importance of the selected plant taxa within each vegetation type was collected by means of estimating the relative ground cover of each selected plant taxon for a series of vegetation relevés of 10 x 10 m. Even though the amount of vegetation types is limited, the relative abundance of the most important taxa within each vegetation type may vary to some extent due to the strongly variable topography (altitude, slope, orientation) of the landscape (Fontaine et al. 2007; Kaniewski et al. 2008b). In order to compensate for this variation, the same vegetation type was visited at various locations throughout the Territory of Sagalassos, the number and locations depending on the available time and the location at which the geological and geographical surveys were taking place. At each location four different vegetation relevés were performed in order to compensate for possible differences in plant abundance at a local scale. The relative ground cover of each selected plant taxon within each vegetation type is given in Tables 6.1 and 6.2.

For both maps, relative vegetation abundance was measured using the HUMPOL software package for modelling pollen dispersal and deposition (Bunting and Middleton 2004). HUMPOL is a suite of different programs which form an easy to use front-end for the often complicated mathematical calculations involved in modelling the relationship between pollen and plant abundance (see section 6.1.1). The software enables the simulation of pollen assemblages from vegetation maps using the Prentice-Sugita model of pollen dispersal and deposition, as well as the ability to calculate PPE and RSAP values using ERV analysis. Furthermore, the software enables researches to create hypothetical landscapes with which to carry out thought experiments and test hypotheses concerning the response of the pollen signal to certain changes in the vegetation.

For the low resolution map, vegetation abundance was measured for 200 concentric rings around the sample sites, each with a width of 10 meters. For the high resolution map, vegetation abundance was measured for 500 concentric rings around the sample sites, each with a width of 2 meters.

Table 6.1. An overview of the vegetation types selected for use in the ERV analyses of the whole of the study area, the abundance of the individual taxa selected for the analyses, and their average relative abundance in each vegetation type, as determined using the methods described in section 6.2.2. Although *Cedrus* forest is included as a vegetation type, cedar pollen itself is not selected for inclusion in the analyses as *Cedrus* forest itself is too rare and not enough sample points are located near enough for the creation of a reliable relationship between pollen and plant abundance. The methods involved in calculating the average abundances are explained in section 6.2.2.

Vegetation group	Taxa	Avg. abundance
Pine forest	Asteraceae	0.4%
	Juniperus	6.6%
	Pinus	37.1%
	Poaceae	9.6%
	Q. coccifera	3.3%
Quercus shrub/woodland	Apiaceae	0.4%
	Asteraceae	6.0%
	Juniperus	2.5%
	Plantago	0.1%
	Poaceae	11.3%
	Quercus coccifera	31.9%
Juniperus shrub/woodland	Apiaceae	2.0%
	Asteraceae	2.4%
	Caryophyllaceae	0.3%
	Chenopodiaceae	0.1%
	Juniperus	24.3%
	Plantago	0.1%
	Poaceae	18.3%
	Quercus coccifera	5.0%
Herbaceous steppe	Apiaceae	0.4%
	Asteraceae	3.3%
	Caryophyllaceae	0.3%
	Chenopodiaceae	0.1%
	Juniperus	0.8%
	Poaceae	15.4%
	Quercus coccifera	1.3%
"Brown fields" :12.5% Fallow, 86.5% harvested/unharvested grain fields, 1% Borders	Apiaceae	0.8%
	Asteraceae	6.7%
	Caryophyllaceae	0.0%
	Chenopodiaceae	0.2%
	Juniperus	0.0%
	Plantago	0.1%
	Poaceae	2.7%
	Poaceae cerealia	31.4%
Grassy/moist fields	Asteraceae	3.0%
	Chenopodiaceae	0.0%
	Plantago	0.0%
	Poaceae	15.0%
Borders/ditches (Innermost circle only, deciduous trees calculated seperately)	Asteraceae	0.1%
	Plantago	0.4%
	Poaceae	24.4%
Cedrus forest	Apiaceae	0.3%
	Asteraceae	0.3%
	Juniperus	2.7%
	Poaceae	16.7%
	Quercus coccifera	2.0%

Table 6.2. An overview of the vegetation types selected for use in the ERV analyses of Gravgaz marsh and environs, the abundance of the individual taxa selected for the analyses, and their average relative abundance in each vegetation type, as determined using the methods described in section 6.2.2. This additional analysis is used specifically to study the RSAP and PPE of less prodigious pollen producers. Because of this, *Pinus* pollen was left out of the taxa used for this analysis due to their relatively high pollen production. The methods involved in calculating the average abundances are explained in section 6.2.2.

Gravgaz marsh					
Vegetation group	Taxa	Avg. abundance	Vegetation group	Taxa	Avg. abundance
Pine forest	Asteraceae	0.4%	Grassy/moist fields	Asteraceae	3.0%
	Juniperus	6.6%		Chenopodiaceae	0.0%
	Poaceae	9.6%		*Plantago*	0.0%
	Q. coccifera	3.3%		Poaceae	15.0%
Quercus shrub/woodland (outer low-resolution zone)	Apiaceae	0.4%	Cereal fields	Apiaceae	0.7%
	Asteraceae	6.0%		Asteraceae	5.9%
	Juniperus	2.5%		Chenopodiaceae	0.1%
	Plantago	0.1%		*Plantago*	0.1%
	Poaceae	11.3%		Poaceae	1.8%
	Quercus coccifera	31.9%		Poaceae cerealia	35.8%
Juniperus shrub/woodland (outer low-resolution zone)	Apiaceae	2.0%	Fallow field	Apiaceae	1.4%
	Asteraceae	2.4%		Asteraceae	11.7%
	Caryophyllaceae	0.3%		Caryophyllaceae	0.1%
	Chenopodiaceae	0.1%		Chenopodiaceae	0.5%
	Juniperus	24.3%		*Juniperus*	0.2%
	Plantago	0.1%		*Plantago*	0.3%
	Poaceae	18.3%		Poaceae	7.2%
	Quercus coccifera	5.0%	*Quercus* shrubs	*Quercus coccifera*	100.0%
Herbaceous steppe	Apiaceae	0.4%	*Juniperus* shrubs	*Juniperus*	100.0%
	Asteraceae	3.3%	Marsh: transition zone	Asteraceae	1.0%
	Caryophyllaceae	0.3%		Poaceae	20.0%
	Chenopodiaceae	0.1%	Marsh: inner swamp	Poaceae	10.0%
	Juniperus	0.8%			
	Poaceae	15.4%			
	Quercus coccifera	1.3%			

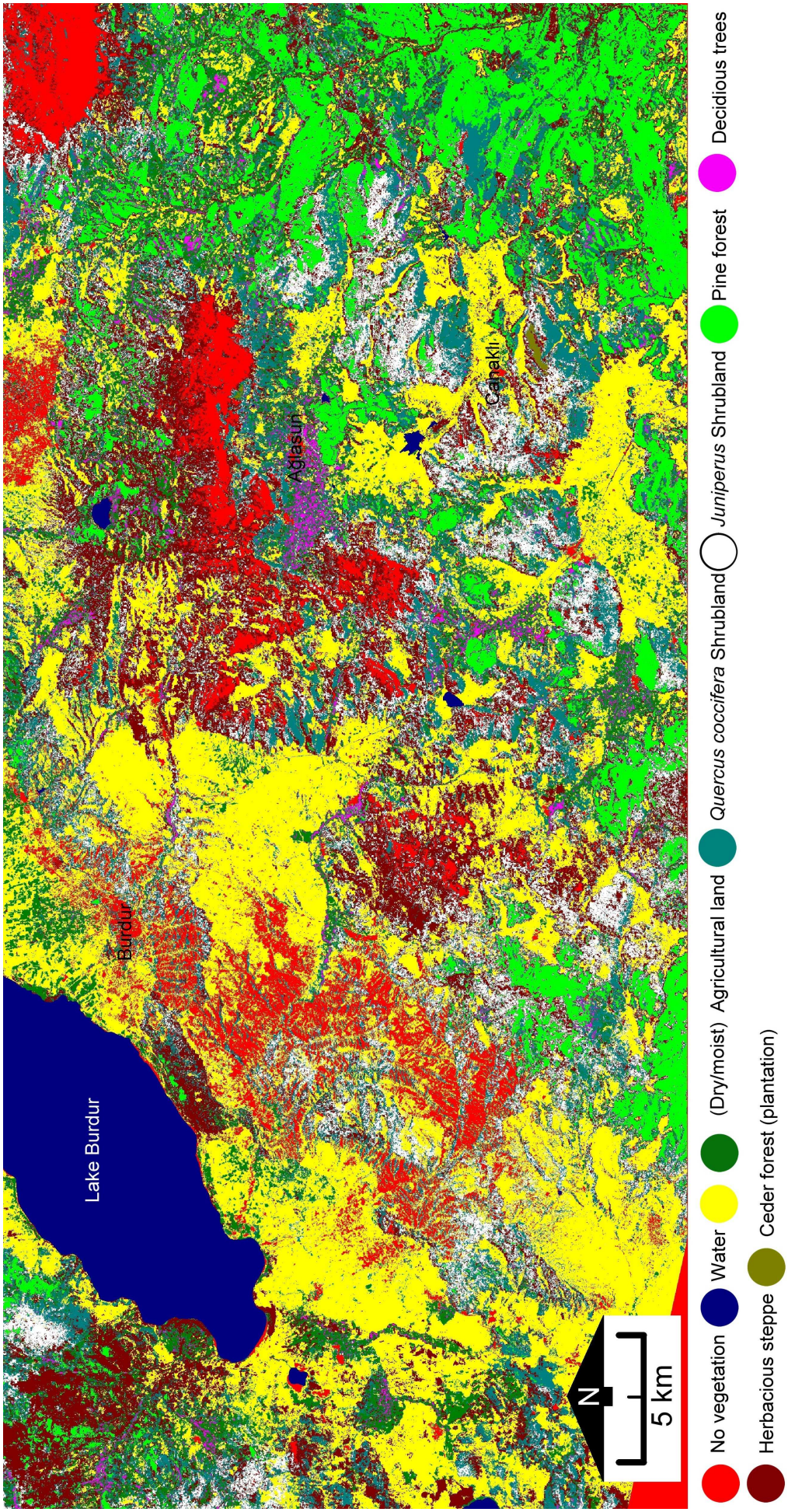

Fig. 6.2. A vegetation map created by of the whole of the territory of Sagalassos, based on multispectral remotely sensed images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The images were acquired on June 28, 9.08 am GMT and October 18, 9.03 am GMT in 2001. This vegetation map was created by Hanne de Brue.

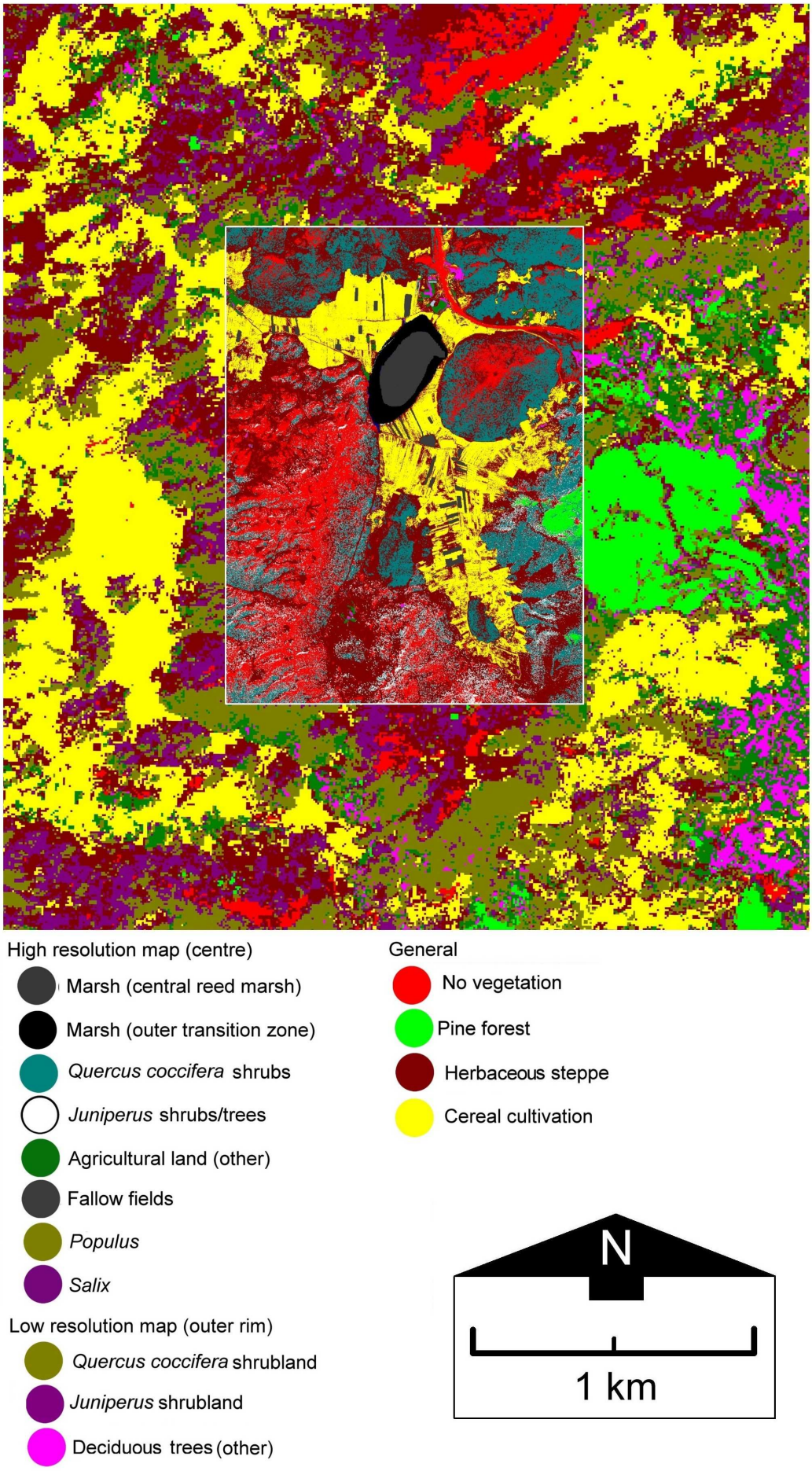

Fig. 6.3. A vegetation map of Gravgaz marsh and the surrounding valley basin. The central part of the map is based on multispectral remotely sensed images from the Quickbird 2 sattelite. This high-resolution map is embedded into a cut-out of the lower-resolution ASTER map displayed in Fig. 7.3. The Quickbird-2 image used here was acquired on September 19, 8.34 am GMT in 2003. This vegetation map was created by Hanne de Brue.

6.2.3. Modern pollen data

Modern pollen data was collected from 32 sample sites distributed around the study area. For the high resolution map of Gravgaz marsh, 14 sample sites were used while for the low-resolution map, 22 sample sites were used. Four sample sites were used for both maps (Fig. 6.4., Table 6.3). The set of sample sites consists of a selection of 17 samples from a set of 62 modern pollen samples collected and analyzed by Vermoere (2004), and a set of 14 additional modern pollen samples collected specifically for the current study.

The purpose of this research is to provide the basis with which future research may reconstruct the landscape which was once located in the vicinity of the sites where fossil pollen was collected (e.g. the drill sites in Bereket and Gravgaz). However, many of the samples collected by Vermoere (2004) were collected at locations characterized by a physical environment and vegetation which in no way represented a natural environment which is present or ever has been present in the vicinity of the locations where fossil pollen data has been collected. Sample sites at locations where it could be expected that the moss polster could not be expected to produce a modern pollen spectrum not representative of any realistic landscape (e.g. a sample site on top of a very exposed hill top) were also excluded. As a consequence only 17 out of 62 samples were used in the present research, and it was necessary to collect additional modern pollen data.

The locations of the additional sample sites were distributed as randomly as possible within the study area, in accordance with Broström et al. (2004). However, the distribution of the extra pollen sites was limited by the restrictions in the timeframe and locations of the fieldwork. Unfortunately due to the different nature of the research performed by Vermoere (2002) and the restrictions in time and location for the more recent palynological fieldwork campaigns, the number of useful sites turned out to be limited, but high enough to be used with the ERV models.

At each sample site, a moss polster was collected. Where it was impossible to collect a moss sample, a surface soil sample was collected instead. Moss polsters are commonly used as a source of modern pollen data and are therefore frequently used in studies of pollen-vegetation relationships when there is no opportunity to successfully place and retrieve pollen traps for several successive years (Broström et al. 2004; Bunting et al. 2005; Mazier et al. 2008). Moss polsters are assumed to record several years of pollen deposition (Heim 1970), therefore eliminating the influence of annual variations in the pollen data (Hicks et al. 2001). However, the exact number of years represented in a moss polster is uncertain and depends on the species of moss and the size of the polster (Heim 1970; Bradshaw 1981; Cundil 1991). In order to maximise the chances of obtaining a good representation of the regional and local pollen rain for multiple years, moss from various places within a 0.5 m^2 area was collected, sampling both the green as well as the brown parts. The laboratory techniques used for the preparation of pollen samples from moss polsters and soil surface samples is described in detail in appendix 1. As the summers in this region are very dry, it is important to verify that the pollen found within a moss polster has not suffered from degradation due to desiccation. Pollen conservation was assessed by summing corroded, degraded, broken and crumpled pollen in a “deterioration assemblage” (Cushing, 1967), and rejecting samples where more than 30% of the pollen were damaged.

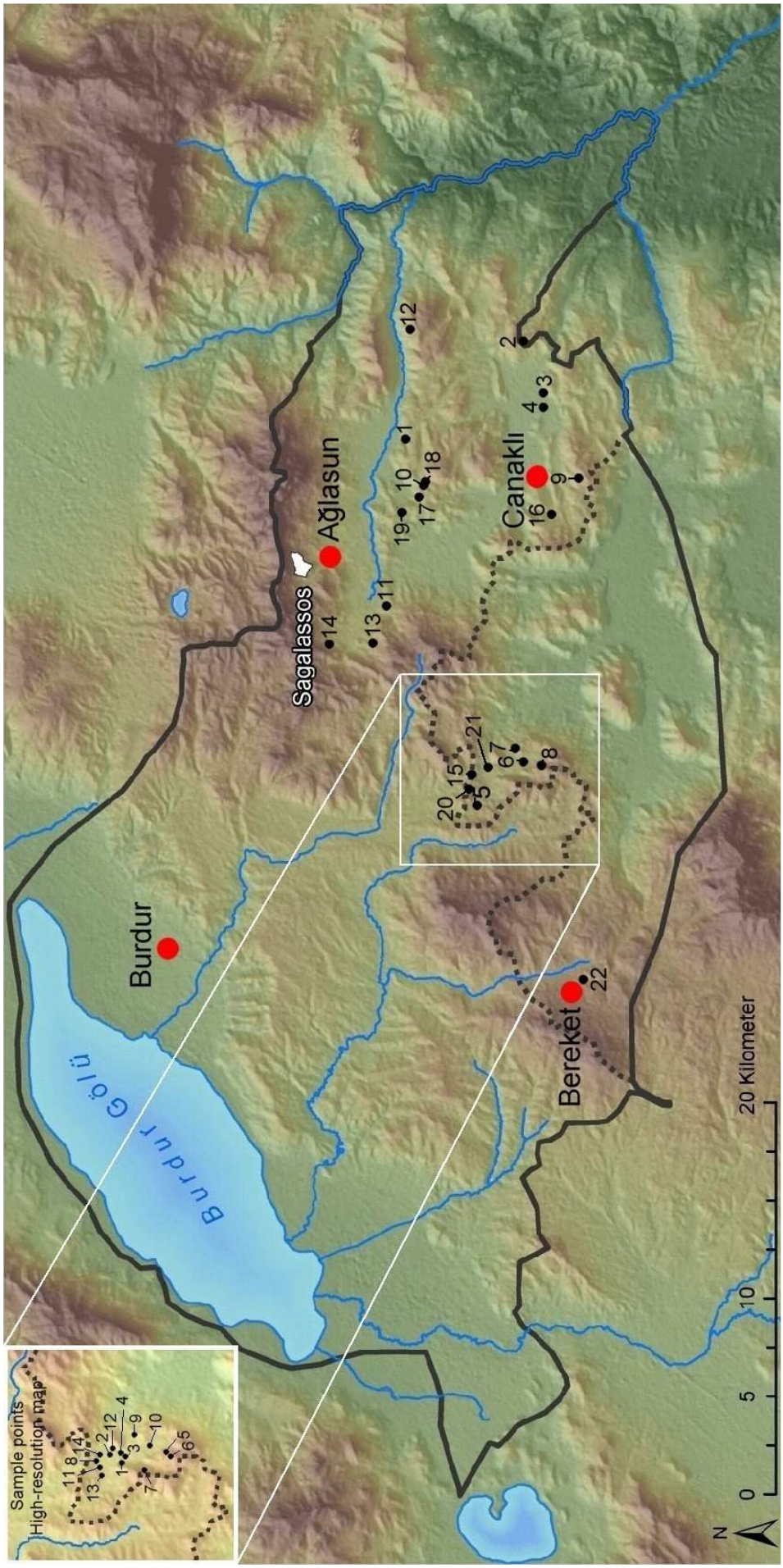

Fig. 6.4. A map of the territory of Sagalassos, indicating the locations of the sample sites from which modern pollen data and distance-weighted vegetation data was collected. The numbers of the main map correspond with those given in Table 7.3. The insert shows the sample sites used for the analysis of Gravgaz marsh. The numbers in this insert correspond with those given in Table

7.4.

Table 6.3. Top: An overview of the locations of the 22 modern pollen sites within the territory of Sagalassos. Bottom: An overview of the locations of the 12 modern pollen sites in the vicinity of Gravgaz marsh. Codes starting with RS were collected by Vermoere (2004). Codes starting with SA were collected during the 2009, 2010, and 2011 geographical surveys. Coördinates are in UTM 36N.

Low-resolution map of the territory of Sagalassos				
Number on map	Code	Northings	Eastings	Site description
1	RS62	4167254	287681	Small copse of pine trees in *Quercus coccifera* shrubland
2	SA29	4161688	292118	Small copse of *Quercus coccifera* shrubland in sizable open place covered by fields and surrounded by *Pinus* forest
3	SA30	4160404	290031	Along a road. Fields on both sides
4	SA67	4160344	289316	Cereal fields
5	SA07	4160344	289316	Rocks and herbaceous steppe with some *Quercus coccifera* shrublands
6	SA04	4161233	271184	Cereal fields
7	SA02	4161748	271641	*Quercus coccifera* shrubland with some juniper shrubs. Downslope from Pine forest
8	RS09	4160504	270852	Open juniper shrubland
9	RS26	4158761	285888	*Cedrus* plantation
10	RS63	4166632	285067	*Quercus coccifera* shrubland
11	RS55	4168050	278993	Roadside in open herbacious steppe w some *Quercus coccifera* bushes
12	RS34	4167215	293254	*Pinus/Abies* plantation
13	RS03	4169087	277105	Open herbaceous steppe
14	RS01	4171096	277183	Open herbaceous steppe with some *Quercus coccifera* bushes. Near fields.
15	SA01	4163632	270572	*Quercus coccifera* shrubland, near edge of cereal fields
16	RS25	4160247	283976	*Quercus coccifera* shrubland west of Canaklı
17	RS28	4158955	287981	Open *Quercus coccifera* shrubland
18	RS64	4166667	285027	*Quercus coccifera* shrubland
19	RS58	4167593	283873	Roadside in *Pinus* plantation
20	SA05	4163489	269868	Open, rocky steppe vegetation among *Quercus coccifera* shrubland, north of Gravgaz marsh
21	SA06	4162967	270964	The north-eastern end of the central Cyperaceae swamp at Gravgaz marsh
22	SA21	4158113	260061	Steppe vegetation among cereal fields, south of Bereket village

High-resolution map of Gravgaz marsh				
Number on map	Code	Northings	Eastings	Site description
1	RS40	4162533	270363	Herbaceous vegetation near marsh
2	RS41	4162994	270782	Herbaceous vegetation near marsh
3	RS42	4162442	270604	Herbaceous vegetation near marsh
4	RS43	4162596	270743	Herbaceous vegetation near marsh
5	RS09	4160504	270852	Open juniper shrubland
6	RS10	4160475	270765	Open juniper shrubland
7	RS11	4161709	270140	Exposed rock above *Quercus coccifera* shrubland
8	SA01	4163632	270572	*Quercus coccifera* shrubland, near edge of cereal fields
9	SA02	4161748	271641	*Quercus coccifera* shrubland w some Juniper shrubs. Downslope from Pine forest
10	SA04	4161233	271184	Cereal fields
11	SA05	4163489	269868	*Quercus coccifera* shrubland on hillside north of marsh
12	SA06	4162967	270964	Northern edge of Gravgaz marsh, dominated by Cyperaceae
13	SA09	4163441	269661	Northern edge of Gravgaz marsh, dominated by Cyperaceae
14	SA11	4163490	270774	Cereal fields east of small farms

6.2.4. Numerical analyses

6.2.4.1. Distance weighting

Distance weighting is performed using the 1/d method, the $1/d^2$ method, and Prentice's taxon specific methods are used. The latter model is specifically used for pollen deposition at the centre of a sedimentary basin where pollen grains do not move after being deposited. It is therefore especially useful when working with moss polsters. Later modifications by Sugita (1993) and Sugita et al. (1997, 1999) adapted the model for use with lakes and ponds, where pollen may mix and move in the water body after initial deposition.
Values for the fall speed of pollen were either taken from literature (Eisenhut 1961; Gregory 1973; Jackson and Lyford 1999; Broström et al. 2004), or calculated using the formula for Stoke's Law (Gregory 1973), using Beug (2004) and Reille (1992) in order to estimate the average grain sized of pollen. When calculating fall speeds of families rather than individual taxa, the average value for the grain size for all taxa potentially occurring in the study area according to Davis (1965-1988), was calculated. The fall speeds of all plant taxa used in this study is presented in table 6.4.

Table 6.4. An overview of the fall speeds for all plant taxa and families included in the ERV analyses. Values for the fall speed of pollen were either taken from literature (Eisenhut 1961; Gregory 1973; Jackson and Lyford 1999; Broström et al. 2004), or calculated using the formula for Stoke's Law (Gregory 1973), using Beug (2004) and Reille (1992) in order to estimate the average grain size of each pollen taxon.

Taxon/family	Fall speeds (m/s)
Apiaceae	0.037
Asteraceae	0.051
Caryophyllaceae	0.078
Chenopodiaceae	0.031
Juniperus	0.016
Pinus	0.045
Plantago	0.01
Poaceae	0.038
Poaceae cerealia	0.06
Quercus coccifera	0.024
Populus	0.034
Salix	0.022

6.2.4.2. ERV models

Pollen count and distance-weighted plant abundance data were analysed using the HUMPOL software package. As vegetation abundance data are only available as percentages, only ERV models 1 and 2 will be used. If both models provide comparable estimates of α and z, the results are considered to be robust (Prentice and Parsons 1983). Running the ERV models results in PPE's and likelihood function scores at increasing distances from each sample site. Plotting likelihood function scores against distance reveals the relevant source area of pollen, which is located at the point where the graph reaches an asymptote, indicating the pollen-vegetation relationship no longer improves as the size of the RSAP increases (Sugita 1994, 1998, 2007b; Sugita et al. 1999). Beyond the RSAP, PPE estimates should no longer vary to any great extent. In order to account for slight variations in PPE values beyond the RSAP, all the PPE values and standard errors for each taxon, from the RSAP to the maximum surveyed distance are averaged.
Quercus coccifera rather than Poaceae was chosen as the reference taxon due to the fact that, in contrast to Poaceae, it is a monospecific taxon. Furthermore, it is a reasonably copious pollen producer which is widely distributed in the study area and its pollen is present in most of the modern pollen samples at intermediate proportions (see chapter 3).

6.2.4.3. Simulation test of the PPE's

The reliability of the PPE's obtained with both maps was tested by using them to simulate pollen composition for independent (not used for estimating the PPE values being tested) surface samples within the study area. The observed pollen loadings from these samples were compared with the simulated pollen loadings by using a paired samples t-test. The simulations were made with Polflow, a part of the HUMPOL software suite (Bunting and Middleton 2004) and the statistical tests were performed using the computer program PAST (http://folk.uio.no/ohammer/past/). For each data set (territory and Gravgaz) 8 separate independent sample points were used.

6.3. Results

6.3.1. Pollen analysis

The results of the pollen analyses of the 32 moss polsters are displayed in Figs. 6.5 and 6.6. Samples with a code starting with RS were obtained from Vermoere (2002) while samples with a code starting with SA were collected specifically for the current study. Raw modern pollen counts for the taxa used in these analyses are displayed in appendix 5.
The data are displayed as percentages of the total sum of all pollen included in the analyses. *Pinus* and *Quercus coccifera* are the two most dominant pollen types throughout the entire study area, but both vary widely from sample point to sample point. As the new 'SA' samples were collected specifically in locations not previously covered by Vermoere (2002), there may appear to be a discrepancy between average pollen percentages between SA and RS samples for some taxa. For *Pinus*, this seems to support the notion that pine pollen percentages will quickly drop down to background pollen percentages, only a short distance away from pine forests (see chapter 3). The copious pollen production of *Quercus coccifera* seems to be in conflict with the notion that the reproduction of *Q coccifera* is severely impeded by overgrazing (Bottema and Woldring 1995; Fontaine et al. 2007). It must be noted, however, that a sizable proportion of all modern pollen samples used for these analyses were located near a *Quercus coccifera* shrubland. This vegetation type is one of the most important non-agricultural vegetation types in the current landscape (see Table 6.3 and Fig. 6.7). Note that for the low resolution map, *Quercus coccifera* shrubland was defined as a vegetation type, c. 40% of which was covered by *Q. coccifera* bushes. The rest was a mixture of bare rock and herbaceous steppe vegetation. The high resolution map enables the depiction of individual *Quercus* and *Juniperus* shrubs, leading to a redefining of both vegetation types for the high-resolution Gravgaz map (compare Tables 6.1, 6.2), and an increase in the percentage cover of herbaceous steppe on the map.

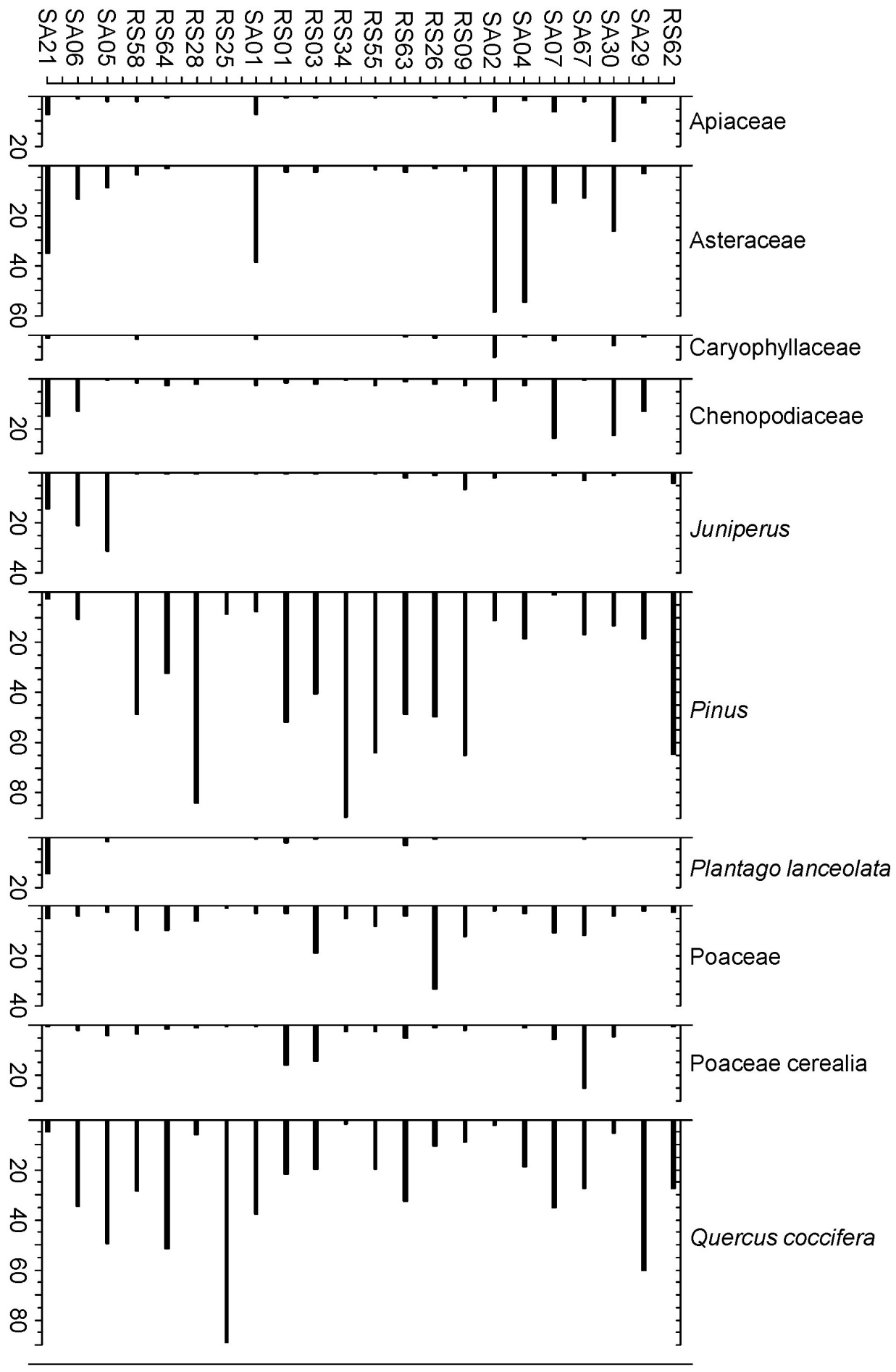

Fig. 6.5. Pollen percentage data for the 10 selected pollen taxa at the 22 sample points used for the ERV analysis incorporating the low-resolution map of the entire study area.

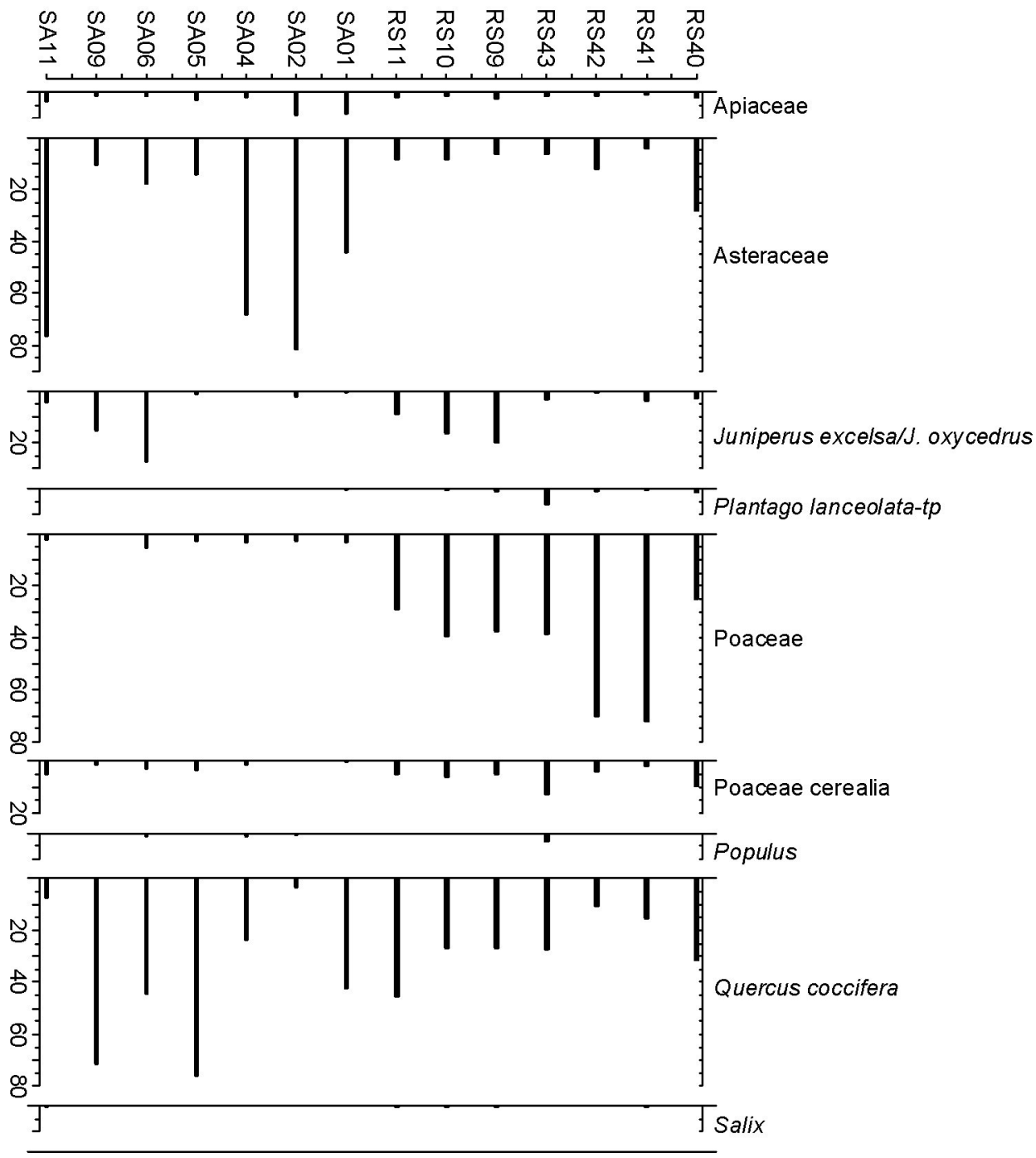

Fig. 6.6. Pollen percentage data for the 9 selected pollen taxa at the 14 sample points used for the ERV analysis incorporating the high-resolution map of Gravgaz. 4 sample points in this overview also appear in the dataset used for the ERV analysis incorporating the low-resolution map of the territory of Sagalassos. As the pollen taxa used in the high-resolution analysis does not include *Pinus*, their pollen percentages will differ between the present figure and Fig. 6.5.

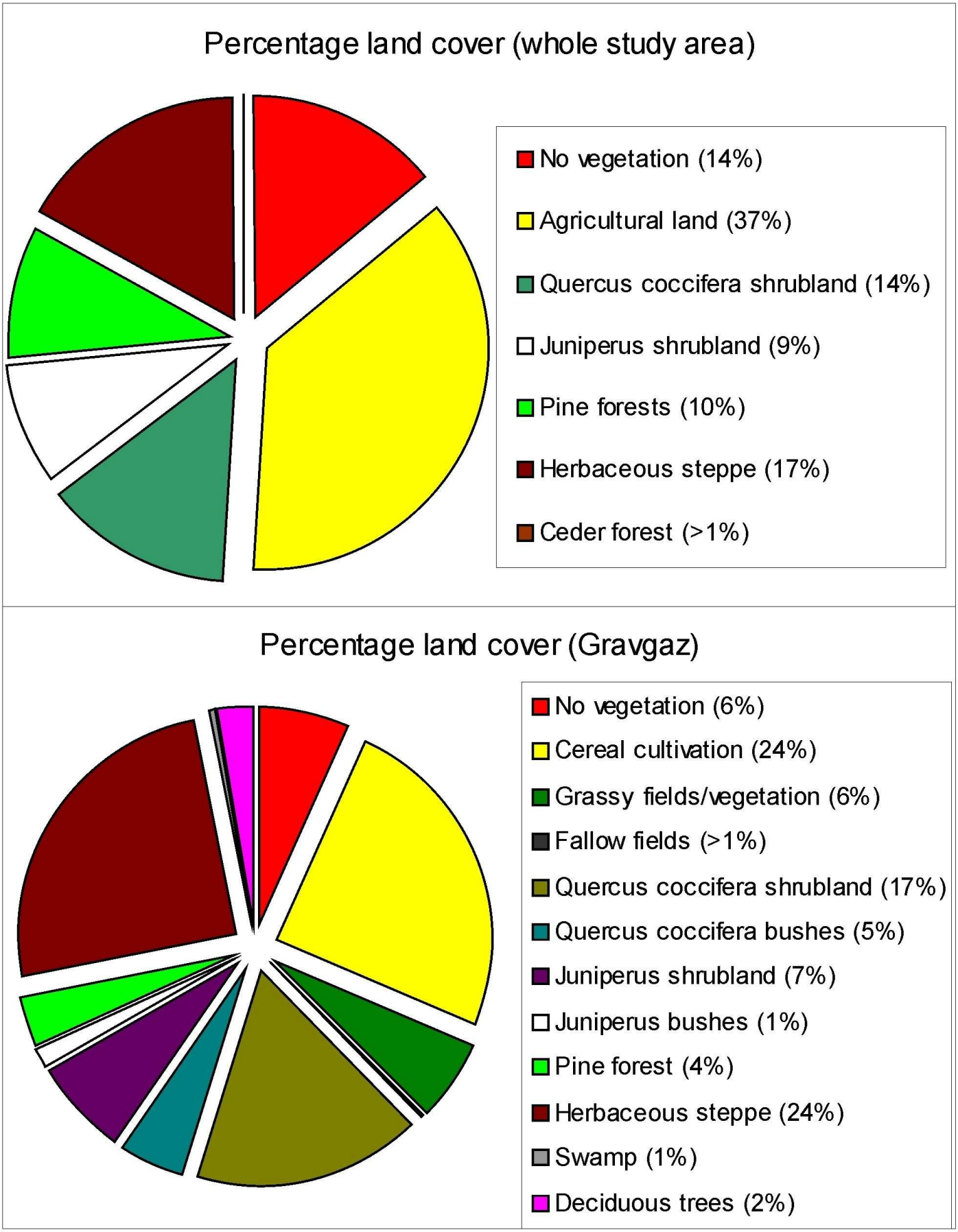

Fig. 6.7. An overview of the relative abundance of the selected vegetation types in the low-resolution (top) and high-resolution (bottom) maps.

6.3.2. Relevant source area of pollen

The estimates of the RSAP based on the low-resolution map of the entire study area, using the two ERV submodels and three distance weighting functions are presented in Fig. 6.8. The estimates of the RSAP based on the high-resolution map of Gravgaz are presented in Fig. 6.10. The likelihood function scores and RSAP distances are given in table 6.5.
The RSAP values were calculated using a moving window linear regression approach. The window width was set to 300 m for the analyses using the low-resolution map and 200 m for the analysis using the high resolution map. The maximum likelihood scores are given as average values of all scores between the RSAP distance and the maximum distance of the vegetation survey. The relevant source area of pollen is determined as the area at a distance that is at the middle of a window, in which the slope of the regression line becomes not significantly different from zero (Sugita 2007b). Figs 6.9 and 6.11 show the average slope for each window for the low-resolution and high-resolution map respectively.

6.3.2.1. The territory of Sagalassos

The 1/d and Prentice's taxon specific distance weighting methods produce similar RSAP estimates within both model 1 and model 2, the RSAP being c. 765 meters for both ERV models and both distance weighting methods. The distance at which the RSAP (the asymptote in the graphs) is reached when the $1/d^2$ distance weighting method is used varies greatly between ERV model 1 and 2, the estimates being c. 1065 and 415 meters respectively (Fig. 6.9).
Because the lowest likelihood function scores should correspond to the best goodness-of-fit between data and model (Sugita 1994), and because the results for ERV model 1 and 2 should be similar if there is a good linear relationship between pollen percentages and relative plant abundances, it is suggested that the $1/d^2$ model is the least suited for calculating the PPE's for this dataset. Based on the lowest average maximum likelihood score, the combination of Prentice's model and ERV model 1 should yield the best results.

6.3.2.2. Gravgaz marsh

The results of ERV model 1 and ERV model 2 for the analysis based on the high-resolution map, are inverse to one another. Fig. 6.10 shows that while the results for ERV model 1 show the typical pattern of gradually diminishing likelihood function scores, they actually gradually increase for ERV model 2. This strange result for model 2 is likely a result of the nature of the model. As shown in Fig. 6.1, ERV model 1 assumes that the background pollen loading is a constant proportion of the total pollen loading (Prentice and Parsons 1983). There may be problems with this assumption if there is a large variation in total pollen loading among sites, e.g. when there are large variations in species composition from site to site. Fig. 6.6 indicates that strong differences in pollen abundance between sites only occur for Asteraceae and Poaceae. ERV model 2 assumes that the background pollen loading is constant relative to the total plant abundance around the sites. This assumption may be violated if the total plant abundance varies greatly between sites, e.g. because of the presence of large patches devoid of vegetation (Prentice and Parsons 1983). A comparison of the high resolution and low resolution maps reveals that this may well be a problem for the high resolution map. Bare soil is an important part of the *Quercus* and *Juniperus* shrub vegetation on the lower slopes. However, the low resolution map was unable to distinguish the bare soil between the shrub vegetation. The vegetation relevés revealed that the proportion of bare soil within such shrub vegetation did not vary greatly from site to site. Therefore it was not needed to make such a distinction anyway in order for the ERV models to work properly with the low-resolution map. The only sizable patches of bare soil recorded in the low-resolution map were the larger areas of exposed rock at higher elevations and located well outside the RSAP of the sample sites. For the high resolution map, it was possible to record, not just a shrubland vegetation type, but individual shrubs. As a result, the patchiness of the vegetation was increased greatly, as did the abundance of bare soil, especially within the area identified as *Juniperus* shrubland on the low resolution map.

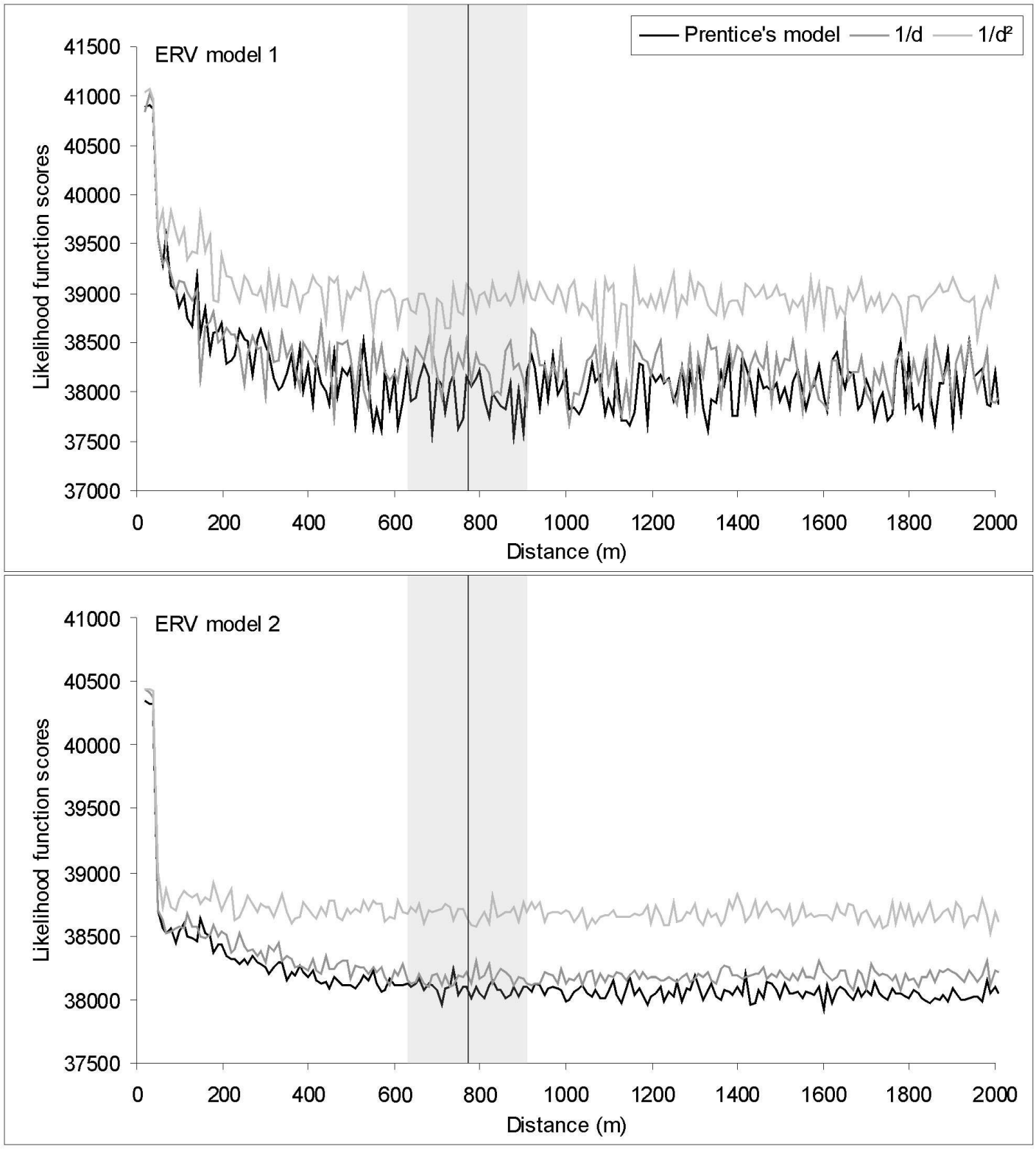

Fig. 6.8. Likelihood function scores for ERV models 1 and 2, obtained using the low-resolution map and three different distance weighting models. The RSAP is determined as the distance at which the graph reaches an asymptote (Sugita 2007b). The vertical grey band indicates the 300 m window within which the graphs for Prentice's model and the 1/d model reach their asymptotes. The vertical black line indicates the middle of the window and the distance at which the RSAP is located.

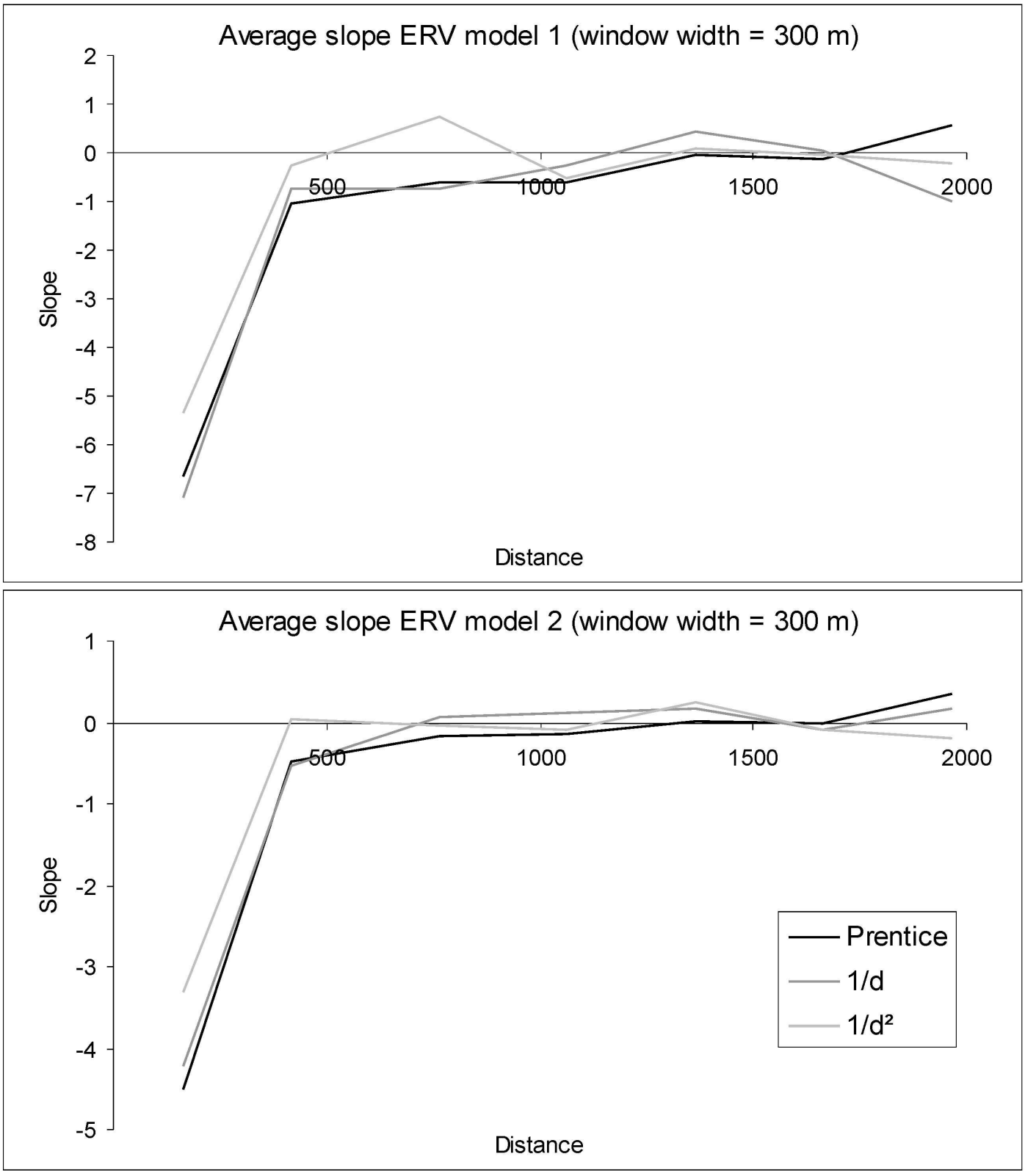

Fig. 6.9. The average slope of the likelihood function scores calculated using the low-resolution map, over a series of 200 meter long sections. The RSAP is determined to be the mid point of the first of multiple sections which yield a slope not significantly different from zero.

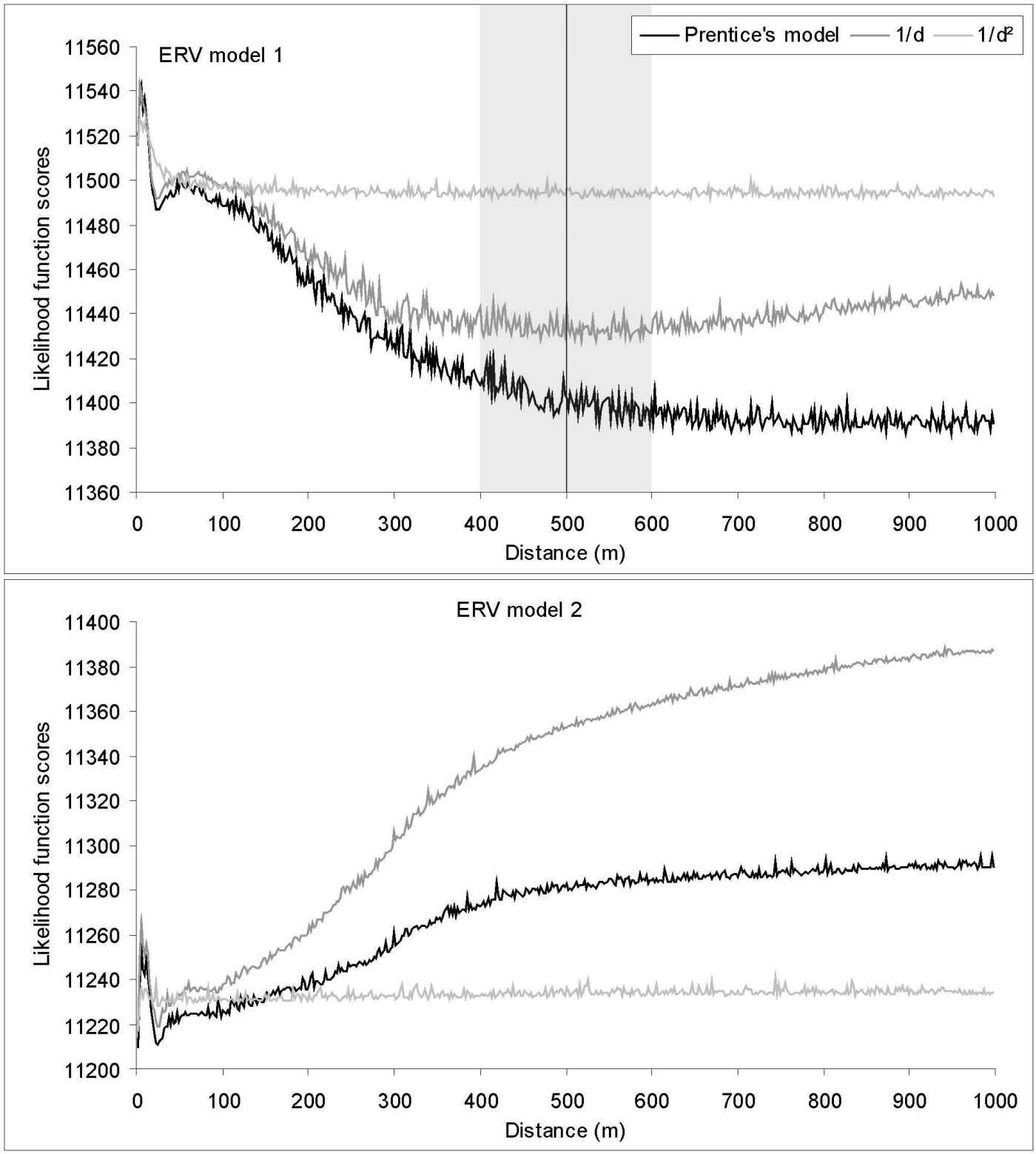

Fig. 6.10. Likelihood function scores for ERV models 1 and 2, obtained using the high-resolution map and three different distance weighting models. The RSAP is determined as the distance at which the graph reaches an asymptote (Sugita 2007b).

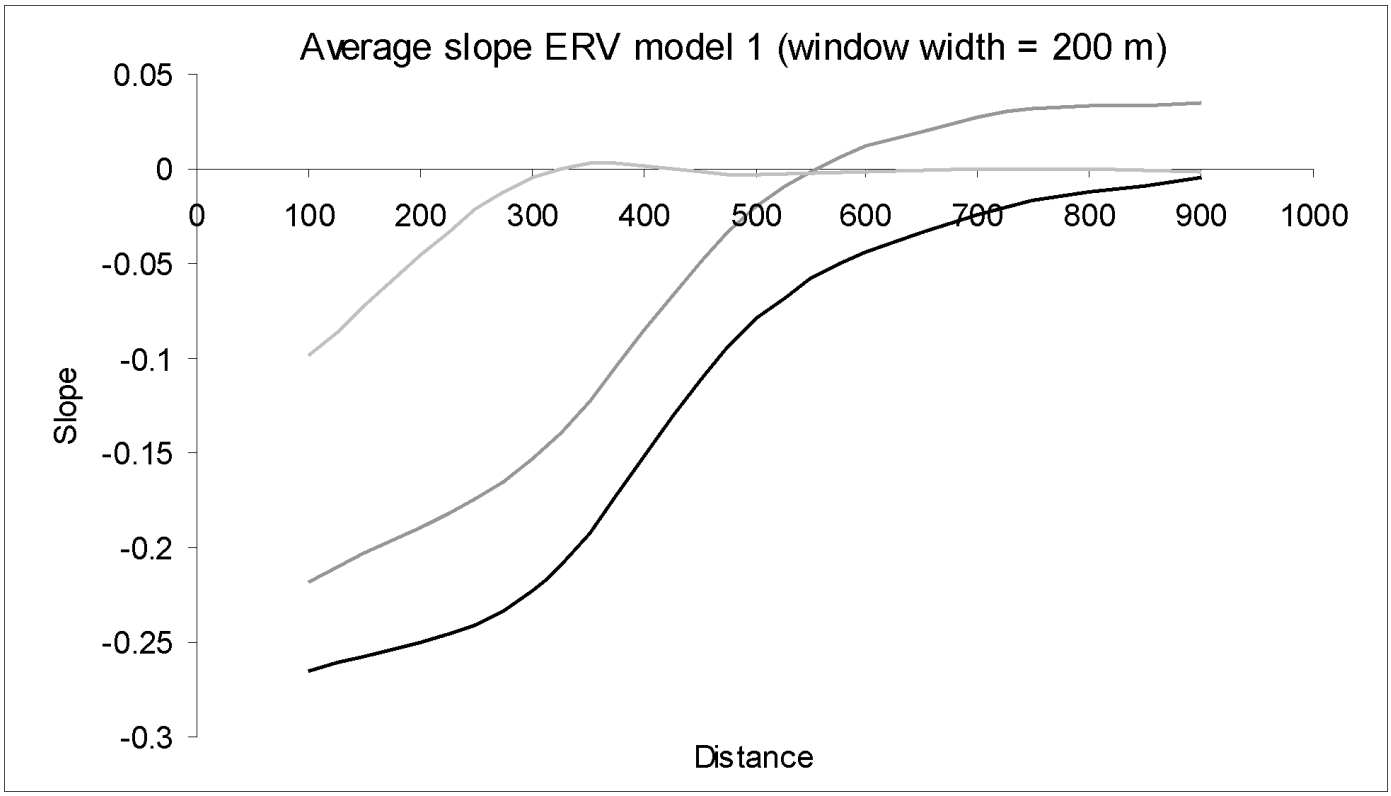

Fig. 6.11. The average slope of the likelihood function scores calculated using the high-resolution map, over a series of 200 meter long sections. The RSAP is determined to be the mid point of the first of multiple sections which yield a slope not significantly different from zero.

Table 6.5. Top: RSAP estimates (m) for the whole of the study area, calculated using the moving window method of Sugita (2007b), and maximum likelihood functions for three different distance weighting methods and two ERV models. Bottom: RSAP estimates (m) for Gravgaz marsh and surroundings, calculated using the moving window method of Sugita (2007b), and maximum likelihood functions for three different distance weighting methods and ERV model 1.

Territory of Sagalassos			
RSAP distance (m)			
	Prentice's model	1/d	$1/d^2$
ERV Model 1	765	765	1065
ERV Model 2	765	765	415
RSAP average maximum likelihood function score			
	Prentice's model	1/d	$1/d^2$
ERV Model 1	38021.46	38198.59	38932.03
ERV Model 2	38055.14	38184.16	38676.55

Gravgaz marsh			
RSAP distance (m)			
	Prentice's model	1/d	$1/d^2$
ERV Model 1	501	500.1	300.5
RSAP average likelihood function score			
	Prentice's model	1/d	$1/d^2$
ERV Model 1	11393.51	11439.78	11494.45

ERV models 1 and 2 are expected to give similar results if the background pollen loading is low compared tot the total pollen loading (Parsons and Prentice 1983). This is the case when using the low-resolution map. ERV model 1 and 2 should give dissimilar results when there are high amounts of background pollen. This should not be the case for the high-resolution map. The analysis using the low-resolution map indicates that only *Quercus coccifera* and *Pinus* have high background pollen loading when using ERV model 2. *Pinus* is not included in the analyses using the high-resolution map because its pollen dispersal capabilities are well known and was expected to drive the RSAP distance. The strange results for ERV model 2 are most likely caused by the artificially increased patchiness and openness of the vegetation, rather than problems with the background pollen loading. Therefore the results of ERV model 1 are deemed trustworthy.
Figs. 6.10 and 6.11, and Table 6.5 show that the RSAP's calculated with ERV model 1 are c. 500 meters, regardless of whether Prentice's model or the 1/d model was used as a distance weighting method. Similar to the analyses using the low-resolution map, the RSAP estimate is much smaller when using the $1/d^2$ estimate, but this distance weighting method also returns the highest likelihood function scores. As with the previous analysis, using the low resolution vegetation map, the combination of ERV model 1 and Prentice's distance weighting model should yield the best results.

6.3.3. Pollen-vegetation relationships

ERV models try to find the best linear relationship between pollen and (distance weighted) vegetation proportions by adjusting the parameters, e.g. PPE and background pollen. The resulting relationships are displayed in Figs. 6.12 and 6.13. The r^2-values for the linear relationships between vegetation and pollen proportions are displayed in table 6.6. These scatter plots only display the relationships between vegetation proportion versus the 1/d and Prentice's model distance weighted vegetation proportion, as the high likelihood function scores attained for the $1/d^2$ distance weighting indicate it is not well suited for the data used here. It is immediately clear that in some cases there is no clear linear relationship between pollen percentage and plant abundance. In some other cases, there appear to be multiple populations of points within the scatterplots. These problems will be discussed in more detail in section 6.3.1.
Three patterns can be observed in the pollen-vegetation abundance scatterplots. The first pattern is a more or less linear, significantly or insignificantly positively correlated relationship between plant and pollen abundance. This pattern can be observed in fig. 6.12, displaying the results of the analysis using the low-resolution map, for *Quercus coccifera*, Apiaceae, Asteraceae and *Pinus*. The second pattern is a relationship where all data points are distributed along the plant abundance (y) axis. This pattern can be observed in fig. 6.12 for Caryphyllaceae, Chenopodiaceae, and *Plantago*. The third pattern shows a relationship where all data points are distributed along the pollen abundance (x) axis. This pattern can be observed in fig. 6.12 for Poaceae Cerealia, *Juniperus*, and Poaceae.
The second pattern is caused by plant taxa that have limited pollen production and or distribution capabilities, but which are relatively evenly distributed around the sample sites, spreading the same low amount of pollen regardless of plant abundance within the RSAP. The third pattern is caused by taxa that have limited pollen production and or distribution capabilities, but which have a patchy distribution in the field. A small clump of such a taxon near the sample site may supply a relatively large amount of pollen to that sample site, even though the overall abundance of this taxon is limited. PPE's calculated for plant taxa showing this third pattern are not reliable.

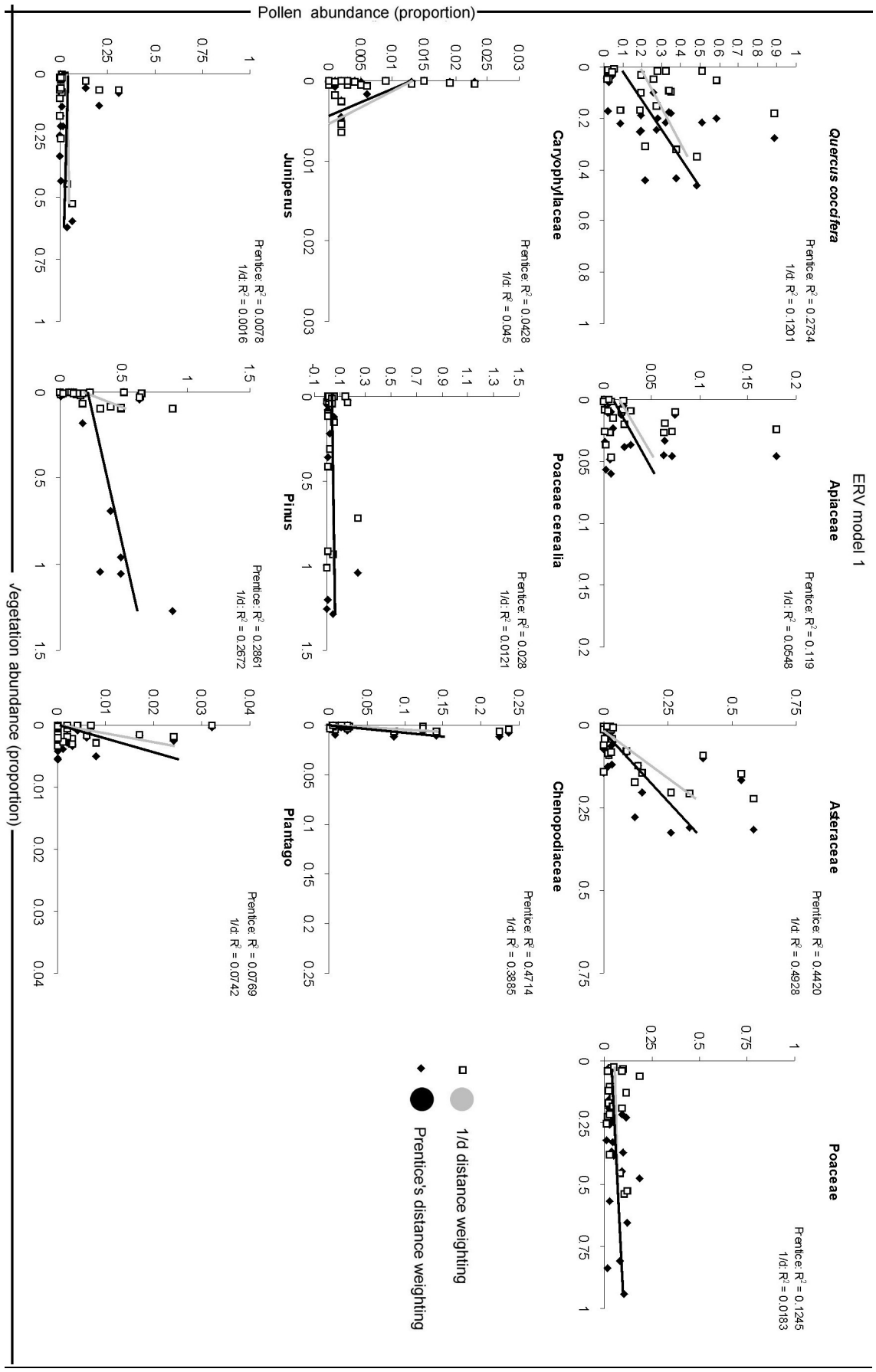

Fig. 6.12a. Scatterplots of pollen and vegetation data within the RSAP for the 10 taxa included in the analysis using the low-resolution map. The data set includes 22 sites from various locations within the territory of Sagalassos and shows results obtained using Prentice's distance weighting model (black line) and the 1/d distance weighting model (grey line). The linear pollen – vegetation relationship found at this distance is indicated with a line. The r^2 value, indicating the linearity of the pollen-vegetation relationships is also provided. The slope of this line indicates the PPE for each taxon, while its intercept with the y-axis indicates the background pollen loading. Fig 7.12a depicts the results for ERV model 1, pollen proportions and adjusted vegetation proportions. Fig 7.12b depicts the results for ERV model 2, adjusted pollen proportions and vegetation proportions.

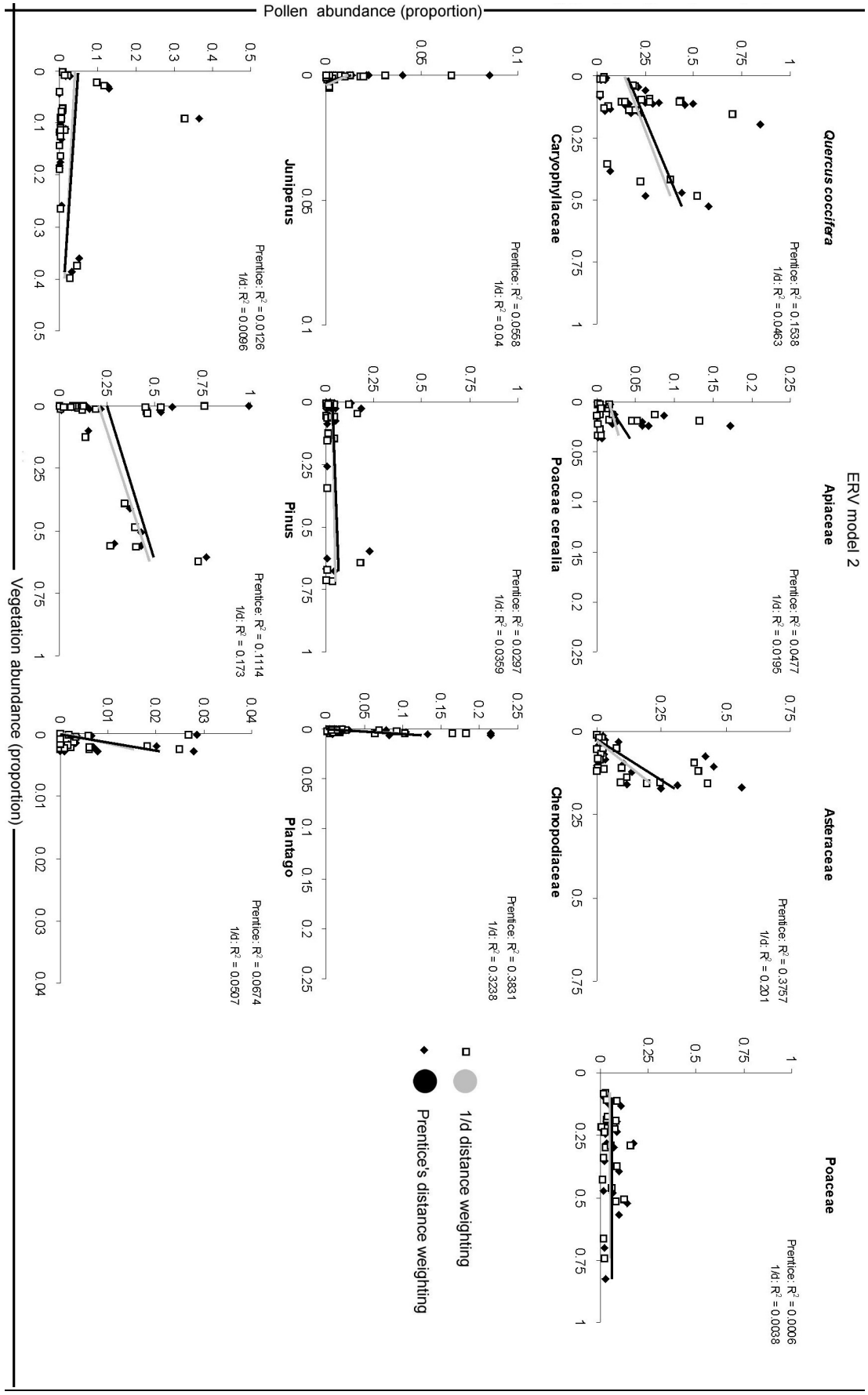

Fig. 6.12b. Same as 6.12a

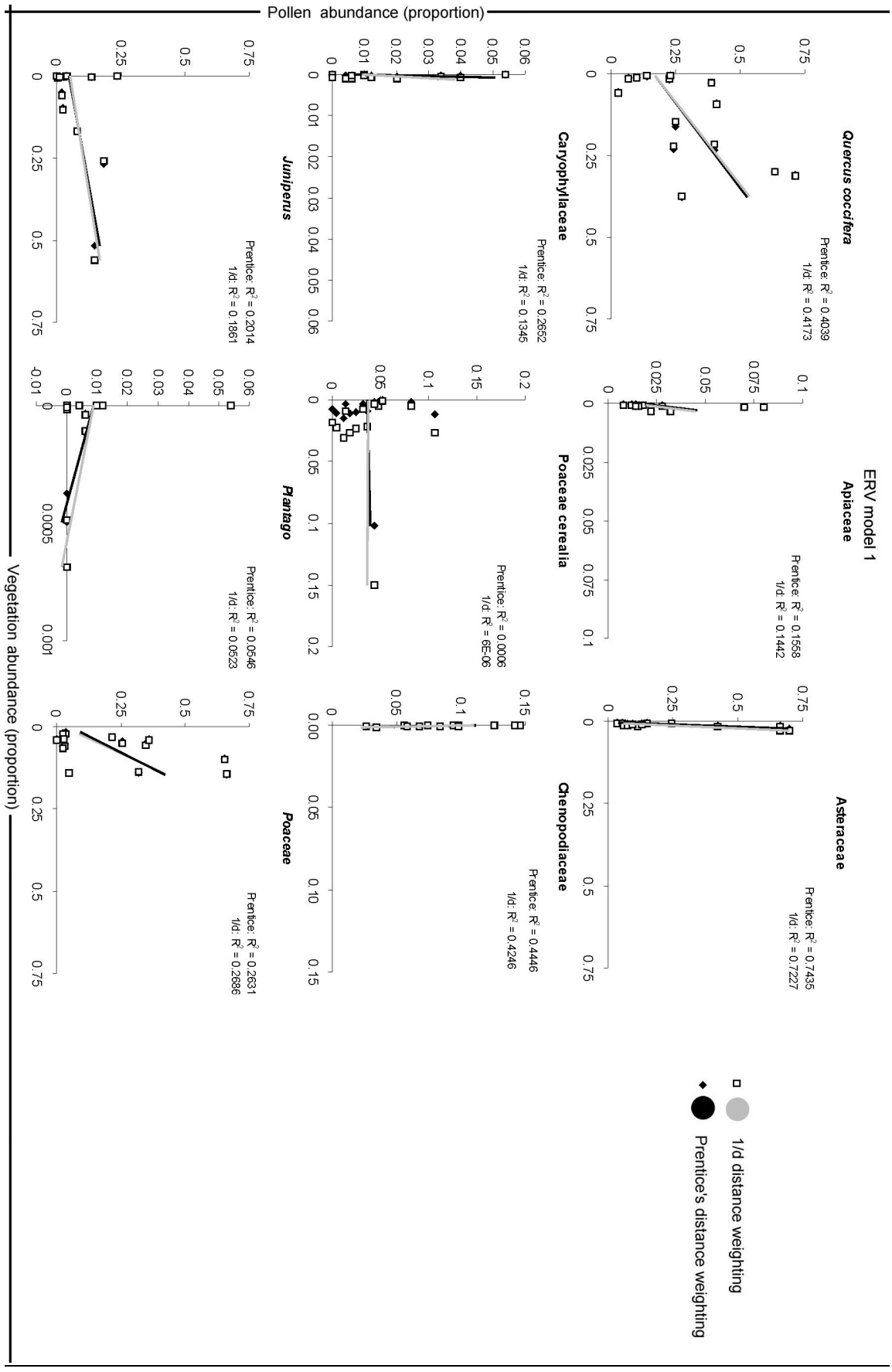

Fig. 6.13. Scatterplots of pollen and vegetation data within the RSAP for the 9 taxa included in the analysis using the high-resolution map. The data set includes 14 sites from various locations within the surroundings of Gravgaz marsh and shows results obtained using ERV model 1, and both Prentice's distance weighting model (black line) as well as the 1/d distance weighting model (grey line). The linear pollen – vegetation relationship found at this distance is indicated with a line. The r² value, indicating the linearity of the pollen-vegetation relationships is also provided. The slope of this line indicates the PPE for each taxon, while its intercept with the y-axis indicates the background pollen loading.

Table 6.6. Top: r^2 scores for the linear relationships between pollen proportion and vegetation proportion for the whole of the study area (top) given for two ERV models and the 1/d and Prentice's taxon specific distance weighting models. Bottom: r^2 scores for the linear relationships between pollen proportion and vegetation proportion for Gravgaz marsh and the surrounding landscape, given for ERV model 1, and the 1/d and Prentice's taxon specific distance weighting models. Significant linear relationships are printed in bold.

Territory of Sagalassos				
	ERV model 1		ERV model 2	
	Prentice's model	1/d	Prentice's model	1/d
Quercus coccifera	**0.27**	0.12	0.15	0.05
Apiaceae	0.12	0.05	0.05	0.02
Asteraceae	**0.44**	**0.49**	**0.38**	0.20
Caryophyllaceae	0.04	0.05	0.06	0.04
Poaceae cerealia	0.03	0.01	0.03	0.04
Chenopodiaceae	**0.47**	**0.39**	**0.38**	**0.32**
Juniperus	0.01	0.00	0.01	0.01
Pinus	**0.29**	**0.27**	0.11	0.17
Plantago lanceolata	0.08	0.07	0.07	0.05
Poaceae	0.00	0.01	0.00	0.00

Gravgaz marsh		
	ERV model 1	
	Prentice's model	1/d
Quercus coccifera	**0.40**	**0.42**
Apiaceae	0.16	0.14
Asteraceae	**0.74**	**0.72**
Caryophyllaceae	**0.27**	0.13
Poaceae cerealia	0.00	0.00
Chenopodiaceae	**0.44**	**0.42**
Juniperus	0.20	0.19
Plantago lanceolata	0.05	0.05
Poaceae	**0.26**	**0.27**

6.3.3.1. The territory of Sagalassos

None of the scatterplots in Fig. 6.12 show curve-linear patterns, indicating a good data-model fit for both ERV models. Poaceae, Poaceae Cerealia, and *Juniperus* show a spread for vegetation abundance which is a lot greater than that for pollen abundance. Caryophyllaceae, *Plantago* and Chenopodiaceae show a high variation in pollen abundance, while the variation in vegetation abundance is much lower. This phenomenon is very visible for Chenopodiaceae, where for ERV model 1, the maximum vegetation abundance is 0.012, while the maximum pollen abundance is 0.24. The largest variation in pollen and vegetation abundance is seen for *Pinus*, followed by *Quercus coccifera* and Asteraceae.
When using ERV model 1, there is a notable discrepancy between the linear relationship between pollen and plant abundance calculated for *Pinus*, using Prentice's model, and using the 1/d model.
The combination of ERV model 1 and Prentice's distance weighting model results in the highest number of significant (correlation ≥ 0.3) relationships between plant and pollen abundance, these being for Asteraceae and Chenopodiaceae, while *Quercus coccifera*, and *Pinus* have r^2 values that are close to significant (Table 6.8). In general, most r^2 values seem to be higher for ERV model 1, than for ERV model 2, and higher for Prentice's distance weighting model, than for the 1/d distance weighting model. The limitations of the data and possible problems with the pollen-vegetation abundance relationships are addressed in more detail in the discussion section of this chapter.

6.3.3.2. Gravgaz marsh

The relationships between pollen and (adjusted) vegetation proportions are displayed in Fig. 6.13 and the r^2-values for the linear relationships between vegetation and pollen proportions are displayed in table 6.9. The largest variation in pollen and vegetation abundance is seen for *Quercus coccifera* followed by *Juniperus* and Poaceae. For most taxa, r^2 values resulting from the analysis of the Gravgaz marsh data are higher than those resulting from the analysis of the entire study area. This is a result of the smaller number of sample sites, decreasing the chance of outliers in the data. Notable differences between the pollen-plant abundance relationships calculated for the entire study area on one hand and Gravgaz on the other are a strongly reduced variation in the abundance of Asteraceae around the sample sites, but similar pollen percentages, and a much improved positive correlation between plant and pollen abundance for Poaceae and *Juniperus* for the latter analyses. The pollen-vegetation abundance relationships for Poaceae Cerealia and *Plantago* are notably different here. Poaceae Cerealia display no clear pollen-vegetation abundance relationship, values for both mostly remaining below 0.05. As a result, the resulting trendlines therefore show very low r^2 values and resulting PPE and z scores are not to be considered realistic. Plant abundance of *Plantago* is minimal, the maximum score in this dataset being c. 0.0008.
As with the analysis of the entire study area, the use of Prentice's distance weighting model results in r^2 values which are either similar or higher than those obtained using the 1/d model.

6.3.4. Pollen productivity estimates and background pollen loading

6.3.4.1. The territory of Sagalassos

Relative pollen productivity estimates (PPE) and background pollen loadings (z scores), calculated for 10 plant taxa, using ERV models 1 and 2, and using Prentice's model and 1/d distance weighting, are shown in Table 6.7 and Fig. 6.14. Being the reference taxon, *Quercus coccifera* has received a PPE of 1 and a standard deviation (SD) of 0 for all ERV and distance weighting models. Chenopodiaceae has received the highest PPE value, as already indicated by the steep slope of the vegetation and pollen abundance relation, shown in Fig. 6.12.
It is of note that the plant taxa with the highest significant r^2 values for the vegetation and pollen abundance relation, and the largest variation in pollen and vegetation abundance (*Quercus*, Asteraceae, and *Pinus*) have similar PPE estimates. The two distance-weighting methods, independent of the ERV model used, produced similar PPE values for these three taxa. PPE estimates vary more for other plant taxa, but only Caryophyllaceae, Chenopodiaceae, and *Plantago*, the three taxa with the lowest vegetation abundance, have strongly differing PPE estimates when different ERV models and distance weighting models are implemented. These three taxa also have the highest PPE estimates
Background pollen signal (z) scores are highest for *Pinus*, reaching an average value of 0.22 with an SD of 0.004, indicating that the relative pollen loading will be 0.22 when plant abundance within the RSAP is zero. Rare herbaceous taxa (Caryophyllaceae, Chenopodiaceae, *Plantago*) have received the lowest z values, in accordance with their poor pollen production/dispersal capabilities and minor abundance in the field. Due to the specific pollen-plant abundance relationship (see fig. 6.12), the Z scores for *Juniperus*, Poaceae, and Poaceae Cerealia may be interpreted as an approximation of the average pollen yield regardless of plant abundance, rather than an approximation of the background pollen loading. It is notable that the background pollen loading (z values) differ significantly for *Quercus coccifera*, depending on ERV and distance weighting models used.

6.3.4.2. Gravgaz marsh

Relative pollen productivity estimates (PPE) and background pollen loadings, calculated for 9 plant taxa are shown in Table 6.8 and Fig. 6.15. Apart from Caryophyllaceae, PPE's calculated using Prentice's distance weighting model do not significantly differ from those calculated using the 1/d model.
The highest PPE's have been assigned to Caryophyllaceae, Asteraceae and Apiaceae. The PPE estimate for Chenopodiaceae is similar to that of *Quercus coccifera*, the reference taxon. The lowest PPE's are assigned to Poaceae Cerealia and *Juniperus*, as was the case for the analysis of the entire study area. Poaceae, however, now have a much higher PPE (3.1 and 2.8 for Prentice's model and 1/d respectively). Except for

Chenopodiaceae, *Juniperus*, and Poaceae, PPE estimates tend to be higher for the analysis which focuses on Gravgaz marsh and environs, then for the analysis including the entire study area.
Background pollen signal (z) scores are highest for *Quercus coccifera*, which is the most important pollen producer, but also restricted to the hillsides surrounding the valley basin. Chenopodiaceae is assigned the second highest z score. The assigned z scores do not significantly differ from those yielded by the analysis including the entire study area. Only the z scores for *Quercus*, Chenopodiaceae, and *Juniperus* are significantly higher.

Table 6.7. Top : Pollen productivity estimates (PPE's) with standard deviation (SD) for 10 key taxa of the most important vegetation types within the study earea (the territory of Sagalassos), calculated for the whole of the study area. *Quercus coccifera* is the reference taxon and therefore has a PPE of 1 and an SD of 0. PPE values for other taxa are expressed relative to the reference taxon. Bottom: Z-score estimates (indicating the background pollen signal - see section 6.1.1.1 and Fig. 6.1) with SD for the same taxa.

	ERV Model 1				ERV Model 2					
	Prentice		1/d		Prentice		1/d		Average	
taxon	PPE	SD	PPE	SD	PPE	SD	PPE	SD	PPE	SD
Quercus coccifera	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00	1.00	0.00
Apiaceae	0.92	0.48	1.10	0.67	1.50	0.48	1.39	0.75	1.23	0.60
Asteraceae	0.83	0.29	0.82	0.48	1.75	0.40	1.60	0.42	1.25	0.40
Caryophyllaceae	4.25	7.29	3.19	5.23	1.10	3.34	0.36	0.98	2.22	4.21
Poaceae cerealia	0.02	0.02	0.01	0.01	0.06	0.03	0.04	0.02	0.03	0.02
Chenopodiaceae	10.39	4.00	12.97	7.80	21.33	6.17	26.20	7.94	17.72	6.48
Juniperus	0.07	0.09	0.11	0.20	0.01	0.02	0.00	0.01	0.05	0.08
Pinus	0.57	0.75	1.25	2.47	0.56	0.21	0.66	0.23	0.76	0.91
Plantago lanceolata	2.48	1.18	3.30	2.32	5.16	2.25	5.75	2.51	4.17	2.06
Poaceae	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.04
taxon	z	SD	z	SD	z	SD	z	SD	alpha	SD
Quercus coccifera	0.03	0.04	0.06	0.06	0.13	0.06	0.16	0.07	0.09	0.06
Apiaceae	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01
Asteraceae	0.01	0.01	0.01	0.01	0.002	0.01	0.001	0.002	0.005	0.01
Caryophyllaceae	0.01	0.003	0.01	0.002	0.01	0.003	0.01	0.003	0.01	0.003
Poaceae cerealia	0.04	0.01	0.04	0.01	0.04	0.01	0.04	0.01	0.04	0.01
Chenopodiaceae	0.01	0.01	0.01	0.005	0.01	0.004	0.01	0.004	0.01	0.004
Juniperus	0.03	0.01	0.03	0.01	0.04	0.01	0.04	0.01	0.04	0.01
Pinus	0.21	0.02	0.20	0.02	0.24	0.06	0.24	0.06	0.22	0.04
Plantago lanceolata	0.01	0.004	0.00	0.004	0.004	0.002	0.005	0.002	0.005	0.003
Poaceae	0.05	0.01	0.05	0.02	0.06	0.02	0.05	0.02	0.05	0.02

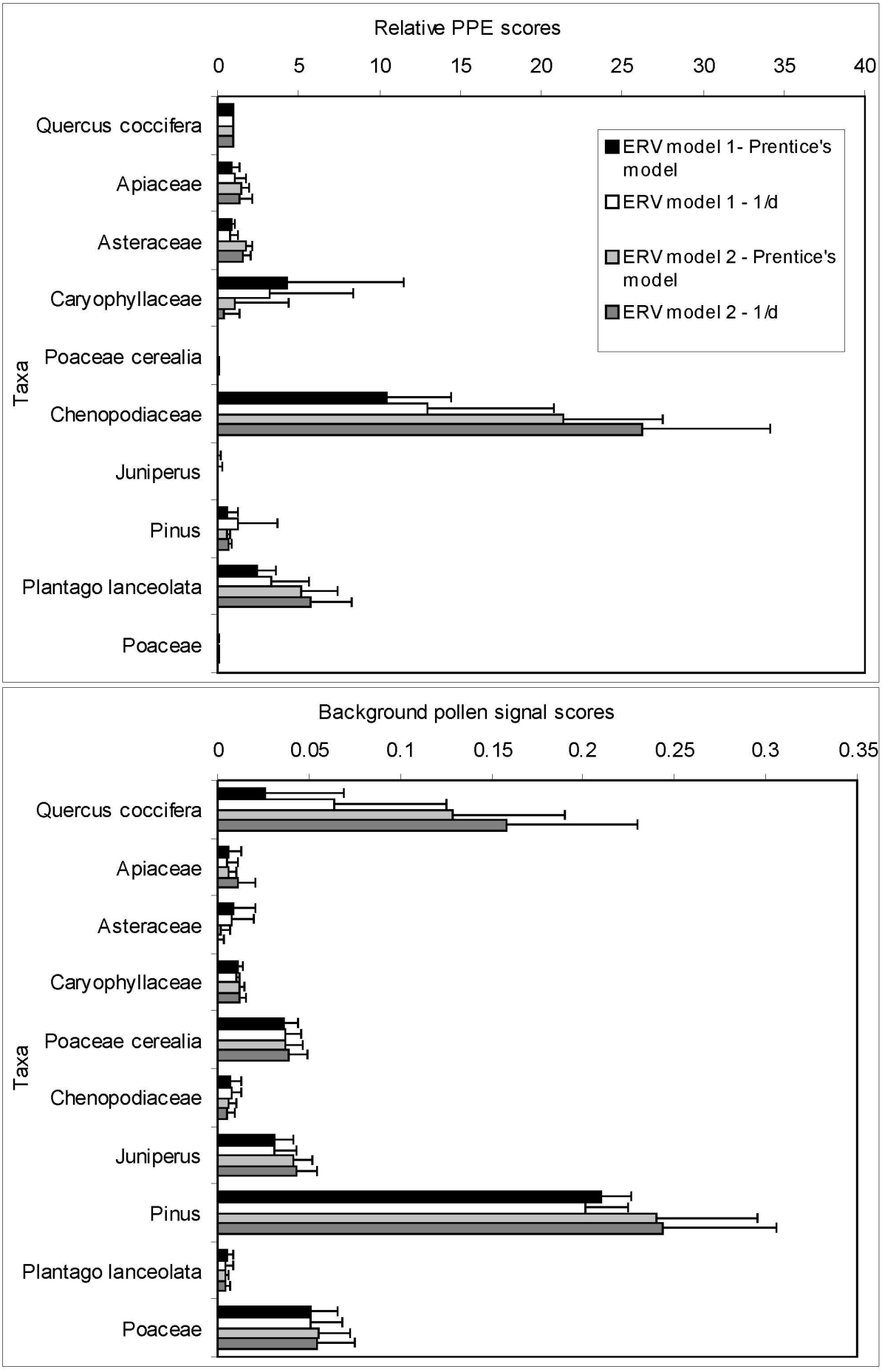

Fig. 6.14. Top: relative pollen productivity estimates (PPE) with standard deviation (thin lines) for the 10 selected taxa. *Quercus coccifera* is set to unity, and the PPE values for the other taxa are expressed relative to *C. coccifera*. PPE values are given for both ERV models and Prentice's and 1/d distance weighting models. Bottom: z scores (background pollen signal) for the same 10 selected taxa and for the same combinations of ERV and distance weighting models. Results based on the low-resolution analysis.

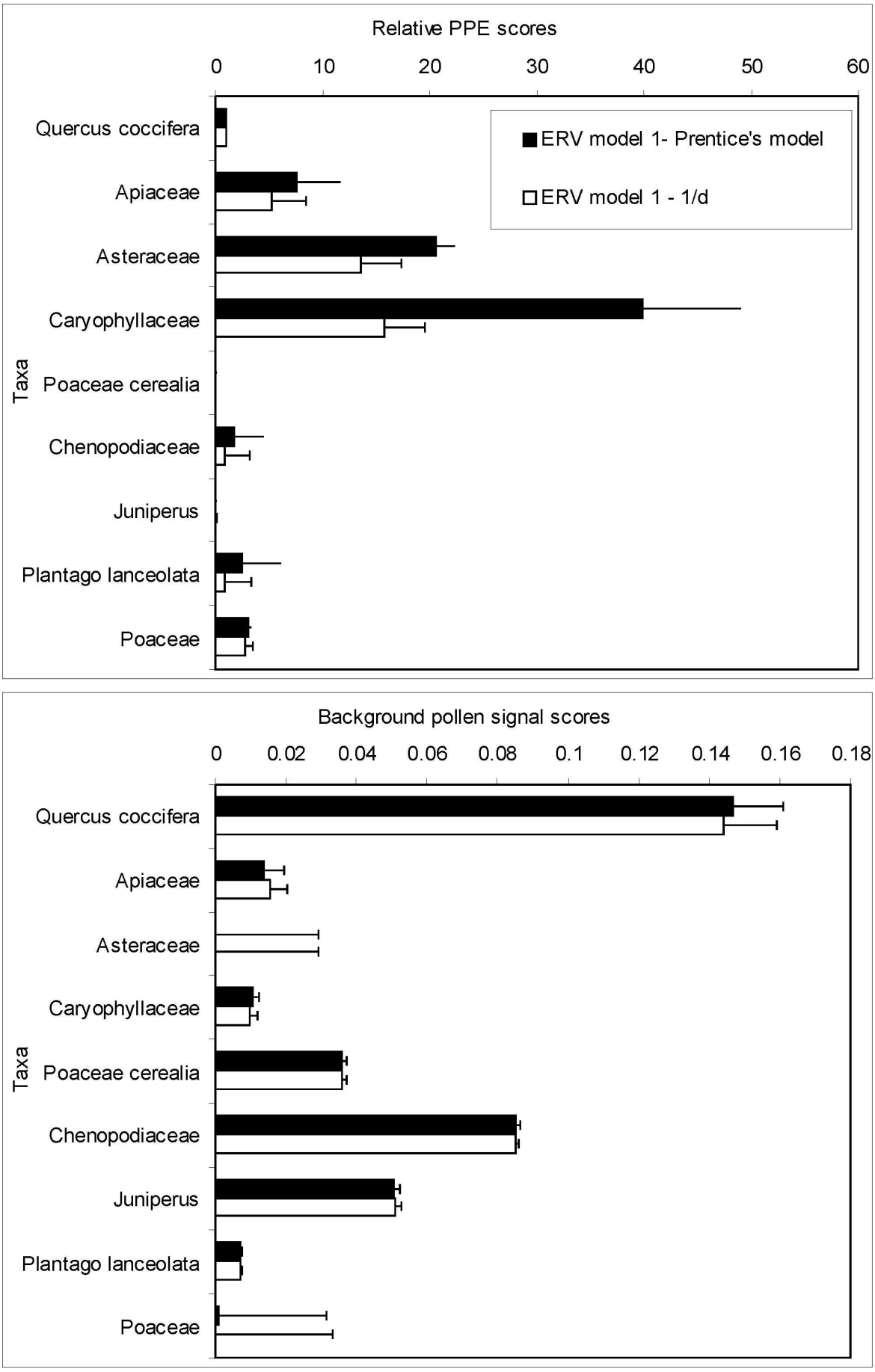

Fig. 6.15. Top: relative pollen productivity estimates (PPE) with standard deviation (thin lines) for the nine selected taxa. *Quercus coccifera* is set to unity, and the PPE values for the other taxa are expressed relative to *C. coccifera*. PPE values are only given for ERV model 1 and Prentice's and 1/d distance weighting models. Bottom: z scores (background pollen signal) for the same nine selected taxa and for the same combinations of ERV and distance weighting models. Results based on the high-

resolution analysis.

Table 6.8. Top: Pollen productivity estimates (PPE's) with standard deviation (SD) for 10 key taxa of the most important vegetation types within the study earea (the territory of Sagalassos), calculated for Gravgaz marsh and surroundings. Quercus coccifera is the reference taxon and therefore has a PPE of 1 and an SD of 0. PPE values for other taxa are expressed relative to the reference taxon. Bottom: Z-score estimates (indicating the background pollen signal) with SD for the same taxa. Only data for ERV model 1 is shown.

	Prentice's model		1/d		Average	
taxon	alpha	SD	alpha	SD	alpha	SD
Quercus coccifera	1.00	0.00	1.00	0.00	1.00	0.00
Apiaceae	7.58	4.05	5.21	3.21	6.40	3.63
Asteraceae	20.55	1.84	13.58	3.83	17.06	2.83
Caryophyllaceae	39.90	9.13	15.82	3.75	27.86	6.44
Poaceae cerealia	0.06	0.08	0.02	0.04	0.04	0.06
Chenopodiaceae	1.70	2.85	0.87	2.29	1.28	2.57
Juniperus	0.20	0.02	0.18	0.03	0.19	0.02
Plantago lanceolata	2.47	3.69	0.93	2.46	1.70	3.07
Poaceae	3.12	0.24	2.79	0.76	2.95	0.50
taxon	z	SD	z	SD	alpha	SD
Quercus coccifera	0.15	0.01	0.14	0.01	0.15	0.01
Apiaceae	0.01	0.01	0.02	0.005	0.01	0.01
Asteraceae	0.0005	0.03	0.0003	0.03	0.0004	0.03
Caryophyllaceae	0.01	0.002	0.01	0.002	0.01	0.002
Poaceae cerealia	0.04	0.001	0.04	0.001	0.04	0.001
Chenopodiaceae	0.08	0.001	0.08	0.001	0.08	0.001
Juniperus	0.05	0.002	0.05	0.002	0.05	0.002
Plantago lanceolata	0.01	0.0003	0.01	0.000	0.01	0.0003
Poaceae	0.001	0.03	0.0003	0.03	0.001	0.03

6.3.5. Simulation test of the PPE's

The results of the comparison between the simulated (using ERV model 1 and Prentice's distance weighting model) and observed pollen loadings are shown in Fig. 6.16. Data on the 16 new test sample points are given in Table 6.9. The results of the paired samples *t*-test are shown in Table 6.10. *p*-values higher than 0.05 indicate that there is no statistically significant difference between observed and simulated pollen percentages.
The PPE's calculated using the territory map predicted pollen percentages not significantly different from observed pollen percentages for Asteraceae, Caryophyllaceae, Poaceae Cerealia, Chenopodiaceae, *Juniperus*, Poaceae, and *Pinus*. While the observed and predicted pollen percentages differed significantly for *Quercus coccifera*, a cross correlation showed that there was a significant relationship between predicted and observed pollen percentages, but that the predicted values consequently overestimated the pollen percentages by a given value. The results showed that *Quercus coccifera* pollen percentages were overestimated by 41% on average, with a SD of 16.
The PPE's calculated using the Gravgaz map predicted pollen percentages not significantly different from observed pollen percentages for Apiaceae, Caryophyllaceae, Poaceae Cerealia, Chenopodiaceae, *Juniperus*, and *Plantago*. The observed and predicted pollen percentages differed significantly for Asteraceae. However, cross correlation revealed that the PPE for Asteraceae did give an accurate prediction, but merely overestimated Asteraceae percentages by 47% on average, with a SD of 10. A significant correlation between *Quercus coccifera* pollen and plant abundance has also been found. Results show that the predicted pollen percentages underestimated the actual plant cover by 28% on average. However, the very large SD of 32 indicates that the PPE for *Quercus coccifera* calculated using the Gravgaz map is, in contrast to the PPE calculated using the territory map, not very reliable.

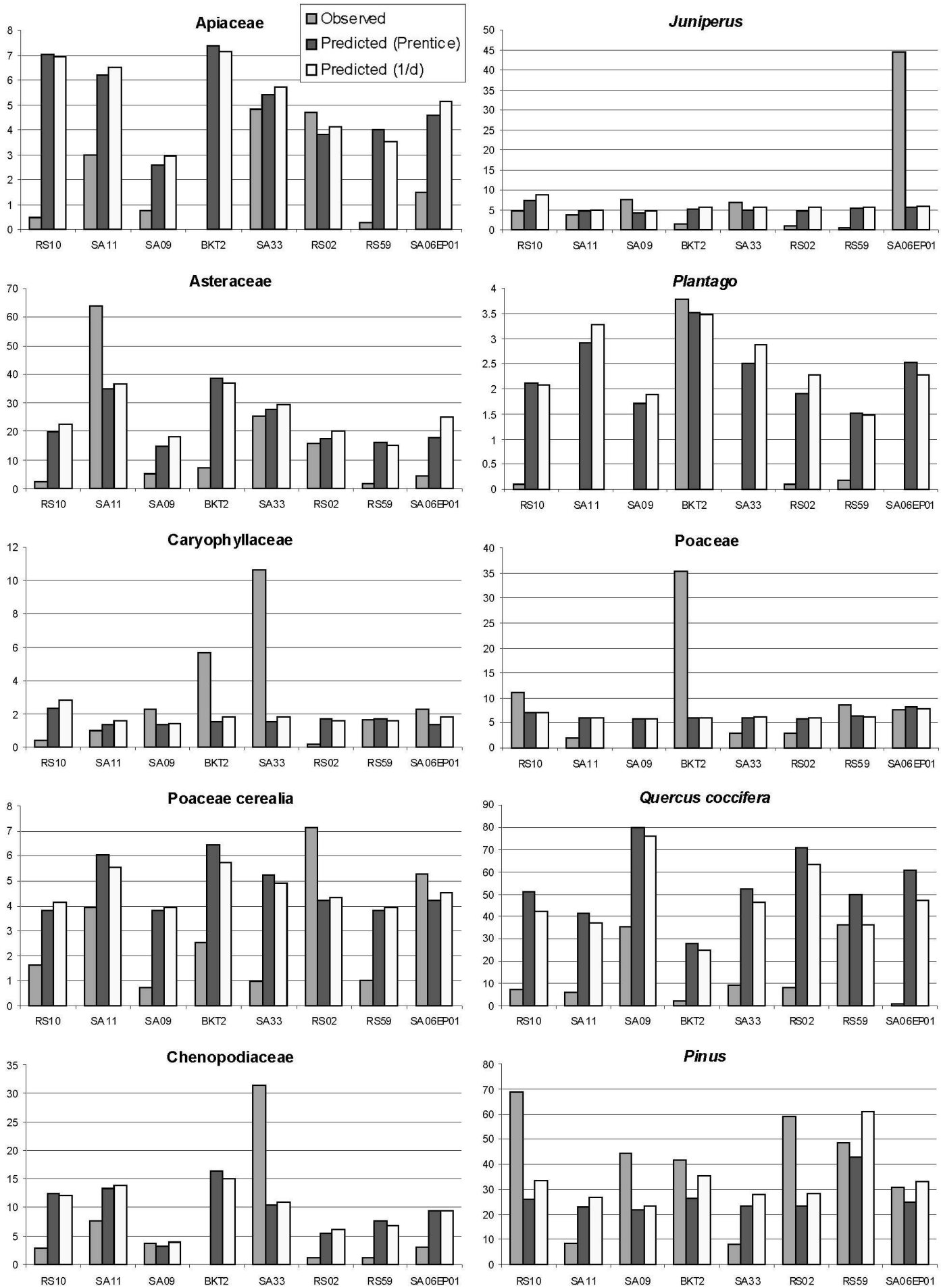

Fig. 6.16a. Two sets of simulated and observed pollen loadings (pollen percentages of the total pollen sum of the six taxa) from 8 independent sites from the study area. Fig 7.16a depicts the test results for the PPE's obtained using the low-resolution map. Fig.

7.16b depicts the test results for the PPE's obtained using the high-resolution map.

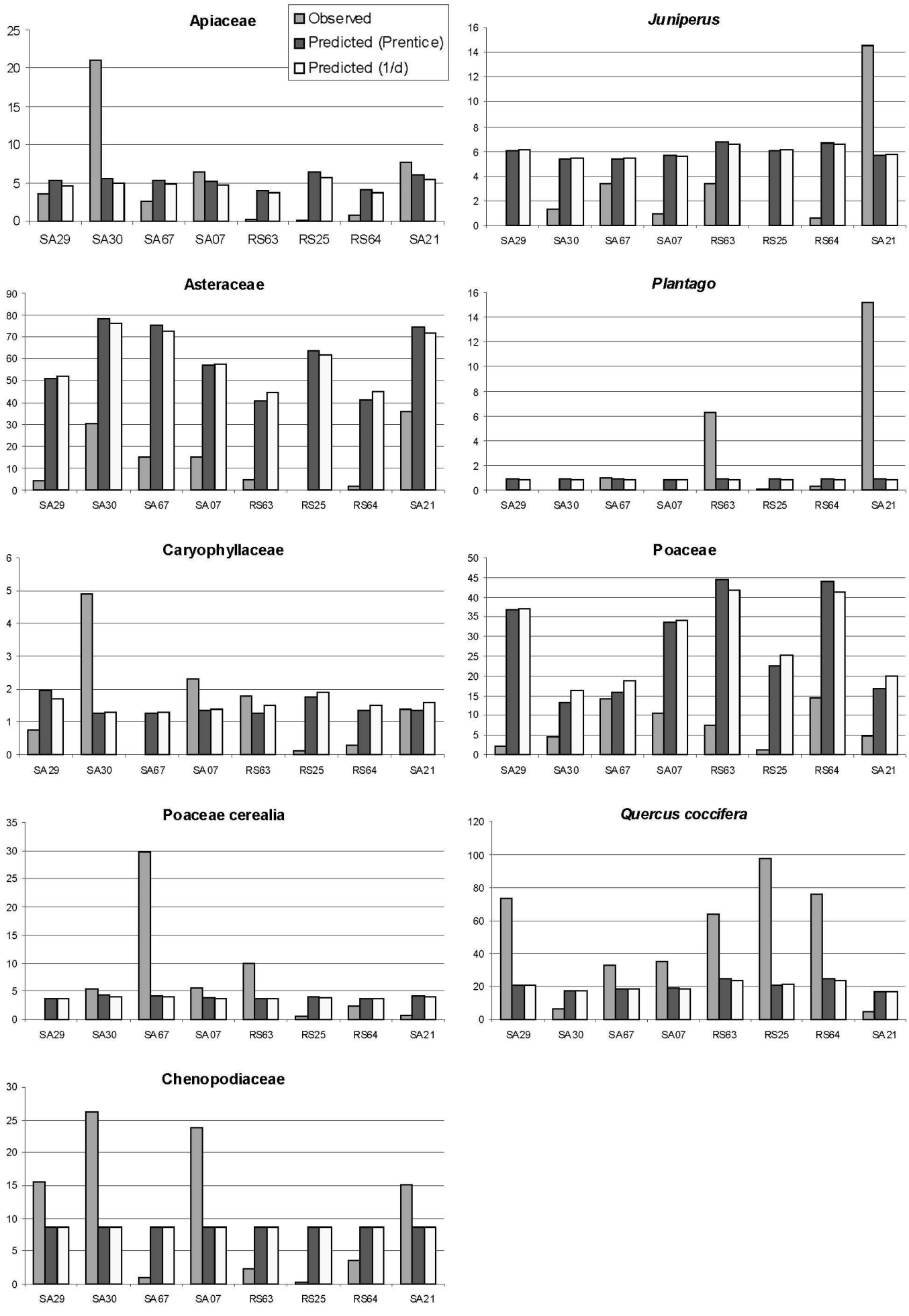

Fig. 6.16b. Same as 6.16a.

Table 6.9. An overview of the code, location and description of the additional sample sites used for the testing of the PPE's.

Sites used to test PPE's calculated using the low-resolution map								
Northings	4160475	4161709	4160504	4158793	4158848	4161748	4166968	4162858
Eastings	270765	270140	270852	261032	269018	271641	284621	270740
Code	RS10	RS11	SA09	BKT2	SA33	SA02	RS59	SA06EP01
Location	Gravgaz	Gravgaz	Gravgaz	Bereket	Ovacık	Gravgaz	Ağlasun	Gravgaz
Description	Open juniper shrubland	Exposed rock above *Quercus coccifera* shrubland	Open juniper shrubland	Sample site pollen core BKT2 (Kaniewski et al. 2007a, b), located within agricultural fields.	Small rock covered in *Quercus coccifera* shrub on the edge of agricultural fields.	Quercus coccifera shrubland w some Juniper shrubs. Downslope from Pine forest	Edge of *Quercus coccifera* woodland above a zone of herbacious steppe near agricultural fields.	Drill site of pollen core SA06EP01, located in the centre of Gravgaz marsh.
Sites used to test PPE's calculated using the high-resolution map								
Northings	4161688	4160404	4160344	4160344	4166632	4160247	4166667	4158113
Eastings	292118	290031	289316	289316	285067	283976	285027	260061
Code	SA29	SA30	SA67	SA07	RS63	RS25	RS64	SA21
Location	Canaklı	Canaklı	Canaklı	Gravgaz	Ağlasun	Canaklı	Ağlasun	Bereket
Description	Small copse of *Quercus coccifera* shrubland in sizable open place covered by fields and surrounded by *Pinus* forest	Along a road. Fields on both sides	Cereal fields	Rocks and herbacious steppe w some *Quercus coccifera* shrublands	*Quercus coccifera* shrubland	*Quercus coccifera* shrubland west of Canaklı	*Quercus coccifera* shrubland	Steppe vegetation among cereal fields, south of Bereket village

Table 6.10. Overview of the paired t-test results, comparing observed and predicted pollen percentages using Prentice's model and 1/d Distance weighting. T-tests were performed on predicted pollen percentages based on PPE's calculated using the low-resolution vegetation map (top), and the high resolution vegetation map (bottom).

PPE's territory map		Apiaceae	Astera-ceae	Caryophylla-ceae	Poaceae cerealia	Chenopodia-ceae	*Juniperus*	*Plantago*	Poaceae	*Quercus coccifera*	*Pinus*
Prentice DW	*T*	-3.2290	-1.2220	-1.0900	-2.0310	-0.8786	0.6910	-5.1980	0.5250	-7.9600	1.6570
	P	0.0145	**0.2613**	**0.3119**	**0.0818**	**0.4087**	**0.5118**	0.0013	**0.5785**	0.0002	**0.1414**
Cross correlation for taxa where P < 0.05		-0.16168						n/a		**0.43532**	
1/d DW	*T*	-3.632	1.588	-0.9377	2.096	0.9173	0.5545	-5.017	-0.5858	-5.707	-0.65
	P	0.00838	**0.1563**	**0.3796**	**0.0743**	**0.3895**	**0.5965**	0.00154	**0.5764**	0.000730	**0.5364**
Cross correlation for taxa where P < 0.05		-0.03464						n/a		**0.40708**	
PPE's Gravgaz map		Apiaceae	Astera-ceae	Caryophylla-ceae	Poaceae cerealia	Chenopodia-ceae	*Juniperus*	*Plantago*	Poaceae	*Quercus coccifera*	
Prentice DW	*T*	0.0221	-13.0400	-0.0119	0.8026	0.6264	1.6630	1.0180	4.6980	2.5230	
	P	**0.9830**	0.0000	**0.9908**	**0.4486**	**0.5509**	**0.1402**	**0.3426**	0.0022	0.0396	
Cross correlation for taxa where P < 0.05			**0.7537**						0.2359	**0.7565**	
1/d DW	*T*	-0.2388	-15.0600	0.1257	-0.8292	-0.6402	1.6730	-1.0610	-5.7970	2.5380	
	P	**0.8181**	0.0000	**0.9035**	**0.4344**	**0.5424**	**0.1383**	**0.3238**	0.0007	0.0388	
Cross correlation for taxa where P < 0.05			**0.7751**						0.2057	**0.8086**	

6.4. Discussion

The ERV analyses performed on vegetation and pollen data from the territory of Sagalassos, using ERV model 1 and Prentice's distance weighting model, produced the best results. This combination of models produced reliable PPE's for *Quercus coccifera*, Asteraceae, and *Pinus*. The low PPE values for Poaceae, Poaceae Cerealia, and *Juniperus* accurately predict the low pollen yield regardless of the abundance of these taxa in the field (see section 6.3.3) and these PPE's may be considered to be reliable. The PPE's of only these six taxa are given in Fig. 6.17.

These PPE values can be used for the quantitative reconstruction of past plant abundance and distribution from fossil pollen records using the landscape reconstruction algorithm and its two models, REVEALS and LOVE (Sugite 2007a, b). Apart from reconstructing past landscapes, PPE values can also be used to test hypotheses concerning how the pollen signal would respond to changes in the vegetation within and beyond the RSAP. The MOSAIC software, part of the HUMPOL suite (Bunting and Middleton 2004) allows for the creation of new landscapes and the study of the response of the pollen signal to an alteration in this hypothetical landscape. For the Middle East, such simulation tests may for instance reveal whether the apparently abrupt rise of *Pinus* pollen after the end of the BO Phase was a result of an increase in pine trees, or a result of the disappearance of any important pollen producers from the vicinity of the sample sites.

Even without further modelling, PPE's and RSAP estimates can give valuable insights concerning how to best interpret fossil pollen data. For instance, the quantification of the background pollen signal for important pollen taxa will improve the explanatory capabilities of these taxa in fossil pollen assemblages, e.g. when pollen percentages decrease below the background pollen signal calculated for the present landscape. The relatively high PPE and exceptionally high background pollen loading (z score) for *Pinus* indicates the excellent long-distance dispersal capabilities of this pollen type and a quantification of the background pollen signal for *Pinus* will provide additional information concerning the discussion on the role of *Pinus* in the post BO Phase landscape (see chapter 3). For *Pinus*, the estimated background pollen loading is 21% for a dataset containing only the 10 plant taxa used for the current ERV analyses.

The high pollen production of *Quercus coccifera*, higher than that of *Pinus*, contradicts the notion of Bottema and Woldring (1995), who proposed that *Quercus coccifera* pollen production was severely limited due to overgrazing. The new data indicates that, dispite severe overgrazing, evergreen oak remains an important pollen producer. However, it remains to be seen what the PPE and z value would be for ungrazed *Quercus coccifera* trees. Nevertheless, while *Quercus coccifera* may have been less important in the landscape than previously thought, the indicative value of changes in the relative abundance of *Q. coccifera* in a fossil pollen record remains unchanged.

The results of the ERV analysis reveal that both cereals as well as other grasses have a very low PPE, resulting from a limited pollen production and/or dispersal capability. While this was known for cereals, it was unknown that species of wild grasses occurring in SW Turkey may also have very limited pollen dispersal capabilities. However, more data are needed to see if this pattern is persistent throughout the wider region.

Even if it is impossible to obtain a reliable PPE for certain taxa, this knowledge is still useful. The results of the ERV analyses for herbaceous taxa such as Caryophyllaceae, Chenopodiaceae, and *Plantago* show that for the most part, these taxa are very limited in both their pollen, as well as their vegetation abundance (Fig. 6.12). The PPE values for these taxa are mostly driven by the presence of outliers caused by the patchiness of the vegetation for these species. These data imply that the RSAP for these taxa must be very small. This is in accordance with earlier/previous research results. For instance, Bunting and Hjelle (2010) found that the relevant source area of non-arboreal pollen types in heathland ecosystems is less than 4 m. To test this conclusion, an additional analysis was performed on only the herbaceous taxa in Gravgaz, calculating plant abundance using a ringh-width of 1 meter for the entire studied area. However, this analysis failed to yield a reliable RSAP estimate.

The notion that such small, herbaceous taxa have a very limited RSAP does not mean that changes in their pollen percentages are only indicative of vegetation change in a very limited area around the sample site. For instance: when pollen percentages increase above the background pollen signal estimate calculated for the modern landscape, this would imply an increased abundance of these taxa in the wider region, especially when local NPP and pollen taxa indicate that the environment at the sample site itself was unfit for the occurrence of these herbaceous taxa.

It may be that the RSAP for a sample site located in the centre of a marsh is larger than that of a moss polster. The RSAP for a given taxon varies according to the type of sedimentary system studied (Bunting 2003). In the case of a marsh, RSAP size would depend on the physical characteristics of that marsh at the location of the sample point. For instance, the presence, depth, size, etc. of standing water, which will facilitate and influence the amount of horizontal movement of pollen after deposition, causing the redistribution of pollen deposited on the water surface due to mixing and focussing (Davis et al. 1984). However, before further interpreting the research results presented in this chapter, it is of vital importance to observe the limitations of the data used for this research and the problems and uncertainties these limitations cause in the research results.

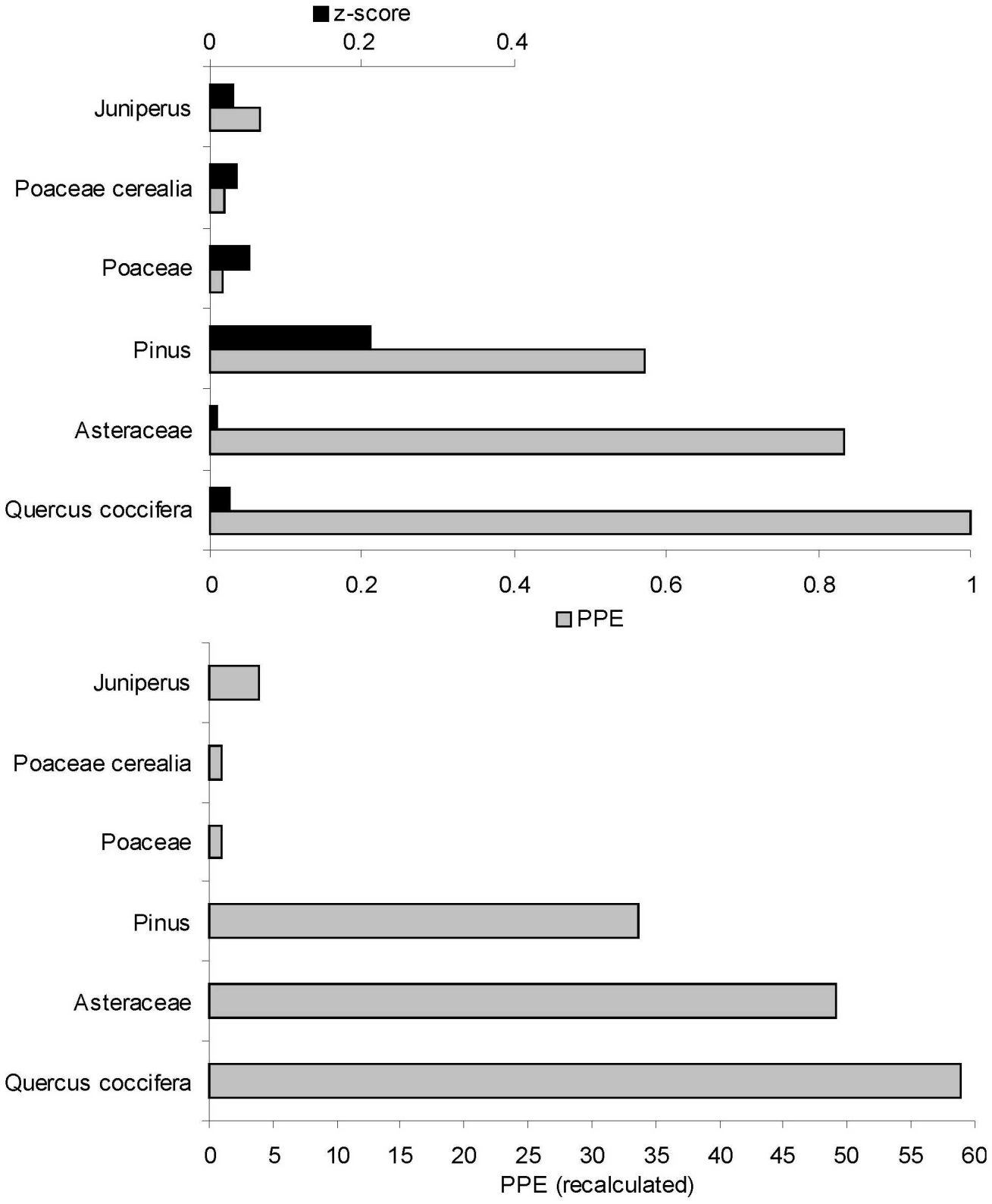

Fig. 6.17. Top: the PPE and z scores for the plant taxa which yielded reliable PPE estimates. Bottom: the same PPE estimates, but

recalculated with Poaceae set as unity.

6.3.1. Concerns of the data

It is clear from the results that in some cases the pollen-vegetation abundance relationships leave something to be desired. For several taxa, the relationships are driven by the presence of individual outliers (as with Asteraceae and *Juniperus*). A careful study of the location of these sample points in the landscape indicates that in some cases they become outliers due to the fact that they are located near a plot of vegetation which, due to its distribution in the landscape or because of their pollen production/dispersal capabilities, supplies a sizable amount of pollen to one or several particular sample points, while the total abundance of this vegetation type remains limited within the RSAP. Groups of sample points located near such patches can give the impression of being a separate population of points on a pollen-vegetation abundance scatterplot, decreasing the reliability of the pollen-vegetation abundance relation.

While the exclusion of sites yielding outliers from the dataset seems advisable when creating reliable PPE's, this creates other problems with the dataset as sample points may provide problematic data for one taxon, but perfectly good data for others. The deletion of sample sites from the dataset may improve the pollen-vegetation abundance relationship for one taxon, but worsen it for others in the process, while removing all outliers for all taxa would result in the removal of most of the dataset.

The best solution to the current less-then-optimal correlations between plant abundance and pollen percentages is to collect additional sample points in the hope of filling in the empty space between groups of points on the pollen-vegetation abundance scatterplot. Even though Broström et al. (2005) advocate that sample points should be placed randomly in the study area, in order to reduce the chances of bias, this notion seems unrealistic and unworkable in mountainous areas. Based on the present study results, it is more advisable to carefully select sample points within a physical environment which is similar to that surrounding the pollen cores which will eventually be used to reconstruct the past landscape with the aid of the ERV models. In the case of Sagalassos, where all pollen cores are located in (former) marshes in basin- or valley floors, sample points should be placed on these environments exclusively. Furthermore, sample points should not be placed in or near small patches of relatively strong pollen producers (*Pinus*, Asteraceae), although the pollen data from such sites will provide additional valuable information for the proper interpretation of fossil pollen assemblages. Ideally sample points would be distributed as a regular grid along the valley floors, an approach which may be hampered by the absence of sufficient well-preserved moss stands in the agricultural landscape. A possible alternative to using moss polsters may be the use of pollen traps. The use of pollen traps will also allow for the use of pollen influx data, rather than pollen percentages, greatly increasing the accuracy of the model. However, experiments with the use of pollen traps by Vermoere (2002), as well as during the 2009 and 2010 fieldwork campaigns revealed that most pollen traps will be lost. Furthermore, in order to compensate for annual variations in pollen production, pollen trap data must be collected for a period of several years.

While detrimental to the ERV analyses, outliers can still yield valuable information concerning the behaviour of the pollen rain as a result to the unusual (e.g. very patchy) distribution of vegetation in the field. A good example of this is *Pinus* pollen. When a sample point is located within a forest, the high pine pollen production causes the proportion of *Pinus* pollen to be very high, even if the stand of pine trees is very small (see chapter 3). Including such sample points in a data set used to create RSAP's and PPE's would have a detrimental effect on the model, causing a U shaped pollen-vegetation abundance relation, even when the vegetation data are distance weighted. Nevertheless, it is entirely possible that high *Pinus* pollen percentages may be caused by a small stand of pine trees near a sample site, rather than a general increase of pine throughout the area within the calculated RSAP. Such a phenomenon can not be predicted by an ERV model. Another possible cause for problems, especially within mountainous areas, is that sample sites on relatively exposed, open locations on hill slopes or hill tops will receive more pollen originating from a relatively long distance, than sample sites located on a valley floor. This was also briefly discussed in chapter 3.

A good example of this phenomenon is sample point (RS25). This sample point is located on a small, exposed hill in the middle of a valley, the outer slopes of which are covered in *Quercus coccifera*, while the valley floor is not, resulting in high *Quercus coccifera* pollen percentages, while the total abundance of *Quercus* is low within the RSAP. However, removing this outlier from the data set did not have a significant influence on the r^2 values for *Quercus coccifera*.

An additional concern is that the vegetation maps used for the ERV analyses are based on satellite images collected c. 10 years ago. Changes in the landscape during the intermediate time period may make the pollen-vegetation abundance relationship less accurate. During the past few years, the study area was subjected to a rigorous reforestation campaign. From 2009 onwards, the area around Gravgaz Marsh has been subjected to reforestation by pine and *Juniperus*. Although most of the newly planted trees are too young to severely alter the pollen signal in comparison to that of 10 years ago, their presence in the landscape may show up on the more recent pollen data.

It is vital that the reliability of the pollen-vegetation abundance relationships is tested before the resulting PPE's and z values are used in additional research, as was done in the present study. Thus far, such practices remain rare. Many articles (e.g. Broström et al. 2004; Räsänen et al. 2007; Soepboer et al. 2007; Mazier et al. 2008) forgo such simple tests entirely, despite the fact that they require no extra fieldwork, very little time, and provide a much greater measure of reliability than a simple visual assessment of the data. A good example of this phenomenon is Soepboer et al. (2007), where the PPE and z value of *Picea abies* are the result of the presence of one single outlier in the dataset.

Even if PPE's are based on reliable positively correlated linear relationships between pollen and vegetation abundance, it is still necessary to test the predictive capabilities of these PPE's before using them for a reconstruction of the historical landscape. Comparing the actual pollen spectrum of a series of modern pollen records with ERV model-based reconstructions, can reveal if a PPE is usable. A cross-correlation between apparently unrelated pollen and vegetation data can reveal whether a PPE does accurately predict pollen abundance, but over- or underestimates the pollen yield. Unfortunately these steps are also rarely taken.

In general the ERV analysis using the low-resolution vegetation map yields more reliable PPE's as the sample points, which are spread across a larger area, encompass a greater variation in pollen and vegetation abundance than the ERV analysis using the high-resolution map. Furthermore, while the lower detail appears to be a disadvantage, the patchiness of the vegetation recorded on the high-resolution map is actually detrimental to the reliability of the PPE's. ERV model 1 appears to be the best at coping with outliers and creating a linear relationship between pollen and plant abundance, indicated by the lower maximum likelihood scores, as well as the higher r^2 values for the resulting pollen-vegetation abundance scores.

The main problem with the research results presented in this chapter is the low number of usable sample sites they are based on. In general, it is advised that the number of sample sites should be at least twice the number of taxa used for the analyses. The current dataset conforms to this demand, but PPE and z score estimates would be greatly improved with the addition of more sample points collected from the moist valley bottoms. Many of the modern pollen data collected by Vermoere (2002) originated from locations not suited for the ERV analyses, while a sizable part of the moss polsters collected between 2009 and 2011 had problems with pollen preservation.

Wind speed and dominant wind direction may have a significant influence on pollen dispersal. Furthermore, in mountainous areas, the local topography (e.g. the shape and orientation of a valley), may influence local wind direction, while the angle and orientation of the slopes around a valley may induce katabatic winds. The HUMPOL software suite allows for the inclusion of wind speed and wind direction into the reconstruction models. However, no data are available concerning dominant wind speed and wind direction for the study area as a whole, let alone for individual valleys. Therefore it was chosen to use neutral values for wind speed and imply no dominant wind direction within the study area. It is beyond doubt that the inclusion of more realistic climatic data will improve model fit.

Apart from local climatic variables, PPE's will vary from location to location depending on the local physical environment and vegetation, as each region has its own combination of species composition, geology, soil type, vegetation cover density, etc. (Calcote 1995). Considering the mountainous topography of the study area, it is assumed that local environmental conditions for each individual valley are important and will produce different PPE's for the same taxa. This notion could not be tested as it was impossible to obtain high-resolution vegetation maps for other valleys within the study area due to time constraints. Using a low-resolution map of a larger area, and a large number of sample points spread out across as many valleys as possible, would partially compensate for the variation in the pollen-vegetation relations caused by the particular physical environments of individual valleys, as well as the differences in local wind force and direction. The resulting PPE's would provide a general estimation of the average pollen production and background pollen signal for the entire study area as a whole.

6.4.2. Relevant source area of pollen

The RSAP's estimated using the low-resolution map were similar regardless of the ERV model used and regardless of whether Prentice's model or 1/d distance weighting was implemented. Therefore the most reliable estimate of the relevant source area of all pollen, including *Pinus*, for moss polsters in this region is 765 m, more realistically described as c. 750 m.
The RSAP is markedly larger when estimated using the low-resolution map, than when using the high-resolution map. The spatial structure of the vegetation is the main factor which determines RSAP size, particularly the patch size (Calcote, 1995; Bunting et al. 2004; Nielsen and Sugita 2005). It is possible that the differences observed may also stem from the way vegetation data are presented, e.g. the resolution of the vegetation data and the number of vegetation classes (Soepboer et al. 2007). Another factor of influence is that the presence of major pollen producers in the landscape will obviously increase the RSAP size. The absence of *Pinus* from the vegetation recorded for the high-resolution vegetation relevé may therefore also have lowered the RSAP.

6.4.3. Distance weighting method

Comparing the RSAP estimates obtained for three different distance weighting methods (Figs. 6.9 and 6.11) showed that the selection of the distance weighting method is important. While the RSAP calculated using Prentice's model and the 1/d distance weighting model produced similar results, the $1/d^2$ distance weighting method produced a much smaller RSAP. Jackson and Kearsley (1998) suggested that this lower RSAP was an artefact due to the fact that the majority of the distance weighting would take place within a short distance from a sample site.
The nature of the distance weighting results also depends on the width of the concentric rings used for distance weighted recording of the vegetation. Step-wise distance-weighting models place equal weight on all vegetation within each ring. It is especially the case for exponent-based schemes (e.g. the $1/d^2$ model) that the proportional weight on the vegetation near the site of deposition increases as ring width decreases (Jackson and Kearsley 1998). This may also partially explain the smaller RSAP for the analysis using the high-resolution map.
It is of note that, while using the Prentice's model resulted in the best PPE's, the results were only marginally better than the 1/d distance weighting method, supporting the notion that, regardless of the discussions on how best to incorporate environmental, atmospheric factors into a distance weighting model (e.g. Jackson and Lyford 1999), atmospheric conditions (stable or unstable) do not significantly influence estimates of the RSAP and PPE's (Broström et al. 2004).

6.4.4. Pollen productivity estimates

A high spread in vegetation abundance combined with a low spread in pollen abundance, as was found for Poaceae Cerealia, *Juniperus*, and Poaceae (the latter two only in the analysis using the low-resolution map), is indicative of a limited pollen production and/or limited pollen dispersal capabilities, while these taxa are relatively evenly distributed in the vicinity of the sample sites (see section 6.3.3). For Poaceae Cerealia, it is known that pollen production is low, while its large pollen (fall speed 0.016 m/s) is not spread over longer distances (Bottema and Woldring 1990). *Juniperus* may produce relatively large amounts of pollen, while the very low fall speed of this pollen type (Table 6.5) indicates that dispersal of *Juniperus* pollen is also quite good. However, *Juniperus* pollen is relatively frail and rarely preserve under less-then-optimal conditions. Therefore, even when the abundance of *Juniperus* is relatively high around a sample site, its pollen percentages will not increase. When a taxon has limited pollen production and distribution capabilities, but occurs relatively uniformly throughout each vegetation type, resulting in similar pollen abundances regardless of vegetation abundance, the PPE will be reliable. However, in such cases a PPE is not necessary as distance weighting the plant abundance is not needed, the pollen abundance will not differ significantly from the background pollen signal (z) and the PPE itself would be extremely low.

The characteristic pattern, indicating poor pollen production and/or dispersal capabilities, and a patchy distribution in the field, is seen for Apiacaeae, Caryophyllaceae and Chenopodiaceae. Asteraceae only show this pattern for the analysis using the high-resolution map. A pollen-plant abundance relationship where there is a small spread in plant abundance, but a large spread in pollen abundance will yield unreliable PPE's, as predicting pollen abundance using a PPE does not take into account the location of a plant or patch of vegetation in relation to the sample site beyond the scope of distance weighting. The solution to this problem would be a more detailed approach, focussing on only herbaceous taxa and calculating plant abundance in the field using very small ring increments and up to a distance not greater than 10 meters.
The notable difference between the pollen-vegetation relationships of Poaceae for the analysis using the high-resolution map and the analysis using the low resolution map is most likely caused by the characteristic distribution of Poaceae in wet environments, mainly on and around marshes. As explained in chapter 3, Poaceae are highly abundant on the Gravgaz marsh itself, but far less abundant on the cereal field surrounding the marsh, while being nearly absent on the rocky slopes lining the basin. The pollen-vegetation abundance relationship based on the analysis incorporating the low-resolution map implies that Poaceae have relatively poor pollen production and/or distribution capabilities. In the present climate and with the present land use, this is also evidenced by the fact that sample points located within or near the marsh will have a high abundance of Poaceae pollen, while the pollen abundance is significantly far lower for sample sites within the basin, but outside of the marsh. The data indicate that the significant positive correlation for the pollen-vegetation abundance relationship, found for Poaceae using the high-resolution map, is purely the result of the presence of the sample sites near the marsh, and is actually not a realistic representation of the true relationship between Poaceae pollen and plant abundance. Even if, for instance during wetter climatic periods, Poaceae were more abundant in the vegetation, the pollen signal would still be a mostly local one due to the low pollen production and poor pollen distribution capabilities of Poaceae (see sections 6.3.3 and 6.4.3).
The pollen-vegetation abundance relationship for *Quercus coccifera* shows a significant positive correlation for both datasets, but the r^2 value for the pollen-vegetation abundance relationship obtained using the high-resolution map is much higher as this dataset contained fewer points (see section 6.3.3.2).
However, less data points is not always a good thing. The pollen-plant abundance relationship of Asteraceae calculated using the high-resolution map is mostly driven by the presence of a small number of outliers (see Fig. 6.12b). Apart from these outliers, pollen and plant abundances are too small to yield a reliable pollen-plant abundance relationship and a reliable PPE. Therefore the pollen-vegetation abundance relationship obtained using the high-resolution vegetation map is deemed to be unreliable. Even though those outliers are also present in the data set based on the territory map, the total number of samples, and therefore the total spread in pollen and plant abundance is far greater.
Although the PPE for *Quercus coccifera* obtained using the high-resolution vegetation map seems more promising, the severe underestimation of pollen percentages using this PPE in combination with the high background pollen loading caused by the fact that most of the sample points were located on the valley floor while *Q. coccifera* is mostly restricted to hill slopes, as well as the results of the simulation test (section 6.3.5) cast doubt on the reliability of this PPE.

6.4.5. Comparisons with PPE estimates from other regions

It is important to keep in mind that, apart from local environmental circumstances, different vegetation data collection methods also produce different PPE's and background pollen estimates (Bunting and Hjelle 2020). Because of this, pollen productivity estimates from the literature should only be combined for land-cover reconstructions where the vegetation survey method is similar. It is therefore expected that the PPE's calculated for the territory of Sagalassos differ strongly from those calculated for NW Europe. Furthermore, most of the taxa (or groups of taxa) used in the current chapter do not occur in the other areas for which PPE's have been calculated.

Regardless of the differences in landscape type, species used, and methods of vegetation data collection, some general comparable trends are visible, such as the PPE values for various species of *Quercus* are generally higher than those for *Pinus* pollen. The PPE estimate for Asteraceae is very high compared to European PPE estimates, regardless of the techniques used to collect vegetation data. Broström et al. (2004), as well as Soepboer et al. (2007) report PPE's for Asteraceae Cichorioideae, which is also the most dominant asteraceious pollen producer in the study area (see chapter 3), which are much lower than that of Poaceae. This will be caused by differences in the importance of Asteraceae between both regions and the reproductive characteristics of the individual species comprising both taxon groups.

6.5. Conclusions

Pollen productivity estimates were obtained for ten key taxa in the study area in SW Turkey, providing the first PPE's for the Eastern Mediterranean region. A critical statistical assessment of the pollen-vegetation abundance relationships and a series of simulation tests showed that the PPE's obtained for six taxa, Asteraceae, *Juniperus*, Poaceae Cerealia, Poaceae, *Pinus*, and *Quercus coccifera*, were relatively accurate. The combination of ERV model 1, Prentice's distance weighting model and the low-resolution vegetation map has yielded reliable PPE's for *Pinus*, Asteraceae, and *Quercus coccifera*, although the latter PPE underestimates the actual vegetation abundance by a fixed value (41% with and SD of 16). The relevant source area of pollen for moss polsters in this region was estimated to a ca. 750 m radius.

While the preliminary results produced in this study are not without problems and complications, they may aid in a better understanding of fossil pollen data in this region.

Although it was known that *Juniperus* and Poaceae Cerealia would be underestimated in the field because of fragile pollen and poor pollen production/dispersal capabilities respectively, it was previously unknown that the pollen of wild Poaceae species are also badly represented in the pollen data. The high background pollen signal for *Quercus coccifera* apparently contradicts the notion that pollen production is hampered by overgrazing, while the data suggests that the pollen production and dispersal of Asteraceae is much greater in the Middle East, than in Europe.

In the current, relatively deforested landscape, *Pinus* pollen loading when no pine forests occur within the RSAP is c. 22% of the total sum of all pollen used for the analyses. This information may be used to test hypotheses concerning the rise of *Pinus* following the BO Phase, although additional information concerning the PPE important BO Phase taxa (e.g. *Olea, Castanea, Juglans*) is also required.

The commonly advocated method of randomly placing sample sites within the study area is unrealistic for mountainous areas since there is a high risk of incorporating pollen from sample sites which produce pollen data not representative of the physical environment one wishes to reconstruct, and creating outliers in the data set. The ideal sampling method would be a relatively regular grid pattern covering only areas which are similar in nature to the locations of fossil pollen cores. In the case of the territory of Sagalassos, this would be relatively moist valley floors such as Canaklı, Ağlasun Çay, Bereket, and Gravgaz.

The results obtained here can be used in future work on quantitative vegetation reconstructions and simulations of pollen dispersal and deposition in the study region (see Fig. 6.18). However, considering the rough topography of the Taurus Mountains, it is not advised to use PPE estimates obtained within the territory of Sagalassos for qualitative reconstructions in other parts of the Middle East, or even within Turkey.

The relatively small relative source area of pollen calculated in this chapter, even for *Pinus pollen*, emphasizes the need of having pollen data from multiple sites within the study area in order to distinguish between purely local and more regional environmental change and shifts in anthropogenic impact. Interpretations of shifts in human impact and vegetation which only occur at one location must be interpreted with care. A notable decrease in pollen percentages of a certain taxon, occurring in the pollen record of a single basin need not indicate the disappearance of that taxon throughout the entire basin, unless there are additional data indicating that this is indeed the case. An example of such a situation is the disappearance of Cerealia type pollen from Gravgaz during the mid 7th century, described in section 3.5.2.5.

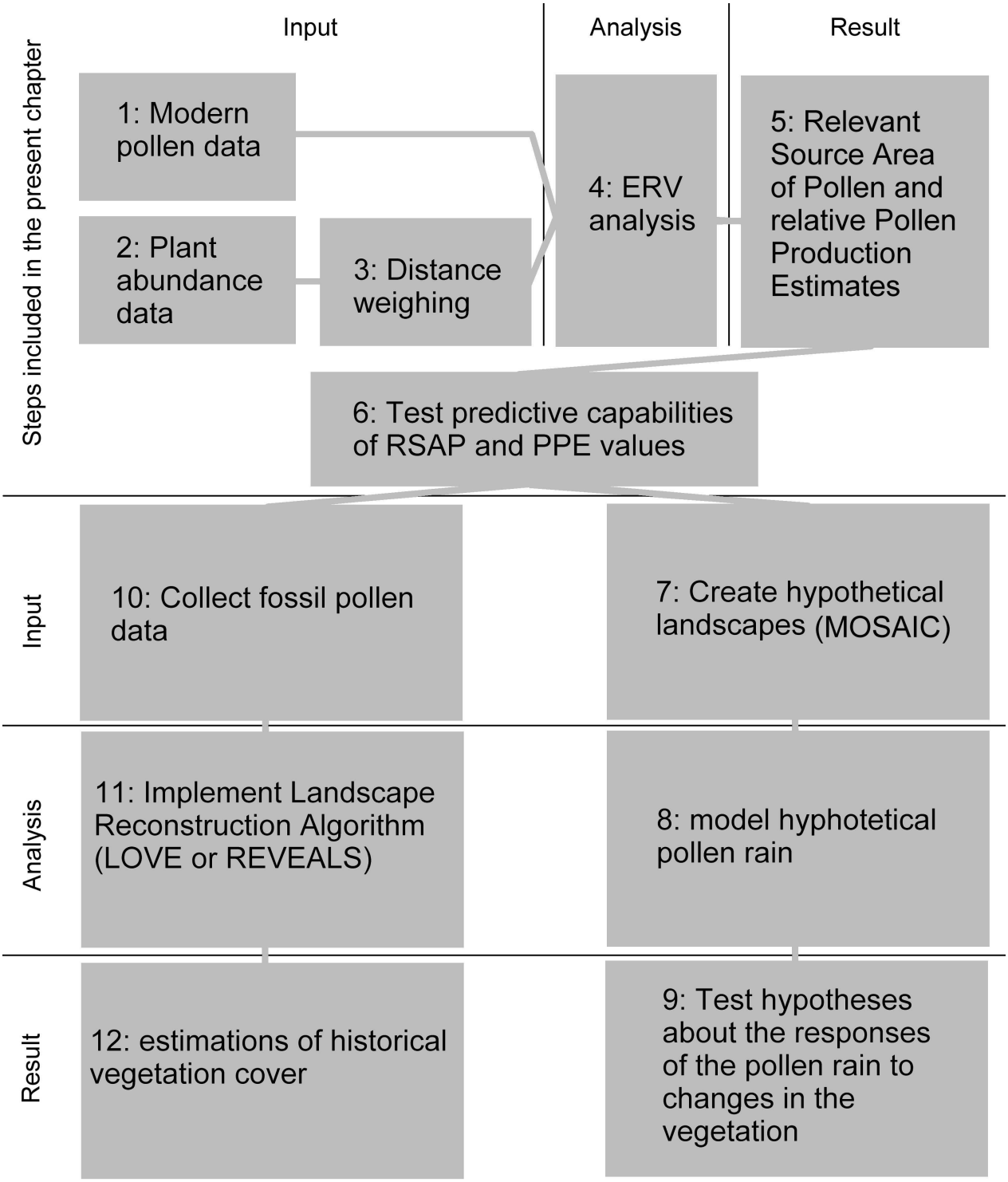

Fig. 6.18. Flowchart depicting the steps involved in reconstructing past landscapes using Extender R-value Models (ERV) and Landscape Reconstruction Algorithms (LRA). Modern pollen data (1) and distance weighted plant abundance data (2, 3) are used as an input for Extended R-value models, with which the researcher attempts to find a linear relationship between the pollen rain at a certain location, and plant abundance around that location (4). The output of these models are an estimate of the relevant source area of pollen (RSAP), and a relative pollen production estimate (PPE) for each pollen taxa included in the analyses, as well as an estimate of the background pollen loading should no plants of a certain taxa be located within the RSAP. The obtained RSAP and PPE estimations can be tested by modelling the pollen rain at locations from which actual modern pollen samples are available, and comparing the modelled pollen percentages with the actual pollen counts (5). If the RSAP and PPE estimations are reliable, then it is possible to use the MOSAIC program of the HUMPOL suite (Bunting and Middleton 2004) to create hypothetical landscapes with which it is possible to test hypotheses concerning the response of the pollen rain to certain vegetation changes (7,8,9). Alternatively it is possible to use fossil pollen spectra, either from one location or averaged percentages from multiple locations and averaged for one particular time period (e.g. the Hellenistic period) and implement them together with the RSAP and PPE estimates into a Landscape Reconstruction Algorithm (Sugita 2007a, b) in order to get estimations of past plant abundance (10,11,12). Knowledge on the ecological preferences of the plants involved in the reconstruction, past land-use methods, and geomorphologic processes, may aid a quantitave reconstruction of past landscapes.

Part III: The aggregation of the research results with the archaeological record, General discussion and main conclusions

Chapter 7

New insights into the interconnectedness of vegetation, climate, and human impact in the Eastern Mediterranean since the 3rd century AD

7.1. Introduction

Chapter 3 revealed changes in the local and regional vegetation, as well as changes in the local environment through pollen, NPP and sediment analyses. The data showed the timing of increases and decreases in human impact in the territory of Sagalassos in the form of crop cultivation and grazing/pastoralism. The pollen and sediment data also gave indications of changes in moisture availability indicative of regional environmental change. Chapter 4 revealed the presence and timing of a number of multi-centennial late Holocene periods of bioclimatic change in southwest Turkey, corresponding with known periods of climatic change including the Medieval Climate Anomaly (MCA) and the Little Ice Age (LIA) enabling for the first time the disentangling of the influence of climate and human impact on historical records of vegetation change in the Eastern Mediterranean. Chapter 5 revealed the limited influence of fire on the vegetation near the sample sites, while revealing the manner and speed with which the vegetation recovered after periods of human impact. Chapter 6 provided additional indications on the nature of the pollen signal and confirmed the need to have two or more pollen records in order to formulate hypotheses and theories concerning the wider region.

The present chapter will link the changes in the local and regional vegetation with newly constructed records of anthropogenic and climatic change, assessing which change in the vegetation can be related to changes in human impact, which may be caused by a climatic amelioration or deterioration, and will examine the possible links between climatic change and changes in human impact, either through providing an opportunity for changes in human impact (e.g. a climatic amelioration allowing for an increase in agriculture), or by directly forcing a change in human impact (e.g. a climatic deterioration preventing the cultivation of certain crops). By comparing the changes in climate and human impact observed in the pollen record with the archaeological data available for the territory of Sagalassos, both records become mutually complimentary. On one hand the new pollen data can provide evidence of the nature and timing of human impact for time intervals for which archaeological data are as of yet still rare or absent. Furthermore, the observed climatic changes may provide an additional source of information concerning changes in habitation patterns observed in the archaeological record of the territory and city of Sagalassos. On the other hand, the archaeological and historical record of both the Sagalassos Research Project, as well as records from elsewhere in Anatolia, will provide the political and/or economical background for the observed changes in anthropogenic activity, explaining and accounting for the observed anthropogenic change.

Despite the presence of some notable hiatuses in the archaeological record concerning the rural landscape of the study area, the archaeological record available for the present study area is still highly detailed and complete compared to other sites in SW turkey. The study of how both the landscape and the human population in the surrounding rural landscape of the study area evolved may be an indication of the evolution of landscape change and human impact in the wider region.

Although supporting the notion that archaeological and palaeoecological records can be mutually complimentary, England et al. (2007) warn that such a comparison can be problematic. Even though the use of AMS dates may result in a relatively trustworthy chronology, the calibration of ^{14}C data may result in age ranges which are still too imprecise to be used for a direct comparison with historical and archaeological data (Baillie, 1993).
The detailed chronological framework of the Gravgaz and Bereket cores, which has been proven to be highly accurate, at least for the latter half of the period under scrutiny, makes the palynological and sedimentological records of Gravgaz and Bereket relatively well suited for such a comparison. However, as stated before, all ages given in this study are estimations based on the inter- or extrapolation of average values of the age ranges presented in chapter 3. Therefore a measure of carefulness and scrutiny must still be applied when performing such a comparison using the pollen data from Gravgaz and Bereket.

7.2. Discussion

Note that the following text features two subdivisions into time periods. Only the first subdivision (in bold) is based upon the historical chronology established for the territory of Sagalassos (see chapter 1, table 1.3). The second subdivision (in italics) is based upon major changes in the pollen and sediment records, indicative of climatic change and changes in human impact on the landscape that occur *within* one of the historical periods delineated in the first subdivision. Figs. 7.1, 7.2 and 7.3 reproduce the pollen diagrams displayed in chapter 3, but now along a time axis rather than a depth axis, in order to facilitate the assessment of patterns of vegetation and sediment dynamics in relation to historical periods and ease a comparison with independent historical, archaeological and geographical data, where it is more common to present data along a time axis.
Unless the interactions in human activity, e.g. the way changes in the city of Sagalassos influence the surrounding rural areas, are fully understood, it is advisable to remain careful when attributing changes in anthropogenic activity in a limited number of pollen records directly to regional or pan-regional political or socio-economical processes. Although such links are proposed in the present chapter, it must be stressed that these should be interpreted only as possibilities and in no way imply that these links have actually occurred. Furthermore, it is quite likely that a change in anthropogenic impact or the vegetation in general, occurring simultaneously at both sitesn indicates a response to a major anthropogenic of climatic shift. But the small RSAP revealed in chapter 6, as well as the different responses to a similar shift in the environment observed in chapters 3 and 4, indicate that the nature of the changes observed in the two pollen records need not be indicative of how the environment responded outside of the two basins, but only that they somehow must have responded in some unknown way.

7.2.1. Late Roman and early Byzantine period (until AD 602/20)

7.3.1.1. Climatic change and decrease in crop cultivation (Late 3rd to mid 5th century AD

The relatively early end of olive cultivation in the Bereket basin had also been observed in earlier cores from the Bereket basin (Kaniewski et al., 2007a, b). But a precise date could not be given due to a hiatus in the earlier pollen record. A decrease in agriculture from the Late Roman period onwards is not described in earlier pollen records from Gravgaz marsh, although it may be visible as a decrease in olive and a rise in *Artemisia* pollen percentages in the most detailed of the pollen records analyzed by Vermoere (2004). A new type of amphora produced in the city of Sagalassos since the mid 4th century AD is thought to have been used, amongst other things, to transport vegetable oil, after earlier attempts at producing wine in the study area failed (Poblome et al. 2008; Romanus et al. 2009; Neyt 2012). Sherds of this type of amphora have been found during recent intensive archaeological surveys in Bereket by Kaptijn et al. (in prep.). It has been postulated that these amphorae may be a sign of the import of vegetable oils by the settlements in the Bereket basin, after the local production of such oils had stopped.

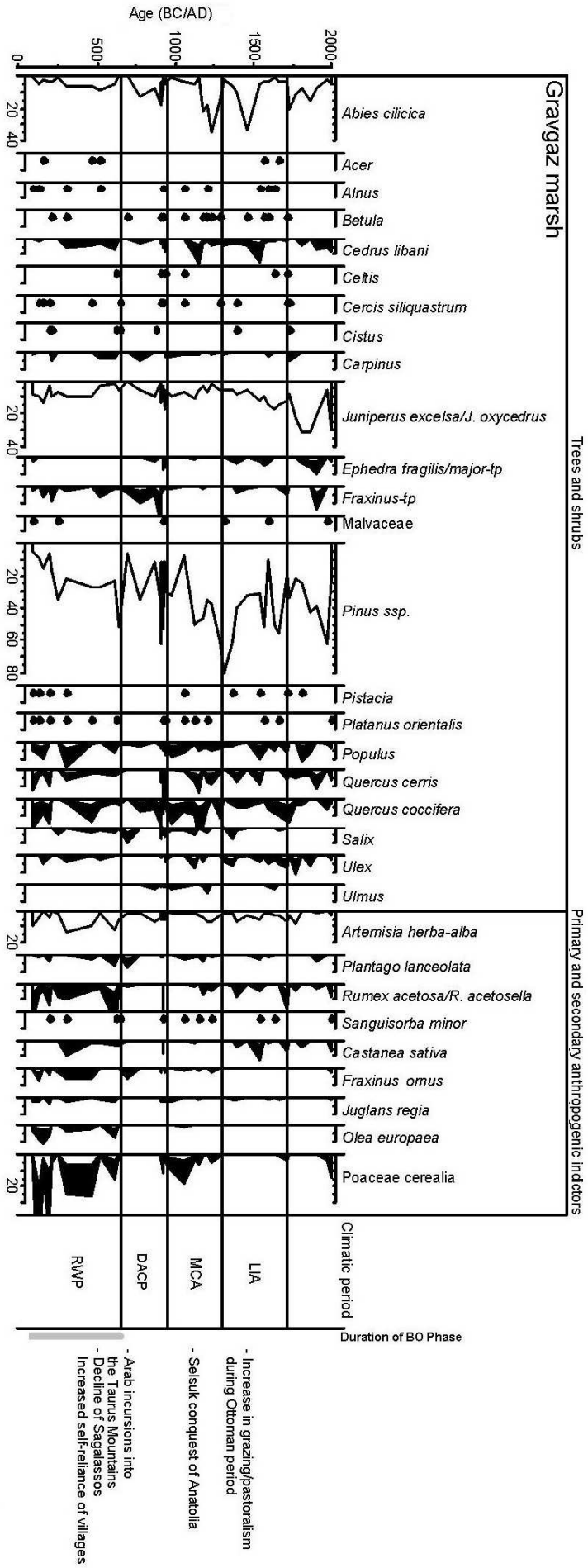

Fig. 7.1a. A summary pollen diagram showing the percentage pollen curves for the most important types of vegetation for the Gravgaz and Bereket cores, displayed along a time axis. Selected curves show a 4X exaggeration.

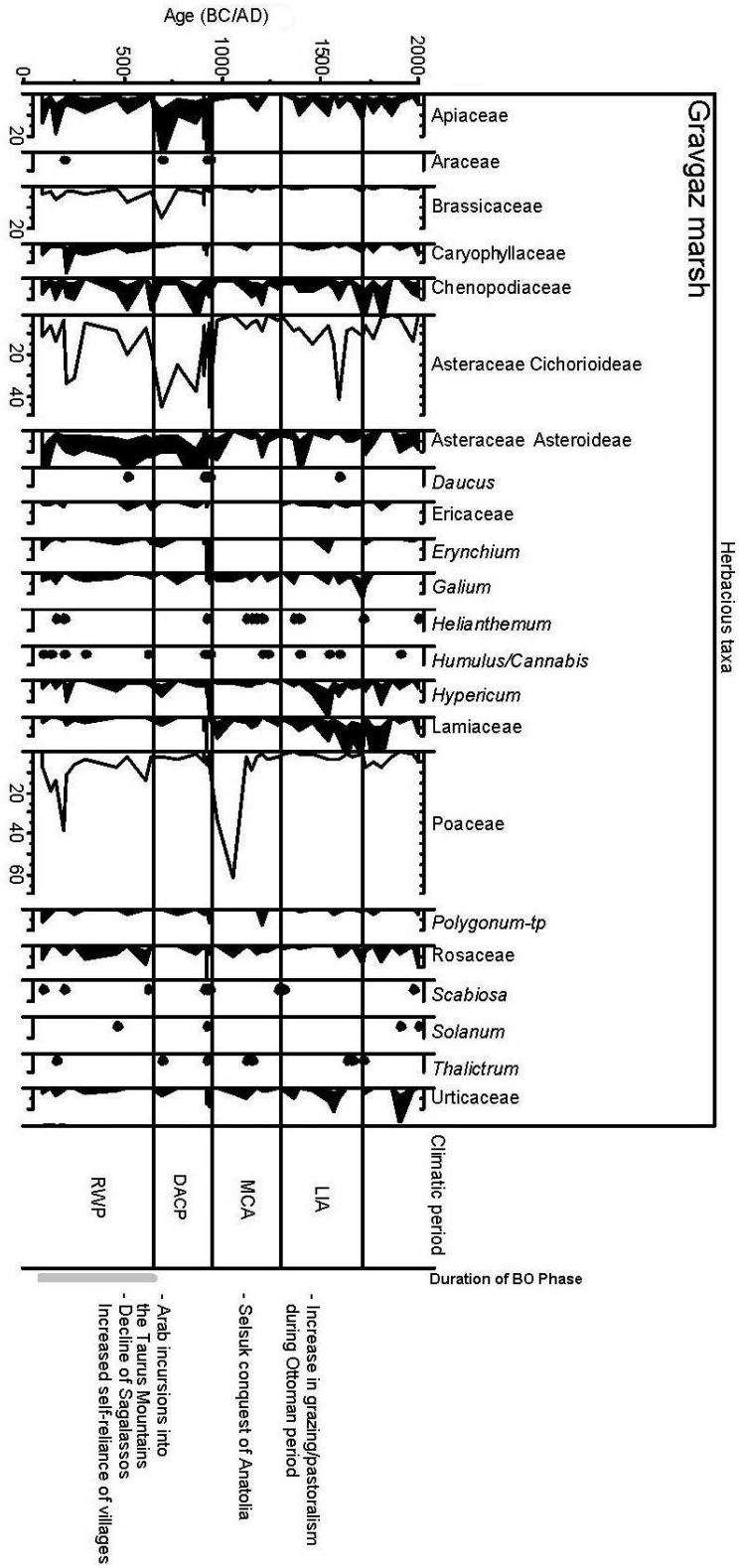

Fig. 7.1b. Same as 7.1a.

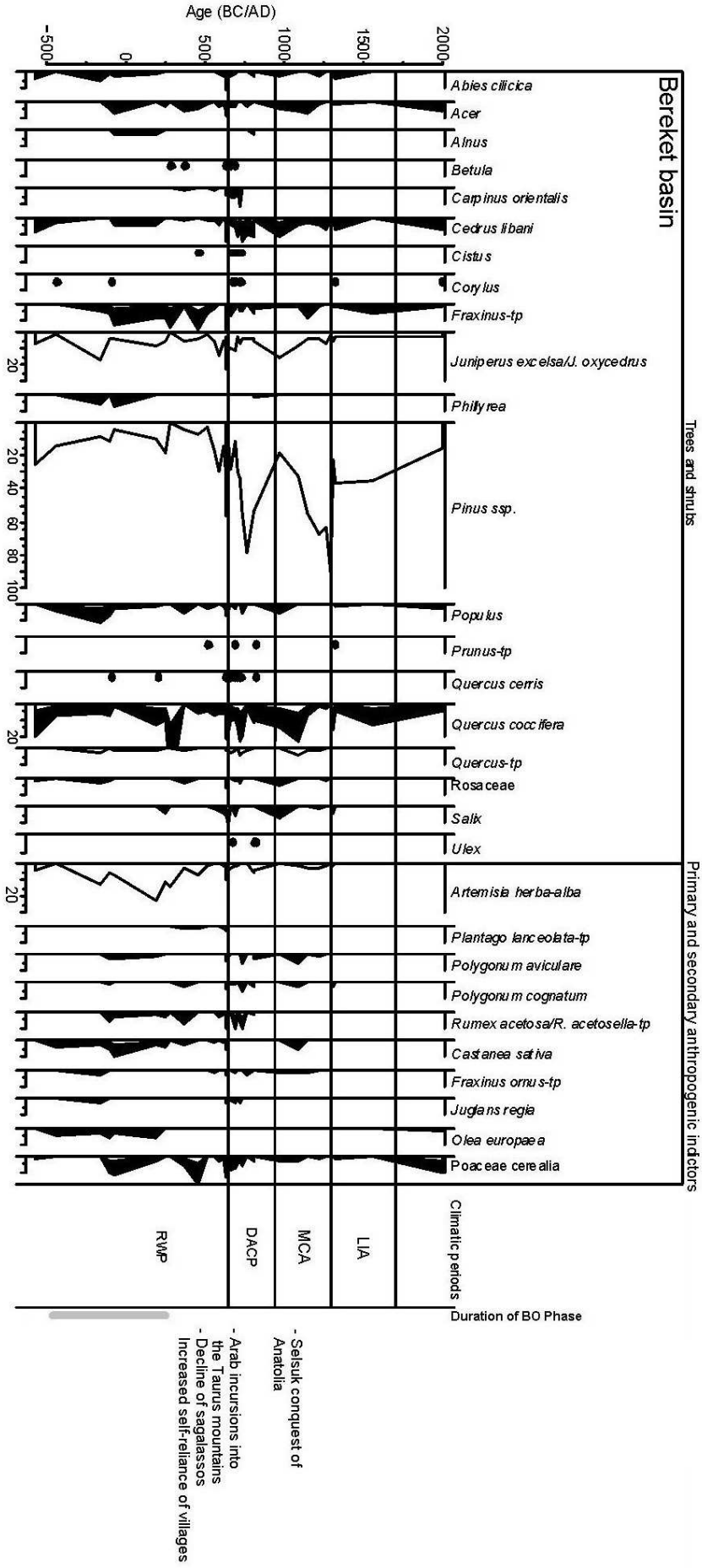

Fig. 7.1c. Same as 7.1a.

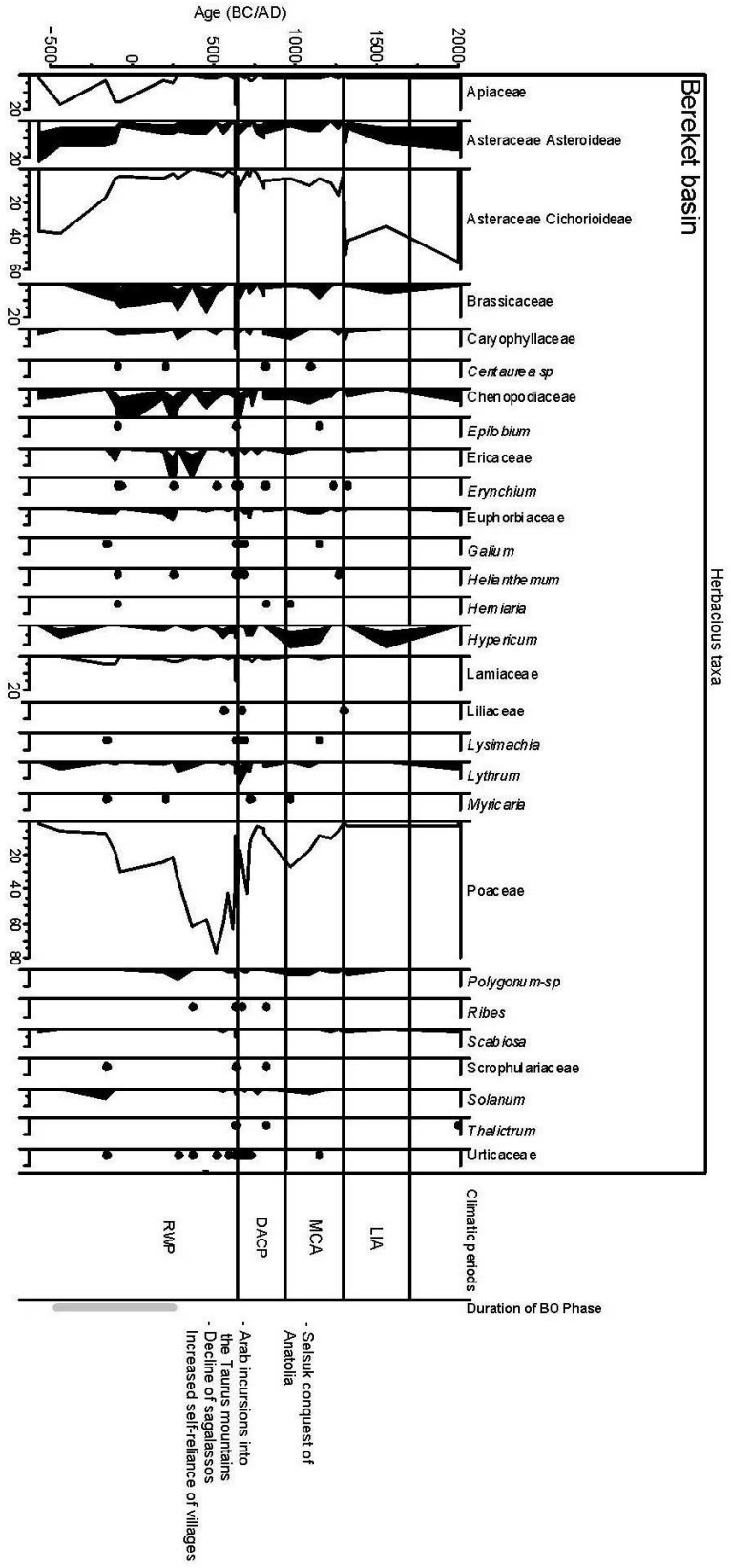

Fig. 7.1d. Same as 7.1a.

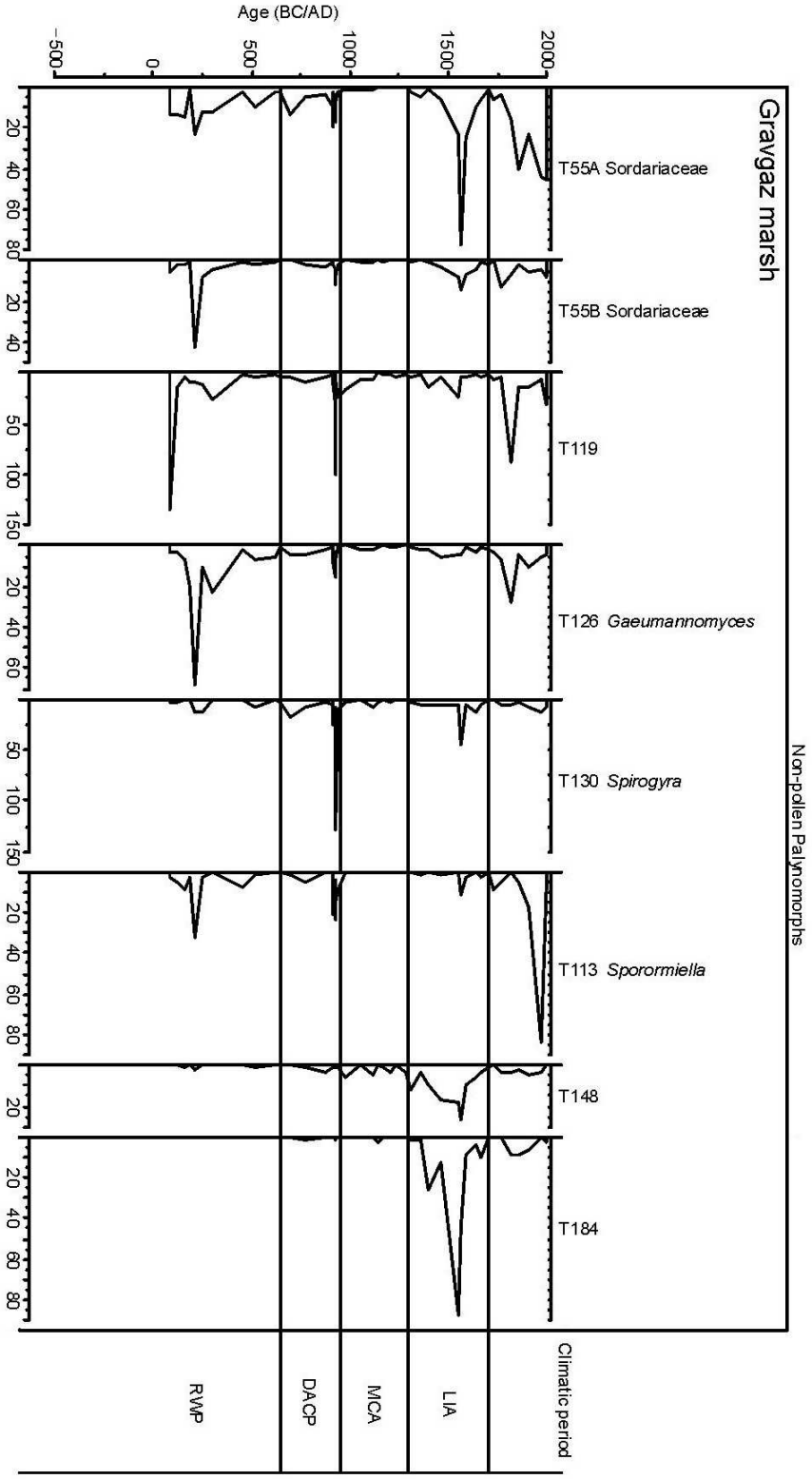

Fig. 7.2a. Local pollen and NPP percentage values in the Gravgaz and Bereket cores, displayed along a time axis.

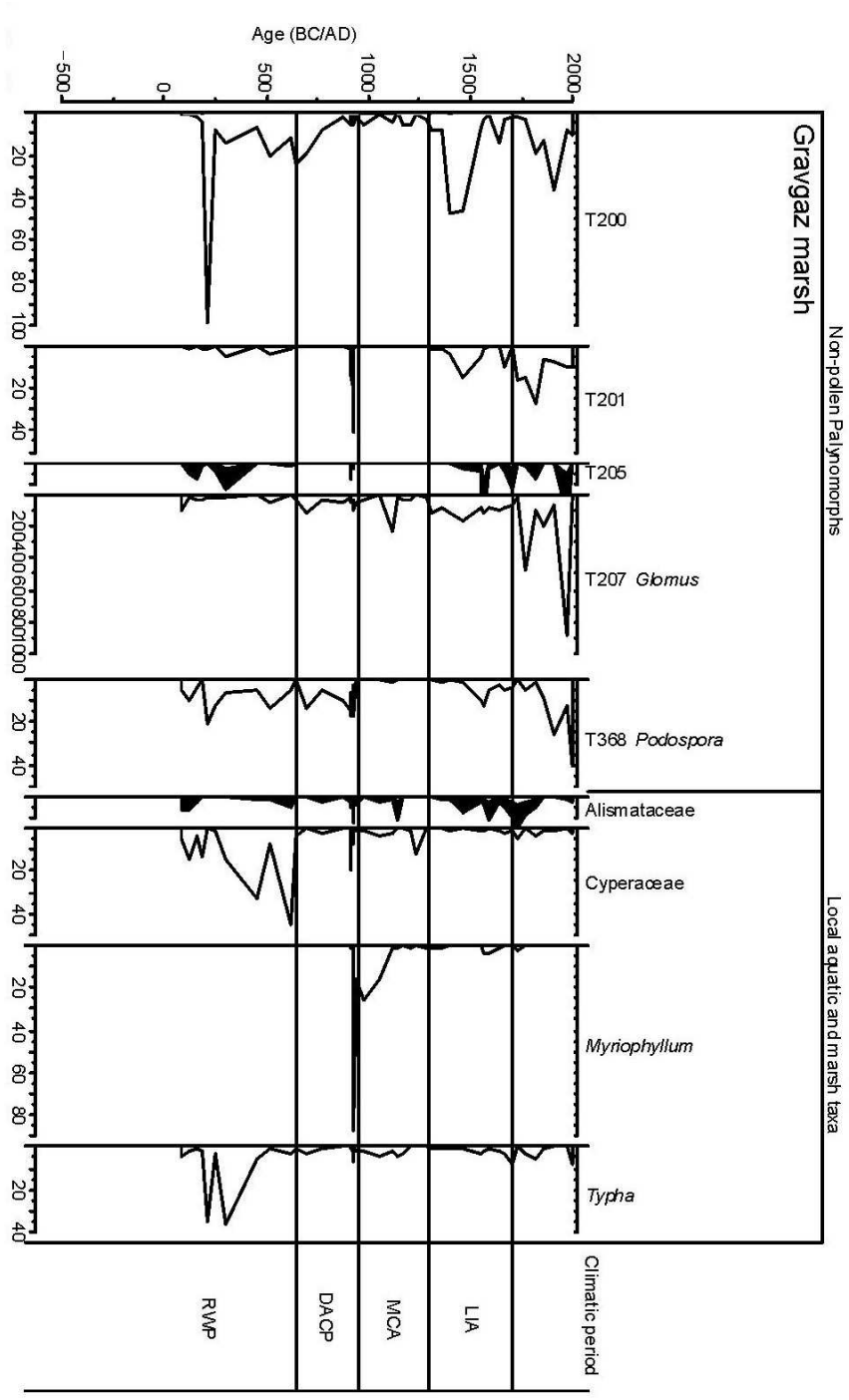

Fig. 7.2b. Same as 7.2a.

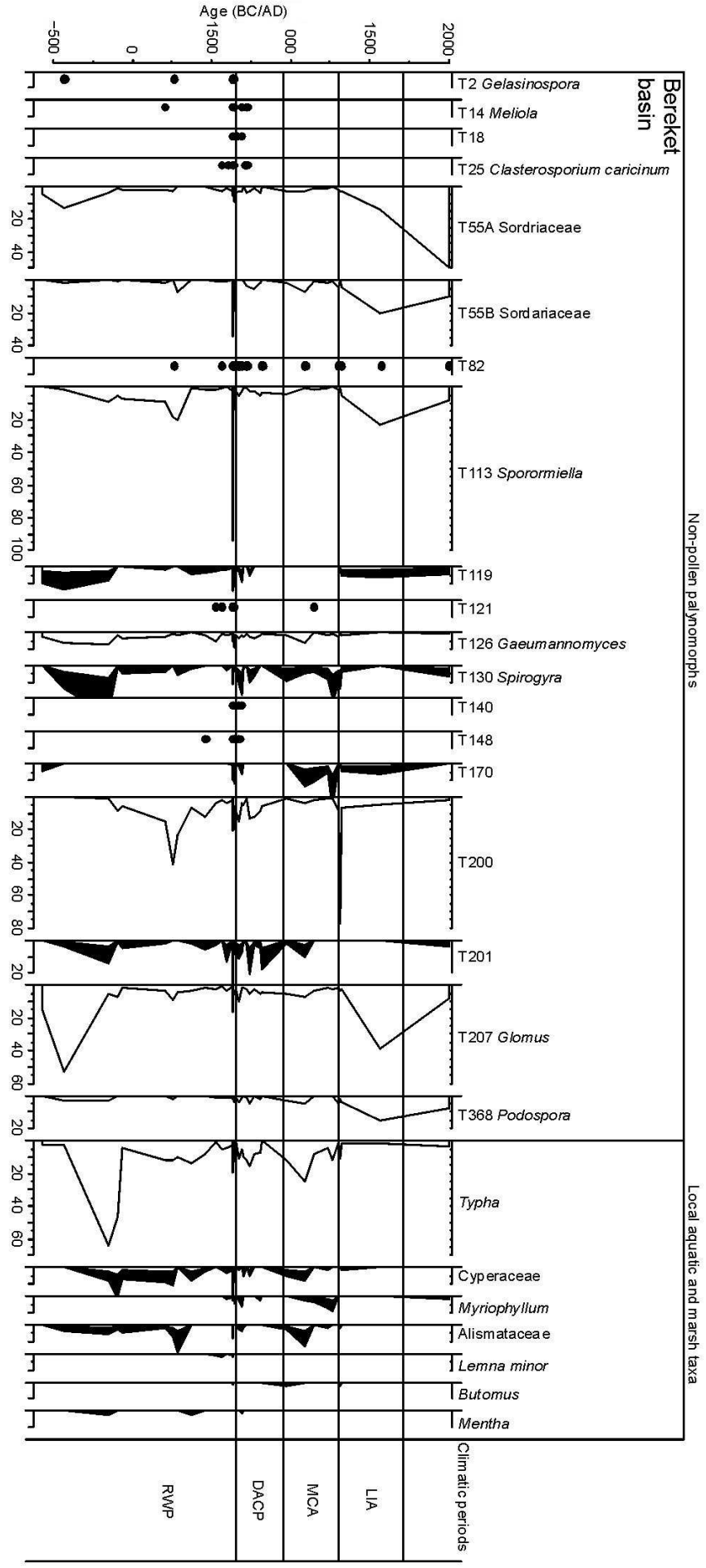

Fig. 7.2c. Same as 7.2a.

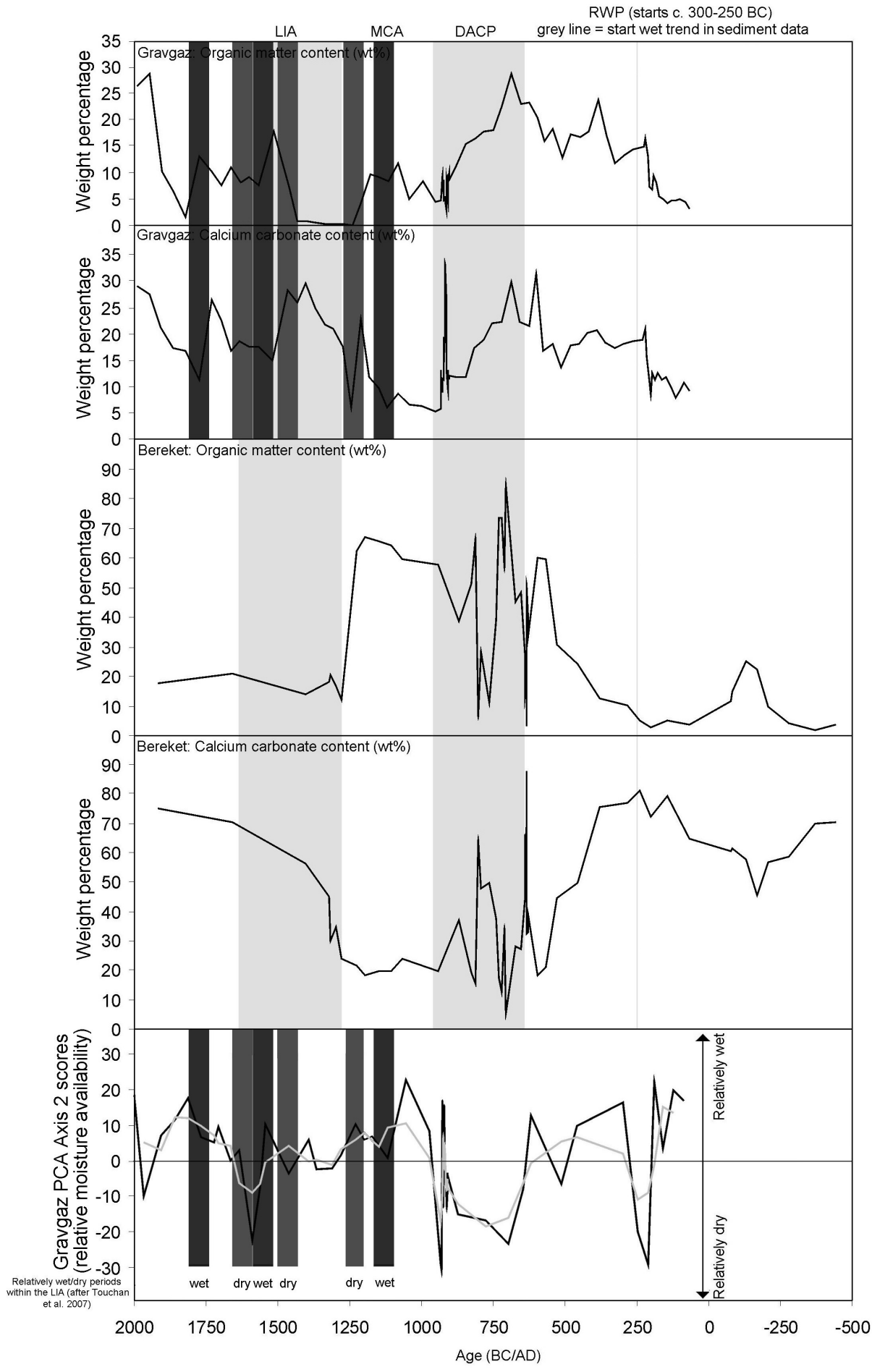

Fig. 7.3. A comparison of the Gravgaz marsh pollen-based climatic proxy (Bakker et al. 2011b) with the organic matter and calcium carbonate content (wt%) for both sites, placed along a time axis, and the wet and dry extremes observed by Touchan et al. (2007).

The decrease in arboriculture and cereal cultivation in both sites, and subsequent shift towards herding/pastoralism, is unusual as it is in contradiction with other Late Roman/Early Byzantine historical and palaeoecological records throughout the Eastern Mediterranean, which show BO Phase agriculture persisting into at least the 7th century AD (Bottema et al. 1986; Eastwood et al. 1998, 1999; England et al. 2008), or even an expansion of agriculture (Harrison et al. 2001; Baird, 2003; Leroy et al. 2010; Izdebski, 2011). Also within the territory of Sagalassos itself, the Late Roman Imperial period, from the early 4th to mid 5th century AD, is characterized by continued prosperity (Vanhaverbeke et al., 2007). Recent archaeological surveys within the Bereket basin indicated that there is no evidence for, or against a population decrease as the BO Phase agriculture disappeared from the pollen record at that location in the mid 3rd century AD, and it remains unclear what the impact was of the disappearance of agriculture around the sample site in Bereket. Unfortunately no intensive archaeological survey was ever performed in Gravgaz marsh, and it remains unknown whether a similar phenomenon occurs at the archaeological sites surrounding Gravgaz marsh.

As explained in chapter 1, from the mid 3rd century AD onwards, changes in the manner in which cities in the empire were governed resulted in a high financial burden on the local governing class, the members of which frequently could no longer afford to properly function. The 4th century AD also saw the emergence of a 'super-elite' class, consisting of ex members of the provincial administration, who were exempt from taxes and had little interest in the maintenance of the city and its surrounding countryside. It is known that much land belonging to the cities was confiscated by the state during the 4th century AD, as these cities were unable to pay their taxes. This process may have led to a true crisis in some parts of the Empire (Mitchell 2007). In Sagalassos, the result of this process is visible as a notable stagnation in building activities during the 3rd and 4th century AD (Vanhaverbeke and Waelkens 2003; Waelkens and Poblome 2011). This economic debacle would have come as an extra setback, on top of the already ongoing financial problems in the whole of the Roman Empire, caused by the lack of a powerful government and the constant threat of invasion, and which led to a strong inflation and devaluation during the 4th century AD (Mitchell 2007). The financial troubles, within Asia Minor, as well as in the Roman Empire as a whole, may have led to a decrease in the demand and a decrease in the value of (agricultural) goods produced within the territory. This may have prompted a change in agricultural practices, or perhaps a partial breakdown of the agricultural system as land owners could no longer afford their activities.

However, other evidence suggests that the impact of the economic and political troubles of the 3rd century AD may have been less far-reaching than elsewhere in the empire. During the second half of the 3rd century AD, the territory of Sagalassos was tasked with providing the food supplies of the Roman fleet stationed at Side, Pamphylia, which may have provided a measure of financial security. The continuation of the production of Red Slip Ware pottery in Sagalassos throughout this period is another indicator of a continued relative prosperity within the study area (Poblome 2006). In any case, more research is needed to obtain an accurate overview of how the city of Sagalassos and its surrounding countryside coped in this troubled period.

Rather than a general, anthropogenic cause for the decrease in agriculture at both locations, it may be that the observed changes in land use had a more localized, environmental cause. Earlier publications linked the disappearance of *Olea* cultivation in the Bereket basin to an undefined climatic change, although no indications of a decrease in temperature, which would potentially limit the ability of *Olea* to occur at the altitude at which Bereket is located, were identified (Kaniewski et al, 2007a, b). The recent pollen data indicate that the decrease or disappearance of intensive crop cultivation in Bereket and Gravgaz coincided with an increase in moisture availability. This notion is also supported by an increase in wetlands in Aglasun Çay valley, in the direct vicinity of the city of Sagalassos (Fuller et al. submitted; (Fig. 7.3). This 3rd century AD climatic shift may be analogous to an increase in moisture availability observed throughout the Eastern Mediterranean (von Rad *et al*., 1999; Hirschfeld, 2004; England *et al*., 2008; Jones *et al*., 2006; Sorell *et al*., 2007; Neumann *et al*., 2007a,). However, a climatic link may still exist. As suggested in chapter 3, it is possible that the amount of arable land in the Bereket and Gravgaz basins had shrunk, as the marshes and wetlands on the valley floors increased in size during this relatively wet period. Since these wetlands are hardly the typical landscape of the territory, agriculture should be unimpeded in the drier areas of the territory, or would perhaps have benefited from increased precipitation, allowing for the continued prosperity of the city and the territory under its control. Even though an increase in moisture availability can be described as an amelioration of the climate in the dry Eastern Mediterranean, as is proposed in Izdebski (2011), the pollen data from the territory of Sagalassos indicates that this need not be the case on a local scale. Especially considering the notion proposed by Dusar (2011), that most of the arable land present on the hill slopes in the

study site had been completely eroded during previous centuries, and that agriculture during the Late Roman Imperial period would only have been possible on the valley floors.
While the notion of the abandonment of farmland due to the encroachment of marshes and wetlands may explain the decrease in cereal cultivation observed in Gravgaz and the older Bereket record (Kaniewski et al. 2007a, b), it does not explain the decrease of olive cultivation, or other cultivated trees for that matter. Cereals are mostly autogamous and produce only a small amount of pollen. Furthermore, the large pollen produced by wild and cultivated Cerealia-type grasses are not transported over larger distances (van Zeist et al, 1975). Therefore, the presence or absence of Cerealia type pollen in the pollen record indicates the presence or absence of cereals near the sample site. Olive trees are wind pollinated and produce a relatively large amount of pollen which has the potential to be transported over large distances. Bottema and Woldring (1990) suggested that trace amounts of olive pollen found in cores located in the Oro-Mediterranean vegetation zone, may actually originate from the Eu-Mediterranean vegetation zone. However, Eastwood et al. (1998) suggest that the presence of high mountain ranges may have provided a barrier for olive pollen. Furthermore, olive pollen disappears from the Bereket basin pollen spectrum during the late 3rd century, while olive cultivation continues around Gravgaz marsh, c. 11 kilometres away. Olive pollen is also rare or absent in modern pollen samples from many parts of the territory of Sagalassos (Vermoere 2004), while sizable (semi)wild olive stands occur at the eastern edge of the territory. This indicates that the extent of the distance over which olive pollen may be transported may be limited within the rough topography of the Taurus Mountains. Nevertheless, the presence of olive pollen in the Bereket record could still be indicate of olive cultivation anywhere within the basin, including locations not affected by the encroachment of the marsh.
In reality, it may be a combination of all the factors mentioned above. The economic and military troubles may have caused a decrease in the demand and value of agricultural produce. Decreasing profits in combination with increasing costs involved in being a member of the local ruling class may have caused a decrease in intensive crop cultivation as land owners were faced with increasing financial difficulties. On top of this phenomenon, the increase in wetlands, proven to occur in three valleys, but possibly occurring in a larger number of valleys within the study area, may also have caused an additional shrinkage in agricultural land.
Detailed records of vegetation change during this particular period are rare for southwest Turkey. The observed shift in agricultural practices, in combination with an increase in wetlands and marshes on the valley floor, may have occurred throughout the wider region. However, earlier records may not have recorded these phenomena due to limitations in chronology and/or sampling resolution.

7.2.1.2. Changing landscape use during the early Byzantine period (mid 5th to mid 7th century AD)

The ongoing decline of signs of anthropogenic activity may be in line with a nucleation of the settlement pattern in the study area, and an increase in importance of strategically located hill or mountaintop sites (Vanhaverbeke et al. 2004, 2007; Vanhaverbeke and Waelkens 2003). Archaeological evidence indicates that it is possible that rural sites started to play an ever larger economic role as they became increasingly self-sufficient and involved in economic activities previously confined to the city of Sagalassos (Poblome et al. 2000; Degryse et al. 2003; Vanhaverbeke and Waelkens 2003; Waelkens 2006; Vanhaverbeke et al., 2004, 2007, 2011a;). However, more evidence is needed to corroborate the hypothesis that this phenomenon occurred throughout the study area.
The mid 5th century AD saw the city of Sagalassos, the political and financial centre of the study area during Roman Imperial times, continue to decline in importance (Waelkens and Poblome 2011). Even though an actual decline in the population is not evidenced (Vanhaverbeke et al. 2007), animals were kept closer to the polluted urban centre of the city while import of cattle and meat from outside of the city decreased (Fuller et al. submitted). At the same time barley and millet became more popular in favor of bread wheat. Bread wheat, as indicated by its name, was used for making bread, while barley and millet were predominantly used for porridge and similar products. Both barley and millet do not have high requirements concerning soil and humidity conditions and can be cultivated on less favorable locations, closer to a village or city (Vanhaverbeke et al. 2007; Fuller et al. submitted). The ruralisation of the city of Sagalassos from the mid 6th century onwards, had a progressive character, with various areas of the city being abandoned or used for agricultural purposes before the mid 7th century AD (Waelkens et al. 2006; Vanhaverbeke et al. 2007). The decline of the city is not definitive proof of a decline in the wealth of all villages within the study area. The recent survey data for the Bereket Basin (Kaptijn et al. in press; Vanhaverbeke et al. 2011b) indicates that the settlements

there remained fairly prosperous throughout this period. However, the increasing ruralisation and changing trade relationships of the city of Sagalassos is likely related to a change in the social structure within the wider region which resulted in a change in landscape use.

It has been proposed that the observed shift in settlement patterns and land use was a response to an increased threat of attack (Vanhaverbeke and Waelkens 2003; Vanhaverbeke et al. 2004, 2007, 2011a) as the wider region was threatened by raids of the Isaurian tribes, the revolts of Ostrogothic mercenaries around AD 400. Ongoing brigandage has been reported to occur throughout the early 6th century AD (Liebeschuetz 1992; Vanhaverbeke and Waelkens, 2003; Vanhaverbeke et al. 2007). The increasing preference for goats and sheep, rather than cattle, as livestock could be a response to an increasing threat of violent incursions. Sheep and goats are more easily moved then cattle and therefore more flexible during times at which there is an increased danger of violence.

The plague of AD 542 is thought to have caused an additional decline in large scale agricultural activities. The epidemic that spread through the Middle East and, commonly referred to as the Justinian Plague, is thought to have been a form of bubonic plague (Achtman et al. 2004). It is estimated that this plague reduced the population of Asia Minor by 30 percent by the end of the century (Stathakopoulos 2004). The devastation of the Justinian plague resulted in a simplification of culture by cutting down the size of the cities and decreasing the number of the clergy, and ruling elite. The loss of a significant proportion of the workforce must also have had a devastating impact on agriculture and food production. The loss of workforce and inability to properly farm the land also had severe financial repercussions for the land owners (Russell 1968).

It is likely a combination of all of these phenomena resulted in the continuing decrease of agriculture further away from the settlements in the study area. The available data are not precise enough to attribute the observed decline in agriculture to one or several individual phenomena. In order to do that, one would need an absolute chronology for both the palynological, as well as the archaeological data.

One additional cause may have been climatic change (Vermoere 2004; Vanhaverbeke 2007). It is suggested that increasingly dry climatic conditions could have led to poor harvests and famine during the fifth and sixth century (Belke and Mersich 1990; Waelkens 1993). In Western Europe, there was a climatic trend towards colder and wetter environmental conditions since the 5th/6th century AD (Bond et al., 1997; Chapman and Shackleton, 2000; Grudd et al., 2002; Desprat et al., 2003). Such a trend in north-western Europe is often mirrored in the Eastern Mediterranean by a trend towards colder and drier environmental conditions (see chapter 3). However, a persistent climatic deterioration in the Eastern Mediterranean only occurred from the mid 7th century AD onward (Schillman et al., 2001, 2002; Lamy et al., 2006; Neumann et al., 2010). Although there is some variation in the timing of climatic trends throughout the Eastern Mediterranean, the newly constructed pollen-based climatic proxy reveals that the SW Taurus Mountains also remained relatively moist until the mid 7th century AD (Fig. 7.2, chapter 4).

The main evidence for the occurrence of drought in the study region is the increasing problem that the city of Sagalassos had in procuring fresh water (Waelkens 1997; Martens 2001; Vanhaverbeke et al. 2007). However, the increasing dependence of Sagalassos on rainwater and snow for their water supply may be linked to the possible occurrence of a heavy earthquake during the early 6th century AD. Seismic action may have disrupted the water supply by causing springs to dry up (Waelkens et al. 1995; Martens 2001). This does not mean that individual droughts did not occur in Asia Minor. Historical evidence points to the occurrence of several episodes of dry and cold weather during the early Byzantine periods (Telelis 2000, 2005). However, it must be noted that basing a history of climate change on Byzantine historical records is a risky business. Such records often focus on extreme conditions and are biased by the selective perception of the observers. The structure of the meteorological information is discontinuous, heterogeneous, and relatively scarce (Telelis 2000; 2005). In any case, the palynological evidence shows that the general trend throughout this period was towards relatively moist conditions.

7.2.2. The Byzantine "Dark Ages" to Late Byzantine/Selçuk period (AD 602/20 – 1243)

7.2.2.1. Arab incursions and aridification (mid 7th to mid 10th century AD)

In contrast to the records from Gravgaz and Bereket (Vermoere et al. 2002a, b; Kaniewski et al. 2007a, b; Bakker et al. 2011a, b), olive pollen continued to be present in cores from the valley of Ağlasun (Vermoere 2004). While olive pollen may well have originated from within that valley, it concerns only individual pollen grains observed in only a small number of samples. The notion of continued olive cultivation after the mid 7th century is therefore highly doubtful. In contrast to the current pollen record, cereals remained present in one earlier, lower resolution record from Gravgaz marsh (Core 99, Vermoere et al. 2002a, b). However, the pollen percentages did not reach values high enough to be interpreted as signs of local cereal cultivation. Continued cereal cultivation is indicated in one older core originating from the valley of Ağlasun (Vermoere 2004). The prevalence of species characteristic of herbaceous steppe and degraded shrub steppe/maquis, as well as the (temporarily) suspended increase in pine forest indicates that, safe for the close vicinity of habitation sites, crop cultivation was mostly abandoned in favour of livestock herding.

Increases in runoff volumes and gully erosions associated with overgrazing by sheep and goats are not observed in the sediment record, except in Bereket, where two detritic calcium carbonate rich deposits intercalated between the clayey peat, indicated erosion of soft sediments. The latter of these may be related to the removal of vegetation by fire, but the former seems to be related to the presence of open steppe vegetation, indicating that the sedimentation event was the result of overgrazing. It is hypothesized that most easily erodable soils had already been deposited on the valley floors during the intensive period of agriculture which occurred during the Roman and Late Roman periods (Dusar 2011; Dusar et al. in press).

This sudden and drastic shift towards livestock herding appears to be a separate event from the gradual transition observed during previous centuries and seems to coincide with a drastic drop in the number of settlements in the study area (Fig. 7.4). However, present day villages may cover middle to late Byzantine and more recent remains. Furthermore, the identification and dating of pottery finds in the territory remains problematic (Vanhaverbeke and Waelkens 2003; Vanhaverbeke et al. 2009). Vanhaverbeke et al. (2009) note that while many sites seem to have been abandoned after the mid 7th century, new sites would be established in less obvious places which may not have been included in earlier extensive archaeological surveys. An increasing number of sites have been found during more recent intensive survey campaigns (Vanhaverbeke et al 2011b). The rare finds of settlement sites for the period from the late 7th to the 9th century are thought to be small-scale agricultural sites or other types of less-intensive occupation.

A similar shift from crop cultivation to pastoralism during the 7th century AD is observed throughout the Eastern Mediterranean (de Cupere, 1998; England et al., 2008; Leroy 2010; Bakker et al., 2011a, 2011b). Whether these shifts in land use were driven by climate or by cultural and political turmoil is subject to ongoing debate (Vanhaverbeke and Waelkens, 2003; Haldon, 2007; Neuman et al., 2007b; England et al., 2008; Leroy, 2010). In all these records the end of the BO Phase roughly coincides with both the start of the Islamic period, as well as with the onset of drier climatic conditions (Heim et al. 1997; von Rad et al. 1999; Lückge et al. 2001; Jiang et al. 2002; Lamy et al. 2006; Migowski et al. 2006). It must be noted that the precision in the dating of these events varies from location to location. In most cases it remains uncertain what the link is between vegetation, climate, and the Arab invasions, if there is one at all.

The new pollen-derived bioclimatic proxy indicates that the observed change in land use and an abrupt and severe aridification of the environment occur simultaneously. Colder and drier environmental circumstances in the study area are also evidenced by increased consumption of C4 plants by livestock (Fuller et al. submitted). C4 carbon fixation is one of three biochemical mechanisms used in carbon fixation and enables plants to better cope with relatively dry climatic conditions. A causal link between a decrease in precipitation and a population decline, as well as a shift in focus from rain-fed agriculture to (semi-)pastoralism has been observed in archaeological and palaeoclimatic data (Kaniewski et al. 2012).

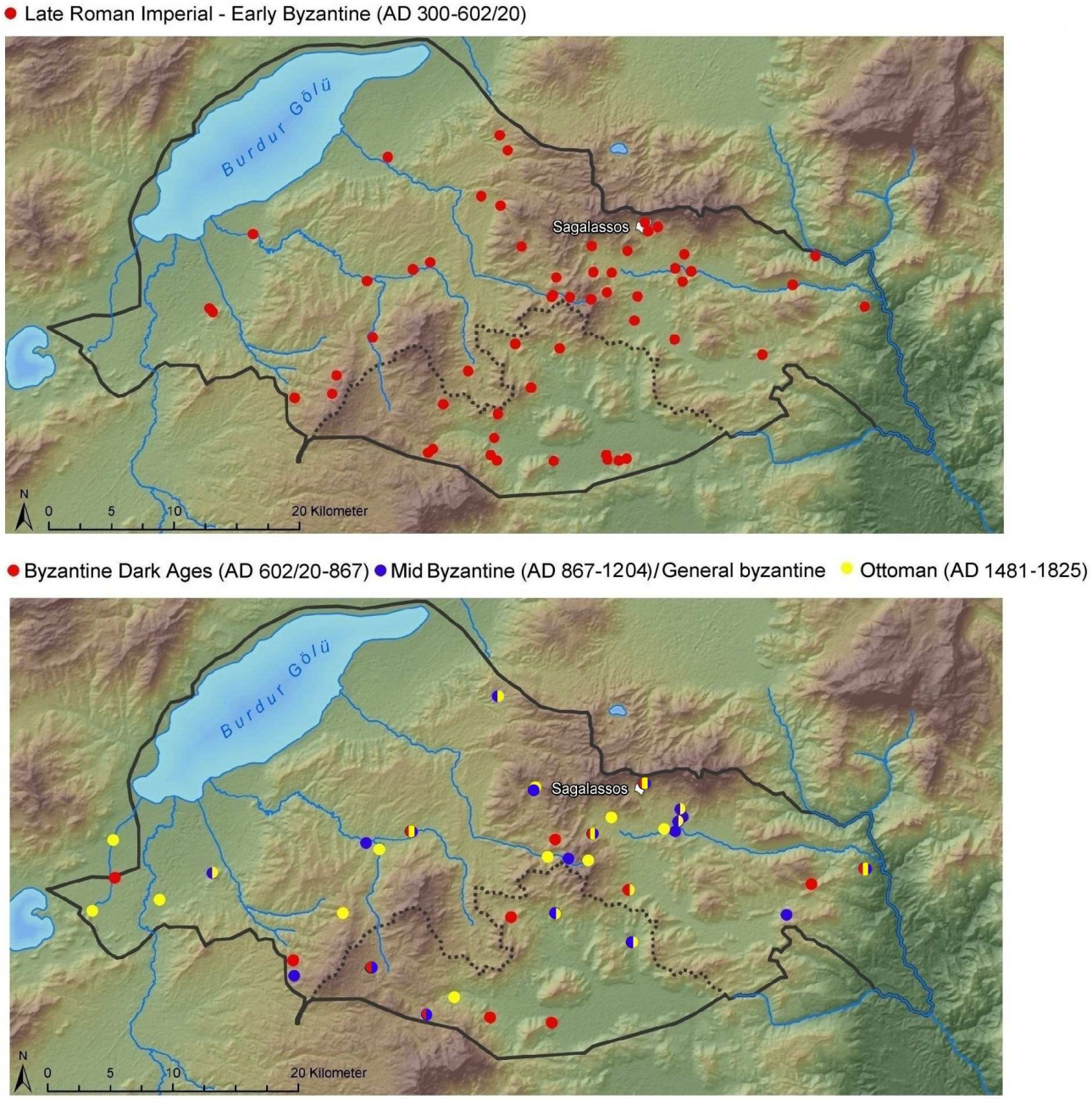

Fig. 7.4. An overview of the number of archaeological sites found in the territory of Sagalassos, dating from the late Roman, Early Byzantine (Vanhaverbeke and Waelkens, 2003; Vanhaverbeke et al. 2011; Waelkens et al. 2011) and mid/late Byzantine periods (Vanhaverbeke et al. 2009).

Nevertheless, a link between the observed change in land use patterns and the arrival of Arab forces in the region is also possible. The Arab victory over the Byzantine fleet in 655 AD at Finike, near Antalya, known as "the Battle of the Masts" (Threadgold, 1997, Nicolle 2009), coincides with the estimated age of the changes in land use in the study site. Arab forces initially retreated after their victory, having suffered heavy losses, and the outbreak of civil war amongst the Arabs (known as the First Islamic Civil War, or First Fitna) from 656 to 661 caused a pause in Arab incursions into Anatolia (Robinson, 2010). However, afterwards, up to 680 AD, Anatolia saw yearly raids into the Taurus Mountains and into Cilicia, Arab forces frequently overwintering on Byzantine territory (Lilie 1976; Gregory 2010). Within the study area, this period saw the appearance of a fortified hamlet on the site of the old temple of Hadrian and Antonius Pius (Waelkens and Poblome 2011). This threat may have resulted in a change in lifestyle of poorer farmers, from sedentary agriculture, to (semi)pastoralism. The aridification of the climate would merely have influenced the shape of the vegetation change, and not its occurrence. Furthermore, due to the Arab threat, many of the main agricultural lands in Anatolia were abandoned by their aristocratic owners. By the end of the 7th century AD, these lands were redistributed into a system known as the stratiotika ktèmata, where a man would be given a patch of land in return for military service. Measures taken in the 9th century attempted to protect smaller, poorer farmers

against the expansionist tendencies of larger land owners who made use of the military and political instability in the empire (Gregory 2010). These reforms and measures indicate a continued instability in land ownership and management, which may have contributed to the lack of a recovery in large scale crop cultivation throughout the study area.
In reality, it is most likely a combination of climatic deterioration and political instability that caused the abandonment of farmland and settlements observed in Gravgaz and Bereket. The Arab incursions, through direct violence and through the problems in land ownership and management resulting from the Arab threat, may have prevented the local populace to recover from, or adjust to adverse climatic conditions.
It has been suggested that increasing drought throughout the Near East sparked the start of the Arab invasions into Syria and Anatolia (o.a. Issar 1995; Brown 2001). However, a detailed record of climate change in the Arabian Peninsula itself for this period is not yet available. Therefore one must be careful when proposing such a link, no matter how plausible it seems.

7.2.2.2. Resurgence in anthropogenic activity and the Medieval Warm Period (Mid 10th to mid 12th century AD)

The mid 10th century resurgence in anthropogenic activity was not noted in earlier pollen records from southwest Turkey (van Zeist, 1975; Bottema and Woldring, 1884), likely due to the limited time resolution of these studies. A more or less similar phenomenon does occur in one previous record from Gravgaz, ending before c. AD 1050 according to the chronology of that record (Vermoere, 2004), but no attention is given to this phenomenon as the focus of the earlier palynological research at Gravgaz lay with the timing and impact of the BO Phase. The present data reveals this resurgence in anthropogenic activity occurred between the mid 10th and mid 12th century AD, at multiple locations within the study area, as well as outside of the study area. A similar resurgence, characterized by a distinct deforestation phase and resurgence in cereal cultivation, has also been recorded in the pollen record from Nar Lake, central Anatolia (England et al., 2008; Eastwood et al., 2008).
The resurgence of agriculture from the 10th century onwards coincides with a social and economical revival throughout the Byzantine Empire (Bintliff, 2000; Haldon, 2007; Knipping et al., 2008; Vionis et al. 2009a). This phenomenon is considered to be a result of 8th and 9th century AD administrative reforms (Gregory 2010). A series of military victories by Byzantine forces, starting with the battle near Amisos on the Black Sea coast in AD 863, resulted in the recapture of lost territory while rendering previously insecure territory to a more stable footing (Eastwood et al. 2008; Vionis et al. 2009b).
However, historical, archaeological and palaeoenvironmental studies show the results of this Byzantine renaissance only became apparent in the Byzantine countryside during the 10th century AD (Koder 2994, Bintliff 2000; Eastwood et al. 2008; Vionis et al. 2009a). At this time, Byzantine military successes enabled the (re)conquest of Crete and Aleppo, removing the threat of Arab pirate activity in that region, allowing for a further economic growth of the empire. Under emperor Basilios II (AD 976-1025), the Byzantine Empire reached the height of this Renaissance (Gregory 2010). At Sagalassos itself, this renewed prosperity may be indicated by the ruins of a finely decorated church, constructed around c. 1000 AD on the so-called Alexander Hill, in the direct vicinity of the site of Sagalassos.
While the political re-organisation of the Byzantine Empire and the relatively peaceful situation in the areas reconquered by the Byzantines since the 8th century AD may have played a role in allowing for an eventual resurgence in agricultural activity in the countryside, the role of climate change should not be ignored. The shift towards wetter environmental conditions during the mid 10th century, observed in the pollen-derived climatic proxy, coincides with the onset of the warm and wet MCA in the Middle East (Bar-Matthews et al. 1999; Bond et al. 2001; Schilman et al. 2001, 2002; Gupta et al., 2003; Lamy et al. 2006; Kaniewski et al. 2010; Bakker et al., 2011a). This climatic shift coincides with the increased anthropogenic activity observed throughout Anatolia, previously exclusively linked to the military and political developments of previous centuries.
It is tempting to consider that, while the relatively positive political climate in the Byzantine Empire since the 8th century AD may have sowed the seeds for the resurgence in agriculture, the amelioration of the climate may have been a catalyst, further enabling the expantion of renewed agricultural activities into territories unsuitable or less suitable for such activities during the DACP. However, the continued economic resurgence related to the successive military victories of Byzantine forces should not be ignored.

The presence of cultivated species in the Gravgaz and Bereket pollen diagrams remain much more limited than during the BO Phase. Furthermore, it is notable that arboriculture remains absent during the MCA. The focus of human activities remained on pastoralism and limited cereal cultivation, rather than arboriculture. Eastwood et al. (2009) attribute the lack of olive cultivation, in the pollen record of Nar Lake, to the fact that during such unstable times as the Mid-Byzantine, it was not worth the effort to invest in such potentially vulnerable, time-intensive crops. Olive, for instance, requires up till 30 years before reaching maturity. On the other hand, cereals can be harvested yearly and flocks of goat and sheep are easily moved away to more secure areas in times of unrest, making cereal-pastoralism preferable to arboriculture. This same phenomenon appears to have taken place in the study area.

7.2.2.3. Abrupt decline in anthropogenic activity (Mid 12th to mid 13th century AD)

The resurgence of anthropogenic activity in the study area stops abruptly during the mid 12th century AD, and is followed by a period where pine forests become important. No signs of anthropogenic activity are found during this period. Both the abruptness of this shift, as well as the complete lack of signs of anthropogenic activity in the pollen records are notable.

The Nar Lake record, which is the nearest Anatolian high resolution pollen record to the territory of Sagalassos that also covers this time period in detail, also records a sharp decline in human impact during the twelfth century (Eastwood et al. 2008, 2009). But this decline is not as abrupt and complete as that found in the territory of Sagalassos. At Nar Lake, the pollen data indicate that there must have been a much greater continuity in land use between the mid Byzantine and Selçuk periods, than there was between the late antiquity and the Byzantine Dark Age. The fact that the decline in Gravgaz and Bereket was more abrupt than in Nar lake may be due to the fact that the relevant source area of pollen for a marsh, specifically in a mountainous landscape, is much smaller than that of a lake. However, this does not necessarily explain the complete lack of any anthropogenic activity, including livestock grazing, at Gravgaz and Bereket.

One of the possibilities is that the observed decline was linked to Selçuk agression. The Selçuks started to dominate the region following the destabilisation of the Byzantine Empire caused by the outcome of the Battle of Malazgirt in AD 1071 and the ensuing civil war within the Byzantine Empire. Within decades Anatolia fell to the Selçuks. Pisidia became part of the Selçuk sultanate following the Byzantine defeat at the battle of Myriokephalon in AD 1176, after switching hands constantly for most of the 11th century. The study area remained under Byzantine control until AD 1204, when it became part of the Selçuk sultanate of Rum, but it could be possible that incursions into the study area occurred some time before 1204 already.

However, conclusive evidence for violence in the territory of Sagalassos, coinciding with the rise of the Selçuks in Anatolia is mostly absent from the territory of Sagalassos. The apparent destruction of a fortified site on Alexander's hill, near the site of the city of Sagalassos is very tentatively linked to Selçuk aggression in some publications (Poblome and Taloen, 2005; Vionis et al. 2010), but this destruction must have occurred some time after the actual Selçuk conquest (Waelkens and Poblome 2011). Additionally, the construction of the hamam and keravansaray in the village of Ağlasun, located in the valley below Sagalassos, during the 13th century AD indicates a continuity of life during this period (Vanhaverbeke et al. 2009). This is also supported by the continuation of cereal cultivation near Ağlasun (Vermoere 2004).

Rather than a result of the Selçuk conquest, the disappearance of any sign of agriculture in the palynological records of Bereket and Gravgaz may be the result of the political and economical deterioration of the Byzantine Empire during the Komnenoi (AD 1082-1185) and Angeloi (AD 1185-1204) dynasties in the years prior to the Selçuk conquest of the region. However, resurgence in the occupation of the fortified hamlets on the site of Sagalassos, and the construction of an additional fortification on the nearby Alexander's Hill, seems to be at odds with an apparent decline in agriculture. It may be that settlements in the territory shifted their agricultural practices towards more limited activities in the direct vicinity of the settlement in the face of external military threats, similar to the process which occurred during the 5th century. It may also be that shifts in land use were driven by changes in the nature of land ownership. Measures to protect small-scale farmers against wealthy land owners, looking to expand their possessions, were abolished during emperor Romanos III Argyros (AD 1028-1034). Under emperor Constantinus IX Monomachos, the wealthy land-owning nobility was granted increasing of rights while having to pay less and less taxes. Eventually, this period saw the rise of the Pronoia system, with which land-owning nobility was granted full control over their territory in return for specific services to the crown, essentially creating semi-independent fiefdoms.

Based on the climatic data available for the study area, a link with climate change is also possible. Touchan et

al. (2007) observe the occurrence of a period characterized by severe drought occurring at c. AD 1195-1280. The start of this period more or less coincides with the disappearance of anthropogenic impact in the study area in the mid 12th century. However, it may also be that this drought coincides with the occurrence of sediment zone Gv-d in the Gravgaz record, which indicates severe local drying, and is dated to start during the early 13th century according the Gravgaz chronological framework. Furthermore, the apparent complete abandonment of not just the valley floors (indicated by the disappearance of primary and secondary anthropogenic indicators), but of larger parts of the rural landscape (indicated by the increase of pine forests), indicates a change in land use which is much more drastic than can be explained by the onset of a dry climatic period alone. During the mid 7th century period of aridification/Arab incursions, human impact changed in nature, but it did not disappear from the pollen record.

7.2.3. Beylik, Ottoman, and Turkish Republic periods (AD 1243 – present)

The period between AD 1243 and the mid 16th century AD is characterized by a continued dominance of pine forest and an absence of signs of anthropogenic activity at both sample sites. The reliable part of the Bereket basin pollen record stops during the mid 14th century AD. From this period onwards, the interpretations of the pollen data are based on the Gravgaz marsh record alone. The tree ring data of Touchan et al. (2007) confirms that the bioclimatic changes observed in the pollen and sediment data reflects regional climatic change, but it must be noted that changes in the vegetation and presence/absence of human impact can only be proven to have occurred in the vicinity of Gravgaz.

7.2.3.1. Increased landscape openness (Mid 16th to mid 19th century AD)

Historical data indicate that the period from the late 13th century AD onward, after the Selçuks, and later the Ottomans, established their realm, was increasingly characterized by relatively peaceful conditions in Anatolia (Vryonis, 1971). Nevertheless, the pollen data indicate pine forest continued to dominate the area around both sample sites until the mid 16th century AD, after which the landscape gradually became more open. Vanhaverbeke and Waelkens (2003) indicate how the more peaceful Ottoman period saw an increase in the population of the region during the 15th and 16th centuries. The increased pressure on the land and resulting reduced living standards eventually led to the Celali rebellions of the late 16th and early 17th century. The resulting insecure situation may have led to a reduction of the population, a decline in agriculture and a corresponding increase in pastoralism (Vanhaverbeke and Waelkens 2003). However, the 17th century also saw a major tax reform, which caused a shift in land ownership from Timars to Ciftliks. The former term implies a land granted by the Ottoman sultans as compensation for military service. The latter term indicates a system of land management where powerful military officers started to claim land from the Sultan's holding, allowing them to pass the land onto their sons, creating large privately owned estates, the inhabitants of which were essentially used as serfs. The establishment of the Ciftliks may have impinged upon the hamlets and villages populated by independent farmers, forcing a shift from sedentary farming towards pastoralism (Jackson and Lampe 1982; Keyder and Tabak 1991).
Climatic change seems not to have played a role in the increase of pastoralism in the region. Before the mid 16th century AD, sedimentological data indicate severe local drought coinciding with regional dry conditions (Touchan et al. 2007). This period coincided with the Spörer minimum; a 90 year period of low solar activity, linked to lower temperatures. However, the vegetation and sediment data imply that, while local and regional environmental conditions did improve, they were still only roughly similar to those of the early DACP until the early 18th century, after which moisture availability started to increase. This is also reflected in the pollen data, which indicate the increase in dry steppe, similar to that which developed after the mid 7th century AD, rather than an increase in moist grasslands.

7.2.3.2. The origins of the current landscape (mid 19th century AD – present)

The additional opening of the landscape observed in the 19th century AD may be related to the massive deforestation which took place in the Taurus Mountains from AD 1800 onwards. During the 19th century Antalya developed into an important harbour from which raw materials, such as pine wood, was exported (de Planhol 1958).
The 19th century AD also saw a gradual sedentarization of the nomadic population, as the state started to force nomads to settle for the purposes of easier taxation, although many nomads chose to settle down voluntarily (Vanhaverbeke and Waelkens 2003). Agricultural developments, as well as improvements in infrastructure lead to an intensification of agriculture, notably cereal cultivation. Furthermore, during this period, the Ottoman government initiated a policy stimulating the settlement of nomadic tribes. This was done with the purpose of easing tax collection. Many of the current villages in the territory of Sagalassos originate from this period (de Planhol 1958; Hüttenroth 1968). Intensification of agriculture and population size increases continued after World War II and the incorporation of Turkey into the economic support programme of the USA. It is therefore peculiar that such an increase in sedentary farming is not observed in the pollen record.
The absence of a signal resembling modern-day agriculture in the pollen record of Gravgaz may be caused by the fact that the intense cereal cultivation now observed in that basin only started very recently. The exact starting age remains unknown. However, it is known that the marsh located in the centre of the Bereket basin, was only drained in the 1960's (Kaniewski et al. 2007a, b).

7.3. Conclusions

The present study provides the first relatively detailed study of vegetation change for the period from c. cal 300 AD until the present for the southwest of Turkey, and includes information on the interactions of climate change, sediment dynamics and fire activity from the Middle and Late Byzantine era until the present. Both climate change as well as socio-political change influenced vegetation change directly, as well as indirectly via changes in anthropogenic impact. An overview of the changes in vegetation, climate and human impact is given in Table 7.1 and Fig. 7.5.
The new data from southwest Turkey show how a climatic shift towards moister conditions in the 3rd century coincided with a shift in agricultural practices, away from intensive crop cultivation and towards livestock herding. The palaeoenvironmental data imply that an increase in moisture availability led to wetlands on the valley floors becoming too wet to use as arable land, which in combination with the economic and military troubles of the 3rd century, may have lead to the observed changes in land use.
A further, more severe shift towards pastoralism and population decrease during the mid 7th century is attributed to a climatic deterioration which led to relatively dry environmental conditions, perhaps in combination with Arab incursions into the region, more or less coincided with the recorded climatic deterioration. The current study shows that while 7th century climatic change has had an undeniable influence on human society and vegetation dynamics; it need not be connected to the end of the BO Phase proper and that there is not one single phenomenon responsible for the ending of the BO Phase. Although at present, the start of the Byzantine Dark ages in the territory of Sagalassos is dated to c. AD 602-620, coinciding with the occurrence of the heavy earthquake which destroyed much of what was then left of the city. As archaeological evidence finds more and more evidence of continued inhabitation of the site of Sagalassos after this earthquake, perhaps it is more logical to state that the true dark ages for the territory of Sagalassos started with the combination of Arab invasions and climatic deterioration in the mid 7th century.
The first indications of resurgence in agriculture in southwest Turkey occur during the mid 10th century. A similar phenomenon has been observed throughout Anatolia. While this resurgence is seen as a response to increased political stability and military successes against the Arabs since the 8th century AD, the close connection between the start of the MCA and the widespread increase in agriculture indicates that this climatic amelioration in the least worked as a catalyst for the spread of human activity. Crop cultivation did not return to the levels of intensity witnessed during the BO Phase, while intensive arboriculture remained completely absent in the present record from southwest Turkey. The continuing political instability in the Byzantine Empire may have discouraged investment into time-intensive crops such as olive.

Although the pollen data indicate the climate remained relatively wet and warm until the late 13th century, anthropogenic activity dropped abruptly from the 12th century onwards. The decreases in crop cultivation in the territory of Sagalassos during the 12th century cannot be definitively linked to a socio-political change in the territory. However, a link with the possible occurrence of a dry climatic period is also doubtful, as in the past, such an aridification did not lead to the disappearance of human impact, merely to a change in its nature. Increased landscape openness from the 16th century onwards may be linked to political unrest and changing landscape management during the Ottoman era.

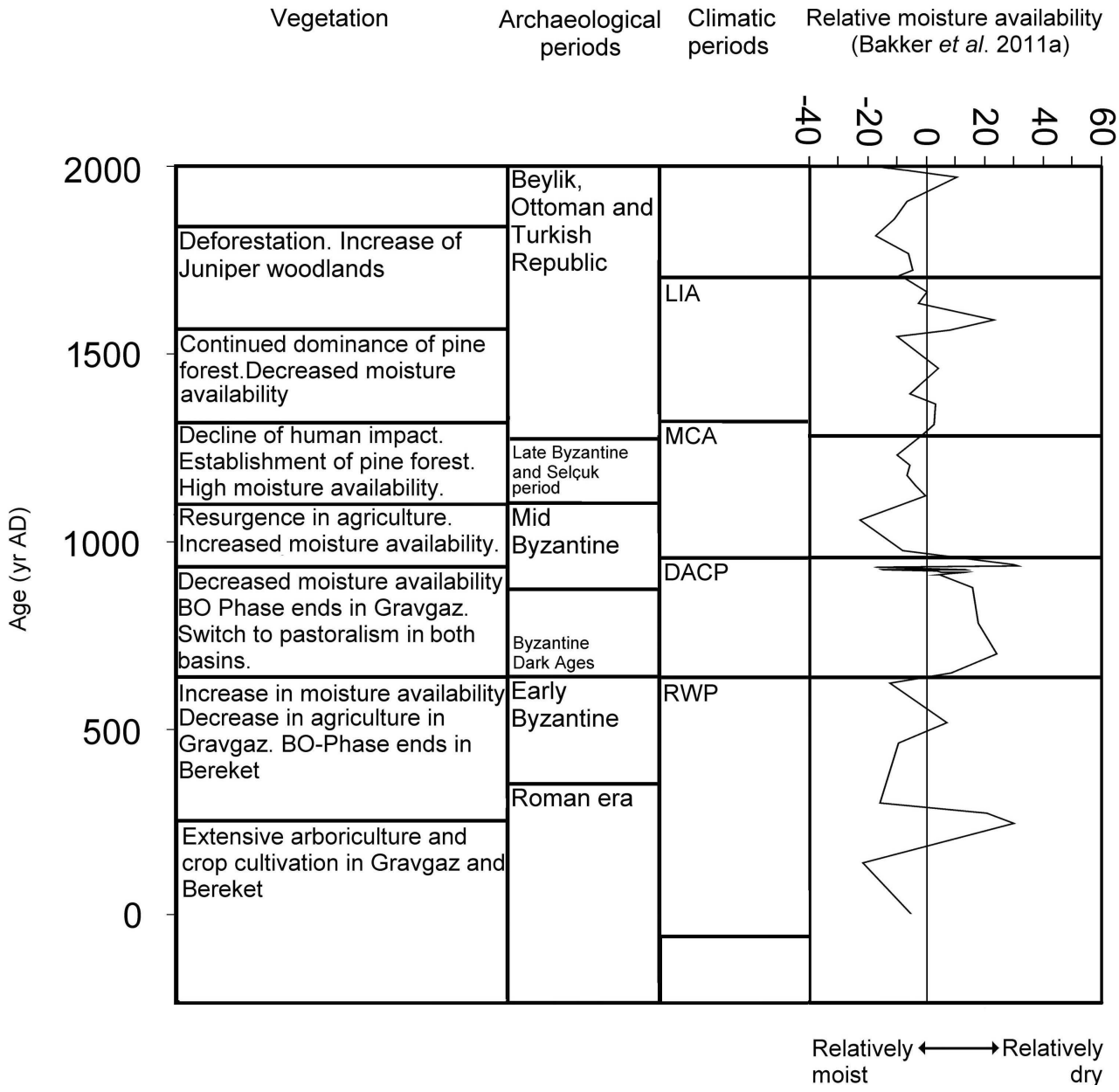

Fig. 7.5. An overview of the main changes in the vegetation and environmental conditions in the territory of Sagalassos, the main historical, and climatic periods (left), and a comparison of the occurrence of humid and dry trends from 0 to 2000 AD in the territory of Sagalassos (Bakker et al., 2011a) (right). The subdivision into historical periods follows that which was presented in chapter 1 of this dissertation and is based on Vanhaverbeke and Waelkens (2003).

Fig. 6.1a. A chronological overview of the main changes in climate, main historical events and important changes observed in the archaeological and archaeozoölogical data.

Date (yr AD)	Climate	Archaeology/history	Archeobotany/archaeozoölogy
1700 to late 19th century	End LIA circa 1710.	Start major rural development: Sedentarization nomadic population, development road/rail network, developments in agricultural techniques, increased export of raw materials.	
mid 16th century		Population increase in Anatolia. Changes in land ownership: Timars to Ciftliks.	
2nd half of 12th century	End MCA, start LIA.		
Mid 12th century		Decrease in prosperity of the Byzantine Empire under Komnenoi and Angeloi dynasties. Land-owning nobility is granded more and more autonomy ("Pronoia"). Start Selşuk period in AD 1204. Construction of hamam and caravanserai in Ağlasun.	
Mid 10th century	End DACP, start MCA.	Increase agricultural activity throughout Byzantium, following political reforms and military success. Construction of a richly decorated church near site of Sagalassos in c. AD 1000.	
Mid 7th century	End RWP, start DACP.	Arab incursions into Pisidia until c. AD 680.	Significant C4 plant consumption by livestock
from late 5th/early 6th century onwards		Focus in habitation shifts to larger, self-sufficient villages on defendable positions. Continued prosperity for territory of Sagalassos.	Introduction of millet and barley indicates small-scale cultivations nearer to Sagalassos. Goats and sheep become more important as livestock, relative to cattle. Livestock around Sagalassos is kept close to the site.
second half of the 3rd century	Start of the final moist period of the RWP.	Introduction of new type of amphora since 4th century AD and change in Red Slip Ware type 4th/5th century implies changes in trading network in Bereket basin.	Amount of wetlands increase near Sagalassos according to archaeobotanical data
Early 3rd century	Relatively dry period of RWP (known from literature).		

Table 6.1b. A chronological overview of the main changes in climate, land use, and vegetation from AD 250 to the present.

Date (yr AD)	Climate	Vegetation	Sediment
1700 to late 19th century	End LIA circa 1710.	Greatest decrease pine forest since start LIA (Gravgaz)	
mid 16th century		Start increase landscape openness (Gravgaz)	
2nd half of 12th century	End MCA, start LIA.	Maximum abundance pine forests (Gravgaz, Bereket)	Dry local conditions 1220-1450 AD (Gravgaz). Peat deposition stops. End of reliable part of the pollen core. Younger sediments are located above the water table (Bereket).
Mid 12th century		Sharp decrease anthropogenic impact, increase in pine forest (Gravgaz, Bereket)	
Mid 10th century	End DACP, start MCA.	Increase in anthropogenic impact (Gravgaz, Bereket)	Local dessication stops, but no wet trend is recorded (Gravgaz).
Mid 7th century	End RWP, start DACP.	Abrupt end of BO Phase, development of open, dry shrub-steppe. Indicating increasing dominance of herding/pastoralism over crop cultivation (Gravgaz). Indications of landscape openess, indicating herding/pastoralism. Development of riparian forest in former marshlands (Bereket).	Organic matter starts to decrease, implying local dessication (Gravgaz). Influx of sediments from nearby marl deposits implies dry, open landscape in the vicinity (Bereket).
from late 5th/early 6th century onwards		Further decrease in crop cultivation suggested by pollen data (Gravgaz).	
second half of the 3rd century	Start of the final moist period of the RWP.	BO Phase ends (Bereket). Decrease in cereal cultivation and arboriculture (Gravgaz). Pollen suggest relatively moist environment, locally and regionally (Bereket and Gravgaz).	Increase in local moisture availability in Bereket and Gravgaz. Peat layer develops in Bereket.
Early 3rd century	Relatively dry period of RWP (known from literature).	Dry open steppe vegetation and presence of olive cultivation (Bereket).	Low organic matter content (Bereket).

Chapter 8

General conclusions and suggestions for future research

8.1. Introduction

The palynological investigations from two sites within the territory of Sagalassos provided the first relatively high-resolution overview of vegetation change for the period following the end of the BO Phase in SW Turkey. The local and regional pollen data was augmented by a detailed sedimentological analysis and a study of NPP's, which provided additional information concerning changes in the local environment around the sample sites.
While a visual inspection of the pollen data revealed how the vegetation responded to changes in human occupation, newly developed numerical analyses allowed for the creation of a proxy which recorded changes in the bioclimate. A comparison of the pollen-derived bioclimatic proxy with the pollen and sedimentological data from both sample sites revealed that the Gravgaz bioclimatic pollen represented changes in moisture availability throughout the wider area. When the different bioclimatic periods were established, these periods were compared to independent climatic proxies from locations in various places of the Eastern Mediterranean, which revealed all bioclimatic periods identified for the study region coincided with the general estimates for the timing of the Roman Warm Period, Dark Ages Cold Period, Medieval Climate Anomaly and the Little Ice Age. While there is no 1:1 relationship between moisture availability and temperature in the Middle East, and the sediment, pollen, and bioclimatic data reveal several dryer and wetter periods within the RWP and LIA, the DACP and MCA are characterized by a continuous trend towards dry and wet environmental conditions respectively. Additionally the end of the RWP and start of the LIA are clearly identified when studying the combined pollen, sediment, and bioclimatic data.
The statistical analysis of charcoal concentrations revealed new insights into the fire history of the study area, revealing the reduced role of fire during the post-BO Phase period. Combined with the available archaeological record, the data expanded the understanding of the history of human occupation of this historically valuable study area. At the same time, the study of the archaeological record has provided possible causes for some of the major changes in the vegetation observed in the two records, illustrating how both sciences can be mutually complementary. Finally, the combination of newly gained knowledge concerning regional climate change and local anthropogenic change allows for a more proper analysis of the interactions between climate, vegetation, the physical environment, and human impact, shedding new light on the history of human-environment interactions both on the more local scale of the Sagalassos Archaeological Research Project, as well as within the under-studied region of SW Turkey in general.

8.2. Answers to the research questions

8.2.1. Is human impact still discernable in the pollen record after the end of the BO Phase?

The results show, for the first time in SW Turkey, two distinct resurgences in human impact following the end of the BO Phase. The first phase occurred between the mid 10th century and mid 12th century AD. At both sites the focus of human impact laid on an increase in animal grazing and deforestation, although in Gravgaz, pine forest had not increased very much after the end of the BO Phase and there was a more pronounced element of crop cultivation present at that site. The second episode was only recorded at Gravgaz, pollen data from Bereket being unavailable for that period, and occurred from the mid 16th century AD onwards. The end date is not clearly distinguishable and it is possible that human impact in the form of livestock herding remained present until the time of the major developments in agriculture in the late 19th and early 20th century AD. The hiatus in human impact observed between the mid 12th century and mid 16th century AD is notable because of its abrupt occurrence and complete absence of any human impact. In both respects it is different from the high-resolution pollen record of Nar Lake, central Anatolia, which does indicate a decrease in human impact, but not a complete disappearance. The abrupt disappearance of human impact occurs at both sites in the territory of Sagalassos simultaneously, and may therefore be interpreted as indicative of a phenomenon that affects the study area as a whole, rather than a local event that influences only a single basin.

However, this does not mean that the entire study area responded to this single phenomenon in the same manner, as chapter 6 revealed that the pollen signals of even the most copious pollen producer most likely only indicates vegetation change within a single basin.

8.2.2. How does the natural vegetation respond to (anthropogenic or fire-related) disturbance?

The pollen and sediment data reveal how the natural vegetation responded to disturbances such as human impact or (natural or anthropogenic) fire activity. The shift from crop cultivation to pastoralism during the mid 7th century AD subdued the natural succession of the vegetation, resulting in an open steppe landscape. Where pastoralism was limited, secondary succession resulted in the establishment of a secondary pine forest. The establishment of pine forest only occurred late during the DACP in Bereket, while in the vicinity of Gravgaz, the amount of pine forest remained limited until the mid 13th century AD. Only from the mid 13th century AD onwards is a general increase in pine forest visible in both records. This pattern differs strongly with that observed in earlier records, and it may be that this pattern is more wide-spread throughout SW Turkey, but not observed due to the low sampling resolution and limited chronological framework of earlier pollen records from this region. The renewed clearance of the pine forests from the 16th century onward resulted in the establishment of juniper shrub and woodland.
Most fires occurring in the vicinity of the two sample sites occurred at times when human impact was limited and when pine forests had become more important in the landscape. The pollen and sediment data indicate that fire events were of a relatively small scale, no charcoal peaks being detected in both basins simultaneously, despite being located only 10 km apart from one another. None of the fire events occurred in the immediate vicinity of the sample sites as fire events never coincided with abrupt changes in local pollen and sediment characteristics. The notable exceptions are two 8th century fire events in Bereket, which coincided with an influx of CC-rich material on the sample site. However, this material most likely originates from the marl deposits located c. 1 km west of the sample site and therefore the charcoal is not indicative of local fires.
Notable increases in pine pollen after some of the recorded fire events may represent instances in which pine forests came to quickly colonize burned terrain. The period within which a burned pine forest can recover is approximately 15-40 years. . The average time interval between two pollen slides for Gravgaz and Bereket is approximately similar to the maximum time needed for pine forests to re-establish themselves, meaning that even in these relatively high-resolution analyses (for SW Turkey), post-disturbance succession from burned lands, to herbaceous steppe, shrublands, and finally pine forests, is therefore in most cases not observed in the recent pollen diagrams from the territory of Sagalassos.

8.2.3. Is it possible to distinguish late Holocene climatic trends in the pollen signal?

Although climatic reconstructions are available from several locations within the Eastern Mediterranean, the patterns of cold/warm and dry/wet climatic conditions usually only show the broadest of similarities from one record to another. Therefore it was vital to create a climatic record specifically for the region of SW Turkey if an accurate comparison of vegetation change and climatic change was to be made.
The statistical analyses performed on pollen data obtained from Gravgaz marsh yielded a bioclimatic proxy of relative moisture availability for this basin. A comparison of this bioclimatic proxy, the raw pollen data, and the sediment data of Gravgaz marsh with the pollen and sediment data collected in the Bereket basin revealed that the trends observed in the Gravgaz bioclimatic proxy were a response to changes in moisture availability in the wider region, rather than a response to changes in the local environmental conditions. A further comparison with independent climatic proxies revealed that this regional bioclimatic signal corresponds with major climatic trends observed throughout the Eastern Mediterranean.
The statistical analyses revealed how the increasingly moist environmental conditions observed throughout the Middle East and into North Africa from the mid 3rd century AD onwards also occurred in SW Turkey. This wet climatic trend resulted in an increase in size of swamps, marshes and wetlands.
The onset of the DCAP occurred during the mid 7th century AD, and was characterized by the onset of relatively dry environmental conditions. This follows the general trend observed in the Levant, although the timing is late compared to the onset of dry conditions in more continental climatic records such as that of Nar Lake. Dry conditions are evident in the pollen record as they indicate the establishment of dry steppe vegetation where human impact prevented the establishment of pine forest. The sediment record indicated

how Gravgaz marsh seemed to gradually dry out throughout the DCAP, while the sediment record of Bereket indirectly indicated the presence of dry, open vegetation on the marl deposits west of the marsh. Relatively moist environmental conditions occurred from the mid 10th century to the second half of the 13th century AD, which is comparable to estimations given for the MCA in Europe and the Middle East.
The pollen data show that moisture availability was generally lower after AD 1300, than during the previous period, which was linked to the MCA. However, a critical comparison of the bioclimatic proxy with the available pollen and sediment records for Gravgaz and an independent tree ring record (Touchan et al. 2007) prompted an adjustment of the estimated end date of the MCA in the study area to the latter half of the 13th century. The pollen data show that moisture availability gradually increased again from c. AD 1800 onwards. However, the sediment data of both Gravgaz and Bereket indicate that this dry period, seen as the SW Turkish manifestation of the LIA, already started during the second half of the 13th century AD.
The remarkable similarities between on one hand the sediment record and, to a lesser extent, the pollen record of Gravgaz, and on the other hand the independent tree-ring record from the same region, indicates that the environmental conditions implied by the data from the territory of Sagalassos can be interpreted as being representative of climatic change over a larger region. Additionally the similarities between these records also indicates the accuracy of the radiocarbon-derived chronology of Gravgaz, despite most start and end dates for bioclimatic periods being based on interpolations assuming unchanging sedimentation rates between carbondates.

8.2.4. Is it possible to create a reasonable estimation of how much of the historic landscape was covered by each vegetation type?

The establishment of the relative pollen production for a number of key taxa, and the establishment of the relevant source area of pollen for moss polsters in this study area, resulted in a better understanding of the relation between pollen and plant abundance in the field. The RSAP of c. 750 m and low percentages of pollen coming in from outside the RSAP emphasized the small area from which the vegetation is recorded in pollen records in this area. This not only made clear that in the SW Taurus Mountains, a single pollen record only records the vegetation change within a very limited distance around the sample site. Even the relevant pollen signal of the taxa with the best pollen production and dispersal capabilities is most likely only indicative for vegetation change within a single basin. Research results emphasized the need to record pollen data from multiple locations in order to distinguish between local and regional environmental change. However, changes in the pollen percentages of such limited pollen producers and dispersers may still be indicative of vegetation change in the wider region if the local environmental conditions, as indicated by pollen of aquatic plant taxa, sediment data, and NPP data, indicate that the plant taxa of interest most likely did not grow close to the sample site.
The high PPE for *Quercus coccifera* directly challenges the notion that overgrazing of the *Quercus* shrubland limits this plant's pollen production capabilities. The relatively modest background pollen loading indicates that it its pollen is simply not spread over long distances. *Pinus* has a lower PPE than *Quercus*, but far better pollen dispersal capabilities. However, even the RSAP of *Pinus* pollen is not greater than c. 750 m. In a modern landscape and using a pollen sum which includes only ten species, the background pollen signal of Pinus is still only c. 22%.
This information provides a first step towards a quantitative model-based reconstruction of the landscape. However, additional fieldwork is required to obtain more reliable PPE data for some of the taxa included in the analyses descried in chapter 6. At present the relation between plant abundance and pollen percentages suffers from the presence of outliers and the date hints in some cases at the existence of multiple populations of points in the data, indicating samples were collected at several groups of locations representative of specific environmental conditions. Additional data from other key plant taxa such as deciduous oak, willow, and olive, is also needed in order to enable a quantitative reconstruction of the BO Phase landscape.

8.2.5. What is the interrelationship between climate, human impact and vegetation?

The research results presented in this dissertation illustrate that it is possible to separate climatic and anthropogenic signals within pollen records. The results also show how both political/social change as well as climatic change may be a driving factor for important changes in the vegetation and sediment record, and human impact, either independently or as a combination of both.
The decrease or disappearance of the intensive BO Phase agriculture from the mid 3rd century AD onwards most certainly coincides with a notable increase in moisture availability and swamp size. It is postulated that the disappearance and decrease of agriculture in the vicinity of the sample sites was related to the encroachment of wetlands and swamps onto agricultural land. However, the role of the military instability, and political and economical deterioration of the Roman Empire during this period may not be ignored. On the other hand, archaeological and historical data indicate that the territory of Sagalassos may have remained relatively prosperous during and after the mid 3rd century crisis.
A similar unclear situation presents itself during the mid 7th century, when the last remaining signs of BO Phase agriculture disappear from the pollen record and are replaced by signs of (most likely pastoral) animal herding. The pollen and sediment records, in combination with independent climatic proxies, show that this shift coincides with the onset of a dry (presumably cold) climatic phase. But this period also sees the arrival of Arab invaders in the region. Both factors, climatic and political, could have led to a shift in agricultural practices from sedentary crop cultivation towards animal herding. The possibility that it was a climatic deterioration that drove the Arabs towards the north, into the Eastern Mediterranean, cannot be proven until more detailed climatic records become available from the Arabian peninsula itself.
The resurgence in anthropogenic activity during the 10th century can perhaps be more convincingly linked to climate change. The Byzantine Empire had begun to stabilise from the 8th century onward, and the increased economic prosperity and stable political situation had allowed for a true renaissance of the Byzantine Empire (Gregory 2010). However, an increase in agriculture, in the study region, as well as at Nar Lake (England et al., 2008; Eastwood et al., 2008) was only visible from the 10th century onward, coinciding exactly with the start of the relatively wet MCA. It is a possibility that the onset of the MCA made the area around the sample sites more attractive for agricultural activities, while the political and military stability and economic prosperity of preceding ages created a situation where expansion of agricultural practices was possible. The end of this period of anthropogenic activity is more difficult to interpret, as it less clearly coincides with the onset of dry climatic conditions, nor is there clear evidence linking the observed disappearance to signs of violence (e.g. linked to the Selçuk advances in the region).
The start of the next resurgence in human impact, marked by a gradual deforestation of the landscape, occurs during a short, very wet interval in the LIA. However, human impact continues and even increases throughout the succeeding dry period(s). This implies that the human activity indicated by the pollen record is not driven by climatic conditions. Furthermore, while human impact starts during a distinct wet period within the LIA, it is unclear how wet this period was in comparison with MCA and RWP conditions. The pollen-based climatic proxy indicates that environmental conditions in the study area were drier than during the MCA and the wet part of the RWP between the mid 3rd and mid 7th century AD.
In conclusion, while it is possible to successfully distinguish between climatic and anthropogenic impact on the vegetation, using a combination of pollen data, sediment data, and numerical analyses, climatic and anthropogenic change frequently occur simultaneously. The resulting pollen signal is a result of the combination of climatic and anthropogenic shifts, which is difficult to properly analyse without the aid of numerical analysis. It remains difficult to discern whether climate drove anthropogenic change during these instances.

8.3. Possibilities for further research

The specific concerns of the research have been discussed in earlier chapters. The present chapter presents suggestions for further research aimed at resolving the present issues and further enlarging the available knowledge concerning the landscape development of the territory of Sagalassos and the wider area of the SW Taurus Mountains.

8.3.1. Palynological research in the territory of Sagalassos

The time interval from the Late Roman Imperial period to the present has been studied using the analysis of two independent pollen and sediment records located in two strikingly different locations within the territory of Sagalassos, and the differences in the pollen and sediment signals illustrate how differently the vegetation and physical environment can react to the same environmental (climatic or anthropogenic) change from basin to basin. This difference in response, as well as the findings of chapter 6 of this dissertation, indicates how important it is to obtain data from multiple records in order to properly distinguish between local and regional environmental phenomena. It would therefore be advisable to continue the search for additional locations within the territory of Sagalassos from which reliable pollen records covering the post-BO Phase interval may be obtained. Additionally, collecting additional pollen data from time periods not yet covered by multiple pollen records may prove worthwhile. In the case of the territory of Sagalassos, this is the period preceding the Iron Age. This period is covered by three pollen cores, but these are all located within a short distance from one another, in the Ağlasun Çay valley (Vermoere 2002).

8.3.2. Quantitative landscape reconstruction in the territory of Sagalassos

As stated in chapter 6, the model fit for the taxa already included in the analyses would be greatly improved if more sample points would be collected. Apart from this, there is also a need to expand the amount of species included in the ERV analyses. Currently no PPE values are available for deciduous tree species other than *Quercus coccifera*. Although *Salix* and *Populus* were originally included in the taxa used for the ERV analyses, they proved to be too rare in the vicinity of the sample sites to yield usable pollen and plant abundances. It is suggested that future sample points should also be located in the Ağlasun Çay valley, where a greater abundance of planted deciduous tree species occurs. When attempting to reconstruct the vegetation of a post BO-Phase landscape, then information concerning *Pinus*, *Quercus*, and Asteraceae should already be enough, although data on riparian tree species are also preferred in order to more accurately reconstruct the landscape on and around a sample site in a wetland or marsh. When attempting to reconstruct the BO-Phase landscape, however, it is vital to also obtain data concerning the important cultivated tree species; *Castanea*, *Juglans*, and *Olea*, while for the period preceding the first signs of human impact, *Quercus cerris* is important, although it is doubtful whether *Q cerris* is currently abundant enough to produce reliable PPE's.
Apart from estimating PPE's based on a single large map of the entire study area, it would also be informative to establish PPE's from each valley basin separately and analyse the differences in PPE estimates and their causes. However, as of yet, no usable high resolution vegetation maps are available for the territory of Sagalassos apart from that of Gravgaz.

8.3.3. Palynological research in SW Turkey

Notwithstanding the incredible amount of work that has been done previously during the 1970's and 1980's at the SW Turkish lakes, and the mass of information these early studier revealed concerning the main changes in vegetation throughout the entire Holocene, the results of this dissertation illustrate how much more information can be collected from pollen data, than has now been the case. Revisiting some of the locations of earlier palynological research and analysing the data using the same proxies (charcoal, NPP's, and sedimentological analysis in addition to pollen) will vastly increase our understanding of the timing, nature, and driving forces behind vegetation change.
It would be a tremendous addition to the available understanding of Holocene vegetation dynamics if efforts towards the quantitative reconstruction of the landscape would be expanded outside of the territory of Sagalassos.
While the individual terrestrial pollen records, such as those collected within the territory of Sagalassos, provide a good proxy to reconstruct the vegetation on a local (basin by basin) scale, the Anatolian Lake District provides an opportunity for a quantitative reconstruction on a more regional scale. The RSAP of a pollen record increases as basin size increases. This is because the proportion of pollen transported from longer distances would increase as well (Prentice 1985; Sugita 1998). Pollen data from large basins therefore record the surrounding vegetation as homogenous and thus are more suitable for reconstruction of regional vegetation and climate (Sugita 1994).

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Appendix 1

Preparing modern and fossil pollen slides

A1.1. Extracting the palynomorphs

Rather than using the standard approach of pollen extraction from a sediment core, described in Faegri and Iversen (1989), or Bastin (1978), fossil pollen was extracted using an adaptation of a technique developed by Annemarie Philip of the University of Amsterdam. This method is adapted to extract pollen from especially clayey samples, while not using hydrofluoric acid and therefore with no need for the special safety precautions and equipment needed to work with this dangerous substance. The further adaptations to the method made at the KU Leuven include the replacing of Bromoform, a confirmed animal carcinogen, with a low-toxicity heavy liquid called LST (http://www.chem.com.au/products/lstheavyliquid/). The method used to extract the pollen is summarized in the text below. All chemicals used must be of a “pro analyse” quality.

About one cc of material is collected from the middle of a sub-sample, weighed and then soaked in a solution of 10% or 20% Na-Pyrophosphate. If the sample is dry, it must be crushed with a hammer before being deposited in the Pyrophosphate solution. Refrigerated samples can be deposited as they are. The samples should then be left soaking in the solution until the samples have completely fallen apart. Samples that are kept wet and refrigerated only need an hour, while very dry samples are best kept in the solution overnight. After having soaked in the solution for the appropriate time, the solution is boiled for about one hour while being regularly gently stirred. This prevents the sediments from sticking to the bottom of the beaker.

After boiling, the solution is sieved (+/- 200 µm mesh size) to remove larger organic and inorganic material. The residue in the sieve can then be used to collect additional macro remains and charcoal particles for analysis or radiocarbon dating. The sieved solution is then poured into a centrifuge tube, to which a known number of *Lycopodium* spores has been added. The addition of a known number of *Lycopodum* spores enables the researcher to properly calculate the concentration of palynomorphs in the sample.

The tubes containing the sieved sample and the *Lycopodum* spores are mixed with a vortex until all sediments are in suspension in the pyrophosphate solution, and then centrifuged at 4500 rpm for two minutes. Sand and organic material will be pushed to the bottom of the tube, while a portion of the fine clay fraction will remain in suspension in the pyrophosphate solution. After centrifuging the samples, the supernatant is disposed of and the tubes are refilled with distilled water. This procedure is repeated until the suspension contains little or no clay after centrifuging. When most of the clay is removed, the samples are dehydrated by repeating the previous step three times, but using 95% acetic acid, rather than demineralised water.

After dehydrating, the samples are ready for acetolysis, a process which destroys cellulose and which gives the fossil pollen grains and NPP’s a yellow to brown colour. The acetolysis is carried out by filling the tubes containing the dehydrated residue, with a mixture of 9 parts acetic anhydride and one part sulphuric acid, vortexing the tubes and then boiling the samples for 10 minutes. After boiling, the tubes are cooled in water and then centrifuged, after which the supernatant is removed.

After the acetolysis, the residues are washed four times by adding distilled water, vortexing, and centrifuging the tubes for two minutes at 4500 rpm. The process is then repeated three times, using Ethanol, rather than water.

Although the clay has been removed prior to the acetolysis, the sand particles present in the sample also need to be removed. This is done by adding circa one or two cc of LST s.g. 2 to the residues, vortexing, and centrifuging the samples for 10 minutes at 1500 rpm. The sand is pushed to the bottom of the tube while the organic particles form a collar on top of the LST solution.

This collar is poured into a fresh centrifuge tube, filled two-thirds with ethanol, after which the new tubes are centrifuged for two minutes at 4500 rpm. The density of the LST/ethanol mixture is low enough for the organic material to be pushed to the bottom. After centrifuging, the LST and alcohol supernatant is removed. Several drops of glycerine are added to the residue, after which the tubes are stored overnight in a stove at a temperature of 40 to 60 degrees Celsius, evaporating the remaining Ethanol.

A1.2. Preparing samples from moss polsters

In order to prepare pollen samples from moss polsters, the collected clumps of moss are gently boiled for c. 1 hour in a 10% KoH solution, while occasionally stirring the moss. After boiling, the sample is sieved (+/- 200 µm mesh size), taking care to thoroughly rinse the moss in the sieve with demineralised water. The sieved solution is then, depending on the amount of sand/mud in the solution, either centrifuged and washed as described in section A1.1, or immediately dehydrated with acetic acid and put through the acetolysis process. After acetolysis, the samples are treated in the same way as the regular soil samples, described in section A1.1.

A1.3. Mounting and preparing microscopic slides

After having been placed in the stove overnight, the residues in the tubes consist of pollen, NPP's, charcoal particles and generic organic material in glycerine. Pollen slides are created by using a pipette to deposit a portion of this putty onto a microscope slide. The slide is then heated over an alcohol flame and a small amount of paraffin is applied to the slide, and cover slip is placed on top of the putty and molten paraffin. After cooling, the paraffin will act as glue, holding the cover slip and the sample in place on the slide. Mounting the palynomorphs in glycerine allows for the palynomorphs to be pushed about and turned over by applying some pressure to the cover slip.

Appendix 2

Raw pollen and NPP counts: Bereket basin and Gravgaz marsh (digital only)

The raw pollen data are included in the online-only package. The data include all pollen counted, also rare types not included in numerical analyses and pollen diagrams. It excludes unknown pollen however.

Appendix 3

Raw sedimentological data (digital only)

The data data are included in the online-only package and are presented in an *.xls file. The spreadsheet presents an overview of organic matter content (wt %), calcium carbonate content (wt %) and other detritic material content (wt %) for the Gravgaz marsh and Bereket basin cores. The Gravgaz marsh record is taken from Six (2004).

Appendix 4

PCA axis 1 and 2 scores (digital only)

The data data are included in the online-only package and are presented in an *.xls file. The spreadsheet presents the PCA axis 1 and 2 scores for the Gravgaz marsh and Bereket basin datasets. The ages of the samples are calculated using linear inter- and extrapolation based on the available radiocarbon dates.

Appendix 5

Pollen counts of the modern pollen samples used in the ERV analyses.

All counts were recalculated to a total number of 500 pollen grains in order to facilitate the statistical analyses.

Site	Apiaceae	Asteraceae	Caryophyllaceae	Poaceae cerealia	Chenopodiaceae	*Juniperus sp*	*Pinus spp*	*Plantago lanceolata tp*	Poaceae	*Quercus coccifera*
RS01	2	14	2	79	8	1	258	12	14	109
RS03	4	14	0	72	10	2	203	4	94	98
RS09	4	11	1	9	13	32	324	2	61	44
RS10	3	12	2	8	15	23	344	1	56	38
RS25	1	1	1	2	1	0	45	1	5	445
RS26	2	7	5	4	11	4	247	4	165	51
RS27	2	20	2	4	2	2	367	0	79	22
RS28	0	2	2	5	11	2	421	0	29	29
RS34	1	1	2	13	3	0	448	0	25	10
RS53	0	13	6	6	1	3	426	1	20	25
RS55	3	9	1	13	12	3	319	1	40	99
RS58	10	18	8	18	8	3	242	2	48	142
RS59	2	9	8	5	7	3	242	1	43	181
RS62	1	1	1	2	1	20	322	2	13	138
RS63	1	13	5	25	6	9	243	16	19	164
RS64	3	6	1	8	12	2	162	1	49	257
SA29	14	18	3	0	63	0	92	0	9	301
SA01	37	194	10	2	13	3	39	3	14	188
SA02	31	294	45	0	43	9	55	0	11	12
SA04	9	271	3	5	14	0	91	0	14	94
SA07	32	75	11	27	118	4	4	0	52	175
SA11	15	320	5	20	38	19	43	0	10	31
SA14	7	13	2	3	16	0	439	1	2	18
SA30	91	132	21	23	114	6	68	0	20	27
SA33	24	126	53	5	157	34	41	0	14	46
SA67	11	64	0	124	4	14	84	4	59	137
BKT2	0	36	28	13	0	8	208	19	177	11
SA06EP01	8	23	11	26	15	222	154	0	38	4

Appendix 6

Distance-weighted plant abundance data (digital only)

The data data are included in the online-only package and are presented in *.csv spreadsheets. The number in the filename indicates the sample site. The rows correspond with increasing distance from the sample site (Step size = 10 m for the dataset using 22 sample sites. Step size = 2 m for the dataset using 14 sample sites). The first column indicates the distance from the sample site. The other columns correspond with the selected plant taxa.

Low-resolution map (22 sample sites)			High-resolution map (14 sample sites)		
File number	Sample site	Taxa names (left to right)	File number	Sample site	Taxa names (left to right)
1	RS62	Apiaceae	1	RS40	Apiaceae
2	SA29	Asteraceae	2	RS41	Asteraceae
3	SA30	Caryophyllaceae	3	RS42	Caryophyllaceae
4	SA67	Poaceae cerealia	4	RS43	Poaceae cerealia
5	SA07	Chenopodiaceae	5	RS09	Chenopodiaceae
6	SA04	*Juniperus*	6	RS10	*Juniperus*
7	SA02	*Pinus*	7	RS11	*Plantago*
8	RS09	*Plantago*	8	SA01	Poaceae
9	RS26	Poaceae	9	SA02	*Quercus coccifera*
10	RS63	*Quercus coccifera*	10	SA04	
11	RS55		11	SA05	
12	RS34		12	SA06	
13	RS03		13	SA09	
14	RS01		14	SA11	
15	SA01				
16	RS25				
17	RS28				
18	RS64				
19	RS58				
20	SA05				
21	SA06				
22	SA21				

Appendix 7

Pollen and NPP diagrams sorted according to the CA and NJ results

In order to illustrate which pollen type drive the dynamics through time of each CA and NJ-derived PDVP, this appendix reproduces the original pollen diagrams, but with the taxa sorted according to the PDVP divisions. As no NJ analysis was performed on the NPP data, this part of the original pollen diagram is omitted from figures a7.3 and a7.4.

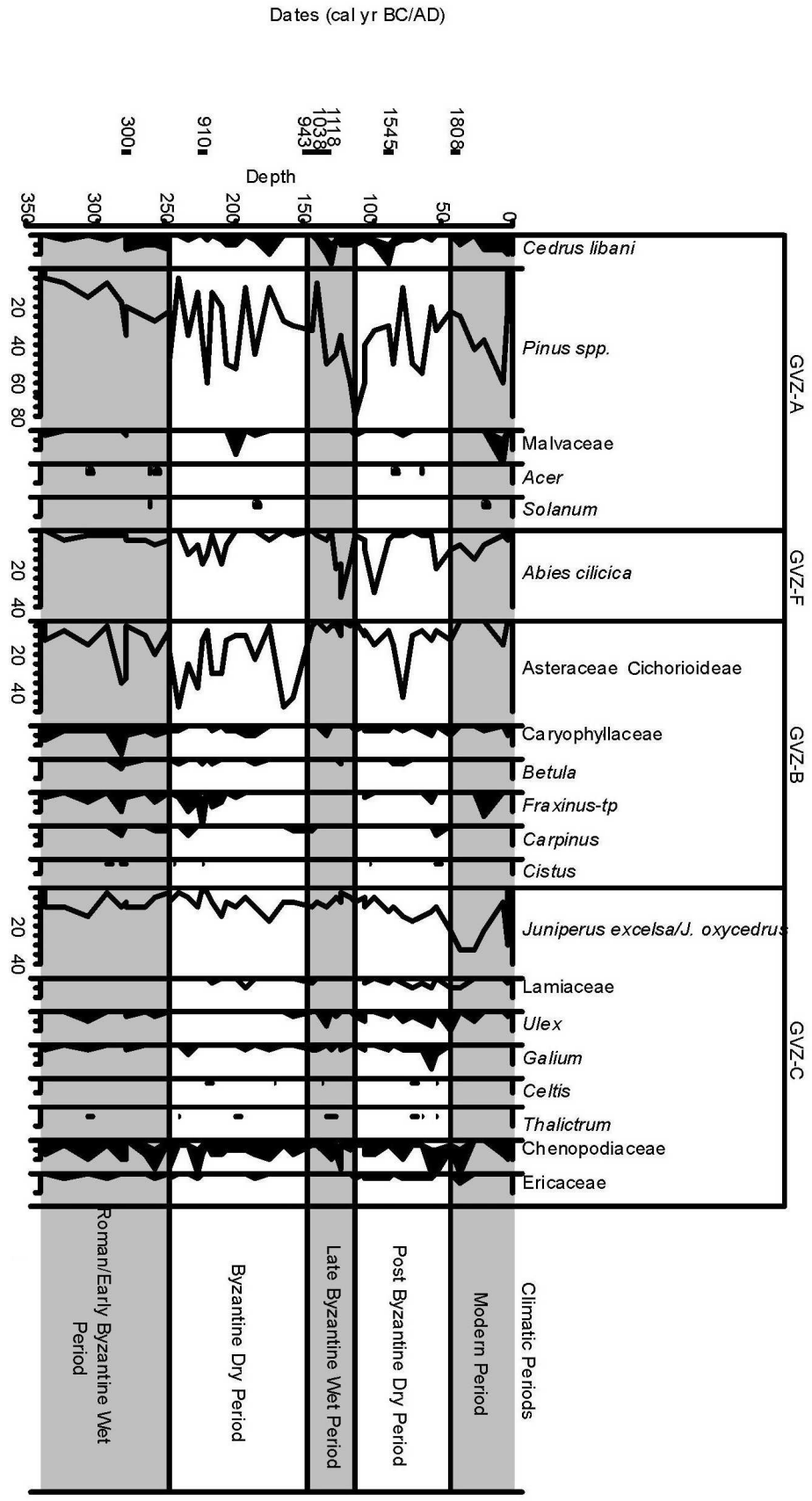

Fig. a7.1a. Percentage pollen and non-pollen palynomorphs diagrams for core SA06EP1 (Gravgaz marsh), showing the taxa used for the numerical analyses. The taxa are grouped per Cluster Analysis-derived PDVP, as used in chapter 4 of this thesis. Cultivated species are shown separately, as they were kept separate during the numerical analyses. The black curves indicate a 4-fold exaggeration of the pollen signal.

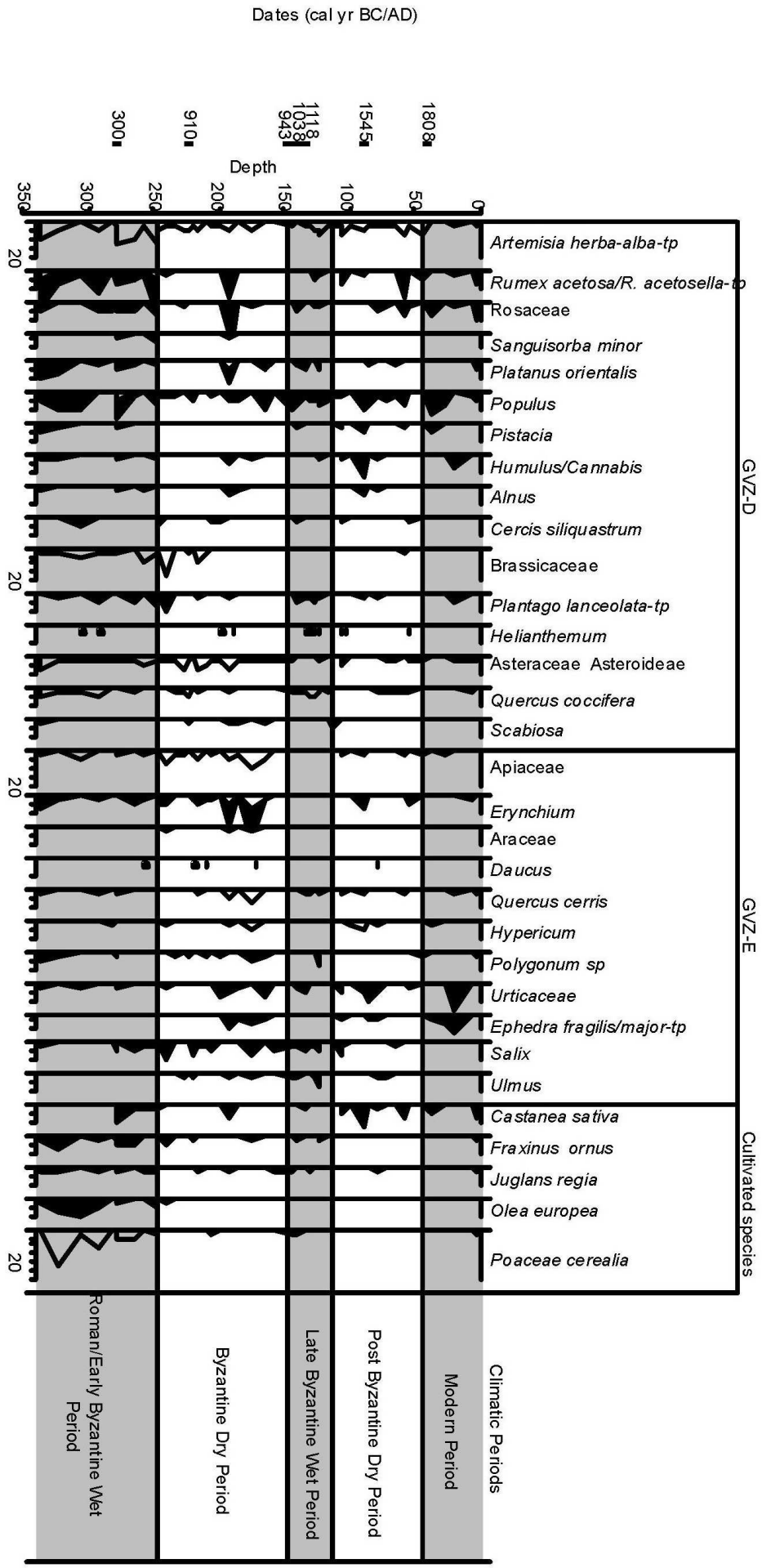

Fig. a7.1b. Same as a7.1a.

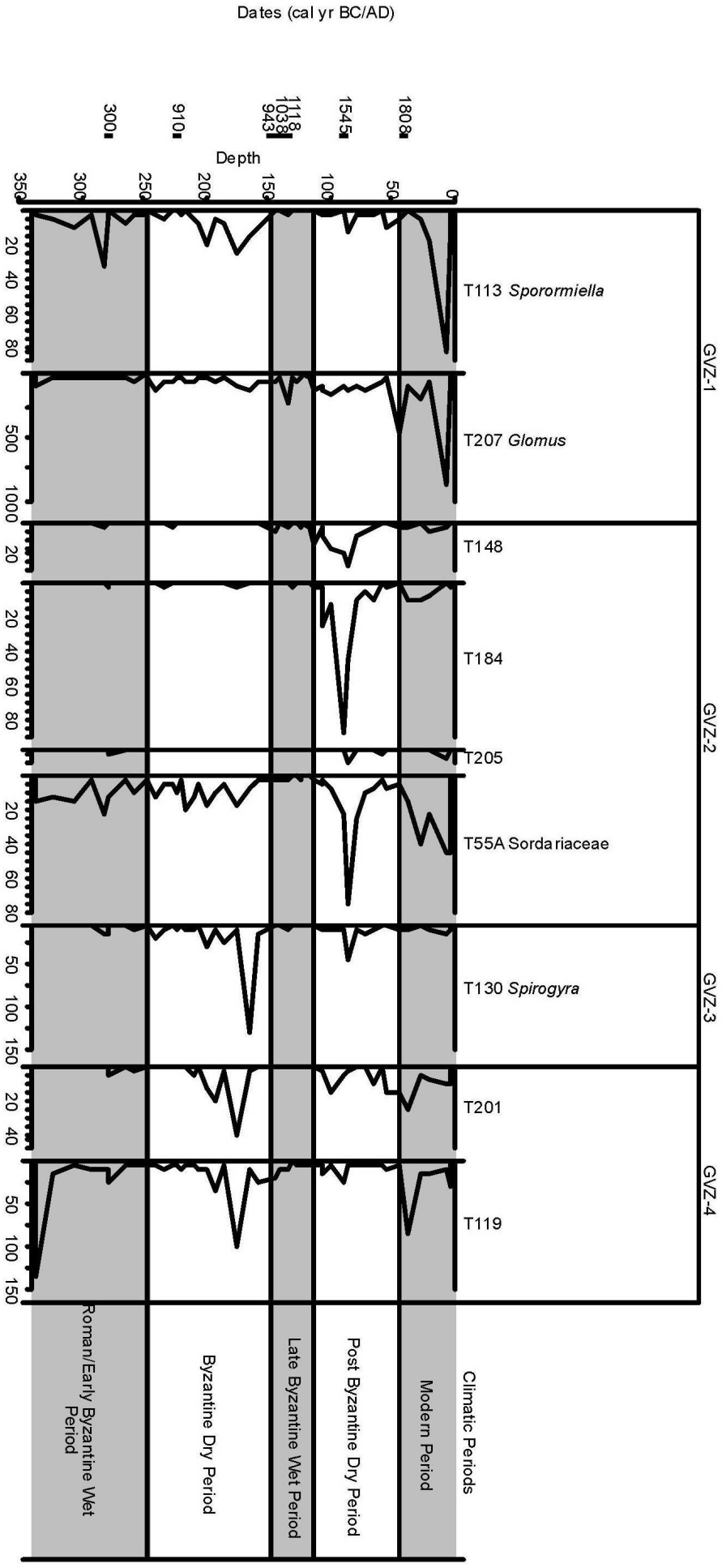

Fig. a7.1c. Same as a7.1a.

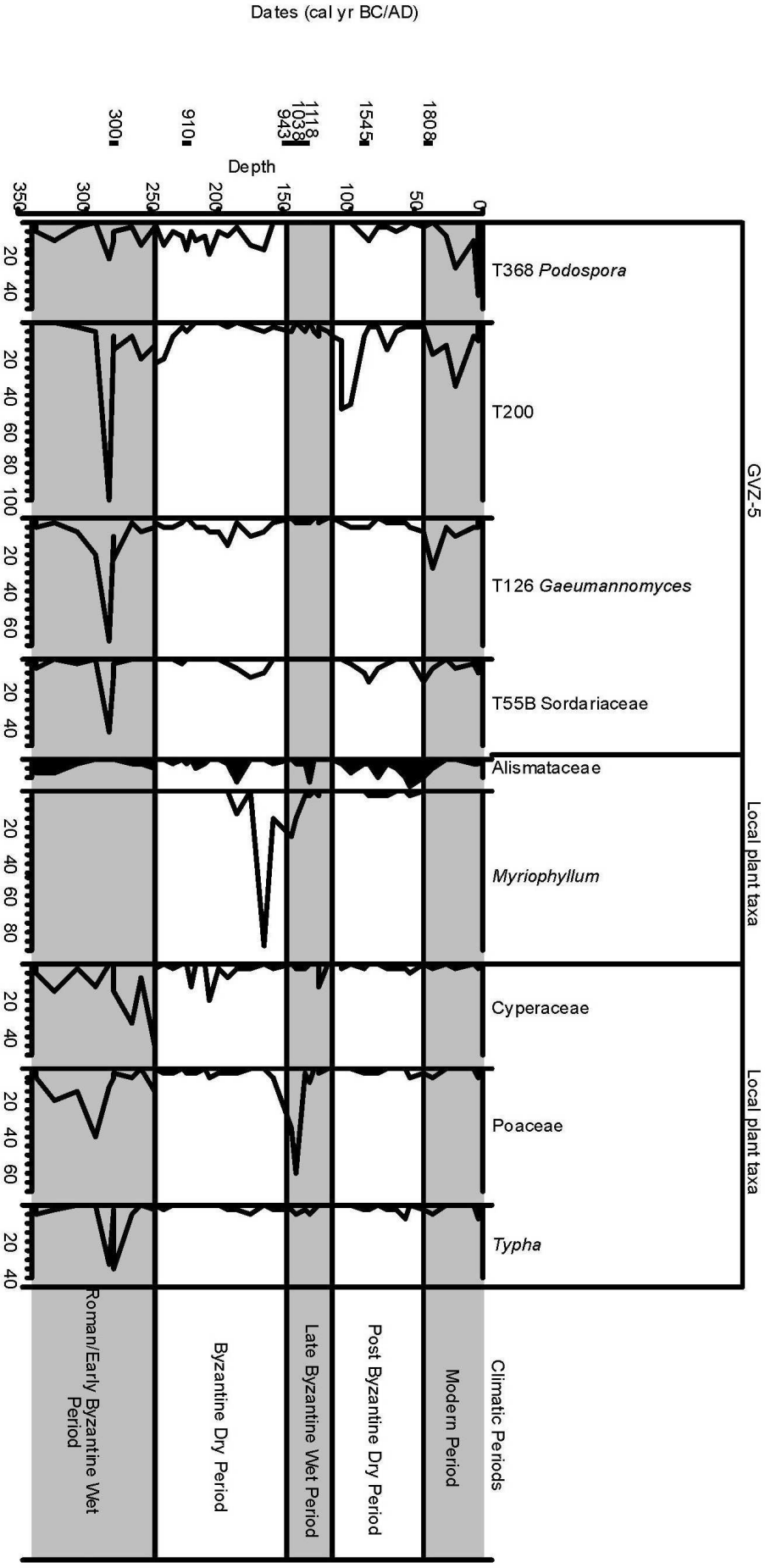

Fig. a7.1D. Same as a7.1a.

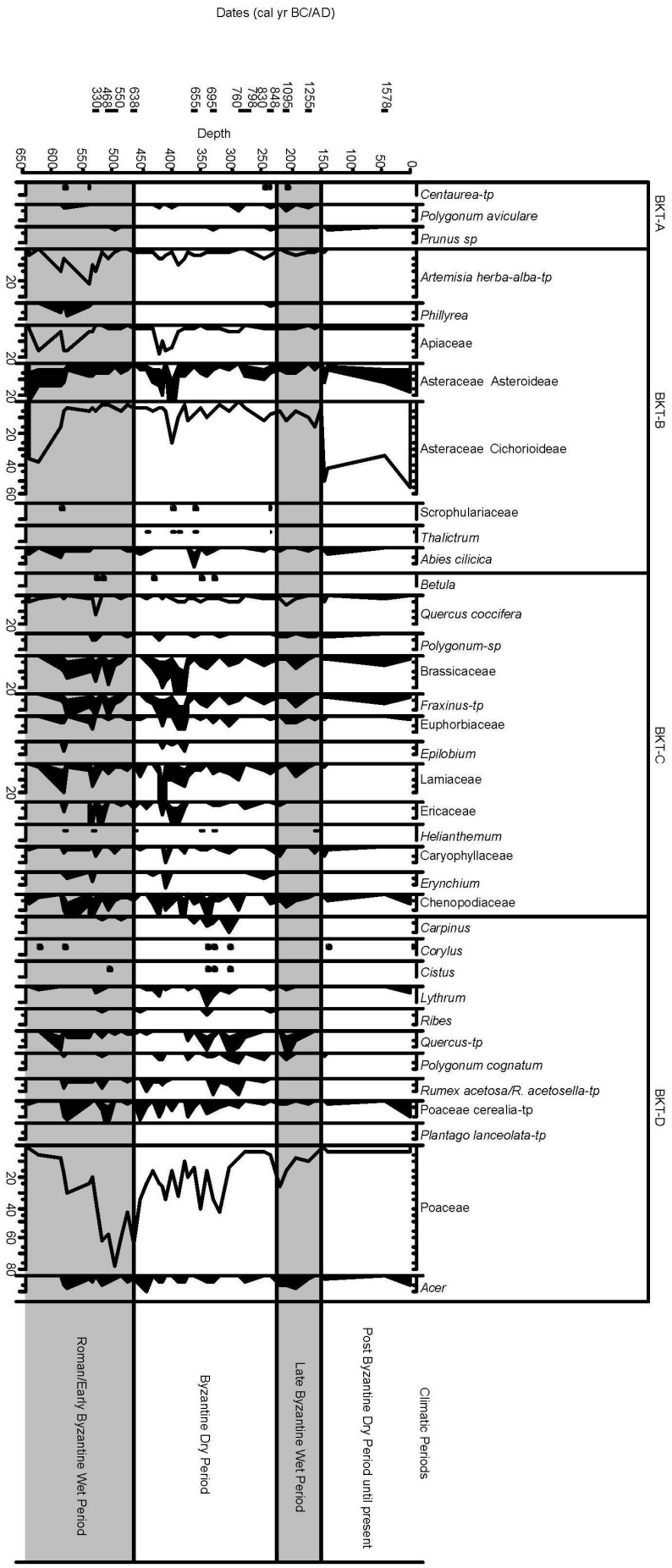

Fig. a7.2a. Percentage pollen and non-pollen palynomorphs diagrams for core SA09JBDrill02 (Bereket basin), showing the taxa used for the numerical analyses. The taxa are grouped per Cluster Analysis-derived PDVP, as used in chapter 4 of this thesis. Cultivated trees are shown separately, as they were kept separate during the numerical analyses. The black curves indicate a 4-fold exaggeration of the pollen signal.

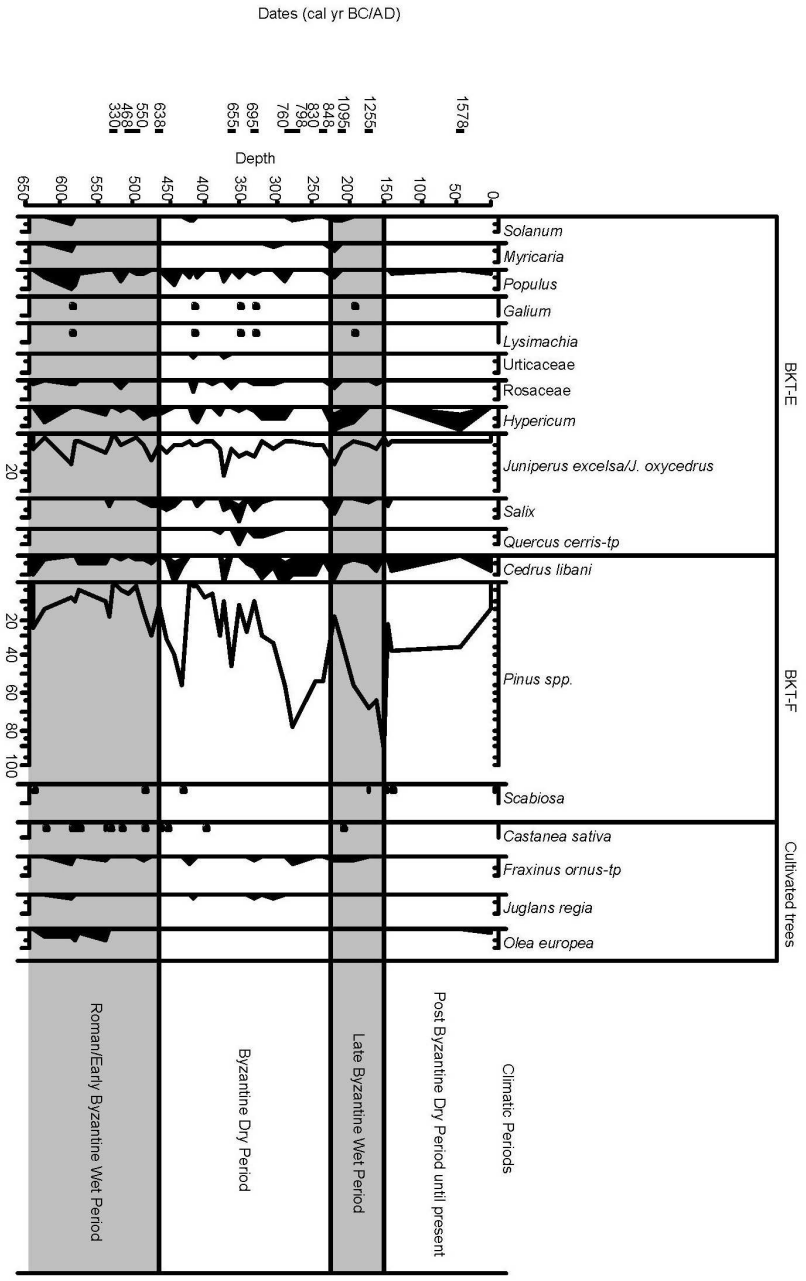

Fig. a7.2b. Same as a7.2a.

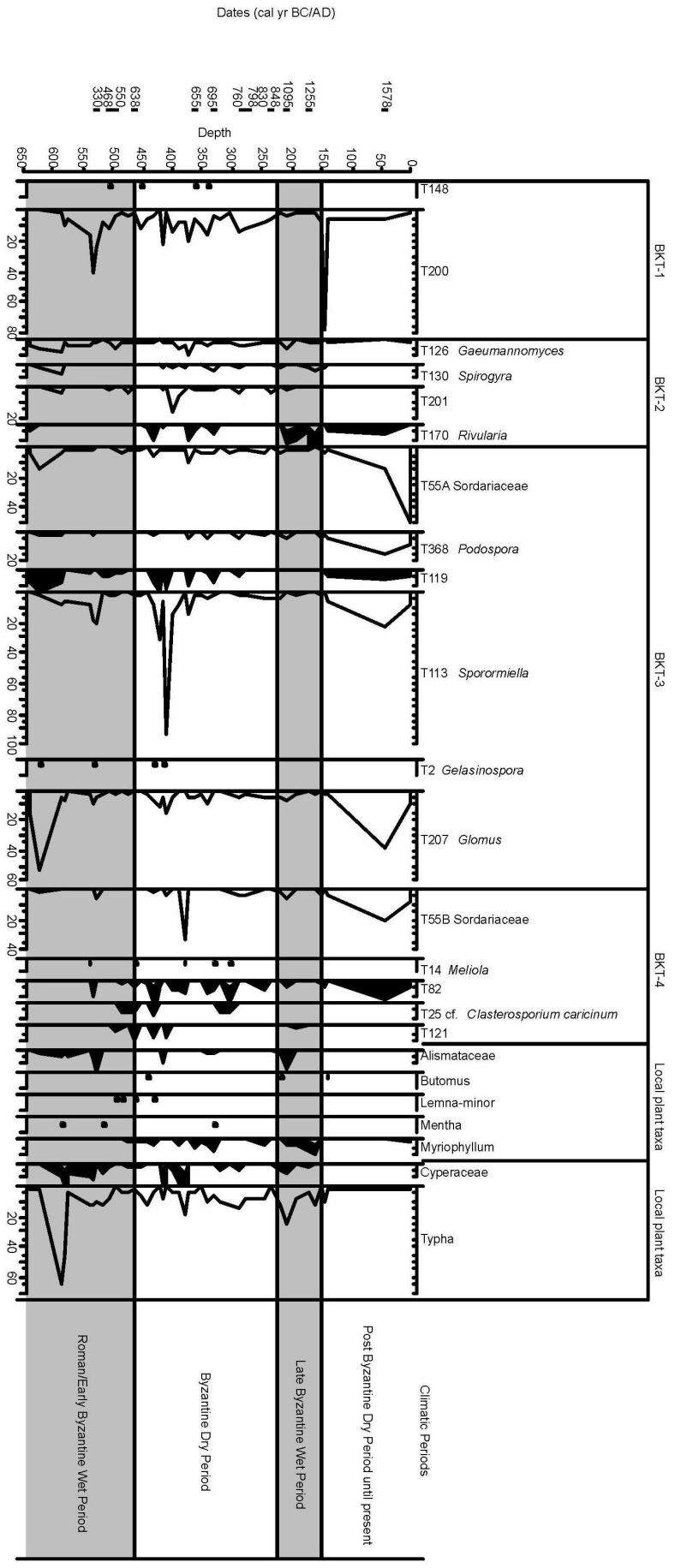

Fig. a7.2c. Same as a7.2a.

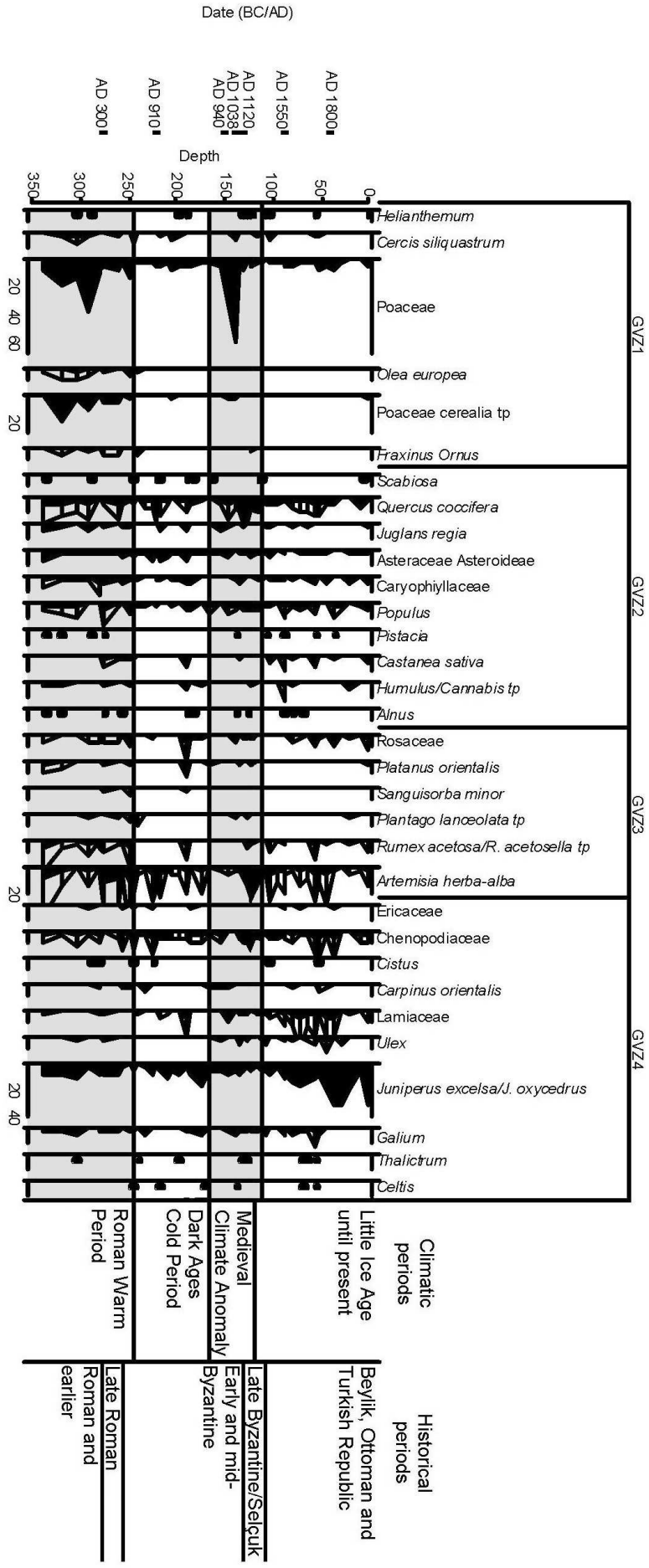

Fig. a7.3a. The individual pollen percentage curves for core SA06EP1 (Gravgaz marsh), showing all pollen taxa used in the numerical analysis, grouped according to the neighbour Joining-derived PDVP percentage values, as used in chapter 5 of this thesis. Curves for NPP's are not displayed as they were not used in a NJ analysis.

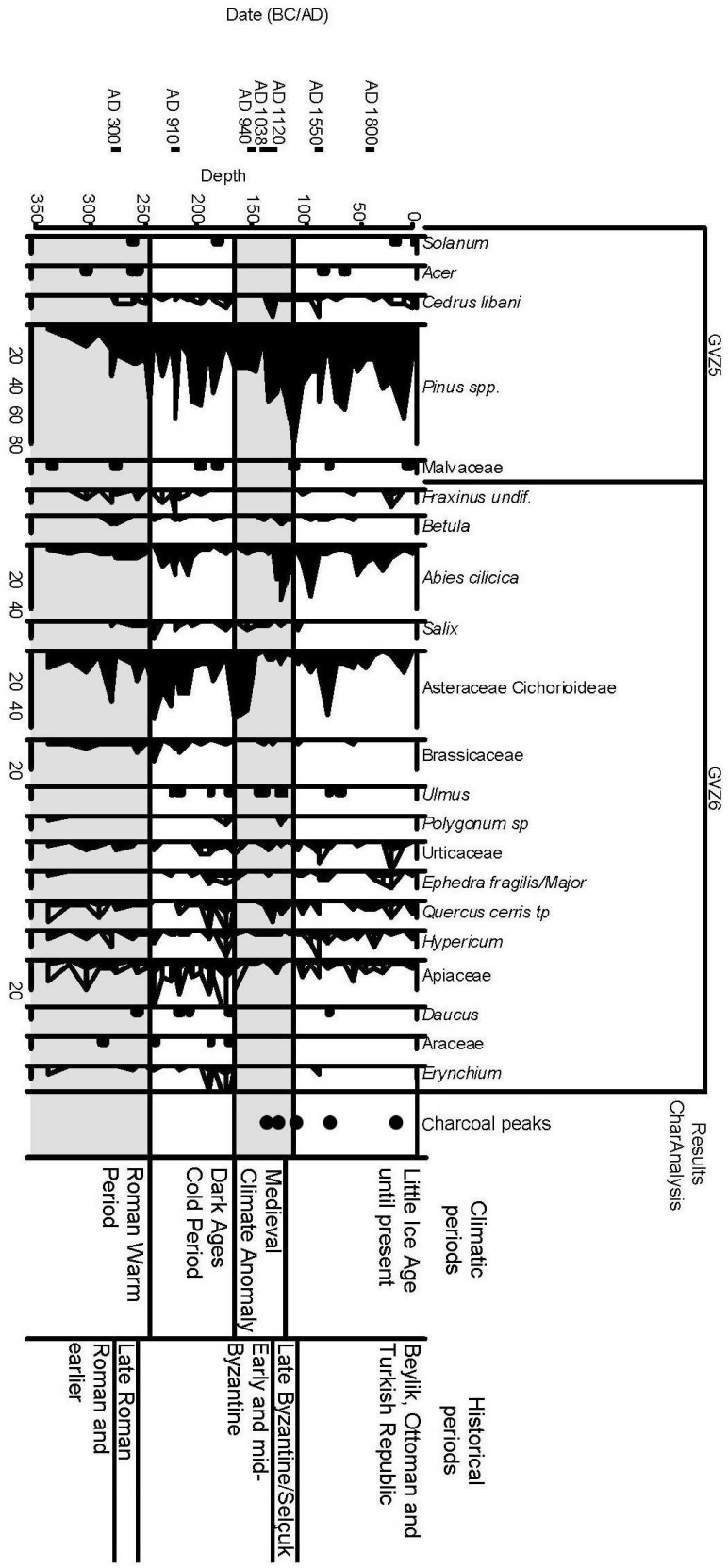

Fig. a7.3b. Same as a7.3a.

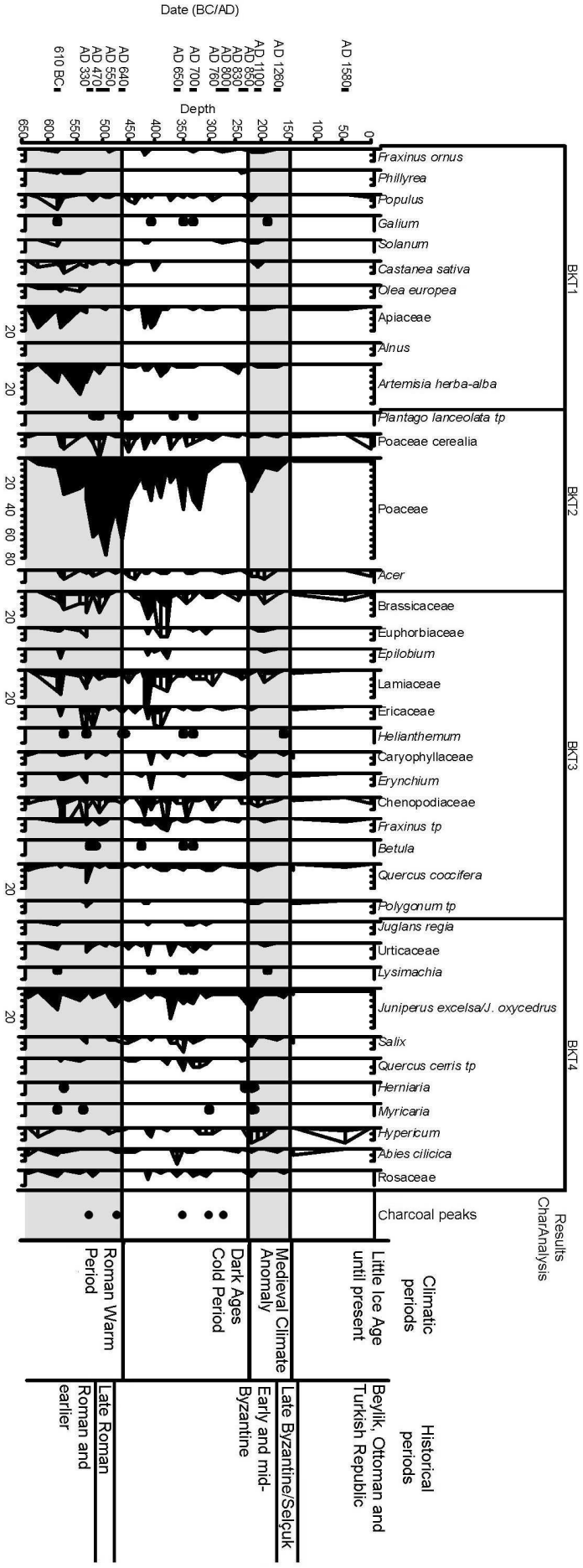

Fig. a7.4a. The individual pollen percentage curves for core SA09JBDrill02 (Bereket basin), showing all pollen taxa used in the numerical analysis, grouped according to the neighbour Joining-derived PDVP percentage values, as used in chapter 5 of this thesis. Curves for NPP's are not displayed as they were not used in a NJ analysis.

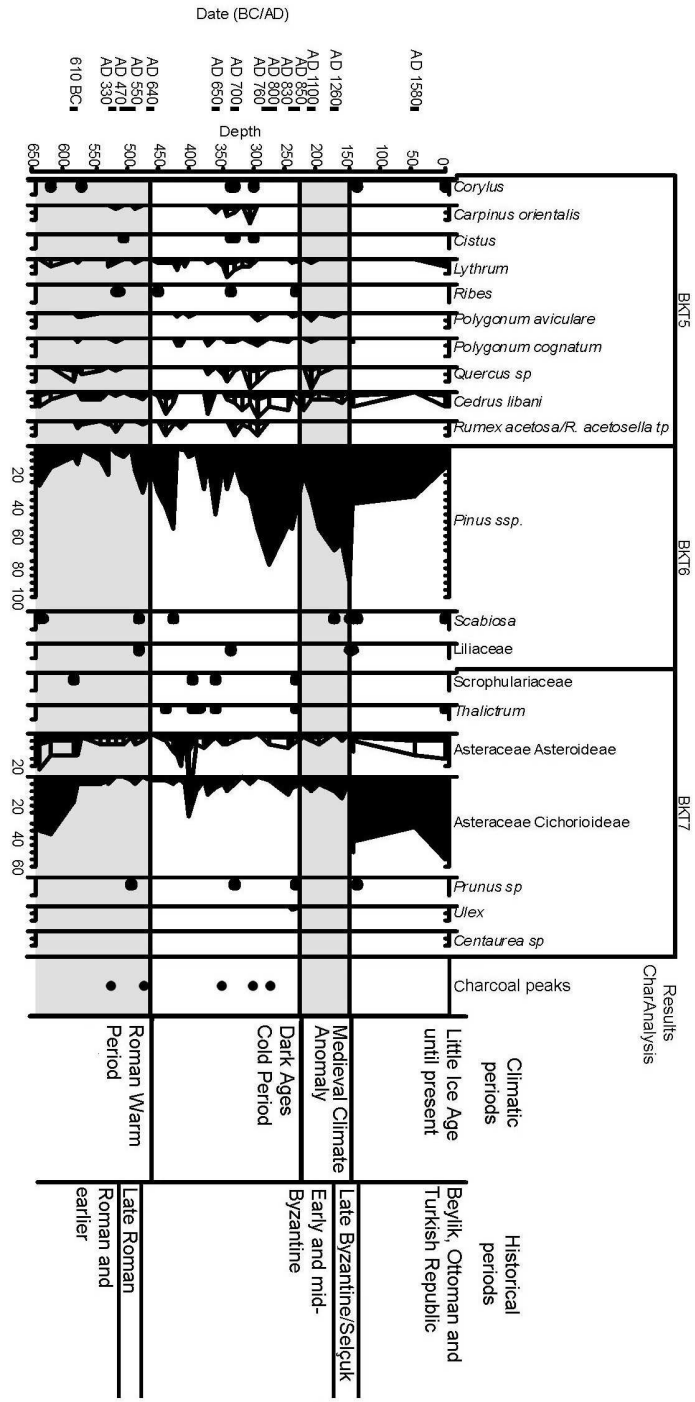

Fig. a7.3b. Same as a7.3a