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A comparison between modern pollen spectra of moss cushions and Cundill pollen traps

Implications for the interpretation of fossil pollen data from Southwest Turkey

MARLEEN VERMOERE, LEO VANHECKE, MARC WAELEKENS and ERIK SMETS

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Pollen spectra of 23 Cundill pollen traps from 23 different sampling sites in Southwest Turkey are compared with the corresponding pollen spectra of moss cushions from the same sites. The Cundill pollen traps represent the modern pollen rain data from one year whereas the moss cushions represent the pollen rain of several years. The comparative study reveals some main differences between the two pollen entrapment media. The one-year entrapment medium (pollen trap) appears to be more sensitive for local (relevé area 10 × 10 m) and regional (100–500 m, or a few kilometres for *Olea europaea*) vegetation. Pollen spectra of moss cushions are dominated by high pine pollen percentage values and hardly sense fine vegetation structures. The conclusion of this comparative modern pollen study allows to interpret fossil sediment spectra from the Near East in a more critical way. It is concluded that one should preferably sample rapidly deposited sediments for palynological analyses, as the resulting high-resolution pollen diagrams will be most informative about the former vegetation patterns.

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Since 1995, palynological studies have been carried out within the frame of the interdisciplinary project 'The Economy and Ecology of Sagalassos'. Sagalassos is an archaeological site situated in the Pisidian Lake District (Southwest Turkey), occupied from prehistoric times until the 7th century AD. The Roman territory of Sagalassos embraces approximately 1800 km², situated between the cities Burdur, Isparta and Bucak, and the Aksu river (Fig. 1). Several deposits (clay sediments in Canaklı, peat sediments in the marsh of Gravgaz, travertine profiles in the valley of Başköy) (Fig. 1) have already been palynologically analysed in order to give a picture of the former vegetation from the early Holocene till now (Vermoere et al. 1999, Vermoere et al., 2000).

It remains a difficult task to interpret the fossil pollen data from the territory of Sagalassos in terms of vegetation patterns. Since 1997 modern pollen studies were carried out in the same area in different vegetation types to study the pollen production and dispersal of the plants in the different vegetation types. This information can help interpreting fossil pollen data more exactly (Wright 1967).

In Southwest Turkey, unlike in Europe and in America, modern pollen studies have rarely been carried out, and the results are seldom efficiently extrapolated to fossil pollen diagrams. Only a few studies discuss the pollen content of moss cushions/surface samples from different vegetation types (van Zeist et al. 1975, Bottema & Woldring 1990, 1995, Eastwood 1997).

Two different approaches were used in this study to measure the modern pollen precipitation: 1) moss cushions

were sampled as they act as natural pollen collectors; 2) pollen traps were placed at the surface of the soil for the period of one year. Several designs of pollen traps are known (Cundill 1986, Tauber 1974). In this study it was preferred to use the Cundill pollen trap (Cundill 1986, 1991, 1998), as this type of pollen trap is easy to construct. The Cundill pollen trap consists of a plastic flower pot (10 cm diameter) in which a coffee filter filled up with acetate wool is placed. Finally, a metal wire mesh on top of the construction keeps the acetate wool in the flower pot. The acetate wool acts as an artificial pollen-collecting medium, and can easily be dissolved by acetone.

This paper presents the results and global comparison of 23 pollen traps and moss cushions originating from 23 different places in the territory of Sagalassos. The pollen trap data represent the pollen precipitation of one year from the summer of 1997 until the summer of 1998.

A few studies comparing different types of pollen entrapment are already known. A pilot study in Scotland concerning the pollen influx values in mosses (green and brown shoots, and moss humus) on the one hand and pollen influx values in Cundill pollen traps on the other hand has already been discussed by Cundill (1991). The study of this author reported several inconsistencies between the pollen contents of mosses and Cundill traps. Spieksma et al. (1994) carried out a similar study, comparing the pollen content of a volumetric air sampler with the pollen content of moss cushions. Again, the latter study reports differences between both pollen entrapment media.

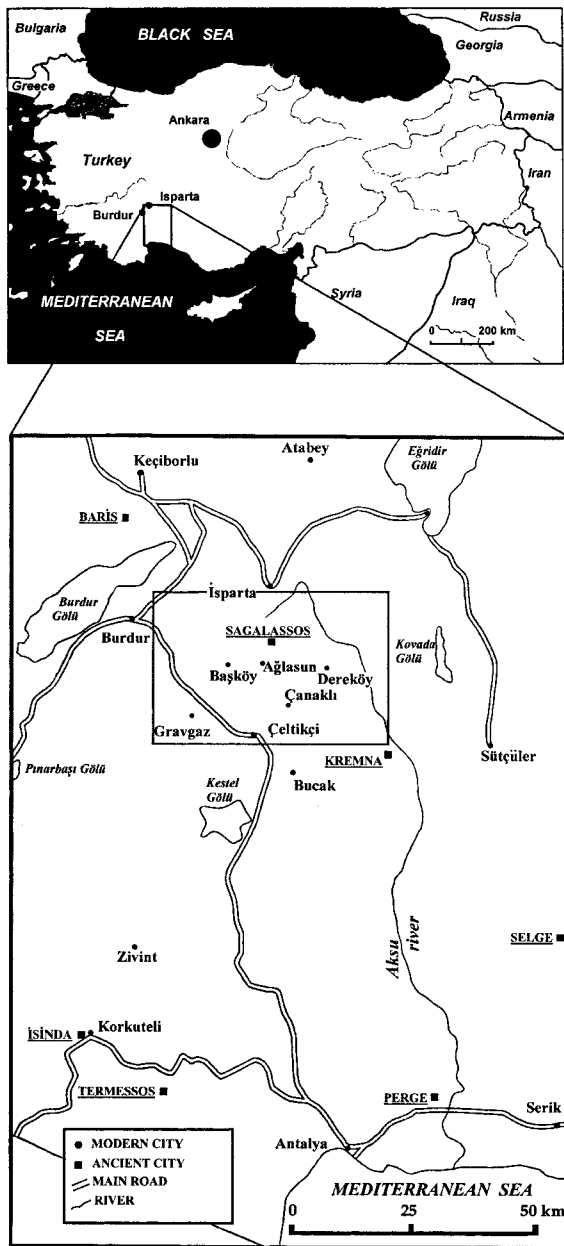


Fig. 1. Location of the study area in Turkey. The rectangle in the detailed map of the Pisidian Lake District represents the area largely covered by the forest map shown in Fig. 2.

Climate and present vegetation in the study area

Although the Mediterranean is situated about 100 km to the south of the study area, the climate is still considered as Mediterranean, as it is characterised by pronounced winter precipitation and summer dryness (Paulissen et al. 1993). Climatic data from three villages in the territory of Sagalassos are summarised in Table I.

The assumed natural vegetation of the area as proposed by Frey & Kürschner (1989) is mixed broad-leaved and coniferous woodland resistant to cold temperatures. According to van Zeist et al. (1975), the area around Sagalassos is located in the oromediterranean vegetation zone. This

vegetation belt can be subdivided into two units. The lower unit, between 800 and 1200 m, is characterised by conifer forests of *Pinus brutia*, maquis (dominated by *Quercus coccifera* or *Juniperus excelsaloxycedrus*), and woodland of deciduous oak trees (*Q. cerris*, *Q. infectoria* and *Q. ithaburensis*). Other constituents of this lower unit are *Ostrya carpinifolia*, *Fraxinus angustifolia*, *Fraxinus ornus*, *Fontanesia philliraeoides* and *Styrax officinalis*. The higher unit, between 1200 and 2000 m, is characterised by natural vegetation of *Cedrus libani*, *Pinus nigra* and *Abies cilicica*. However, the present vegetation at this elevation is often deforested and degraded.

A forest map of the region (Ağlasun Orman İşletme Şefliği 1997) shows the location of natural and planted forests, maquis vegetation and agricultural areas (Fig. 2). Extensive forests of *Pinus brutia* are situated in the southeast of the territory of Sagalassos. A small remnant of mixed forest of *Pinus nigra* var. *pallasiana*, *Abies cilicica* and *Juniperus excelsa* occurs in the east of the area. Furthermore, remnants of a *Cedrus libani* forest are located in the south of the area (south and north of the village Canaklı). Also, degraded woodland of *Cedrus libani* forest is situated west of Sagalassos, facing the site. In the last few decades, the local Forest Service has tried to reforest large areas. For example, the area east of Sagalassos is reforested with young *Cedrus libani* and *Pinus nigra* trees. Remnants of natural *Quercus cerris* forest are present about 20 km west of Sagalassos (in the village of Kayaaltı) and about 15 km south of Sagalassos (near the village of Canaklı). Thus, the present landscape around Sagalassos is a very complex mixture of degraded and overgrazed maquis, extensively and intensively exploited agricultural areas, degraded herbaceous vegetation, steppe-like vegetation at high elevations, remnants of natural forests and reforested areas.

MATERIAL AND METHODS

For the modern pollen rain studies, as many as possible different vegetation types were visited in the territory of Sagalassos. Sixty-four places were examined: plant species were identified, vegetation cover was estimated and moss cushions were sampled. Moss cushions were sampled as a whole thus maximising the period represented by the pollen content entrapped by the mosses. All mosses used for this study grew on limestone or flysch rocks. The mosses were dry and brown at the moment they were collected. Pollen traps were placed at the soil level in 40 of the 64 places. A text written in Turkish, explaining the scientific aim of the pollen traps, was attached to the pollen traps in order to protect the traps from elimination by local inhabitants. Plant cover in the 64 sampling sites was estimated using the Braun-Blanquet scale adapted by Barkman et al. (1964). This was done in the summer of 1997 and in the spring of 1998. Latitude, longitude, elevation as well as inclination and exposition were recorded. Only 23 of the 40 pollen traps could be recovered after one year. Short vegetation descriptions of these 23 places, completed with geographic and topographic data are provided in Table II. The location of the 23 pollen traps in the territory of Sagalassos is shown in Fig. 2.

Scientific names used in this paper are given in conformity with the 'Flora of Turkey and the East Aegean Islands' (Davis 1965–1988).

Prior to usual chemical treatment, acetone was added to dissolve the acetate wool of the pollen traps. The laboratory procedure of Bastin (1978) was used afterwards to isolate pollen grains entrapped

Table I. Climatic conditions in the study area

Data from T. C. Başbakanlık Devlet Meteoroloji İşleri genel Müdürlüğü (1984).

Village	Altitude 25 L	Mean annual temperature °C	Mean temperature of warmest month °C	Mean temperature of the coldest month °C	Annual precipitation mm
Ağlasun	1150 m	10.7	20.7	1.4	844.2
Burdur	967 m	13	24.2	2.3	423
Bucak	850 m	13.9	25.4	3.5	679.8

by the pollen trap. The same method was used for the moss cushions. Sample residus were mounted in silicone oil. Identification of the pollen types was carried out using a reference-slide collection, pollen keys (Moore et al. 1991) and pollen floras (Reille 1992, & 1995). The modern pollen spectra histograms are constructed using TILIA and TILIA GRAPH (Grimm 1991). The results of the pollen analysis are expressed as percentage values of the pollen sum. The pollen sum includes trees (coniferous and broad-leaved species) and herbaceous plants. Pollen types of Poaceae (except cereals), wetland plants and indeterminable pollen grains as well as pteridophyte spores are excluded from the pollen sum. The exclusion of these types allows the comparison of both moss cushion and pollen trap spectra with fossil pollen data (using a similar pollen sum). A discussion of the 64 moss cushion spectra, and the comparison of the moss spectra with fossil spectra from a marsh core is provided by Vermoere et al. (accepted).

A multivariate approach (principal components analysis) is used to compare the 23 pollen trap spectra with the corresponding 23 moss cushion spectra. Principal components analysis (PCA) is one of the ordination procedures that reduces the multidimensional

character of a data set into a few dimensions (defined by principal components) with a minimal loss of information (Hair et al. 1998). Principal components scores of the pollen spectra as well as loadings for the variables can be positioned on the main principal components in an ordination plot. The distances between the sample scores approximate the Euclidian distances between the samples in the multidimensional space (Lamb 1984). PCA has been frequently applied to pollen data sets as the analysis is easy to implement on large data sets and the results can be displayed graphically (e.g. Caseldine & Gordon 1978, Ritchie & Yarranton 1978, Prentice 1980, MacDonald & Ritchie 1986). In this study, principal components analyses are carried out both for the two separate modern pollen data sets (Cundill trap pollen spectra and moss pollen spectra), and for the combined data set (data set of both Cundill trap spectra and moss spectra). Prior to these principal components analyses pollen types were merged into 15 (indicator) groups to present the results in a more comprehensive way. These groups are (1) Eumediterranean indicators (*Olea europaea*, *Pistacia terebinthus*, *Myrtus communis* and *Ostrya carpinifolia*), (2) the major maquis shrub constituents (*Juniperus* and *Quercus coccifera*), (3)

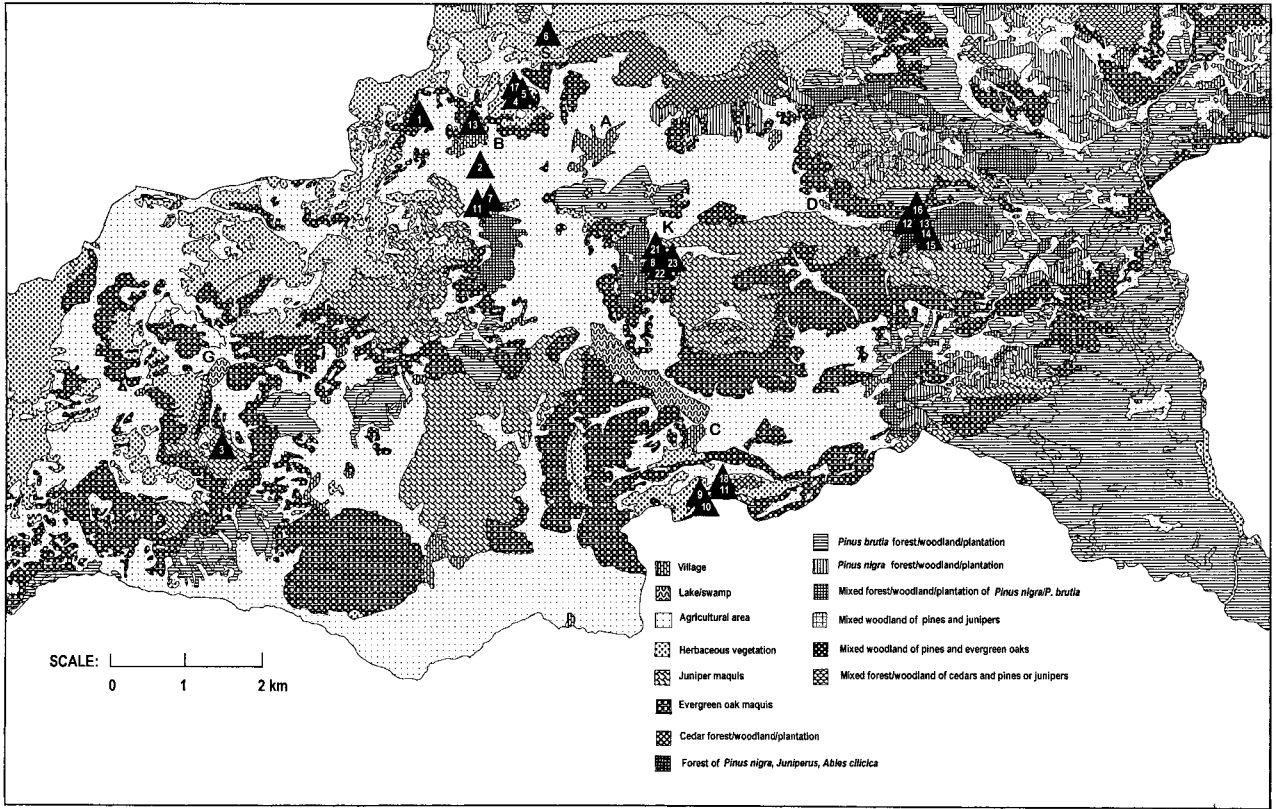


Fig. 2. Location of the 23 sampling sites in the study area (forest map). Some villages are indicated: A=Ağlasun; B=Başköy; C=Canaklı; D=Dereköy; G=Gravgaz; K=Köyönü; S=Sagalassos.

Table II. Sampling sites data: site number, landscape type/pollen spectra group, localisation (latitude, longitude, altitude), vegetation description, inclination and exposition.

Landscape type/pollen spectra groups: a=agricultural fields; C= *Cedrus libani* forest; c=herbaceous vegetation nearby *Cedrus libani* forest; D=degraded or open maquis of *Quercus coccifera* shrubs; J=area with *Juglans regia* cultivation; k=degraded herbaceous vegetation; M=well-developed *Quercus coccifera* maquis; P=*Pinus* forest or woodland; q=open degraded deciduous oak woodland; s=degraded herbaceous vegetation with high representation of *Sanguisorba minor*.

Site	Group	Village	N	E	Altitude (m)	Vegetation	Inclination	Exposition
1	a	Başköy	37°39.601'	30°28.438'	1316	Herbaceous vegetation between fields	5°	SE
2	J	Başköy	37°38.744'	30°29.748'	1150	Herbaceous vegetation on travertine, nearby <i>Juglans</i>	30–40°	NE
3	k	Gravgaz	37°33.785'	30°24.335'	1394	Open place in <i>Q. coccifera</i> and <i>Juniperus</i> maquis	30°	NNE
4	k	Sagalassos	37°40.043'	30°30.499'	1522	Degraded <i>Q. coccifera</i> and <i>Juniperus</i> maquis	30°	NNE
5	k	Sagalassos	37°40.087'	30°30.512'	1447	Herbaceous vegetation below <i>Cedrus</i> woodland	45–50°	NNE
6	k	Sagalassos	37°41.105'	30°30.824'	1774	Herbaceous alpine vegetation	30°	N
7	s	Başköy	37°38.175'	30°29.970'	1350	Degraded herbaceous vegetation	35°	NNW
8	M	Ağlasun	37°37.287'	30°33.549'	1239	<i>Q. coccifera</i> and <i>Juniperus</i> maquis	35°	NW
9	C	Canaklı	37°33.060'	30°34.571'	1348	<i>Cedrus</i> forest	35°	N
10	C	Canaklı	37°32.949'	30°34.701'	1400	<i>Cedrus</i> forest	35°	N
11	C	Canaklı	37°33.194'	30°35.988'	1232	<i>Cedrus</i> forest	40°	NNE
12	P	Dereköy	37°38.086'	30°30.196'	1040	<i>Pinus</i> forest	20°	N
13	P	Dereköy	37°38.024'	30°39.291'	1036	Herbaceous vegetation between <i>Pinus</i> forests	40°	N
14	P	Dereköy	37°37.766'	30°39.346'	1244	<i>Pinus</i> forest	45°	NW
15	P	Dereköy	37°37.729'	30°39.427'	1356	<i>Pinus</i> forest	45°	NW
16	P	Dereköy	37°38.255'	30°39.602'	1056	<i>Pinus</i> forest	45°	SE
17	c	Sagalassos	37°40.039'	30°30.473'	1488	Herbaceous vegetation above <i>Cedrus</i> woodland	50°	NNW
18	c	Canaklı	37°33.340'	30°35.048'	1182	Herbaceous vegetation below <i>Cedrus</i> forest	25°	NNW
19	D	Başköy	37°38.079'	30°29.699'	1237	Open place in maquis	45°	NW
20	D	Başköy	37°39.502'	30°29.573'	1397	Open place in <i>Quercus coccifera</i> maquis	5°	SE
21	D	Ağlasun	37°37.447'	30°33.566'	1166	<i>Q. coccifera</i> maquis	10°	NNE
22	D	Ağlasun	37°37.155'	30°33.671'	1285	<i>Quercus coccifera</i> maquis	5°	ZZE
23	q	Ağlasun	37°37.230'	30°33.848'	1269	Open vegetation + isolated <i>Quercus cerris</i> stands	45°	NNE

Pinus, (4) *Abies*, (5) *Cedrus*, (6) *Juglans*, (7) deciduous oak trees, (8) all other tree species, (9) cereal pollen type, (10) *Plantago lanceolata* major, (11) *Sanguisorba minor*, (12) *Polygonum cognatum*, (13) the ruderal *Centaurea*, (14) the light-demanding steppe-indicator *Artemisia* and finally (15) other herb types. All multi-variate analyses were executed with the software package SAS (SAS Institute 1990).

In Vermoere et al. (accepted), the 64 moss cushions were classified into 14 landscape types according to the vegetation/landscape unit from which they originated. The a priori classification was tested using discriminant analysis, and it was concluded that this classification was satisfactory. The same classification is used in the present study. The 23 pollen trap spectra (and corresponding 23 moss cushion spectra) represent only 10 of the original 14 landscape types. These 10 landscape/pollen spectra groups are *Pinus* forest or woodland (group P), open degraded deciduous oak woodland (group q), *Cedrus libani* forest (group C), herbaceous vegetation nearby *Cedrus libani* forest (group c), well developed *Quercus coccifera* maquis (group M), degraded herbaceous vegetation (group k), degraded or open maquis of *Quercus coccifera* shrubs (group D), degraded herbaceous vegetation with high representation of *Sanguisorba minor* (group s), agricultural field areas (group a) and areas with *Juglans regia* cultivation (group J). In this study groups, a, J, M, q and s, each consist of one sample.

RESULTS

Modern pollen spectra

The pairs of pollen spectra (moss cushions and pollen traps) of the 23 sample sites are given in Fig. 3. Mean, maximum and minimum percentage values for some pollen types are

calculated for each group of pollen spectra (Table III). Each sampling site is numbered, and the landscape type/pollen spectra group to which the pollen spectra belong is also added on the right side of the pollen spectra pairs (Fig. 3). The pollen trap spectrum and the moss spectrum of most pairs appear to be quite similar to each other at first sight. Traps and moss cushions from pine forest contain both high pollen percentage values for pines. The same accounts for *Juglans* in the area where walnuts are cultivated; for *Cedrus libani* in cedar forests; for *Quercus coccifera* in maquis; for deciduous oaks in oak woodland. In the agricultural area (sample site 1) cereal pollen percentage values are high both in the traps and in the mosses. Pollen percentage values for *Juniperus* are low both in pollen traps and moss cushions from areas where *Juniperus* (*Juniperus excelsa* and *J. oxycedrus*) grows. *Juniperus* pollen percentage values are not higher than 5 and 6% respectively for pollen spectra and moss cushions from sampling sites where *Juniperus* occurs locally. *Fraxinus ornus* is recorded with high pollen percentage values both in the moss spectrum and the pollen trap spectrum of a site where *Fraxinus ornus* is locally recorded (site 3), but the pollen percentage values remain low in the pollen spectra (moss and pollen trap spectra) of all other sites.

However, some systematic differences exist between moss spectra and Cundill trap spectra. Pollen traps seem to catch more pollen from wind-pollinated plants (except for *Juniperus*) growing in the neighbourhood (100–500 m) of the sampling sites. A first example of this observation is the

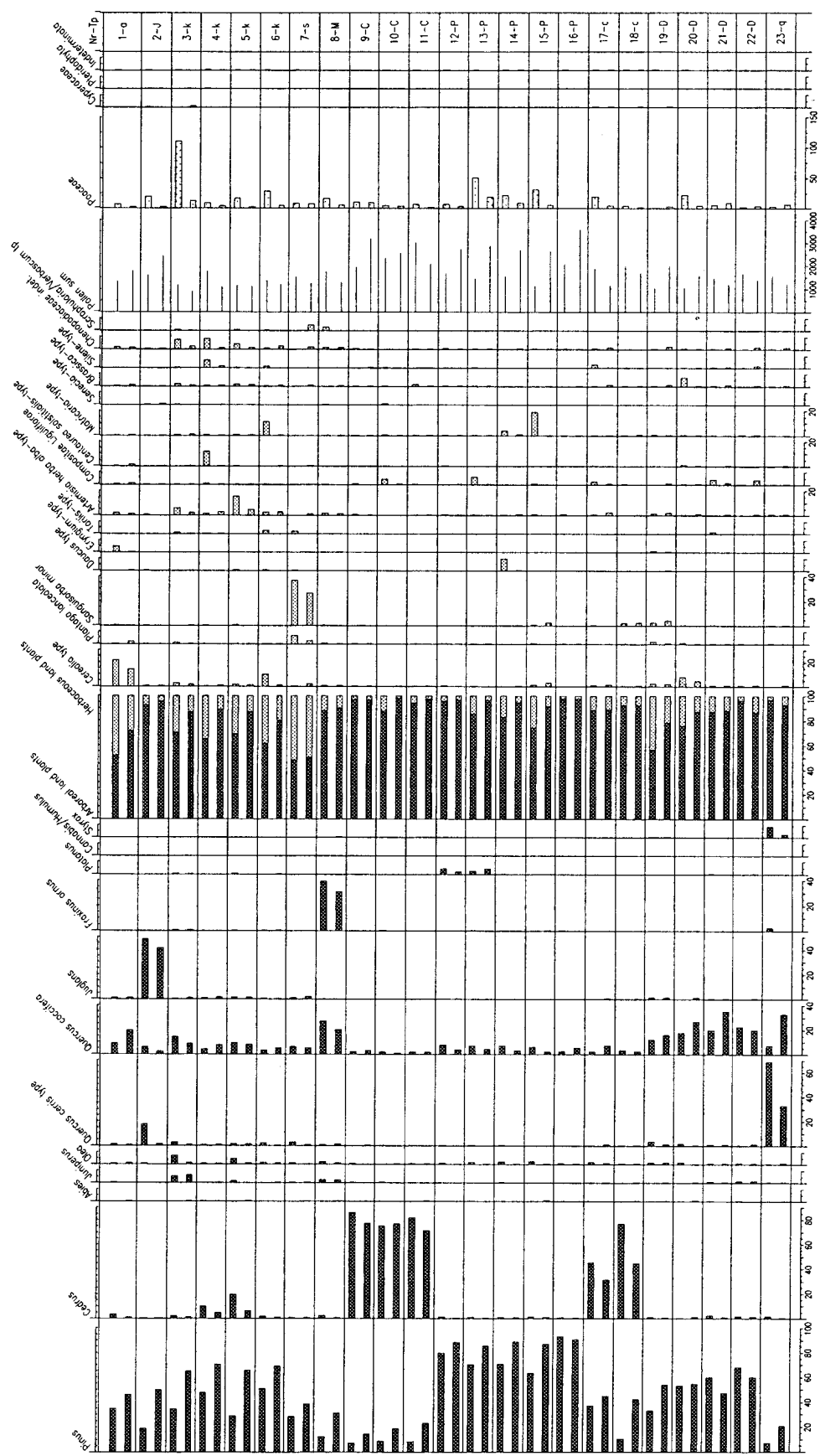


Fig. 3. Pairs of pollen spectra (pollen trap spectra above, moss spectra below) from the 23 sampling sites. Numbers of sampling site and code of landscape types/pollen spectra groups are added. a = agricultural fields; C = *Cedrus libani* forest; c = herbaceous vegetation nearby *Cedrus libani* forest; D = degraded or open maquis of *Quercus coccifera* shrubs; J = area with *Juglans regia* cultivation; k = degraded herbaceous vegetation; M = well-developed *Quercus coccifera* maquis; P = *Pinus* forest or woodland; q = open degraded deciduous oak woodland; s = degraded herbaceous vegetation with high representation of *Sanguisorba minor*.

Table III. Mean, minimum and maximum percentage values for some pollen types in the pollen trap and moss spectra of the different pollen spectra groups.

		<i>Pinus</i>		<i>Cedrus</i>		<i>Quercus</i> <i>cerris</i> -type		<i>Quercus</i> <i>coccifera</i>		<i>Olea</i> <i>europaea</i>		<i>Fraxinus</i> <i>ornus</i>		<i>Juglans</i>	
		trap	moss	trap	moss	trap	moss	trap	moss	trap	moss	trap	moss	trap	moss
group a (n=1)	Value	34,70	46,36	3,43	1,01	1,57	0,67	9,18	19,57	0,82	1,01	0,00	0,00	0,97	0,95
group J (n=1)	Value	18,95	49,77	0,19	0,16	17,44	1,60	5,98	2,34	0,94	0,04	0,00	0,00	48,17	41,24
	Mean	40,48	66,93	8,16	3,96	1,88	1,33	7,87	8,17	3,62	1,14	0,23	0,22	0,89	1,44
group k (n=4)	Minimum	28,87	64,78	1,76	1,00	0,79	1,09	3,44	7,62	0,95	0,82	0,00	0,00	0,43	1,11
	Maximum	50,92	70,42	19,36	6,07	3,06	1,67	14,46	8,78	7,23	1,44	0,60	0,67	1,38	1,72
group s (n=1)	Value	28,36	38,69	0,66	0,72	2,76	0,96	6,18	5,18	1,25	0,40	0,07	0,00	1,12	2,31
group M (n=1)	Value	12,41	31,17	2,45	0,62	0,97	1,62	27,32	20,11	2,05	1,31	39,27	31,09	0,11	0,15
	Mean	8,15	18,83	80,86	75,06	0,36	0,27	2,02	1,90	0,57	0,27	0,09	0,01	0,03	0,06
group C (n=3)	Minimum	7,02	14,31	75,02	71,21	0,21	0,12	1,93	1,13	0,21	0,00	0,00	0,00	0,00	0,04
	Maximum	8,80	23,16	85,96	77,27	0,50	0,50	2,19	2,94	0,77	0,43	0,17	0,03	0,04	0,09
	Mean	75,42	88,02	1,00	0,46	0,39	0,17	5,90	3,68	1,62	0,46	0,11	0,08	0,12	0,16
group P (n=5)	Minimum	63,27	85,60	0,53	0,26	0,09	0,06	2,30	1,90	0,77	0,38	0,00	0,00	0,06	0,00
	Maximum	93,00	90,62	1,32	0,84	0,66	0,30	7,52	5,28	2,37	0,56	0,28	0,30	0,18	0,29
	Mean	23,83	43,63	61,17	38,22	0,46	0,69	2,85	4,80	1,20	0,96	0,03	0,00	0,10	0,46
group c (n=2)	Minimum	10,45	42,50	45,32	31,56	0,45	0,36	2,42	2,49	0,66	0,71	0,00	0,00	0,05	0,24
	Maximum	37,21	44,77	77,03	44,87	0,47	1,03	3,28	7,12	1,74	1,20	0,05	0,00	0,16	0,69
	Mean	53,68	53,85	1,36	1,14	1,79	1,21	17,98	24,51	1,38	0,83	0,03	0,10	0,48	0,92
group D (n=4)	Minimum	33,11	47,15	0,37	0,70	0,48	0,56	12,18	16,05	0,96	0,50	0,00	0,00	0,00	0,33
	Maximum	68,27	59,86	2,39	1,44	3,52	1,65	22,36	35,18	1,87	1,44	0,07	0,31	1,52	1,49
group q (n=1)	Value	7,28	20,70	1,55	0,24	68,96	32,90	6,95	32,98	0,45	1,29	2,25	0,00	0,00	0,16

		Cereal type		<i>Sanguisorba minor</i>		<i>Artemisia</i> -type		<i>Centaurea solstitialis</i> -type		<i>Liguliflorae</i>		<i>Matricaria</i> -type	
		trap	moss	trap	moss	trap	moss	trap	moss	trap	moss	trap	moss
group a (n=1)	Value	21,72	14,21	0,37	0,00	2,31	1,51	0,45	1,40	0,75	1,23	0,15	0,62
group J (n=1)	Value	0,69	0,78	0,19	0,12	0,82	0,25	0,06	0,16	0,25	0,16	0,31	0,04
	Mean	3,78	1,27	0,28	0,07	6,43	3,26	3,06	0,30	0,46	0,35	3,25	0,56
group k (n=4)	Minimum	0,39	0,91	0,07	0,00	1,40	2,22	0,00	0,09	0,17	0,26	0,56	0,18
	Maximum	10,26	1,67	0,52	0,22	15,56	4,67	11,79	0,44	1,12	0,45	10,99	0,89
group s (n=1)	Value	0,46	2,07	36,91	26,35	0,13	1,04	0,00	0,32	0,26	0,48	0,33	0,16
group M (n=1)	Value	0,80	0,77	0,17	0,08	2,05	1,47	0,00	0,15	0,40	0,08	0,23	0,31
	Mean	0,17	0,26	0,04	0,03	0,57	0,29	0,01	0,06	1,80	0,30	0,31	0,16
group C (n=3)	Minimum	0,13	0,22	0,00	0,00	0,30	0,00	0,00	0,03	0,30	0,05	0,13	0,10
	Maximum	0,23	0,33	0,13	0,09	0,87	0,53	0,04	0,10	4,59	0,74	0,60	0,20
	Mean	0,48	0,77	0,20	0,51	0,68	0,49	0,06	0,01	1,46	0,20	4,69	0,22
group P (n=5)	Minimum	0,05	0,03	0,00	0,00	0,48	0,22	0,00	0,00	0,10	0,04	0,10	0,04
	Maximum	1,49	3,19	0,70	2,24	0,90	0,78	0,24	0,07	6,36	0,48	18,98	0,74
	Mean	0,57	0,98	1,04	1,24	0,49	1,63	0,24	0,00	1,21	0,32	0,18	0,54
group c (n=2)	Minimum	0,20	0,59	0,16	0,00	0,25	0,59	0,00	0,00	0,15	0,12	0,05	0,26
	Maximum	0,95	1,37	1,92	2,49	0,74	2,66	0,47	0,00	2,26	0,51	0,32	0,83
	Mean	2,93	2,05	0,72	1,10	0,61	1,16	0,30	0,10	1,24	1,77	0,40	0,32
group D (n=4)	Minimum	0,66	0,86	0,00	0,00	0,12	0,66	0,00	0,00	0,10	0,82	0,34	0,13
	Maximum	8,03	4,46	2,47	4,27	1,71	2,09	1,12	0,19	4,31	3,80	0,48	0,50
group q (n=1)	Value	0,13	1,05	0,00	0,40	0,90	0,89	0,00	0,32	0,13	0,16	0,06	0,32

relative high *Cedrus libani* pollen percentages in the pollen traps from sampling sites 17 and 18 (45 and 77% versus 31.5 and 45% in the moss cushions) (group c: herbaceous vegetation adjacent to cedar forests), and to a less extent in pollen traps from sites 4 and 5 (10 and 19% versus 5 and 6% in the moss cushions) (two samples in the neighbourhood of some isolated *Cedrus libani* stands). It can even be observed that in all pollen traps (except for sample site 10) *Cedrus libani* pollen percentage values are higher than in the moss cushions. Another example is given by the high deciduous oak pollen percentages in the traps of sampling sites 23 and 2. *Quercus cerris* trees were recorded in the vegetation relevé (a quadrat of 10 by 10 m) of site 23, but

not in the relevé of site 2. Nevertheless, isolated stands of *Quercus cerris* were observed in the vicinity of site 2 (at distances of 100–500 m). A third example indicating the sensitivity of traps for wind-pollinators in the vicinity (but on a larger distance than 500 m) of the sampling site is given by the high *Olea europaea* pollen percentage value (7.23%) in the trap of sample site 3 (versus 1.4% in the moss cushion from the same site). No olives were recorded in the immediate vicinity of the sampling site, but these trees are cultivated a few kilometres southeast of the sampling site where the climate is more favourable for the cultivation of olives. In the pollen trap of sampling site 5 the olive pollen percentage value is also relatively high. However, no olives

are present in this area, and thus the olive pollen is transported from more southern areas. In all 23 moss cushions olive pollen occurs only as a background noise ($<1.4\%$).

A second difference between traps and mosses is the observation that locally recorded wind-pollinated or insect-pollinated plants (registered within the quadrats of 10 by 10 m) are more abundantly recorded in the pollen traps. This is illustrated by the high cereal pollen percentage value (21.7%) in the trap of sample site 1 (versus 14.2% in the moss cushion from the same site). *Aegilops umbellata*, a wild grass species which produces pollen classified as 'cereal pollen type' was abundantly recorded in the vegetation relevé of sampling site 1 (cover: 87.5–100%). The pollen percentage values of the other Poaceae (non-cereal pollen types), which are excluded from the pollen sum, are higher in the pollen traps than in the moss cushions. In sampling site 3 the difference between the Poaceae percentage value in the pollen trap on the one hand and in the moss cushion on the other is exceptionally high (110 versus 12%). In sites 19, 21, 22 and 23 where the Poaceae values are higher in the moss cushions the differences are only minimal. Another example is given by the high *Sanguisorba minor* pollen percentage (37%) in the trap of site 7 (versus 26.4% in the moss cushion from this site). *Sanguisorba minor* was abundantly present in this vegetation relevé (cover: 1–5%). In sampling site 15, *Anthemis cretica* was recorded in the vegetation relevé. This is clearly reflected in the high *Matricaria* pollen percentage value (19%) of the pollen trap, but not in the moss cushion of the same site. In sample site 8, a locally observed *Fraxinus ornus* tree has a big influence on the pollen content of the pollen trap and the moss cushion of this site, although the pollen percentage is again higher in the pollen trap (39.3% in the pollen trap versus 31.1% in the moss cushion from this site). In the pollen trap of sample site 23, *Styrax officinalis* is represented with a high pollen percentage value in the pollen trap (9%). *Styrax* covered 1–5% of the surface of the vegetation relevé in site 23. In the moss cushion of this sampling site, the *Styrax* pollen percentage value is not higher than 2.5%.

Furthermore, the moss pollen spectra differ from the trap spectra by their high *Pinus* pollen percentage values. Only a few exceptions occur in site 21 and 22. Both sites occur in an area where *Pinus nigra* and *Pinus brutia* were planted a few years ago by the Forest Service of Burdur. In pollen spectra group P (sampling sites from pine forest) the pine pollen percentages vary between 86 and 91% in the moss cushions. On the contrary, the pine percentages show higher variations in the pollen traps of group P (variations between 63 and 93%). It is clear that the pollen traps register more efficiently locally vegetation differences in the pine forest (open areas versus closed areas). The pollen traps seem to be more sensitive for local pine cover variations and local undergrowth in pine forest areas. Detailed information concerning pine cover and undergrowth in the 5 sampling sites of group P is given in Table IV. The highest pine pollen percentage values are observed in sampling site 16, a small open place in a dense *Pinus brutia* forest. This place is overgrazed by goats, and therefore the undergrowth (mainly shrubby *Quercus coccifera*) is very badly developed and the

degraded plants or not or hardly able to produce pollen. The site with the highest pine cover (site 12) has the second highest pine pollen percentage in the case of the pollen traps. The most open site (site 15) results in the lowest pine pollen percentage value in the trap. As is shown by Table IV, the pine pollen percentage values in the mosses are less in concordance with the local pine cover values and undergrowth richness/development.

In general, except for sampling sites 21 and 22, arboreal pollen is more abundantly present in the moss cushions than in the pollen spectra. This illustrates that pollen traps are more sensitive for the local herbaceous flora.

Principal components analyses

The pollen spectra of the moss cushions and the pollen traps were first analysed by separate principal components analyses to study the structure and patterns in the pollen trap data set and the moss cushion data set. The first two principal components account for 42% of the variance in the data set of the moss cushions, and for 33% in the data set of the pollen traps. These two components are used in this paper for both data sets as they give graphically satisfying results. Ordination of the sample scores of the pollen trap data set on the first and second principal components is given in Fig. 4; the ordination of the sample scores of the moss cushion data set is given in Fig. 5. Loadings for the 15 pollen type groups are shown in Fig. 6 for the pollen trap data set, and in Fig. 7 for the moss cushion data set.

For the pollen trap data set, the variables '*Sanguisorba minor*' and '*Plantago*' have the highest loading on the second principal component axis (Fig. 6), whereas the variables 'maquis pollen types', 'eumediterranean pollen types', 'other herbaceous pollen types' and '*Polygonum*' have the highest values on the first principal component axis. '*Cedrus libani*' has the most negative value on the first principal component axis.

For the moss data set, again the variables '*Sanguisorba minor*' and '*Plantago*' have the highest loading on the second principal component axis (Fig. 7), and the 'Eumediterranean pollen types' have the highest negative loading on this axis. The variables 'other herbaceous pollen types' and '*Centaurea*' have the highest values on the first principal component axis.

The ordination plot of the pollen trap scores (Fig. 4) shows that all spectra of degraded sampling sites (group k: degraded herbaceous vegetation; group D: degraded maquis; sample M: well developed *Quercus coccifera* maquis) are situated on the right side of the ordination plot. Also, the sample of the agricultural field (sample a) and three samples of the pine forest area are situated here. The latter originate from open places in the pine forest (Table IV). On the contrary, the sample of dense pine forest (sample 12) and the sample of degraded and overgrazed pine forest (sample 16) are located at the left side of the biplot. All spectra originating from in and nearby cedar forest are also situated on this side. Finally, the sample from the *Juglans* site, the sample from the site where *Sanguisorba minor* was omnipresent and the sample from the deciduous oak woodland are located on the left side of the plot. The

Table IV. Vegetation description and pine pollen percentage values in the pollen trap and moss spectra for all sites of group P (pine forest) .

Sampling site	Pine cover percentage	Vegetation type + undergrowth	Pollen trap pine pollen percentage	Moss cushion pine pollen percentage
12	50–67.5%	Developed undergrowth: different species of herbaceous plants (mainly Fabaceae, Brassicaceae and Poaceae - 17 species); not grazed by goats	80%	88%
13	1–2%	Situated in a very large open space in the pine forest; well-developed herbaceous layer (43 species); not grazed by goats	70%	86%
14	12.5–25%	Pine woodland (pines on a distance of 10–30 m from each other); well developed herbaceous layer (35 species); not grazed by goats.	71%	89%
15	<1%	Open place on top of the pine woodland; a very well developed herbaceous undergrowth (47 species); not grazed by goats.	63%	87%
16	5–12.5%	Small open place in dense <i>Pinus brutia</i> forest; undergrowth of very degraded and overgrazed <i>Quercus coccifera</i> cushions and <i>Styrax officinalis</i> + 20 species of grazed herbs	93%	91%

sample from the site with *Sanguisorba minor* is very isolated in the ordination plot as it has an exceptional high score for *Sanguisorba minor*.

The ordination plot of the moss scores (Fig. 5) shows that the samples are less evenly spread over the plot as compared to the pollen trap ordination plot. This accounts especially for the moss spectra of group P, but also for the moss spectra of degraded vegetation groups (group D and group k). In this plot, the moss spectra from group k and group D form a clearly distinguishable group in the lower right corner of the plot, whereas the moss spectra from cedar or pine forest are situated on the left side. Only two moss spectra (sample s and sample a) are located in the upper

right corner of the plot. Sample M and sample q are less well distinguishable from each other than in the pollen trap ordination plot (Fig. 5).

Another principal components analysis was carried out on the combined dataset of pollen trap spectra and moss spectra to study the differences between the pollen trap spectrum and the moss spectrum from each sampling site. The distance between the pollen trap spectrum and the moss spectrum of each sampling site is a measure for the dissimilarity between the two pollen spectra from that site. For the combined principal components analysis, the first two principal components account for 31% of the variance in the combined data set of the moss cushion and trap pollen spectra. The PCA ordination plot showing the sample scores of the moss and pollen trap spectra are given in Fig. 8. Loadings for the 15 (indicator) pollen types/pollen type groups are shown in Fig. 9. The variables '*Sanguisorba*

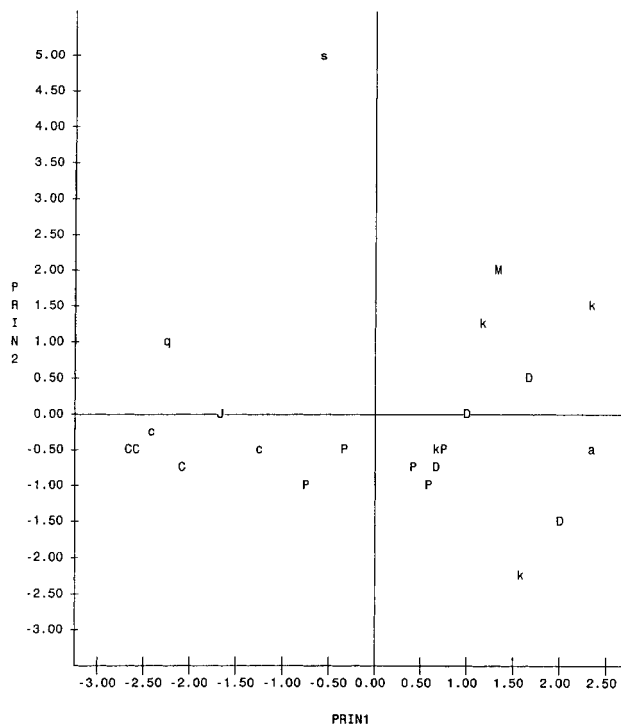


Fig. 4. Positioning of the sample scores of the pollen trap spectra on the first two principal component axes with indication of the modern pollen spectra groups (a, c, C, D, J, k, M, P, q and s).

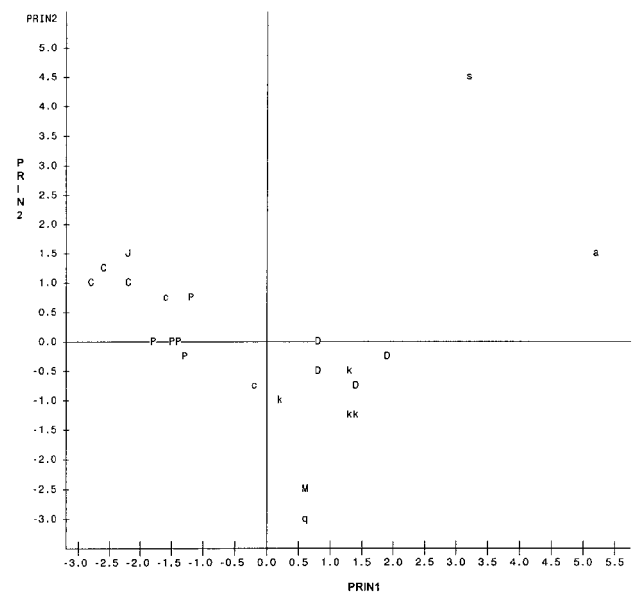


Fig. 5. Positioning of the sample scores of the moss cushion spectra on the first two principal component axes with indication of the modern pollen spectra groups (a, c, C, D, J, k, M, P, q and s).

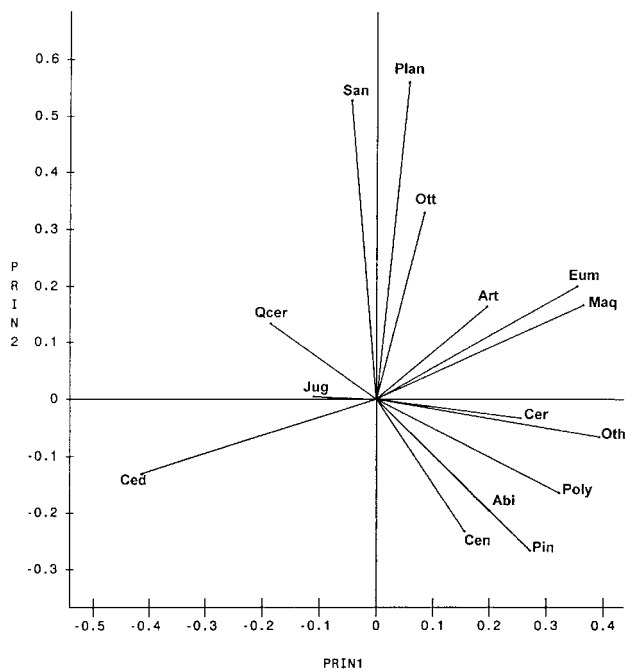


Fig. 6. Loadings of the variables for the pollen trap data set positioned on the first two principal component axes. Pollen types (or pollen type groups) are abbreviated: Abi: *Abies cilicica*, Art: *Artemisia* pollen type, Ced: *Cedrus libani*, Cen: *Centaurea* pollen type, Cer: Cereal pollen type, Eum: Eumediterranean pollen types, Jug: *Juglans regia*, Oth: Other herb pollen types, Ott: Other tree pollen types, Pin: *Pinus* pollen type, Plan: *Plantago lanceolata* major, Poly: *Polygonum aviculare/cognatum*, Maq: *Quercus coccifera* & *Juniperus*, Qcer: deciduous oak pollen type, San: *Sanguisorba minor*.

minor and '*Plantago*' have the highest values on the second principal component axis (Fig. 9), whereas '*Pinus*' has the most negative value on this axis. 'Eumediterranean pollen types' and 'other herb pollen types' have the highest value on the first principal component axis, whereas '*Cedrus libani*' has the most negative value on this axis. It can be deduced from Fig. 8 that the dissimilarities between the two pollen spectra of each site are highest for site 7 (degraded vegetation with *Sanguisorba minor*), sites 3, 4 and 5 (degraded herbaceous vegetation), site 19 (degraded maquis vegetation) and site 23 (*Quercus cerris* oak woodland). Differences in group P depend on the place in the pine forest: the moss spectrum and pollen trap spectrum from dense forest (sites 12 and 16) are very similar, whereas the moss spectrum and the pollen trap spectrum from open forest (sites 13, 14 and 15) are more different from each other.

DISCUSSION

It has to be stressed that the pollen traps represent the pollen precipitation of only one year (from the summer of 1997 till the summer of 1998). The climatic conditions during this particular year may have influenced to some extent the pollen dispersal of the plants. One has to be aware that a pollen trap study of several successive years

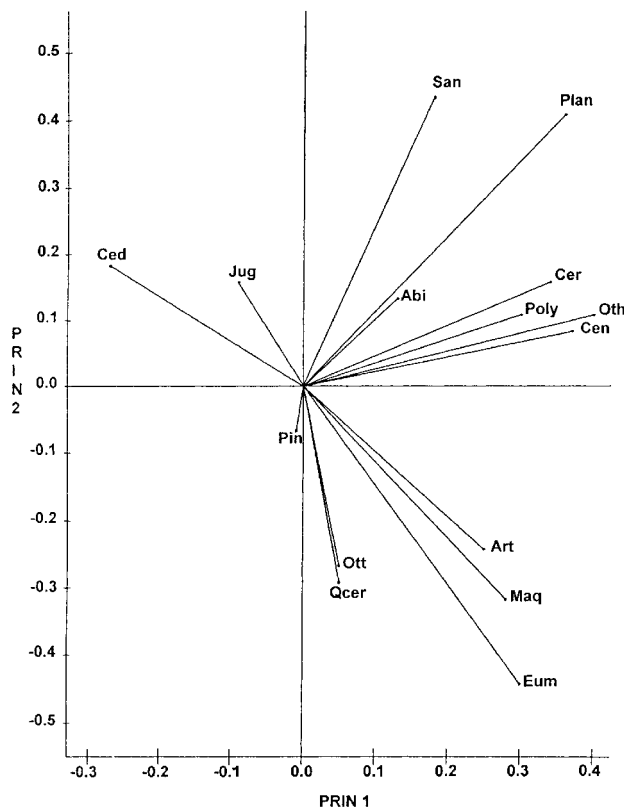


Fig. 7. Loadings of the variables for the moss cushion data set positioned on the first two principal component axes. Pollen types (or pollen type groups) are abbreviated: Abi: *Abies cilicica*, Art: *Artemisia* pollen type, Ced: *Cedrus libani*, Cen: *Centaurea* pollen type, Cer: Cereal pollen type, Eum: Eumediterranean pollen types, Jug: *Juglans regia*, Oth: Other herb pollen types, Ott: Other tree pollen types, Pin: *Pinus* pollen type, Plan: *Plantago lanceolata* major, Poly: *Polygonum aviculare/cognatum*, Maq: *Quercus coccifera* & *Juniperus*, Qcer: deciduous oak pollen type, San: *Sanguisorba minor*.

smoothes possible climatic influences on pollen production and dispersal of pollen. However, a pollen trap project of several years is hard to fulfill in the territory of Sagalassos due to the omnipresence of sheep and goats in the unprotected landscape. These animals often trample on the pollen traps and thus can destroy the constructions. After one year of pollen entrapment only 23 of the original 40 traps were recovered in the field.

Moss cushions represent the modern pollen precipitation during several years. This is illustrated by two sample sites in the neighbourhood of recent pine plantations: site 21 and 22. Pine pollen percentage values are lower in the moss cushions than in the pollen traps. It is evident that during the first years after the plantation pines had not flowered yet, and thus no pine pollen from these plantations could be caught by the moss cushions.

At first sight, the pollen spectra of the moss cushions are comparable with spectra of the pollen traps of the same sampling sites. However closer examination of the spectra pairs of the different sampling sites reveals some main differences between the pollen contents of traps and moss cushions. The PCA ordination plot of the combined dataset

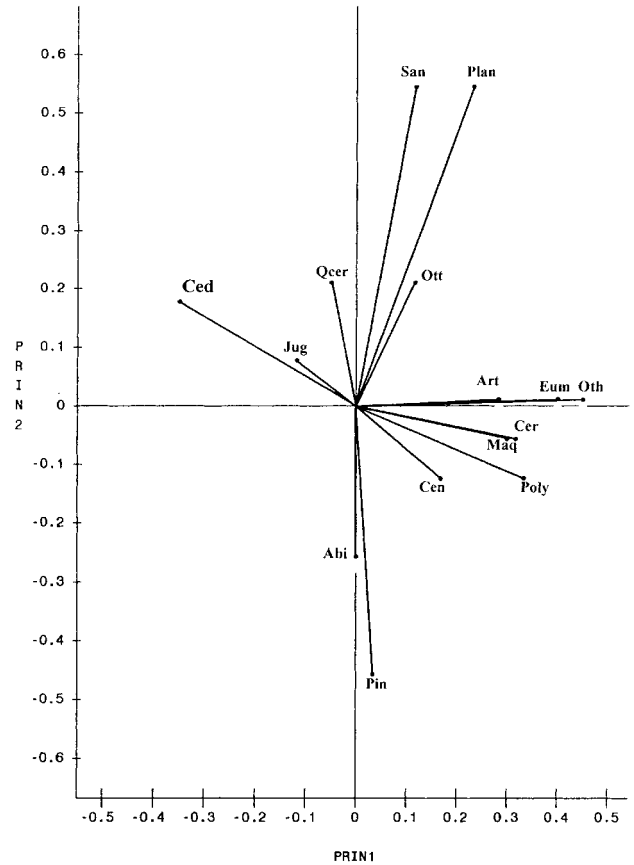


Fig. 9. Loadings of the variables for the combined data set of moss and pollen trap spectra positioned on the first two principal component axes. Pollen types (or pollen type groups) are abbreviated: Abi: *Abies cilicica*, Art: *Artemisia* pollen type, Ced: *Cedrus libani*, Cen: *Centaurea* pollen type, Cer: Cereal pollen type, Eum: Eumediterranean pollen types, Jug: *Juglans regia*, Oth: Other herb pollen types, Ott: Other tree pollen types, Pin: *Pinus* pollen type, Plan: *Plantago lanceolata* major, Poly: *Polygonum aviculare* cognatum, Maq: *Quercus coccifera* & *Juniperus*, Qcer: deciduous oak pollen type, San: *Sanguisorba minor*.

possible to make a distinction between open places in the pine forest and dense pine forest within group **P** in the ordination plot of the moss cushions. The pine pollen percentages do not vary largely in group **P** of the moss spectra (between 86 and 91%).

Pollen traps seem to catch more pollen from other wind pollinated plants growing in the neighbourhood (100–500 m) of the sample sites. The same can be concluded for locally (within an area of 10 m by 10 m) recorded plants (both insect or wind pollinated). This results in high variances within the different pollen spectra groups. For instance, in group k the trap spectrum of site 5 is strongly influenced by the high *Artemisia* pollen percentage. *Artemisia* occurred below the sampling site, and is much less represented in the moss spectrum of the same sampling site. The same pollen trap spectrum is also strongly influenced by high *Cedrus* percentages, whereas the *Cedrus* pollen percentage in the moss spectrum is much lower. The differences between both spectra (moss cushion spectrum and pollen trap spectrum of site 5) is also clear from the

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PCA ordination plot of the combined dataset (Fig. 8). Another trap spectrum (site 3) of group k is strongly influenced by the inflow of *Olea europaea* pollen from the south, whereas this is not the case in the moss spectrum of the same sampling site. Olive pollen grains seem to be dispersed over a large distance (a few kilometres). However, in the mosses of all sampling sites olives are only recorded as a background noise. The differences between the moss spectrum and the pollen trap spectrum from site 3 are also clear from the PCA plot of the combined dataset (Fig. 8).

In summary, pollen trap spectra seem to be appropriate to register local (within an area of 10×10 m) vegetation patterns as well as vegetation in the neighbourhood (100–500 m) of the sampling sites. The moss spectra of the different groups are more similar to each other, and do not register clearly local vegetation differences. It must be stressed again that the high pine pollen percentage values in the moss spectra are mainly responsible for this conclusion, as these high values result in lower pollen percentage values of all other pollen types. However, in sampling sites where locally plants occur that produce and/or disperse high quantities of pollen grains, the overwhelming high pine pollen percentage can be reduced by these plants. This is especially the case in group C (local occurrence of *Cedrus libani*), sample q (local occurrence of *Quercus cerris*), sample M (local occurrence of *Fraxinus ornus*) and in sample s (local occurrence of *Sanguisorba minor*). For sampling sites at a small distance (100–500 m) away from these strong wind pollinated plants, the influence of their pollen signal decreases rapidly in the moss pollen spectra, whereas the pollen signal for these plants is still very high in the pollen trap spectra of the same sites. This is clearly illustrated in group c (Fig. 3). Although the sampling sites of group c (sites 17 and 18) are both situated 100–500 m from *Cedrus* forest/woodland, the *Cedrus* pollen signal in the pollen traps is still very high, whereas the *Cedrus* pollen percentage value is much lower in the moss spectra of these sampling sites.

It has already been argued that climatic conditions can have influenced to some extent the pollen contents in the pollen traps. However, it is hard to believe that climatic influences alone may have caused the systematic differences between pollen contents of pollen traps and moss cushions. Different hypotheses are possible to explain the systematic differences between the two pollen entrapment media. It is possible that differential pollen preservation eliminates some pollen types from the moss cushions, resulting in the dominance of pine pollen. If this is true, one should expect lower *Juniperus* pollen percentage values in moss cushions than in pollen traps. This was concluded from the study of Spieksma et al. (1994), who stated that pollen types with a thin and fragile pollen exine, such as Cupressaceae, are sensitive to destruction, and thus are better represented in pollen traps. However, this was not observed in our study. *Juniperus* pollen percentage values are low both in pollen traps and in moss cushions. The two entrapment media record *Juniperus* pollen only in places where this conifer species occurs locally (sites 3 and 8). Another possibility is that the relatively large pine pollen grains are much easier attached to the mosses, whereas smaller entrapped pollen grains are reentering the atmosphere by air flows. More

research is required to find out the exact mechanisms responsible for the systematic differences between the one-year pollen entrapment medium (pollen traps) and the several-years pollen entrapment medium (moss cushions). However the same mechanisms may be valid for pollen entrapped by sediments. As a consequence, it can be suggested that the results obtained from the comparison between the one-year pollen entrapment medium and the several-years pollen entrapment medium may be used to understand how the vegetation of the former landscape is represented by the pollen content in different sediment types.

Samples used for fossil pollen analysis comprise mostly several years of pollen precipitation. It seems logic to assume that moss cushions pollen spectra are more suitable for comparison with most fossil pollen spectra, since moss cushions also comprise several years of pollen rain. The limitations of the pollen analysis of the moss cushions can be projected to fossil pollen analysis. So it can be suggested that fossil pollen spectra are inefficient sensors of vegetation types present in the neighbourhood of the sampling site in Southwest Turkey. It will be very hard to distinguish from the fossil pollen diagram the former presence of, e.g., deciduous oak forests/woodlands, cedar forests or olive yards in the surroundings (100–500 m) of the sampling sites. If, for instance, olives were cultivated at a few kilometres from the sampling sites, olive pollen will occur in the pollen diagram only as a background noise. Only locally occurring plants will be represented in the fossil diagrams, and if no strong pollen producers were present in the past nearby the core site, pine pollen will dominate the fossil pollen spectra and it will be very hard to propose data about the former regional vegetation.

As a consequence, in order to carry out highly informative pollen analysis, it will be very important to search for rapidly deposited sediments. Ideally, samples for pollen analysis should comprise only 1–2 years of sedimentation. In the territory of Sagalassos, peat deposits have been discovered in Gravgaz (Fig. 1) with a very rapid deposition rate. Three AMS ^{14}C dates were obtained from this core: 1) 2480 ± 120 BP (Cal. 900–200 BC) at a depth of 700 cm; 2) 2495 ± 40 BP (Cal. 790–410 BC) at a depth of 583 cm; 3) 1460 ± 90 BP (Cal. 410–770 AD) at a depth of 300 cm (Vermoere et al. 2000). The chronology of the Gravgaz core implicates that the peat deposition rate was very high: one cm of the core sediment represents between 1.3 and 3.6 years. It seems likely to suggest that the pollen analysis results of these deposits will be relatively informative about the former vegetation types in the area of Gravgaz. However, it may not be forgotten that some pollen types, such as *Fraxinus ornus* or *Juniperus*, are as badly represented in the pollen traps as in the moss cushions. These pollen types are only recorded in the traps when they occur locally (within an area of 10 by 10 m). It can be suggested that these pollen types will be under-represented in the quickly deposited sediments as well.

This study allows to give some guidelines for future palynological research in the Near East. It seems highly appropriate to submit samples for radiocarbon dating prior to pollen analysis. The radiocarbon dates will allow to

estimate the deposition rate of the sediments, and this will indicate how informative the pollen diagram will be about the former vegetation. One should preferably use the most rapidly deposited sediments present in the study area in order to reconstruct the past vegetation of that area. Additionally, it may not be forgotten that other factors, not discussed here, may also influence the pollen representation in analysed (sub)fossil sediments. The way of pollen entrapment in lake sediments was probably different from sediments originating from well-vegetated marshlands.

CONCLUSIONS

The comparison between the moss cushion pollen spectra and the Cundill trap pollen spectra from 23 different sampling sites (10 different landscape types) shows that there are systematic differences between the pollen trap spectrum and the moss spectrum of each site. The variance within each landscape type/pollen spectra group in the pollen trap data set is higher than in the moss cushion data set. Pollen traps seem to be much more appropriate to register local (within the relevé of 10 by 10 m) and regional (100–500 m or a few kilometres for olives) observed plant species (mostly wind pollinated, but on a local scale insect pollinated plants can also have influence on the pollen trap spectra). The pollen spectra of moss cushions are much more similar to each other, and it is hard to detect local and regional vegetation differences between the different pollen spectra groups. This is mainly caused by the absolute dominance of *Pinus* pollen in the moss cushions. It is not known which factors are responsible for this pine dominance.

The results of our study are confronted with similar studies (Cundill 1991, Spieksma et al. 1994). It is clear that the conclusions of these palynologists, who worked in Northwest Europe, can not be extrapolated for modern pollen studies in Southwest Turkey.

The conclusions of the comparison between the one-year pollen entrapment medium (pollen traps) and the several-years pollen entrapment medium (moss cushions) can be extrapolated to the fossil pollen spectra of sediment cores. It is concluded that the pollen analysis of rapidly deposited sediments should be preferred above slowly deposited sediments for palynological analyses. Subsamples of rapidly deposited sediments represent a short time of pollen precipitation. According to the pollen spectra of the one-year pollen entrapment medium, the pollen spectra of rapidly deposited profiles will succeed better to give a detailed picture of the former local and regional vegetation as compared to the pollen spectra of slowly deposited sediments.

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