Stratigraphic analyses of late-quaternary sediments from S'Albufera, North East Mallorca, Spain

MP Lawson

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STRATIGRAPHIC ANALYSES OF LATE-QUATERNARY SEDIMENTS FROM S'ALBUFERA, NORTH-EAST MALLORCA, SPAIN.

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Abstract:

1. Much of the environmental history of the western Mediterranean has been inferred from records obtained throughout a wider region. Very little work has been conducted on Mallorca. Sediments suited to palaeoenvironmental studies are of limited extent within the Balearic Islands, principally as a result of climatic factors. Stratigraphic cores were collected from two sites (Es Colombar, Amarador) on S'Albufera marsh, Mallorca, in the hope that the sedimentary records could provide source material for interpreting environmental history.

2. In order to develop an understanding of past environmental conditions at S'Albufera, and to asses the potential for future studies of this nature, lithological, geochemical and micropalaeontological (pollen and foraminifera) analyses were conducted upon the sediments. Pollen data were explored using the constrained incremental sum of squares (CONISS) multivariate technique. Through these investigations, an understanding of the geomorphological and vegetation history of S'Albufera has been achieved.

3. All data suggest that S'Albufera was a saline lagoon system throughout the period reflected in these sediments. Progressive sea level rise facilitated an areal expansion of this lagoon. Periods of reduced mean water level have also been identified, one of which was initiated in 1856 during drainage of the lagoon, and is still apparent today. In the absence of absolute dates, it is proposed that earlier phases of lower mean water level occurred during the historical period, in response to the influence of anthropogenic disturbance, eustatic flux or climatic shifts. A relative chronology has been inferred from *Corylus* pollen data. Amarador is believed to have been a lagoon since *ca.* 8000 yr. B.P., whilst Es Colombar became inundated *ca.* 3000 yr. B.P.

4. Pollen assemblages suggest the vegetation of S'Albufera has varied little throughout the lagoonal period. Local vegetation, dominated by salt-tolerant, semi-aquatic Chenopodiaceae and Gramineae, has only grown at the coring sites during periods of reduced mean water levels. At other times local pollen contributions were derived from marsh vegetation at the lagoon periphery. Regional pollen signals are dominated by arboreal inputs *e.g. Pinus* and *Quercus*. Regional trends are obscured by low pollen sums and aquatic deposition, which affords highly-mixed assemblages.

5. As a relatively undisturbed sedimentary environment, S'Albufera displays great potential as a site for palaeoenvironmental reconstruction work. The nature of the deposits exerts some influence over the suitability of some lines of investigation, pollen included. It is proposed that maximum gains from future studies would be derived from the study of other assemblages, such as ostracods, diatoms and charophytes. All of these groups are believed to be well-represented within the sedimentary record.

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Chapter One: Introduction

Introduction

In the context of European palaeoenvironmental reconstruction, the Mediterranean region is grossly under-represented; in particular, the southern Iberian peninsular and western Mediterranean islands have been subject to relatively little research. In an attempt to rectify this imbalance, and to investigate the potential for future studies in the region, sedimentary cores were extracted from S'Albufera marsh, a 24 km^2 coastal I.U.C.N./I.C.B.P. designated reserve in Alcudia bay, on the north-east of the Spanish island of Mallorca (39° 45' N, 03° 14' E; Figures 1,2 and 3).

Lithological, geochemical and micropalaeontological (pollen and foraminifera) sequences within the cores were examined and analysed, to provide information relevant to the understanding of the sedimentary and vegetation history of the area (*sensu* Lowe and Walker 1984). Evidence provided by these lines of inquiry may be used as a basis for identifying the possibilities for future research.

Site description:

Climate

Mallorca is the largest of the Balearic Islands, lying 180 km south-east of the Ebro delta and 250 km north of Algiers, and enjoys a variant of the typical Mediterranean climate in which hot, dry summers and cool, wet winters prevail. The maritime position ameliorates extreme temperatures and slightly increases precipitation levels. Climatic seasonality is linked to pronounced changes in atmospheric circulation in the western Mediterranean. In summer, the region is dominated by the Azores anticyclone, giving clear, settled conditions. Autumnal weakening of this system allows Atlantic depressions to track over the region, bringing much of the annual precipitation *e.g.* 19 % of mean total annual precipitation (653 mm yr.$^{-1}$) in October at Alcudia (Shimwell, Spencer and Tout 1984 unpublished). The mean monthly precipitation distribution for Palma is shown in Figure 4.

The mean monthly thermal range for Palma is depicted by Figure 5. Palma experiences 120-150 days yr.$^{-1}$ where temperatures reach 25 °C, whilst less than 10 days yr.$^{-1}$ experience temperatures at or below freezing (Instituto Geographico Nacional 1995). Typically, 2400-2600 sunshine hours yr.$^{-1}$ are received, giving rise to conditions conducive to high primary productivity, provided summer water-stress can be tolerated. Calm conditions are, on average, experienced on 135 days yr.$^{-1}$ (37 % of days; see Figure 6); prevailing winds are the Lebeche winds from the south-west.

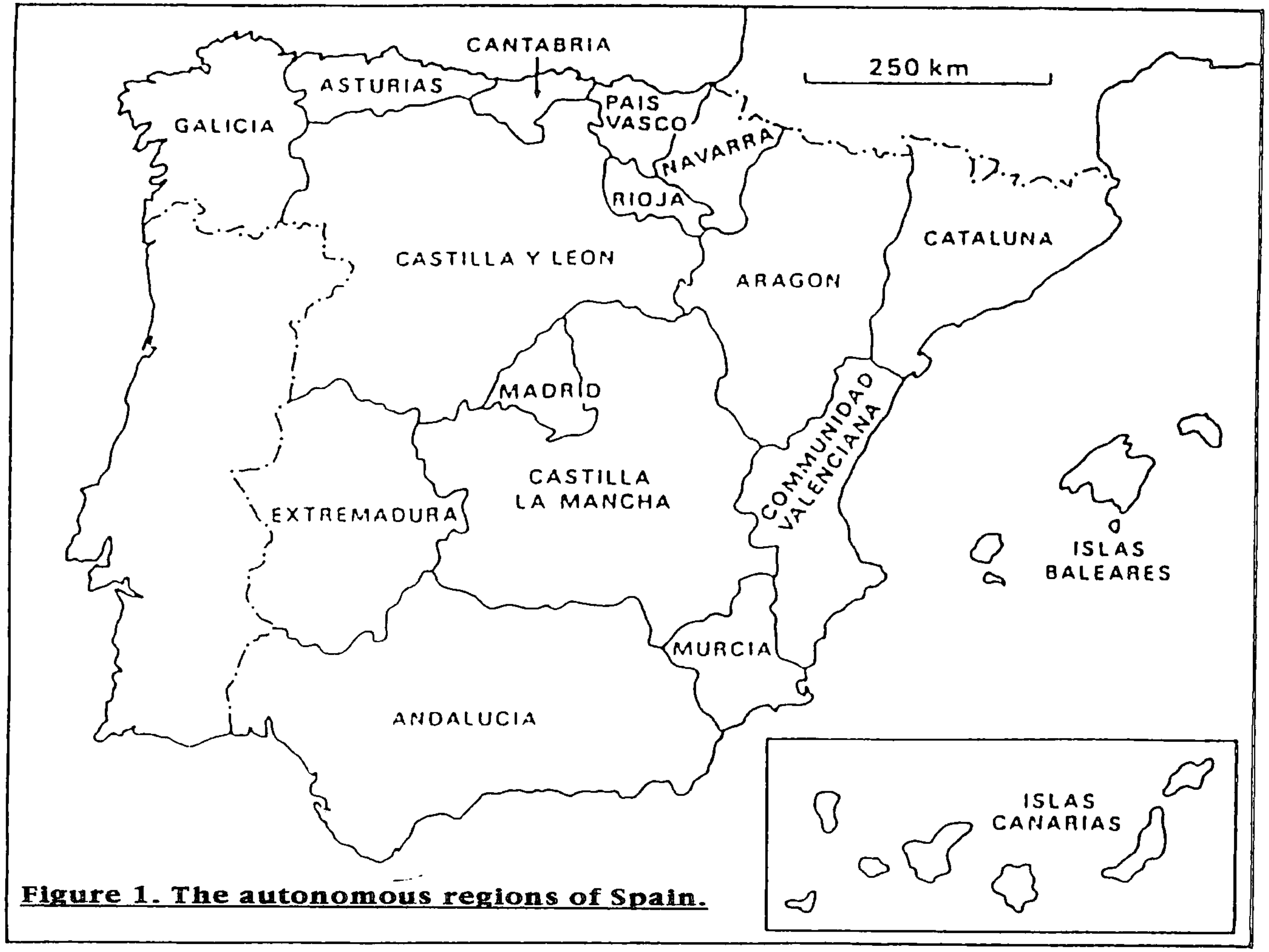
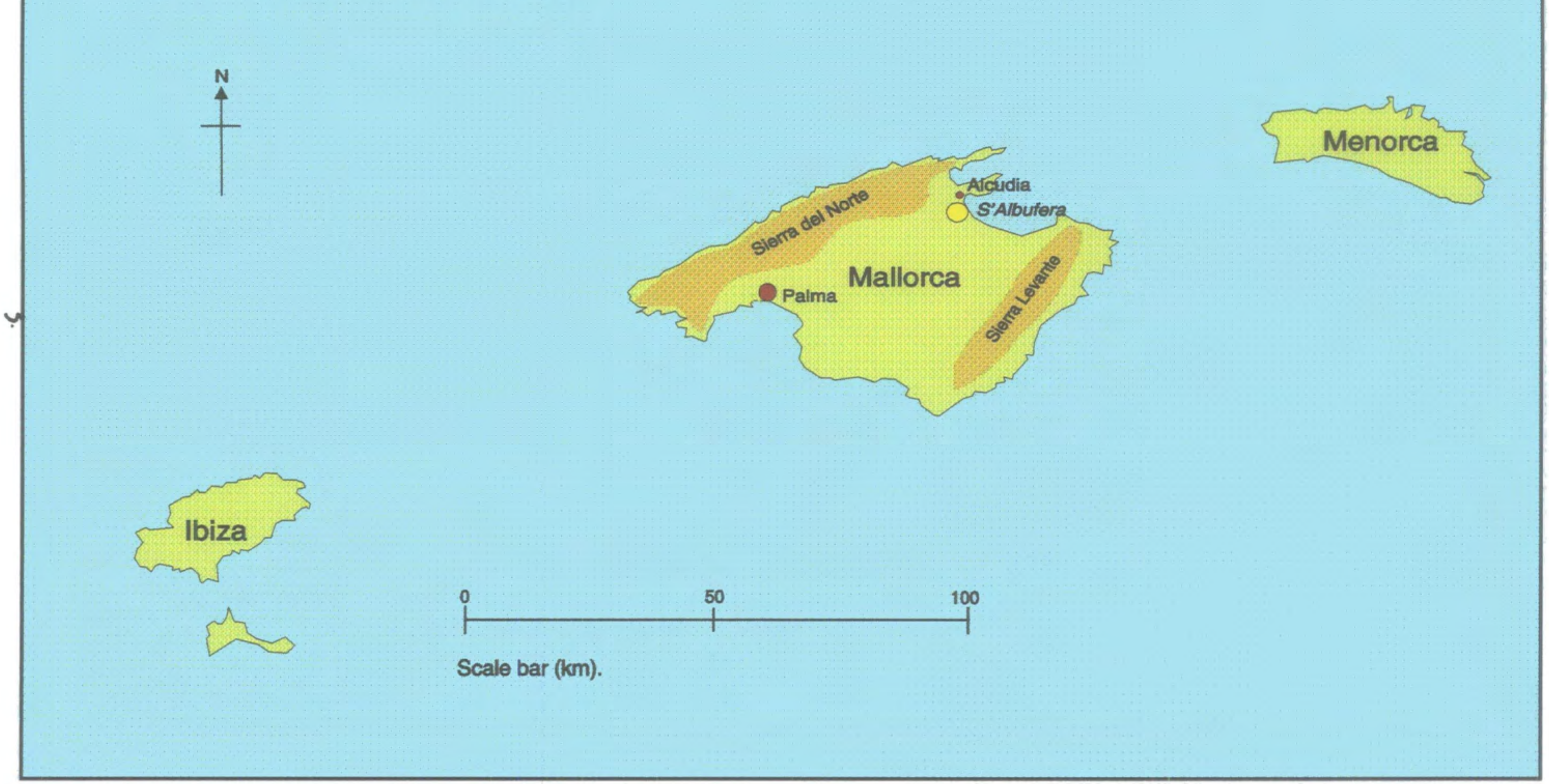


Figure 1. The autonomous regions of Spain.

Figure 2. The Balearic Islands.



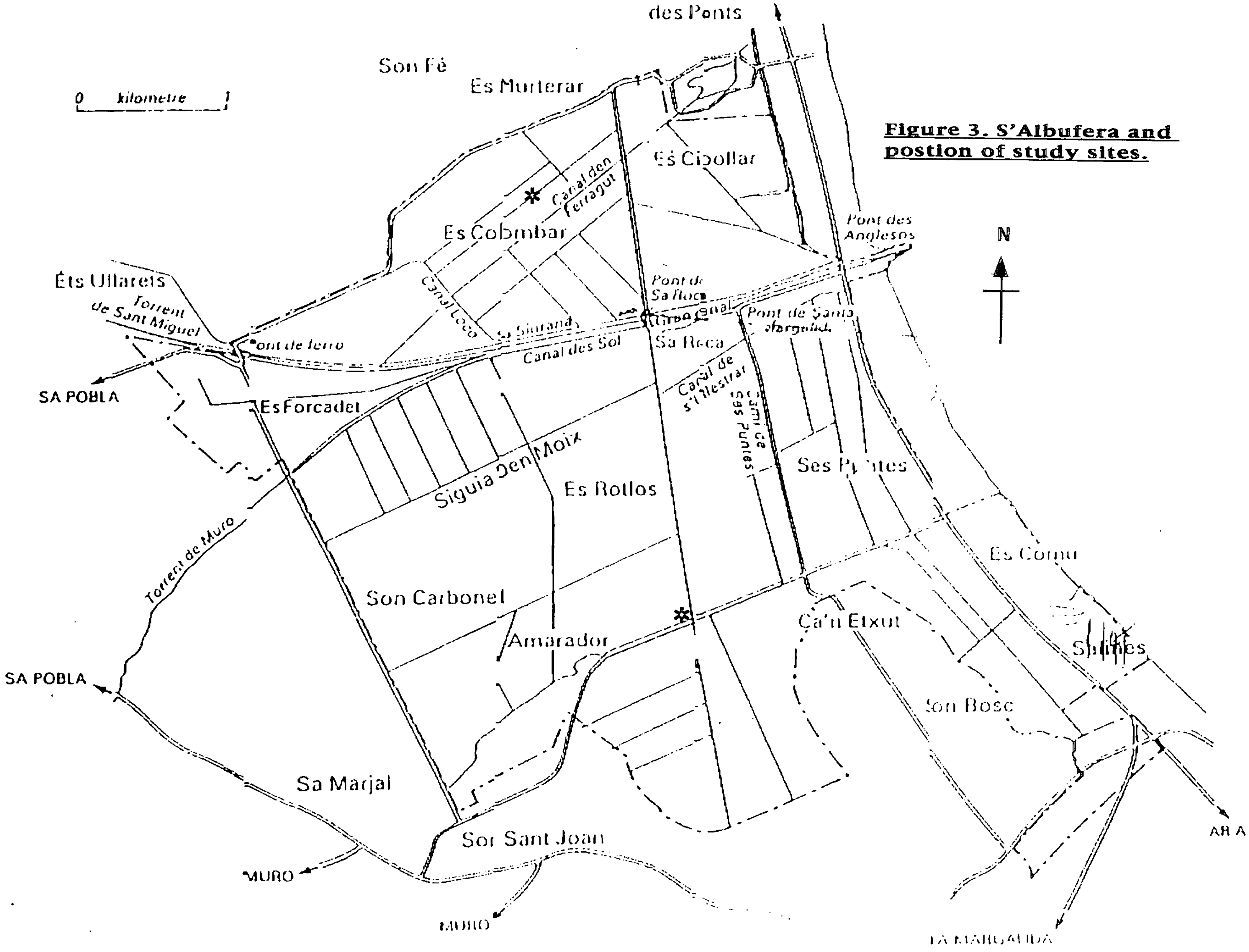
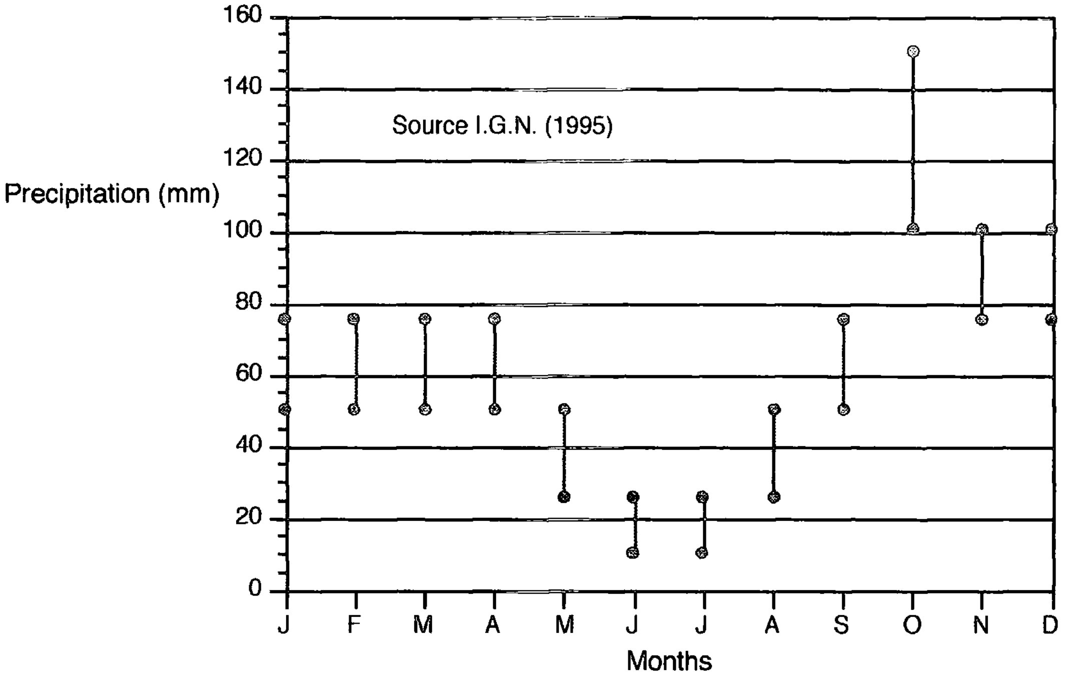


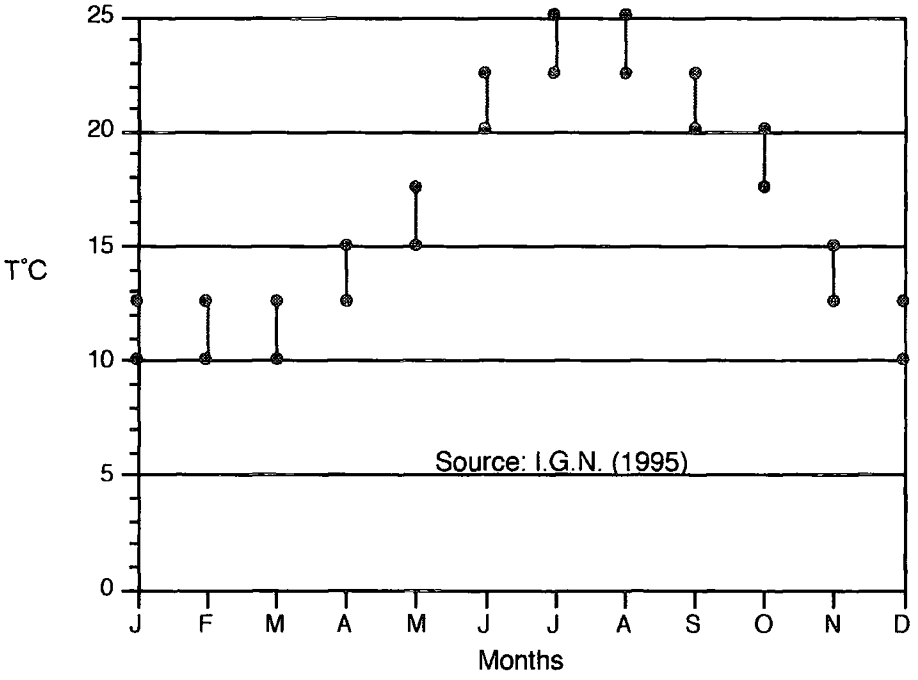
Figure 3. S'Albufera and postion of study sites.

Figure 4. Mean monthly Precipitation (mm), taken from isohyet maps, within 15/25/50 mm ranges (Palma).



Source I.G.N. (1995)

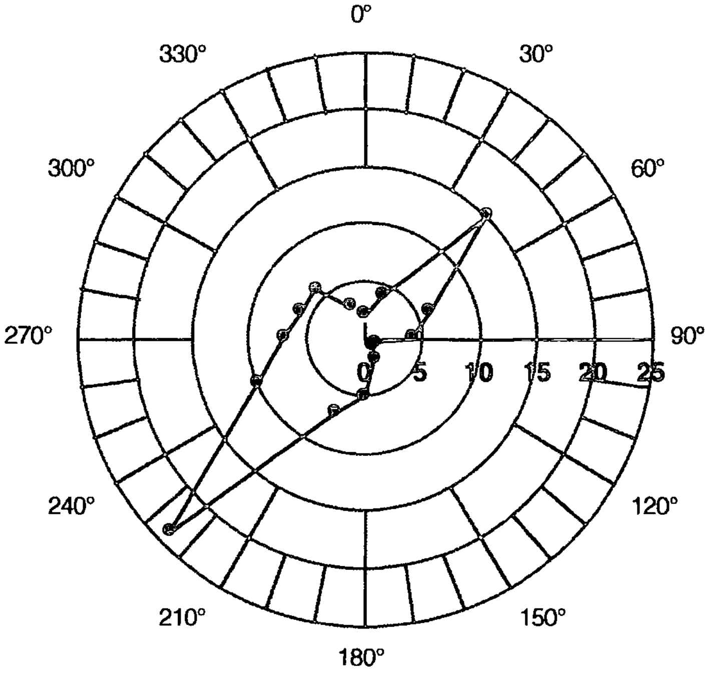
Fig 5. Mean monthly Temperatures, taken from isotherm maps, within 2.5 °C range (Palma).



Source: I.G.N. (1995)

Figure 6. Windrose showing wind direction at Palma. (% days yr.-1).

Note: 0°=North, Calm =37%



Source: I.G.N. (1995).

Geology

Topographically, Mallorca is characterised by two mountain ranges; the Sierra del Norte and Sierra Levante, which run S.W.-N.E. at the extreme north and south of the island, and a low-lying central plain. The eastern end of the Sierra del Norte lies within the 110 km^2 hydrological catchment of S'Albufera. This chain of mountains reaches a height of 1445 m in Puig Major. Comprised of Mesozoic limestones, they were formed by a series of orogenic thrusts in the Eocene and Oligocene epochs. The central plain is composed of Quaternary sediments overlying a Cenozoic basement series (Shimwell *et al.* 1984 unpublished; I.G.N. 1995).

Martinez-Taberner *et al.* (1990a) note that S'Albufera was formed during Rissian (Wolstonian) marine regressions and transgressions (*ca.* 367 Ka B.P.-*ca.* 128 Ka B.P., Jones and Keen 1993), and comprises two basins which have been progressively infilled. Currently, much of the site is a shallow lagoon complex continuously receiving both freshwater and tidal input, giving spatially and temporally varied brackish conditions. The site is isolated from direct marine influence by a 300-500 m wide bar of aeolian sands 8 km in length. Salt water intrusion occurs primarily through the Gran canal, which acts as the main hydrological pathway in over

400 km of canals and ditches constructed in works which commenced in 1856 (Martinez-Taberner *et al.* 1990b).

Freshwater input is from a variety of sources, including numerous springs from bedrock aquifers. Despite local precipitation levels approximating those received by semi-arid regions, precipitation in the upland reaches of the catchment may attain 1100 mm yr.$^{-1}$ (Martinez-Taberner and Moya 1991). The annual distribution of this precipitation is also strongly seasonal, consequently much surface runoff is derived from ephemeral streams.

Environmental history of S'Albufera

As stated above, relatively little work has been published on the Quaternary history of Mallorca; perhaps the best known example is that of Butzer and Cuerda (1962), which provided a Pleistocene (*ca.* 100 Ka-*ca.* 10 ka yr. B.P.) coastal stratigraphy for Palma bay.

In light of this paucity, vegetation history-as inferred from sedimentary sources-can only be described as part of a regional picture. Records providing insights into Pleistocene vegetation patterns of the region are described by Oldfield (1964); Butzer and Freeman (1968); Frank (1969); Florschütz, Menéndez Amor and Wijmstra (1971); Pons and Reille (1988); Turner and Hannon (1988); Carrión (1992a, 1992b); Carrión and Sánchez-Gómez (1992); Hooghiemstra *et al.* (1992); Narcisi *et al.* (1992); Rossignol-Strick *et al.* (1992) and Pérez-Obiol and Julià (1994) *inter alia.*

More pertinently, during the late glacial period (*ca.* 13 Ka-*ca.* 10 Ka B.P.), vegetation belts colonised regions of lower latitude and altitude than are occupied by extant vegetation of the same type. The characteristic steppic vegetation of the region included *Artemisia*, *Ephedra* and Gramineae (Stevenson 1984; Kelly and Huntley 1991). The early Holocene (*ca.* 10 Ka-*ca.* 8 Ka B.P.) was characterised by the appearance of a wide variety of forest taxa from glacial refugia which, in response to changing climatic, geomorphological and successional conditions, spread and contributed greatly to local canopy cover. (Rossignol-Strick *et al.* 1992; Peñalba 1994; Peréz-Obiol and Julià 1994). Records from Granada province, S. Spain, show a predominance of *Quercus ilex*, *Q. suber* and Oleaceae forest (Florschütz *et al.* 1971; Pons and Reille 1988). Across Andaluçia, particularly in coastal regions, woodland dominance was influenced by substrate stability. *Quercus* dominated the most stable soils, *Juniperus* on moderately stable soils and *Pinus* on unstable dune slacks (Stevenson 1985a). Climatic amelioration in north-east Iberia led to the sequential development of heterogeneous woodland, typically with *Pinus* replaced by *Quercus*, *Corylus* and later *Fagus* and *Alnus* components (Reille and Lowe 1993; Peréz-Obiol and Julià 1994).

Vegetation patterns between 8000-5000 yr. B.P. were spatially diverse. Temporal changes were also noted throughout this period across the region, as a result of progressive environmental flux, with peak arboreal pollen recorded in sediments deposited *ca.* 6000 yr. B.P. (Peréz-Obiol and Julià 1994). In central Italy, Frank (1969) and Kelly and Huntley (1991) note a general replacement of closed-canopy mesophyllous Quercucetum forest by more open, sclerophyllous taxa. Concurrently, in southern Spain, cool moist conditions led to the expansion of the *Corylus* and *Betula* forest components (Stevenson 1984). From around 4500 yr. B.P., *Quercus* again began to dominate lowland regions of southern Spain and Catalonia (Stevenson 1984, Stevenson and Moore 1988; Peréz-Obiol and Julià 1994), whilst in the Pyrenees, there was a regional decline of taxa such as *Quercus, Corylus, Ulmus* and *Tilia* (Reille and Lowe 1993). The direct climatic influences upon vegetation in the region become obscured around this time, however, as a result of increasing anthropogenic influence during the Neolithic period.

It is important to consider the manner in which the vegetation composition of S'Albufera has been influenced by human action. During the Holocene, anthropogenic activity was prevalent over much of Mallorca: Neolithic (7200-4000 yr. B.P.) artifacts have been found on the island. The Roman occupation of Mallorca is likely to have influenced the site, following settlement of the island in 123 B.C., since nearby Pollentia (Alcudia) was constructed as a major fortified settlement (Shimwell *et al.* 1984 unpublished). It is understood that S'Albufera has been a lagoon since Roman times, since waterfowl were hunted there for the tables of Rome.

The island was captured during the Moorish conquests of A.D. 707, subsequent to which a system of polyculture was practiced for more than 400 years. Such agricultural practices included the establishment of extensive terrace and irrigation systems, along with widespread felling of *Quercus* for charcoal (Shimwell *et al.* 1984 unpublished). The name S'Albufera is derived from the Arabic Al-buhayra, "the lagoon".

In the seventeenth century, agriculture increased in extent. Marjals, small agricultural plots surrounded by channels, were constructed to the south and west of S'Albufera (Govern Balear 19_ _ unpublished).

Martinez-Taberner *et al.* (1992) note that canalisation had profound effects upon the hydrological characteristics of S'Albufera; for example, the open water area has fallen from *ca. 35*% to *ca. 3*%. The site is currently flooded to a depth of 0-2 m, allowing the expansion of hydrophytes such as *Phragmites australis* and *Cladium mariscus* in the shallower parts (Plate 1). Previously the vegetation type was more diverse, in response to the prevailing hydrological conditions, notably more open-water lagoons, a steeper salinity gradient and lower flow rates.

It is apparent that Mallorca must have had a complex vegetational history, since records from Mediterranean sites approximately equidistant from Mallorca (see above) show distinct patterns of variation. Whilst these changes often occurred concurrently, they show a spatially-marked disparity. Isolated positioning further complicated Mallorcan vegetation history. Like many Mediterranean islands, Mallorca has a relatively high proportion of endemic species *e.g.* 10-20 endemic species/km^{-2} (I.G.N. 1995), equivalent to 2.7 % of total species (Huntley, personal communication).

Aims and objectives

Despite the hydrological changes imposed in the last century, S'Albufera was identified as a potentially useful research site for several reasons. As a lagoon, and latterly as a marsh, the site has acted as a depositional environment, and thus may provide a continuous sedimentary record. Traditional deposits used in palaeoenvironmental studies, such as mire and lake sediments, are sparsely distributed in the region-due to seasonally dry climatic conditions, or have been subject to significant disturbance. Thus other, less-documented sedimentary sources must be sought.

In establishing the value of S'Albufera as a potential research site, several specific considerations must be addressed within this study:

★ Do sediments deposited in the past reflect prevailing environmental conditions at that time? Is any subsequent disturbance to these sediments indicative of the nature of these agents of perturbation? That is to say, can a sedimentary record be obtained from S'Albufera which allows valid interpretations of past environmental conditions?

★ Owing to time constraints placed upon this study, it is not possible to investigative all potential lines of evidence, then interpret and evaluate each one accordingly. However, the stratigraphic investigations encompassed by this study should provide some insights into the potential merits of other environmental indicators.

★ It has been established that S'Albufera has spent much of its recent history as a lagoon. Continuous localised flooding would have had a strong influence on the type of vegetation growing at and around the site. This has several implications for this study, in that it is unlikely that vegetation grew at the immediate site throughout this lagoonal period. Notwithstanding, accomplished palynological studies have been conducted on aquatic sediments lain some distance from pollen source areas (*e.g.* Hooghiemstra *et al.* 1992; Rossignol-Strick *et al.* 1992; D'Costa, Grindrod and Ogden 1993; Devoy *et al.* 1994).

★ The sensitivity of the sedimentary record at S'Albufera may be tested by examination for evidence of documented environmental changes at both the local scale *e.g.* drainage *ca.* 1850 and the regional scale *e.g.* progressive trends noted throughout the Holocene.

★ Attempts will also be made to provide an environmental history for the site. Knowledge of the current state of S'Albufera and existing studies describing past environmental changes in the region provide a basis for documenting any apparent variation, and subsequently suggesting the causal mechanisms behind these shifts. As part of this, certain key research questions may be addressed:

★ To what extent has the site been an aquatic, as opposed to a terrestrial site?

★ Has the extant vegetation at the site arisen as a result of recent environmental changes, such as drainage *ca.* 1850, or have these vegetation components been present at the site throughout the period reflected in the core? If so, has the relative composition of these taxa changed over time?

★ Can the causal mechanisms of any changes be inferred (*i.e.* the relative influence of human action and overriding environmental shifts)?

★ At what spatial scales are the mechanisms driving such changes operating (*e.g.* local, catchment [hydrological], regional, global)? Local-scale spatial variability shall be tested by utilising two study sites: Es Colombar is a peripheral site to the north of S'Albufera where the sediments were overlain by 3 cm of water; the Amarador site has a more central location, and was submerged by 26 cm. Extant vegetation at both sites comprises dense beds of *Phragmites australis.*

★ Is there any evidence for anthropogenic changes at the landscape level? If so, are these temporally variable in magnitude and/or frequency?

Plate 1. S'Albufera marsh, dominated by *Phragmites australis*. View looking N.W. over Amarador (22/3/95, 17:00).

Plate 2. Russian corer with 300 cm-350 cm core section from Amarador in place (22/3/95, 16:00).

Chapter Two: Methods

Field methods:

Four stratigraphic cores were collected on March 22, 1995, during a fieldcourse for the advanced ecology M.Sc. degree. The surface polsters were collected on 21 March.

Core collection

Cores #1 and #2 were extracted from Es Colombar, cores #3 and #4 from the Amarador site; all were obtained using a Russian corer, as described by Jowsey (1966). Each core was constructed from deposits sampled from two points of entry 0.3 m apart. Inserting the corer into the sediment invariably deforms the stratigraphy below, and allows the introduction of contaminating sediments from above. The use of alternate holes negates this problem. The second core obtained from each site was to enhance the potential detection of sediment contamination, these are not discussed within this project.

Upon extraction, each core section was photographed (Plate 2), and brief field notes made of sediment texture, colour and macrofossil abundance. The sections were then individually placed in 55 cm lengths of labelled plastic guttering. These were wrapped securely in two grades of plastic film to minimise water loss and structural damage to the core. On return to the U.K., the cores were stored at 4 °C prior to laboratory examination, analyses and sample preparation.

Polster samples

Each sample consisted of a palm-sized moss polster which had been relatively open to pollen influx from the immediate vegetation. Two polsters were collected from a *Pinus halepensis* dominated regenerating coastal dune system.

Laboratory methods:

Sedimentary analyses

The textural, structural and compositional characteristics of the core were described using the classification of Aaby and Berglund (1986). Subsequent geochemical analyses were undertaken in which 1 cm^3 samples of sediment from various depths were sequentially dried at 105 °C, cooled and weighed, ignited at 550 °C, cooled in a dessicator and weighed and then ignited at 900 °C, cooled in a dessicator and weighed. Treatments lasted for a minimum of six hours and determined respective water (excluding micropore water), organic carbon and inorganic carbon (principally carbonates: $CaCO_3$, $CaMg(CO_3)_2$ and $MgCO_3$) fractions.

Pollen extraction

Pollen extraction from the cores took place between 5 May-18 July 1995. Initially 20 extractions were conducted, eight for Es Colombar and 12 for Amarador. The data from these extractions were used to identify horizons from which a further 16 extractions were made, eight for each core. The methods adopted were in accordance with those endorsed by the University of Durham Environmental Research Centre (Huntley and Allen 1992 unpublished [Appendix 1]). Sediment samples of a known volume were spiked with 1 cm^3 of *Eucalyptus* pollen in a suspension of 39000 $grains/cm^{-3}$. The samples were sieved through a 180 μm mesh, then subject to sequential treatments with the following: 10 % NaOH, $Na_4P_2O_7$ (following Bates, Coxon and Gibbard 1978; Heusser and Stock 1984), 10 % HCL, $ZnCl_2$, glacial CH_3COOH, 9:1 ratio of $(CH_3CO)_2O$ and concentrated H_2SO_4. The $Na_4P_2O_7$ treatment was implemented due to the predominantly clay-rich sediments. $Na_4P_2O_7$ is an effective deflocculant, which shows no tendency to preferentially attack or destroy pollen during preparation (Bates *et al.* 1978).

The substrate left at the end of each extraction was suspended in 2000 cs silicone oil and mounted under 22 mm square coverslips. Slides were examined using a Carl Zeiss microscope. Pollen was identified using keys (notably Moore, Webb and Collinson 1991) and reference material. Identification was made to a suitable level of accuracy, which varied amongst taxa, but was typically to genus or family. The patience shown, and assistance given by Dr Judy Allen at this stage cannot be overstated.

Whilst counting pollen, a balance had to be made between the experimental ideal of large sample sizes (*e.g.* >600 grains, Moore *et al.* 1991) and constraints placed upon the study by low pollen concentrations and time. It was considered, given the preliminary nature of this study, to embark upon a broad scan of the profile as opposed to a more focused approach. Pollen counts between 0-265 grains were recorded for each extraction.

Pollen extraction data is expressed in three forms: as counts, percentages and as concentrations (expressed as $grains/cm^{-3}$).

Foraminiferal inspection

The residual material obtained by the initial sieving of the pollen samples was inspected under a Leica microscope for the presence/absence of foraminifera. In coastal marshes, these benthonic, unicellular organisms have discrete, highly restricted niches of narrow vertical range, and are thus highly accurate indicators of sea level (Scott and Medioli 1978; Cearreta 1993; Gehrels 19_ _ unpublished).

Computational methods

A wide variety of computational platforms, programmes and packages were used for the analysis and display of data. Pollen data were explored using the multivariate analytical technique CONISS (CONstrained Incremental Sum of Squares). Dendrograms depicting the level of association between stratigraphically adjacent pollen assemblages are included on the pollen percentage diagrams for each core.

Another multivariate analysis programme, DECORANA (DEtrended CORrespondence ANAlysis), was implemented on the data for individual taxa and on the total pollen data from each extraction level. However, the results produced did not warrant inclusion in this project, since the respective DECORANA scores of individual taxa and extraction levels did not highlight any emergent environmental gradients that were not otherwise evident from inspection of the pollen diagrams. It would be expected, for example, that DECORANA would produce taxon data scores which, when plotted on an X/Y scatter, would highlight a gradient of taxon response to environmental variables such as available moisture or salinity.

Units

Departmental guidelines strongly urged that this project employed units in strict accordance with scientific notation (S.I.). However the overwhelming precedent set by many palaeoenvironmentalists, even in recent times, has been to measure short-depth core profiles in centimetres *e.g.* Stevenson (1984, 1985a,); Stevenson and Moore (1988); Kelly and Huntley (1991); Stevenson and Battarbee (1991); Waller (1993); Warren and Nierling (1993); Hulme 1994; Peñalba (1994); Reeder and Eisner (1994). Only two examples were found of short-core profiles described in metres (Jennings, Carter and Orford 1993; Cole and Liu 1994). Consequently it was decided to express all core depth measurements in centimetres.

Chapter Three: Results

Introduction

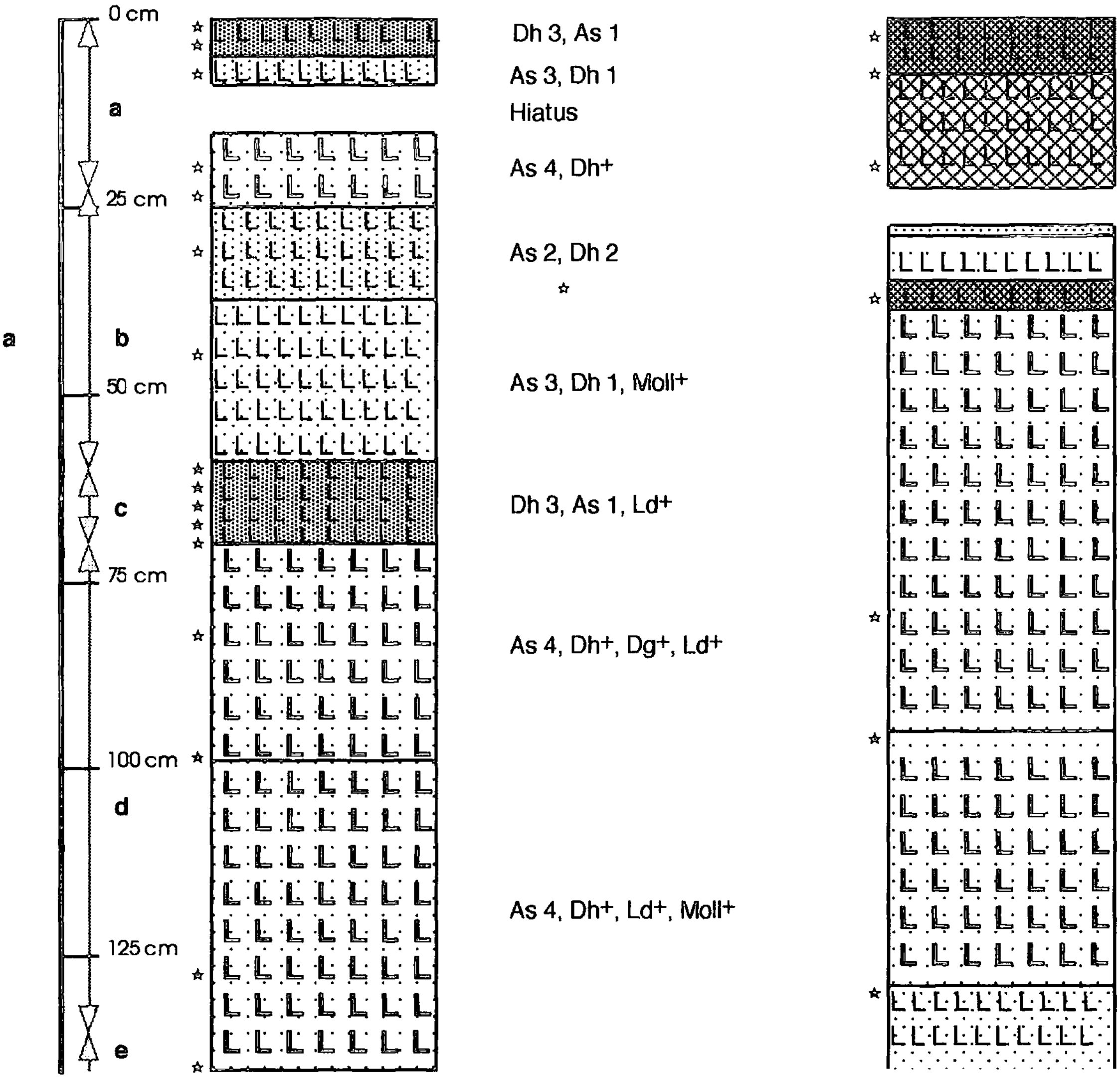
Given the complex nature of the results, groupings of consecutive stratigraphic data, or assemblage zones, have been identified for each core. These sub-groups are by no means totally distinct from adjacent assemblages, but highlight general trends in the data. Assemblage zones were categorised through the level of association shown between stratigraphically adjacent pollen assemblages, as derived from CONISS, and lithological horizons. Zones are presumed to lie sequentially and chronologically. They are named in reverse order, with the uppermost being denoted zone a, since further studies could reveal older sediments which could be then named without confusion. The results are presented within the assemblage zone framework. Each core is first considered individually, then they are compared.

The pollen diagrams display taxon data in a sequential manner. Some studies in the Mediterranean region (*e.g.* Kelly and Huntley 1991) have classified vegetation types according to their broad ecological niche; as opposed to the traditional classification (*sensu* Waller 1993) based on physiological characteristics. It was felt that the adoption of a more traditional approach would best suit this study; since many of the key taxa would require identification to species level before certain, meaningful groupings based on ecological function could be used. Thus the taxa are presented in the order of trees, shrubs, herbs and aquatics. Within each of these groups, an attempt has been made to place taxa with similar ecological niches adjacent to each other. Both *Corylus* and *Alnus* are classified as tree taxa, whilst Chenopodiaceae and *Artemisia* are defined as shrub taxa, since in the Mediterranean most members of these families are shrubs or sub-shrubs. Gramineae and Cyperaceae are considered as herb taxa.

Es Colombar:

The complete lithology for the Es Colombar core is displayed in Figure 7. Pollen count data are presented in Appendix 2, percentage values in Table 1 and Figure 8, whilst pollen concentrations are depicted in Table 2 and Figure 9. Geochemical data are presented in Table 3. The foram *Ammonia beccarii* was present in all samples from this core, data are not shown pictorially.

Figure 7. Lithology of Es Colombar, following Aaby and Berglund (1986). Top 142 cm of Amarador to scale on right.



Key for Figures 7 & 10.

Principle organic sediments:

- ▩ **Ld**-*Limus detrituosus 3*
- ▨ **Ld**-*Limus detrituosus 1*
- ▦ **Dh**-*Detritus herbosus 3*
- ▒ **Dh**-*Detritus herbosus 2*
- ░ **Dh**-*Detritus herbosus 1*
- ⁚ **Dh**-*Detritus herbosus +*

Mineral sediments:

- L L L **As**-*Argilla steatodes* 4
- L L L L **As**-*Argilla steatodes* 3
- L L L L L **As**-*Argilla steatodes* 2
- L L L L L **As**-*Argilla steatodes* 1

Dg-*Detritus granuosus*
Ag-*Argilla grana*
Moll-*Mollusca*
☆ Position of pollen extraction

Table 1. Pollen percentage data (Es Colombar).

Assemblage Zone:		Zone a				Zone b		Zone c I		Zone c II		Zone c III		Zone d		Zone e
	2 cm	8 cm	10 cm	20 cm	24 cm	32 cm	44 cm	60 cm	62 cm	64 cm	68 cm	88 cm	82 cm	83 cm	128 cm	140 cm
Pinus	6.4	26.7	3.1	9.7	17.3	30.8	43.3	11.1	13.5	14.3	9.8	1.6	42.0	21.0	34.3	5.0
Quercus	6.4	12.3	19.7	16.6	10.5	11.9	5.0	10.7	7.3	4.2	3.0	1.4	19.0	21.0	3.0	10.1
Corylus	*	*	4.7	2.4	0.6	*	*	1.6	0.8	*	*	*	*	*	*	2.9
Fagus	*	*	0.0	0.5	*	*	1.7	0.8	*	*	*	*	*	1.6	*	*
Carpinus	*	*	0.8	*	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	3.4	*	*	1.2	2.2	*	*	*	*	*	*	*	4.8	1.5	*
Populus	*	0.7	*	2.9	11.1	8.6	*	0.8	*	1.8	0.8	*	12.0	6.5	3.0	1.4
Alnus	0.9	*	*	1.0	*	*	*	*	*	*	0.4	*	*	*	*	*
Chenopodiaceae	33.9	25.3	34.6	27.6	13.6	18.4	20.0	37.0	22.9	13.7	12.5	64.2	4.0	3.2	7.5	37.4
Tamarix	1.8	*	*	0.5	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	2.8	*	3.9	1.9	0.6	*	*	0.8	0.8	*	*	*	*	*	*	2.9
Thymelaceae	0.9	*	*	2.4	*	*	*	*	*	*	*	*	*	*	*	*
Ericales	0.9	*	*	2.4	*	*	1.7	1.6	*	*	0.8	0.5	4.0	1.6	1.5	8.6
Juniperus	0.9	0.7	*	*	7.4	2.2	1.7	*	*	1.8	0.4	*	*	*	*	*
Oleaceae	8.3	8.2	8.7	8.1	7.4	6.5	5.0	7.4	4.9	3.0	2.3	1.9	8.0	22.6	17.9	1.4
Buxus	*	*	*	*	0.6	*	*	*	*	*	*	*	*	*	*	*
Sambucus	*	*	*	1.0	*	*	*	*	*	*	*	*	*	*	*	*
Rhamnus	*	*	*	*	*	*	*	*	*	*	0.4	*	*	*	*	*
Ribes	*	*	*	1.0	*	*	*	*	*	*	*	*	*	*	*	*
Vitis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.4
Gramineae	18.3	15.8	13.4	7.1	13.6	10.8	6.7	14.8	29.4	49.4	60.0	25.8	12.0	6.5	25.4	14.4
Cyperaceae	3.7	2.1	1.6	*	*	2.2	*	*	4.9	10.1	3.8	0.5	*	*	*	1.4
Comp. Liguliflorae	1.8	2.7	*	1.4	0.6	4.3	11.7	4.9	1.6	*	0.8	0.5	*	1.6	3.0	*
Compositae	3.7	*	1.6	1.0	0.6	*	*	2.5	0.8	*	0.8	0.9	*	*	*	*
Plantago	*	2.1	1.6	3.8	4.3	1.1	*	3.3	6.5	0.6	2.3	0.5	*	4.8	*	1.4
Caryophyllaceae	*	*	*	1.0	8.0	*	*	1.6	0.8	*	0.4	*	*	1.6	1.5	1.4
Rumex type	*	*	*	*	*	*	*	*	*	*	*	*	*	3.2	*	5.8
Umbelliferae	0.9	*	0.8	0.5	*	*	*	0.8	0.8	0.6	0.8	0.5	*	*	*	*
Euphorbia	*	*	*	0.5	*	*	*	*	*	*	*	0.9	*	*	*	1.4
Marrubium	*	*	*	0.0	*	*	*	*	0.8	*	*	*	*	*	*	*
Leguminoseae	7.3	*	3.1	4.8	0.6	*	*	*	3.3	*	1.1	0.5	*	*	*	1.4
Myriophyllum	*	*	2.4	2.4	*	*	*	*	*	*	*	*	*	*	*	*
Potamogeton	*	*	*	*	*	*	*	*	*	*	*	0.5	*	*	*	1.4
Unknown	0.9	*	*	*	1.9	1.1	3.3	*	0.8	0.6	*	*	*	*	1.5	*
Tree Sum	13.8	43.2	28.3	33.0	40.7	53.5	50.0	25.9	21.6	20.2	14.0	3.0	73.0	54.8	41.8	19.4
Shrubs sum	49.5	34.2	47.2	44.7	29.6	27.0	28.3	46.1	28.6	18.5	16.2	66.5	15.0	27.4	26.9	51.8
Herbs sum	35.8	22.6	22.0	20.0	27.8	18.4	18.3	28.0	49.0	60.7	69.8	30.0	12.0	17.7	29.9	27.3
Aquatic sum	*	*	2.4	2.4	*	*	*	*	*	*	*	0.5	*	*	*	1.4
Pollen sum	109.0	146.0	127.0	210.5	162.0	92.5	60.0	121.5	122.5	168.0	265.0	213.5	26.0	62.0	67.0	69.5

Figure 8. Pollen percentage diagram (Es Colombar).
(CONISS plot and basic lithology also shown).

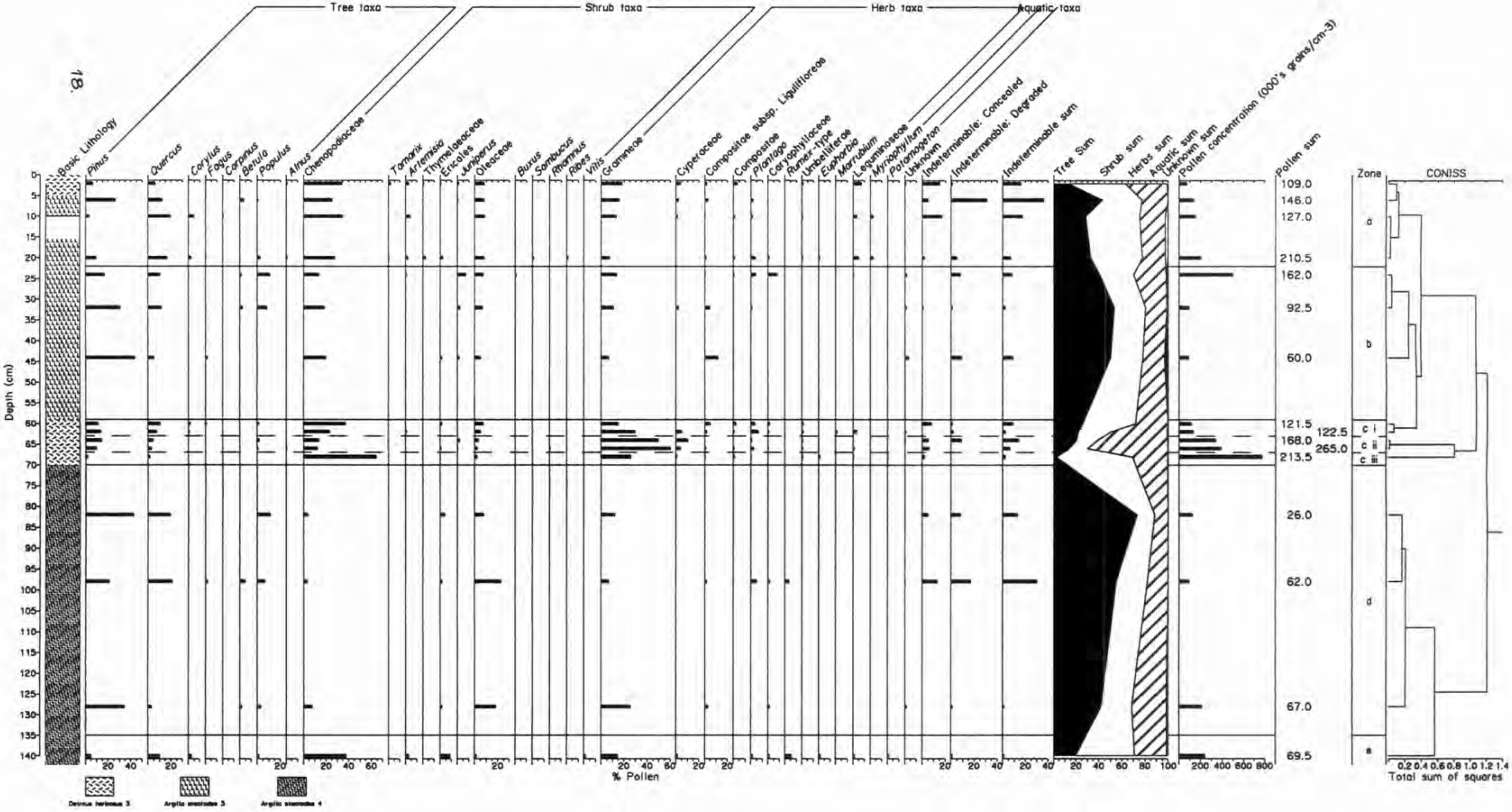
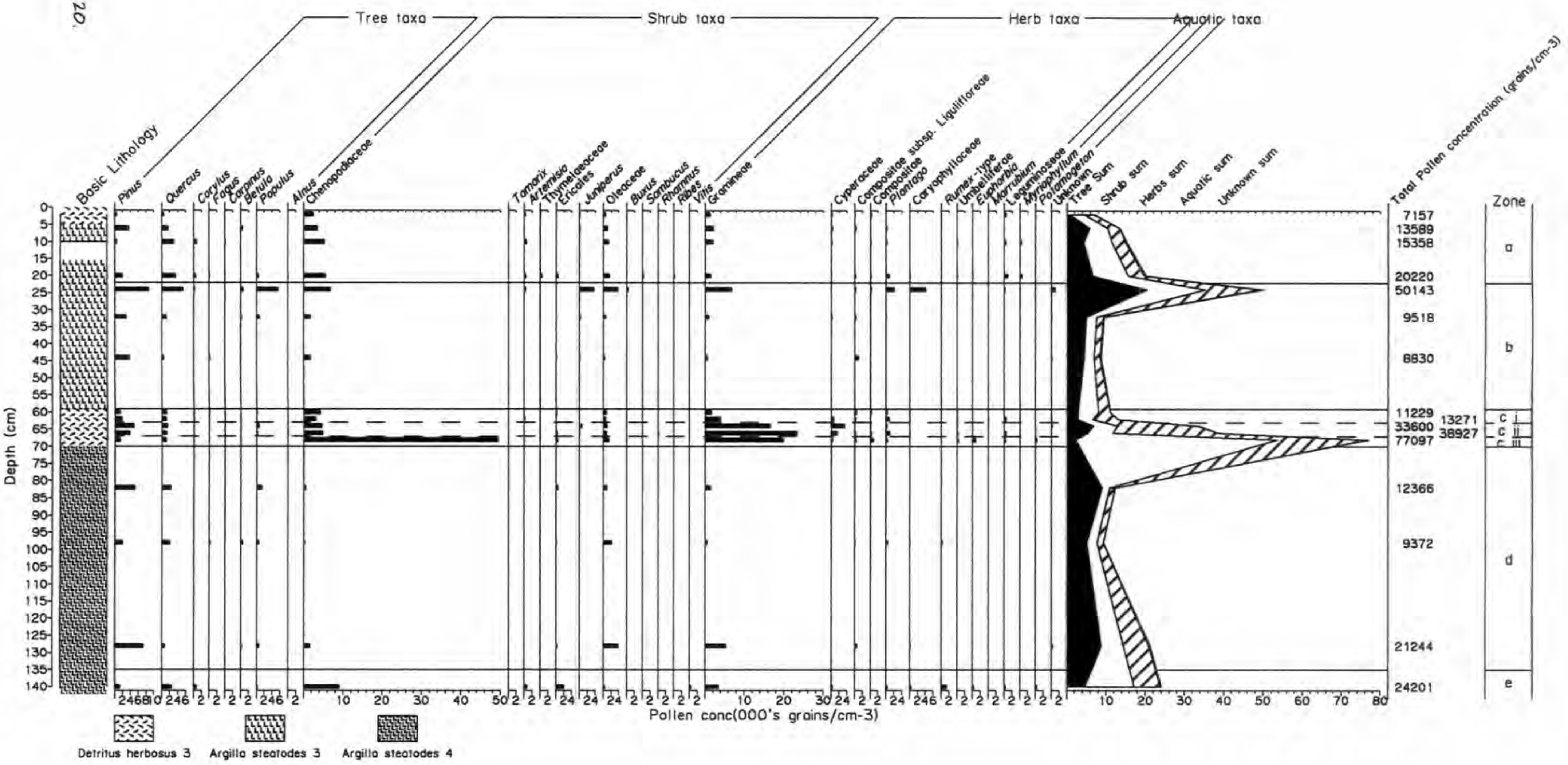


Table 2. Pollen concentration (grains/cm-3) data (Es Colombar).

Assemblage Zone:		Zone a				Zone b		Zone c i		Zone c ii		Zone c iii		Zone d		Zone e
	2 cm	6 cm	10 cm	20 cm	24 cm	32 cm	44 cm	60 cm	62 cm	64 cm	66 cm	68 cm	82 cm	98 cm	128 cm	140 cm
Pinus	459.6	3630.1	483.7	1969.2	8666.7	2932.7	3826.4	1247.6	1787.5	4800.0	3819.2	1263.2	5231.7	1965.1	7292.7	1218.8
Quercus	459.6	1675.4	3023.3	3362.1	5261.9	1131.9	441.5	1201.4	975.0	1400.0	1175.1	1083.3	2378.1	1965.1	634.2	2437.5
Corylus	*	*	725.6	480.3	309.5	*	*	184.8	108.3	*	*	*	*	*	*	696.4
Fagus	*	*	*	96.1	*	*	147.2	92.4	*	*	*	*	*	151.2	*	*
Carpinus	*	*	120.9	*	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	465.4	*	*	619.1	205.8	*	*	*	*	*	*	*	453.5	317.1	*
Populus	*	93.1	*	576.4	5571.4	823.2	*	184.8	*	600.0	293.8	*	1426.8	604.7	634.2	348.2
Alnus	65.7	*	*	192.1	*	*	*	*	*	*	146.9	*	*	*	*	*
Chenopodiaceae	2429.3	3443.9	5320.9	5571.4	6809.5	1749.3	1766.0	4158.8	3033.3	4600.0	4847.5	49472.2	475.6	302.3	1585.4	9053.6
Tamarix	131.3	*	*	96.1	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	197.0	*	604.7	384.2	309.5	*	*	*	108.3	*	*	*	*	*	*	696.4
Thymelaceae	65.7	*	*	480.3	*	*	*	*	*	*	*	*	*	*	*	*
Ericales	65.7	*	*	480.3	*	*	147.2	184.8	*	*	293.8	361.1	475.6	151.2	317.1	2089.3
Juniperus	65.7	93.1	*	*	3714.3	205.8	147.2	*	*	600.0	146.9	*	*	*	*	*
Oleaceae	590.9	1117.0	1330.2	1633.0	3714.3	617.4	441.5	831.8	650.0	1000.0	881.4	1444.4	951.2	2116.3	3804.9	348.2
Buxus	*	*	*	*	309.5	*	*	*	*	*	*	*	*	*	*	*
Sambucus	*	*	*	192.1	*	*	*	*	*	*	*	*	*	*	*	*
Rhamnus	*	*	*	*	*	*	*	*	*	*	146.9	*	*	*	*	*
Ribes	*	*	*	192.1	*	*	*	*	*	*	*	*	*	*	*	*
Vitis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	348.2
Gramineae	1313.1	2140.8	2055.8	1440.9	6809.5	1029.0	588.7	1663.5	3900.0	16600.0	23355.9	19861.1	1426.8	604.7	5390.2	3482.1
Cyperaceae	262.6	279.2	241.9	*	*	205.8	*	*	650.0	3400.0	1468.9	361.1	*	*	*	348.2
Comp. Liguliflorese	131.3	372.3	*	288.2	309.5	411.6	1030.2	554.5	216.7	*	293.8	361.1	*	151.2	634.2	*
Compositae	262.6	*	241.9	192.1	309.5	*	*	277.3	108.3	*	293.8	722.2	*	*	*	*
Plantago	*	279.2	241.9	768.5	2166.7	102.9	*	369.7	866.7	200.0	881.4	361.1	*	453.5	*	348.2
Caryophyllaceae	*	*	*	192.1	4023.8	*	*	184.8	108.3	*	146.9	*	*	302.3	317.1	348.2
Rumex type	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1392.9
Umbelliferae	65.7	*	120.9	96.1	*	*	*	92.4	108.3	200.0	293.8	361.1	*	*	*	*
Euphorbia	*	*	*	96.1	*	*	*	*	*	*	*	722.2	*	*	*	348.2
Marrubium	*	*	*	*	*	*	*	*	108.3	*	*	*	*	*	*	*
Leguminoseae	525.3	*	483.7	960.6	309.5	*	*	*	433.3	*	440.7	361.1	*	*	*	348.2
Myriophyllum	*	*	362.8	480.3	*	*	*	*	*	*	*	*	*	*	*	*
Potamogeton	*	*	*	*	*	*	*	*	*	*	*	361.1	*	*	*	348.2
Unknown	65.7	*	*	*	928.6	102.9	294.3	*	108.3	200.0	*	*	*	*	317.1	*
Tree Sum	984.9	5864.0	4353.5	6676.1	20428.6	5093.7	4415.1	2911.1	2870.8	6800.0	5435.0	2347.2	9036.6	5139.5	8878.1	4700.9
Shrubs sum	3545.5	4653.9	7255.8	9029.6	14857.1	2572.6	2501.9	5175.4	3791.7	6200.0	6316.4	51277.8	1902.4	2569.8	5707.3	12535.7
Herbs sum	2560.6	3071.6	3386.1	4034.5	13928.6	1749.3	1618.9	3142.2	6500.0	20400.0	27175.1	23111.1	1426.8	1662.8	6341.5	6616.1
Aquatic sum	*	*	362.8	480.3	*	*	*	*	*	*	*	361.1	*	*	*	348.2
Eucalyptus count	594.0	419.0	215.0	203.0	126.0	379.0	265.0	211.0	180.0	195.0	177.0	54.0	82.0	258.0	123.0	56.0
Sample Volume (cc)	1.0	1.0	1.5	2.0	1.0	1.0	1.0	2.0	2.0	1.0	1.5	2.0	1.0	1.0	1.0	2.0
Exotic Volume (cc)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Exotic Concentration (grains/ml)	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0
Total Pollen Concentration (grains/cc)	7156.6	13589.5	15358.1	20220.4	50142.9	9518.5	8830.2	11228.7	13270.8	33600.0	38926.6	77097.2	12365.9	9372.1	21243.9	24200.9

Figure 9. Pollen concentration (grains/cm-3) diagram (Es Colombar). (Basic lithology also shown).



Zone e (142 cm-135 cm)

Zone e is composed of dense clay sediments, with elements of organic matter and molluscan macrofossils.

The pollen assemblage at 140 cm (17 taxa) shows a relatively low degree of palynological association with overlying pollen assemblages, and is characterised by moderate pollen concentrations, dominated by the shrub component. Chenopodiaceae pollen dominates, whilst Ericales pollen reaches peak levels for the core. Record values are also recorded for *Potamogeton* (aquatic) and *Rumex*-type pollen, yet a moderate Gramineae count dominates the herb pollen sum. Tree taxa are poorly represented with low *Pinus* and moderate *Quercus* pollen contributions.

Table 3. Percentage extractable water and carbon species values (Es Colombar).

Sample depth (cm)	% H2O	% organic C.	% carbonate
6	63.96	5.24	7.52
12	50.13	4.66	12.26
26	46.05	4.19	13.19
32	56.14	5.10	10.70
48	42.68	5.64	14.79
62	77.54	6.03	2.40
80	38.22	5.60	16.55
98	35.49	5.56	16.21
128	39.13	4.64	17.20

Zone d (135 cm-70 cm)

Lithologically this unit is similar to zone e, although a slight change is apparent around 96 cm, where the molluscan component is replaced by increased levels of humified organic matter. Three samples from this horizon were analysed for extractable water and carbon fraction data. The values for all variables tested are highly comparable, with a substantial water fraction. Carbon is also a major component, largely represented by inorganic compounds.

Three pollen assemblages, at 128 cm (10 taxa), 98 cm (13 taxa) and 82 cm (7 taxa) show a high degree of affinity, but display a progressive shift from shrub-dominated to tree-dominated pollen input. Pollen concentration data show the absolute rise in total arboreal pollen (T.A.P.) to be subdued, occurring through strong input of *Pinus, Quercus* and *Populus* pollen.

A massive reduction in the Chenopodiaceae pollen input is evident, although a contraction in total shrub contribution is mitigated by relatively high input of Oleaceae and Ericales pollen. Herb pollen input also decreases from 98 cm, largely due to relatively low Gramineae counts. The low Gramineae pollen contributions at 98 cm are offset by significant inputs from *Plantago*, Caryophyllaceae and *Rumex*-type and, to a lesser degree, Compositae subspecies Liguliflореae pollen. No aquatic pollen was recorded within these assemblages.

Zone c (70 cm-59 cm)

This zone is characterised by an organic-rich lithology, composed of *detrituosus herbosus*, organic fragments and a clay fraction. Water content is approximately double that of zones d and e, organic carbon levels attain maximum values for the core, whilst carbonate levels fall to a minimum.

Zone c has a relatively complex palynological sequence, which is distinct from adjacent zones. Consequently, it was divided into three sub-zones, purely on the basis of the variation between the component assemblages. This variation is as marked as that between zones b and d; since the changes followed a distinct, progressive pattern, and occur within a distinct horizon, it was decided to consider them as sub-zones.

Sub-group c iii is represented by the assemblage at 68 cm (14 taxa). The shift from the underlying clay-dominated mineral substrate to organic deposits is accompanied by a rise to peak pollen concentration (77097 grains/cm^{-3}). Peak values of shrub pollen are recorded, largely through a massive (64.2 %) Chenopodiaceae input. This high shrub pollen component somewhat obscures the continued moderate T.A.P. contributions, which are depicted most representatively in the concentration data. Herb pollen input is moderate, largely as a function of Gramineae contributions and, again, is best reflected by the concentration data. Aquatic contributions are restricted to minor pollen influx from *Potamogeton*.

A shift in palynological composition is evident in the transition to sub-group c ii, sampled at 66 cm (17 taxa) and 64 cm (10 taxa). Pollen concentrations are lower than in c iii, but are greater than in mineral zones. Notable diminuitions to the Chenopodiaceae and Oleaceae pollen contribution occur, whilst *Pinus*, *Quercus* and *Populus* pollen contributions rise slightly. *Alnus* pollen is evident for the first time. The herb pollen component attains peak levels, principally due an increase in Gramineae pollen accompanied by significant contributions from Cyperaceae, *Plantago*, the Compositae and Leguminoseae.

Sub-group c i, sampled at 62 cm (15 taxa) and 60 cm (15 taxa),is characterised by a continued reduction in the total pollen concentration and a shift in relative pollen values. The fall in *Pinus* contribution is offset by an increase in *Quercus* pollen and the emergence of *Corylus* and *Fagus* pollen, to give a net increase in T.A.P. The shrub pollen component rises even more strongly, as a result of a recovery in the level of Chenopodiaceae input and slight contributions from Oleaceae, Ericales and *Artemisia*. The total herb pollen levels diminishes rapidly, due to a much-reduced Gramineae input. This feature is partially offset by several relatively small individual contributions from the Compositae, *Plantago*, Caryophyllaceae, Umbelliferae and Leguminoseae.

Zone b (59 cm-22 cm)

The zone is composed of three lithological units similar to the dense clay deposits of assemblage d. Visible evidence of organic matter decreases with progress up these units. This is borne out by the geochemical analyses. Water content diminishes in relation to zone c, but is slightly higher than in zone d. Carbonate values approach the levels seen in the underlying mineral horizons.

Zone b is constructed from three pollen assemblages, of relatively low pollen density, at 44 cm (9 taxa), 32 cm (11 taxa) and 24 cm (16 taxa). T.A.P. percentages are high, but fall throughout the zone, from 50.0 %-40.7 %. Contrary to this, T.A.P. concentration is initially low, but rises sharply at 24 cm, principally via contributions from *Pinus*, *Populus* and *Quercus*. Total pollen concentrations rises to a secondary peak at 24 cm. The contribution made by shrub taxa to the pollen percentage sum deviates little through this assemblage. Again, Chenopodiaceae and Oleaceae pollen dominate, with increasing contributions from *Juniperus* at 24 cm. Moderate input of Gramineae pollen is accompanied by significant contributions from Caryophyllaceae, Compositae subspecies Liguliflloreae, and *Plantago*.

Zone a (22 cm-0.0 cm)

This horizon shows a relatively complex lithology, in which a hiatus in the clay sediments exists between 15.5 cm-9.5 cm, and a rapid shift to organic sediments occurs at 5 cm. Geochemical analyses, conducted on sediment lying just below the organic horizon, show a similar composition to zone c. Extractable water content increases substantially, while organic carbon values rise slightly, and carbonate values diminish.

Zone a comprises four extractions, at 20 cm (24 taxa), 10 cm (15 taxa), 6 cm (11 taxa) and 2 cm (16 taxa). Total pollen concentrations fall to their lowest levels (7157 grains/cm^{-3} at 2 cm). T.A.P. contribution falls, with fluctuating values for all taxa, notably *Pinus* and *Quercus*. *Alnus* pollen is evident once more, whilst *Carpinus* (1 grain) is noted for the first time. Relatively high levels of Chenopodiaceae, Oleaceae, and *Artemisia* pollen account for an increasingly dominant shrub pollen component. Herb pollen contributions remain relatively constant, with moderate Gramineae and *Plantago* values. Values of Cyperaceae, the Compositae and Leguminoseae increase in the upper extractions. Again, aquatic taxa are represented by *Myriophyllum* pollen.

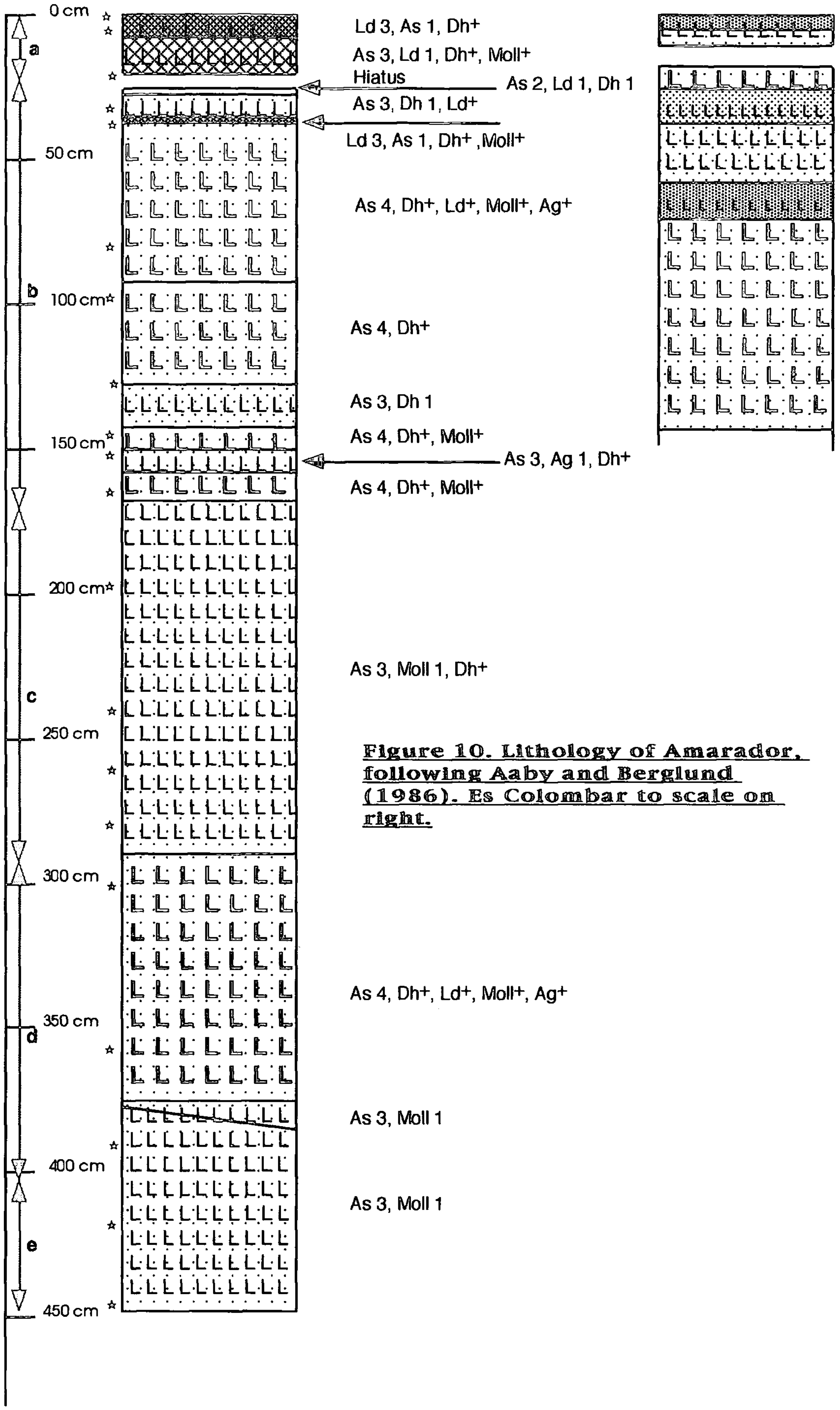


Figure 10. Lithology of Amarador, following Aaby and Berglund (1986). Es Colombar to scale on right.

Table 4. Pollen percentage data (Amarador).

Assemblage zone		Zone a					Zone b						Zone c				Zone d		Zone e	
	2 cm	8 cm	20 cm	32 cm	36 cm	80 cm	96 cm	128 cm	144 cm	152 cm	168 cm	198 cm	240 cm	260 cm	290 cm	300 cm	368 cm	390 cm	418 cm	444 cm
Pinus	7.9	11.2	6.1	10.3	*	1.9	10.3	6.6	*	*	6.1	18.7	36.1	12.8	9.4	3.5	20.9	15.4	7.1	16.3
Quercus	15.8	4.6	2.0	13.4	11.4	22.6	13.8	26.3	25.0	*	16.8	29.3	22.2	38.5	10.4	23.9	29.3	20.2	7.1	6.5
Corylus	*	*	*	*	2.9	*	*	3.9	*	*	*	8.1	*	*	2.1	21.1	2.9	3.9	28.6	12.9
Fagus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0.6	*	*
Ulmus	*	*	*	*	*	*	*	1.3	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	*	*	1.0	*	3.8	6.9	*	*	*	*	*	*	*	2.1	1.4	2.9	2.8	*	*
Populus	3.0	1.5	*	4.1	*	3.8	6.9	*	*	*	*	*	*	*	1.0	3.5	*	5.6	*	*
Alnus	*	*	*	*	*	*	*	*	*	*	*	*	*	2.6	*	2.1	5.1	0.6	*	*
Chenopodiaceae	19.8	25.4	36.7	9.3	17.1	1.9	6.9	13.2	25.0	*	8.2	8.1	8.3	15.4	10.4	23.2	13.2	15.7	35.7	45.2
Tamarix	*	1.0	2.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	2.0	1.0	2.0	6.2	2.9	*	*	2.6	*	*	*	1.6	*	*	2.1	0.7	2.9	2.2	*	*
Ericales	*	2.0	10.2	2.1	20.1	7.5	*	1.3	*	*	4.1	3.3	5.6	7.7	35.4	0.7	0.7	1.7	*	*
Juniperus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.0	*	3.7	10.1	*	*
Oleaceae	6.9	7.1	8.2	12.4	14.3	11.3	27.6	22.4	25.0	*	16.3	14.6	11.1	7.7	13.5	4.9	1.5	0.6	*	19.4
Rhamnus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	2.1	*	*	*	*
Ribes	*	1.0	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gramineae	29.7	22.8	18.4	24.7	25.7	32.1	27.6	13.2	25.0	*	36.7	1.6	2.8	2.6	5.2	*	8.1	14.6	*	*
Cyperaceae	5.0	1.0	*	2.1	*	1.9	*	*	*	*	*	*	*	*	3.1	0.7	0.7	1.7	*	*
Comp. ligulif	3.0	14.7	12.2	3.1	2.9	1.9	*	*	*	*	4.1	*	*	*	*	3.5	0.7	*	*	*
Compositae	*	0.5	2.0	2.1	*	1.9	*	*	*	*	*	*	2.8	5.1	*	*	0.7	*	7.1	*
Plantago	1.0	0.5	*	3.1	*	*	*	5.3	*	*	4.1	4.9	*	5.1	2.1	4.9	0.7	1.7	*	*
Caryophyllaceae	3.0	*	*	*	*	*	*	1.3	*	*	4.1	6.5	*	2.6	1.0	0.7	5.1	*	*	*
Ranunculus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	7.1	*
Umbelliferae	*	1.5	*	1.0	*	*	*	*	*	*	*	1.6	*	*	*	*	0.7	0.6	*	*
Euphorbia	*	*	*	*	*	*	*	*	*	*	*	*	2.8	*	*	0.7	*	*	*	*
Urtica	*	*	*	*	*	*	*	1.3	*	*	*	*	2.8	*	*	*	*	*	*	*
Leguminosae	1.0	2.0	*	*	2.9	*	*	*	*	*	*	*	*	*	*	0.7	*	2.2	*	*
Equisetum	*	1.0	*	*	*	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*
Myriophyllum	*	*	*	*	*	*	*	*	*	*	*	1.6	*	*	*	*	*	*	7.1	*
Lemna	2.0	*	*	3.1	*	*	*	*	*	*	*	*	2.8	*	*	*	*	*	*	*
Potamogeton	*	1.0	*	*	*	9.4	*	1.3	*	*	*	*	*	*	1.0	1.4	*	*	*	*
Unknown	*	*	*	2.1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tree sum	26.7	17.3	8.2	28.9	14.3	32.1	37.9	38.2	25.0	*	22.5	56.1	58.3	53.9	25.0	55.6	61.2	49.0	4.3	35.4
Shrub sum	11.9	37.6	59.2	20.6	54.3	18.9	34.5	28.9	25.0	*	24.5	24.4	25.1	30.8	53.1	31.7	13.9	15.1	35.7	64.6
Herbs sum	39.6	44.2	32.7	36.1	31.4	37.7	27.6	19.7	25.0	*	44.9	8.1	13.9	15.4	10.4	11.3	11.7	20.7	14.3	*
Aquatic sum	2.0	1.0	*	3.1	*	9.4	*	1.3	*	*	*	1.6	2.8	*	1.0	1.4	*	*	7.1	*
Unknown sum	*	*	*	2.1	*	*	*	*	*	*	*	3.3	*	*	*	*	*	*	*	*
Pollen sum	101.0	197.0	49.0	97.0	35.0	53.0	14.5	76.0	4.0	0.0	24.5	61.5	36.0	39.0	96.0	142.0	136.5	178.5	14.0	15.5

Figure 11. Pollen percentage diagram (Amarador) (CONISS plot and basic lithology also shown).

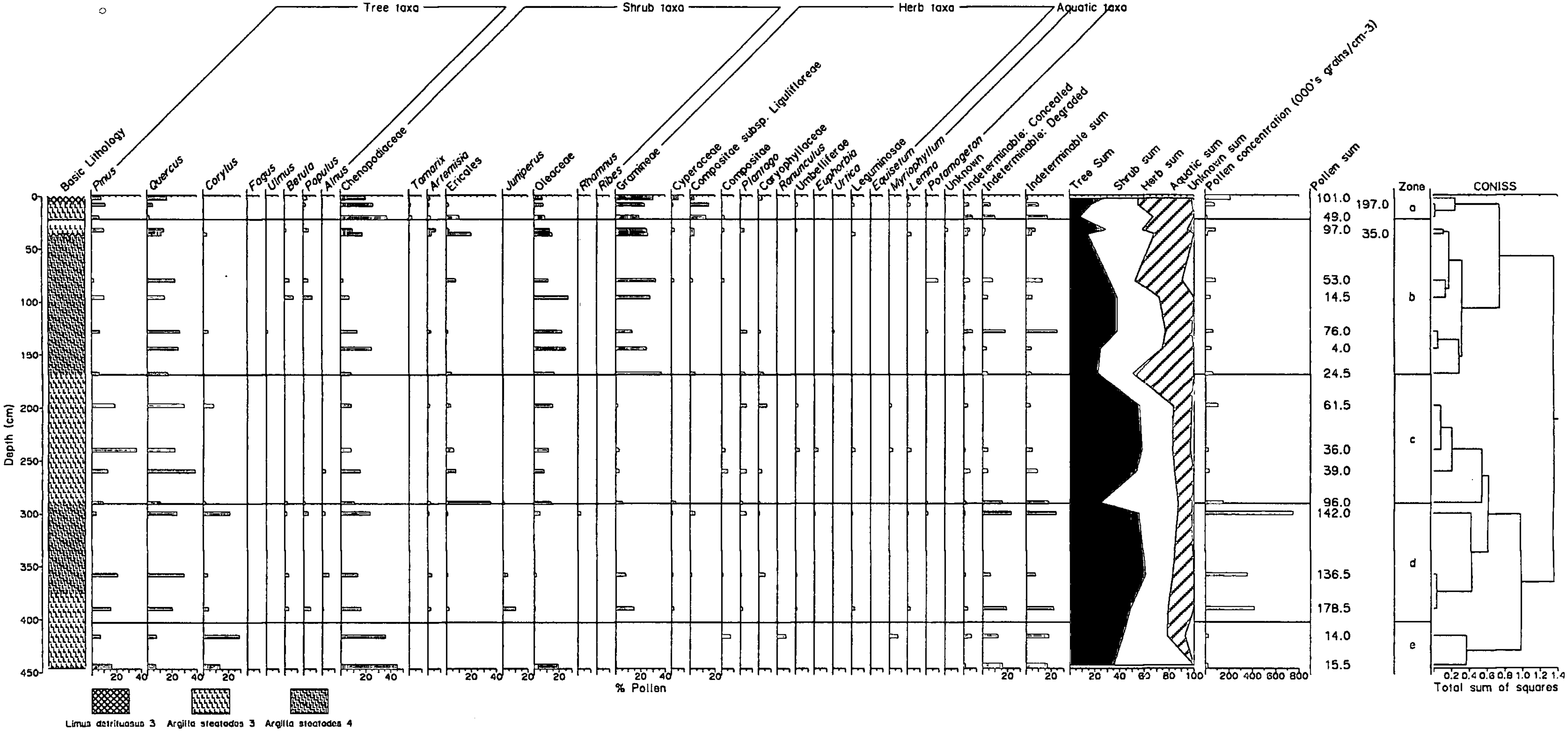
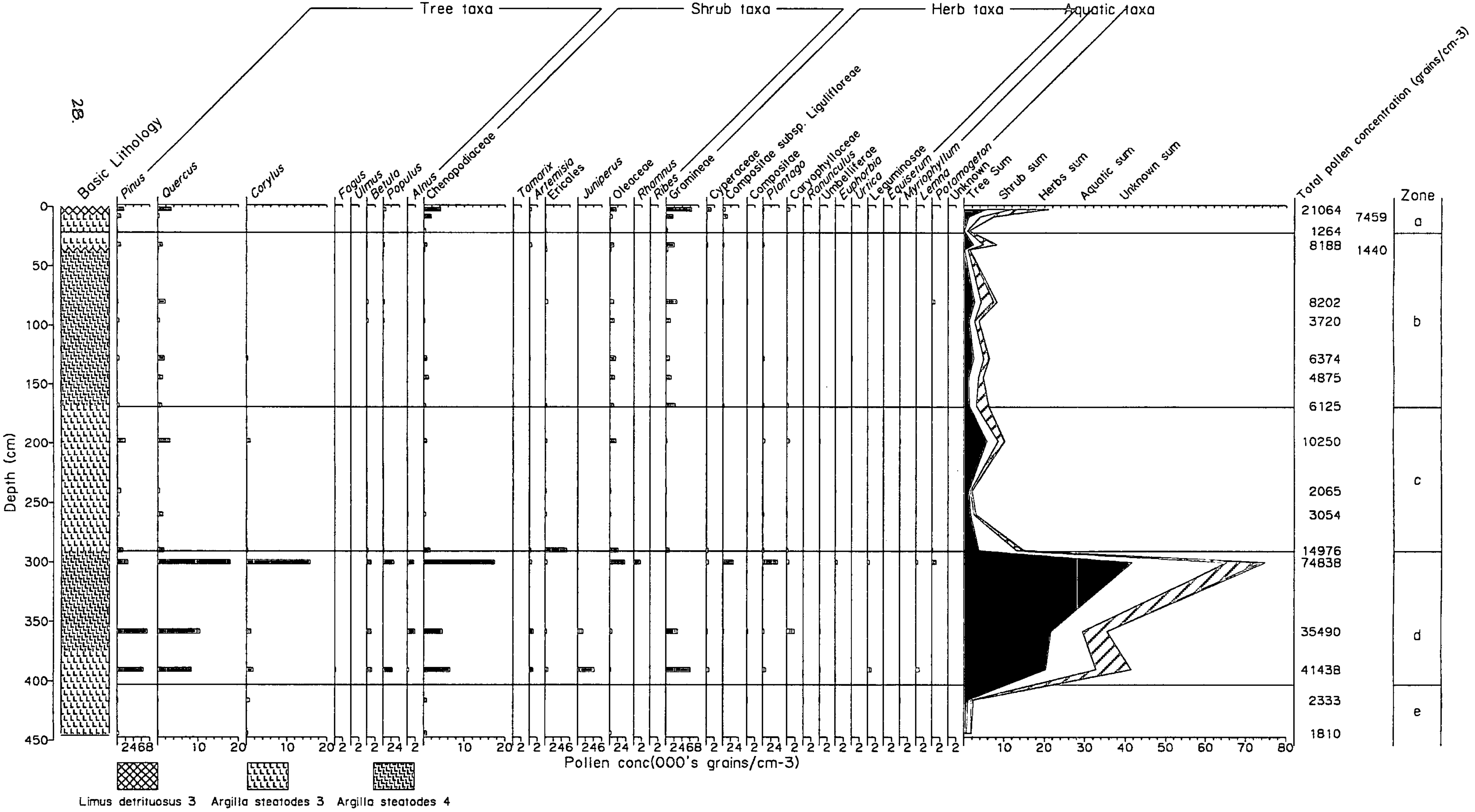


Table 5. Pollen concentration (grains/cm-3) data (Amarador).

Assemblage zone		Zone a					Zone b						Zone c				Zone d		Zone e	
	2 cm	8 cm	20 cm	32 cm	36 cm	80 cm	96 cm	128 cm	144 cm	152 cm	168 cm	198 cm	240 cm	260 cm	290 cm	300 cm	358 cm	390 cm	416 cm	444 cm
Pinus	1668.5	833.0	77.4	844.2	*	154.8	384.9	419.4	*	*	375.0	1916.7	745.6	391.6	1404.0	2635.1	7410.0	63.83.93	166.7	291.9
Quercus	3336.9	340.8	25.8	1097.4	164.6	1857.1	513.2	1677.4	1218.8	*	1000.0	3000.0	458.8	1174.7	1560.0	17918.9	10400.0	8357.1	166.7	116.8
Corylus	*	*	*	*	41.1	*	*	251.6	*	*	*	833.3	*	*	312.0	15810.8	1040.0	1625.0	666.7	233.5
Fagus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	232.1	*	*
Ulmus	*	*	*	*	*	*	*	83.9	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	*	*	84.4	*	309.5	256.6	*	*	*	*	*	*	*	312.0	1054.1	1040.0	1160.7	*	*
Populus	625.7	113.6	*	337.7	*	309.5	256.6	*	*	*	*	*	*	*	156.0	2635.1	*	2321.4	*	*
Alnus	*	*	*	*	*	*	*	*	*	*	*	*	*	78.3	*	1581.1	1820.0	232.1	*	*
Chenopodiaceae	4171.1	1893.2	464.3	759.7	246.8	154.8	256.6	838.7	1218.8	*	500.0	833.3	172.1	469.9	1560.0	17391.9	4680.0	6500.0	833.3	817.4
Tamarix	*	75.7	25.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	417.1	75.7	25.8	506.5	41.1	*	*	167.7	*	*	*	166.7	*	*	312.0	527.0	1040.0	928.6	*	*
Ericales	*	151.5	129.0	168.8	288.0	619.1	*	83.9	*	*	250.0	333.3	114.7	234.9	5304.0	527.0	260.0	696.4	*	*
Juniperus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	156.0	*	1300.0	4178.6	*	*
Oleaceae	1459.9	530.1	103.2	1013.0	205.7	928.6	1026.3	1425.8	1218.8	*	1000.0	15000.0	229.4	234.9	2028.0	3689.2	520.0	232.1	*	350.3
Rhamnus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1581.1	*	*	*	*
Ribes	*	75.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gramineae	6256.7	1703.9	232.1	2026.0	370.3	2631.0	1026.3	838.7	1218.8	*	2250.0	166.7	57.4	78.3	780.0	*	2860.0	6035.7	*	*
Cyperaceae	1042.8	75.7	*	168.8	*	154.8	*	*	*	*	*	*	*	*	468.0	527.0	260.0	696.4	*	*
Comp. ligulif	625.7	1098.1	154.8	253.3	41.1	154.8	*	*	*	*	250.0	*	*	*	*	2635.1	260.0	*	*	*
Compositae	*	37.9	25.8	168.8	*	154.8	*	*	*	*	*	*	57.4	156.6	*	*	260.0	*	166.7	*
Plantago	208.6	37.9	*	253.3	*	*	*	335.5	*	*	250.0	500.0	*	156.6	312.0	3689.2	260.0	696.4	*	*
Caryophyllaceae	625.7	*	*	*	*	*	*	83.9	*	*	250.0	666.7	*	78.3	156.0	527.0	1820.0	*	*	*
Ranunculus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	166.7	*
Umbelliferae	*	113.6	*	84.4	*	*	*	*	*	*	*	166.7	57.4	*	*	*	260.0	232.1	*	*
Euphorbia	*	*	*	*	*	*	*	*	*	*	*	*	57.4	*	*	527.0	*	*	*	*
Urtica	*	*	*	*	*	*	*	83.9	*	*	*	*	*	*	*	*	*	*	*	*
Leguminosae	208.6	151.5	*	*	41.1	*	*	*	*	*	*	*	57.4	*	*	527.0	*	928.6	*	*
Equisetum	*	75.7	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Myriophyllum	*	*	*	*	*	*	*	*	*	*	*	166.7	57.4	*	*	*	*	*	166.7	*
Lemna	417.1	*	*	253.3	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Potamogeton	*	75.7	*	*	*	773.8	*	83.9	*	*	*	*	*	*	156.0	1054.1	*	*	*	*
Unknown	*	*	*	168.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Tree sum	5631.0	1287.38	103.2	2363.6	205.7	2631.0	1411.2	2432.3	1218.8	*	1375.0	5750.0	1204.4	1644.6	3744.0	41635.1	21710.0	20312.5	1000.0	642.2
Shrub sum	6048.1	2801.9	748.0	2448.1	781.7	1702.4	1282.9	2516.1	2437.5	*	1750.0	2833.3	516.2	939.8	9360.0	23716.2	7800.0	12535.7	833.3	1167.7
Herbs sum	8967.9	3294.2	412.7	2954.6	452.5	3095.2	1026.3	1341.9	1218.8	*	3000.0	1500.0	286.8	469.9	1716.0	8432.4	5980.0	8589.3	333.3	*
Aquatic sum	417.1	75.7	*	253.3	*	773.8	*	83.9	*	*	*	166.7	57.4	*	156.0	1054.1	*	*	166.7	*
Unknown sum	187.0	515.0	756.0	462.0	474.0	252.0	152.0	465.0	32.0	*	156.0	234.0	340.0	249.0	250.0	37.0	150.0	168.0	117.0	167.0
Sample volume (cc)	1.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0	1.0	*	1.0	1.0	2.0	2.0	1.0	2.0	1.0	1.0	2.0	2.0
Exotic volume (cc)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	*	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Exotic concentration (grains/ml)	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0	39000.0
Total Pollen concentration	21064.2	7459.2	1263.9	8188.3	1439.9	8202.4	3270.4	6374.2	4875.0	*	6125.0	10250.0	2064.7	3054.2	14976.0	74837.8	35490.0	41437.5	2333.3	1809.9

Figure 12. Pollen concentration (grains/cm-3) diagram (Amarador). (Basic lithology also shown).



Amarador:

The complete lithology for the Amarador core is displayed in Figure 10. Pollen count data are presented in Appendix 3, percentage values in Table 4 and Figure 11, whilst pollen concentration data are depicted in Table 5 and Figure 12. Geochemical data are presented in Table 6. *Ammonia beccarii* was present in all samples from this core, except where mentioned, data are not shown pictorially.

Zone e (446 cm-403 cm)

The lithology of this zone is similar to the clay units of Es Colombar. The organic component is not visually apparent, whilst a relatively high level of molluscs are recorded.

It was decided to isolate the two extractions, at 444 cm (5 taxa) and 416 cm (7 taxa), on the grounds of low pollen counts (<16 grains each).

Table 6. Percentage extractable water and carbon species values (Amarador).

Sample depth (cm)	% H2O	% organic C.	% carbonate
2	10.62	6.04	1.14
14	40.89	3.79	14.41
26	40.22	5.69	12.86
32	46.85	3.89	17.96
36	34.49	4.06	12.72
70	34.39	4.57	11.88
124	55.87	4.52	17.29
142	56.59	4.33	20.17
148	59.68	3.97	20.05
154	57.53	3.51	14.81
162	58.63	4.24	18.80
198	68.21	3.07	25.44
246	69.08	3.51	25.48
290	59.14	4.93	15.64
294	62.42	3.54	15.04
382	62.40	4.07	17.29
390	60.78	5.05	21.75

Zone d (403 cm-291 cm)

The lithology of zone e continues in this unit, with a notable feature being the steep gradient to the sedimentary boundary at 385 cm. Although the core is only 40 mm wide, a 60 mm disparity arose between the point at which the boundary intersects with the core edges giving the lithological boundary an angle of 52°. Above this, the molluscan component diminishes, whilst sand and organic fractions become visible. Organic carbon values decrease through the zone, whilst inorganic carbon values increase slightly. Extractable water values remain constant.

Zone d contains three extractions-at 390 cm (17 taxa), 358 cm (17 taxa) and 300 cm (18 taxa)-and is notable for high taxon diversity and peak total pollen concentration (74838 grains/cm^{-3} at 300 cm). T.A.P. obtains a maximum value (61.2 %), as a result of contributions from *Quercus*, *Corylus*, *Populus*, *Pinus*, *Alnus*, *Betula* and *Fagus*. Shrub pollen contributions rise through increasing input from Chenopodiaceae, Oleaceae and *Rhamnus*. Total herb pollen values are relatively low, and diminishes up the sequence; moderate Gramineae values dominate contributions from a relatively wide variety of taxa.

Zone c (291 cm-168 cm)

This zone is characterised by a discrete clay lithological unit, containing a notable molluscan component. An unhumified band of organic matter is evident at 290 cm. Water and carbonate values increase up the profile, whilst organic carbon values decrease.

Zone c, comprised of four assemblages-at 290 cm (15 taxa), 260 cm (10 taxa), 240 cm (11 taxa) and 198 cm (12 taxa)-is characterised by low herb pollen, despite input from a wide range of taxa, due to minimum Gramineae pollen values. The appearance of *Lemna* and *Myriophyllum* pollen at 240 cm provides an aquatic pollen contribution of 2.8 %. Initially maximum Ericales and moderate Chenopodiaceae and Oleaceae input dominate this sequence, giving high shrub pollen levels. Subsequent reductions to Ericales pollen input and a rise in *Pinus* and *Quercus* pollen allows T.A.P. to dominate the spectrum in the upper horizons. *Corylus* pollen contributions are markedly less pronounced than in zone d.

Zone b (168 cm-22 cm)

Zone b is the largest of either core, and is lithologically complex. Initially it is characterised by a sedimentary sequence of varying clay content, with a visually organic band apparent between 38 cm-35 cm. Subsequent to this, predominantly clay sediments reappear. The unit ends with a hiatus (27 cm-22 cm). Extractable water values fluctuate, reaching highest levels in the organic sediments. Carbon values vary through the unit, with organic carbon content actually decreasing in the apparently organic band. The extraction residue from 36 cm did not contain *Ammonia beccarii*.

This horizon is characterised by low pollen counts and a marked increase in Gramineae pollen levels. Eight extractions were conducted, yet only seven are presented since no data were obtained from 152 cm. Of these, 144 cm and 96 cm have particularly low pollen counts (4 and 14.5 grains respectively). Taxon diversity varies between 15 (32 cm) and 4 (144 cm). T.A.P. contributions fluctuate, but are typically low. *Quercus* and *Pinus* dominate, with slight contributions from *Betula*, *Populus*, *Corylus* and *Ulmus* pollen. Chenopodiaceae pollen influx extends its influence over the total shrub sum, whilst peak Oleaceae contributions arise in the mid-lower extractions. Ericales pollen input increases in the uppermost assemblages. Aquatic pollen levels, featuring input from *Lemna* and *Potamogeton*, reach a peak of 9.4 % at 80 cm.

Zone a (22 cm-0 cm)

This zone contains two lithological units, of which the lower unit is characterised by a high clay content and a moderate organic component. Above this, sediments are predominantly organic. Water and carbonate values are much lower in the lower horizon, whilst near-surface organic content reaches maximum values. The presence of *A. beccarii* was not recorded within the extraction residue from 20 cm.

Zone a is characterised by increasing pollen concentrations. Data were obtained from three extractions; at 20 cm (10 taxa), 8 cm (18 taxa) and 2 cm (13 taxa). Shrub pollen declines from a peak at 20 cm; several taxa, most notably Chenopodiaceae, contribute pollen. The percentage levels and concentrations of tree taxa, specifically *Pinus*, *Quercus* and *Populus* increase. The herb sum also rises, as a result of increasing Gramineae input and significant contributions from the Compositae, Cyperaceae, Caryophyllaceae, Umbelliferae, and *Equisetum*.

Comparison between cores:

Introduction

Since neither core has been dated, the strongest analytical framework for comparing these cores is a 'top-down' approach, since both share a common datum at the sediment surface.

Lithology

Several common features are apparent, in that grey-brown clay deposits predominate, occasional horizons of organic sediments are also found. Figures 7 and 10 allow direct lithological comparison between the sites, since the cores are presented to scale against each other. Common features include a relatively richly organic surface horizon underlain by more mineral sediments and a hiatus. This is subsequently underlain by a mineral layer superimposed upon more organic deposits. These are very restricted at Amarador, and strongly evident at Es Colombar. Subsequent to this, sequences of predominantly mineral material dominated by clay sediments occur.

Geochemistry

Both cores share common geochemical signatures, in that typically water and carbon are major constituents, with carbonates being greater in abundance than organic carbon.

Pollen

The cores share common principal and constituent pollen taxa. Assemblages of these taxa vary both within and between cores, with Es Colombar showing greater taxon diversity, pollen counts and concentrations. Maximum pollen concentrations in both cores were remarkably similar, whilst Amarador sustained a lower minimum concentration. Pollen concentrations varied by approximately one order of magnitude. Levels of unknown and unidentified pollen are broadly comparable between the two cores.

Foraminiferal inspection

Both cores shared a similar foraminiferal assemblage. *Ammonia beccarii* was the only species recorded, and was present in all extraction residues bar two from Amarador.

Chapter Four: Discussion

Introduction

This section follows the format of Chapter three. Results will be discussed for each core within the assemblage zone framework. Subsequently, general patterns will be summarised in a section comparing the two profiles.

Es Colombar:

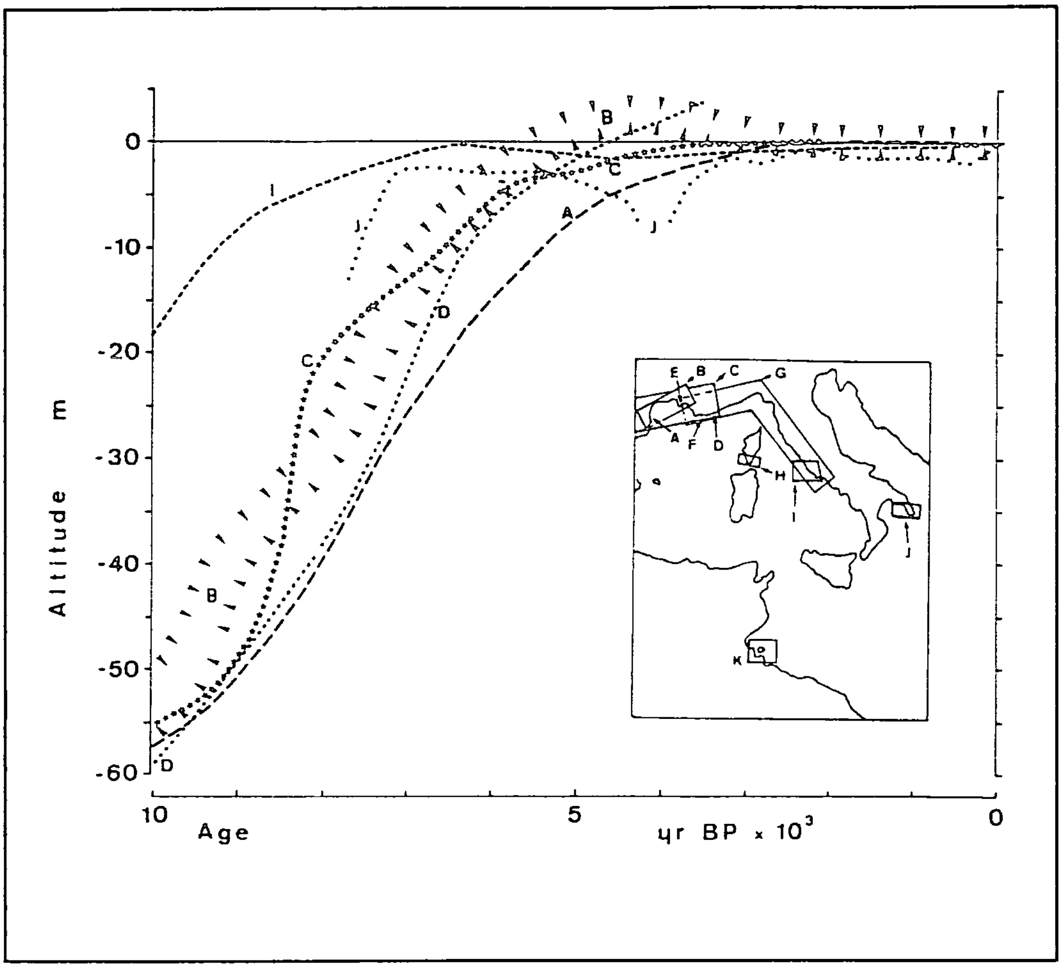
Zone e (142 cm-135 cm)

Consideration must be given to the sedimentary conditions which halted core penetration at 142 cm. Upon removal, the nose of the corer was covered in relatively sand-rich deposits. Given the extensive local occurrence of surface sand deposits, and a recent environmental history in which sea levels have been lower than they are now (Pirazolli 1991; Figure 13), the existence of a basal unit of fossil beach/dune deposits is highly feasible.

Sediment homogeneity suggests a degree of isolation from geomorphologically-active surface drainage systems, since strongly seasonal variations in discharge would allow the suspension and deposition of different-sized sediments. Nevertheless, this uniformity suggests that the sediments were well-mixed prior to settling. Suspended clay particles require relatively calm conditions to settle, due to their low specific gravity (*e.g.* carbonates 2.71-3.20, Ford and Williams 1989). Such conditions may be found in lacustrine, lagoon and shallow, micro-tidal environments such as the Mediterranean. It is likely that these sediments were lain in an environment of some, although perhaps not total, marine influence, given the contemporaneous coastal position of the site. Indeed, the presence of *Ammonia beccarii*, throughout this core confirms that S'Albufera was a coastal lagoon site throughout the period reflected in these sediment, since *A. beccarii* is an indicator of sheltered hypersaline lagoons and lower high marsh zones (Murray 1971; Jonasson and Patterson 1992). At higher latitudes and altitudes, extensive, homogenous clay deposits are often glacially-derived, but this geomorphic agent can be discounted in this instance.

The predominance of Chenopodiaceae pollen and contributions from a variety of ruderal herb taxa in the pollen assemblage may indicate a wide variety of habitat types. However, many of the Mediterranean Chenopodiaceae are coastal species, occupying the margins of saline marshes and shores *e.g. Arthrocnemum* sp., *Suaeda* sp., *Halimione* sp.

Figure 13. Generalised Holocene sea level curves for the west-central Mediterranean (Pirazolli 1991).



and *Salicornea europeae* (Stevenson 1985b; Mésleard, Grillas and Lepart 1991; Soares de Albergaria Moreira 1992; Blamey and Grey-Wilson 1993). These species, which also establish in agricultural and wasteland situations almost certainly diversified from disturbed, salt-stressed coastal environments. It is probable that the Chenopodiaceae component of the pollen assemblage is locally derived, since the lithology suggests a coastal environment. Chenopodiaceae tend to produce low volumes of pollen (Stevenson 1985b), and relatively high sedimentary pollen concentrations could only be found in sites proximal to source plants. However, lithological characteristics, combined with low pollen concentrations, suggest that Es Colombar was inundated or semi-aquatic, and that local pollen was derived some distance away.

Gramineae pollen is not suggestive of any particular habitat type, but may have been derived from a local coastal marsh supporting species such as *Phragmites australis*. Certainly, locally-saturated conditions are indicated by the presence of *Potamogeton* pollen (Stevenson 1984, 1985a). *Rumex*-type pollen is typically interpreted as indicative of disturbance. However, given the nature of this assemblage, the *Rumex*-type pollen may be derived from emergent and marginal aquatic *Rumex* species such as *R. hydrolapicum* (Huntley, personal communication). Low-moderate Ericales and *Quercus* pollen frequencies suggest an extra-local, open woodland, given the high dispersal capacities of these taxa (Stevenson 1985b). Low pine pollen frequencies are indicative of a regional source, since pollen is produced in large quantities and is widely dispersed (Stevenson 1985b): Ayyad, Moore and Zahran (1992), found up to 7 % *Pinus* pollen in surface samples, when the nearest source was 60 km away. A contribution from local pine sources would have given a significantly higher value than that observed in this assemblage. For example, the moss polsters collected contained 93.7 % and 82.5 % *Pinus* pollen (Appendix 4). Regional sources of *Pinus* pollen would be derived from a catchment distended to the south-west by prevailing winds (Figure 6). Raynor, Hayes and Ogden (1974) and Jackson and Dunwiddie (1992), report that some pollen taxa may be carried for great distances across water, often at great heights. Given the extensive distribution of *Pinus* across the region during the Holocene, much of southern Iberia and N.W. Africa may be considered a valid regional pollen-source area. The pollen assemblages evident within this zone are considered to be of Holocene age, since there is little evidence in the regional pollen signal of characteristic late-glacial steppe vegetation.

Zone d (135 cm-70 cm)

Given the lithological similarity between zones d and e, there is little sedimentary evidence for environmental change over the period, and this lower boundary may be considered diffuse. However, low Gramineae and Chenopodiaceae pollen levels within this assemblage suggest a shift in conditions. The reduction in Chenopodiaceae pollen input suggests less-saline edaphic conditions. The shrub-pollen component is dominated by Oleaceae. During microscope analyses, it was considered that most Oleaceae pollen examined were *Phillyrea* grains, probably *P. angustifolia* or *P. latifolia*. Palynological identification of the Oleaceae is notoriously difficult; Moore *et al.* (1991) describe separation of *Olea* sp. from *Phillyrea* sp. by a technique reliant on grain morphology. However, Kelly and Huntley (1991) found that fossil grains could not be confidently assigned to either taxon. *Phillyrea* occurs in a wide variety of Mediterranean habitats; Stevenson (1985a) reported it to be associated to hygrophytic *Quercus* forest, whilst occurrences in Mediterranean marsh conditions are also documented (Stevenson and Moore 1988, Mésleard *et al.* 1991). Indeed, the author observed *P. angustifolia* in and around S'Albufera site growing under a range of conditions, from shady *Pinus*-dominated dune slacks to open marsh. Environmental inferences from Oleaceae pollen are further complicated by high pollen dispersal capacities of this taxon (Pons and Reille 1988).

Increasing T.A.P. is suggestive of progressive regional input. This proportional reduction in local pollen contributions, combined with a relatively strong regional pollen signal, suggest an increase in the volume of water within the lagoon, since both marine and freshwater components will supply regional pollen. Increased water volume will only arise as mean water levels increase, through eustatic transgression. Thus local pollen sources will become increasingly distant.

The significant *Populus* component must arise from local sources, since conditions conducive to the growth of *Populus* on Mallorca are likely to have been restricted, due to its preference for a high water table. *P. alba* currently grows in S'Albufera and the Camargue marshes of the Rhône delta, where it colonises margins of riverine forest and the marsh periphery (Mésleard *et al.* 1991). Furthermore, *Populus* pollen is poorly preserved (Stevenson 1985b, Stevenson and Moore 1988), thus a local pollen source would be required to produce such a pronounced signal.

Caution is advised in the interpretation of the pollen assemblage at 82 cm due to the low pollen sum (26 grains), although small changes in pollen concentration data suggests little variation in arboreal vegetation patterns.

Zone c (70 cm-59 cm)

c iii)

The dramatic shift in lithology at 70 cm is indicative of a major change in local environmental conditions. This highly organic horizon, principally composed of incompletely humified vegetative material, suggests extensive deposition of litter from local vegetation. The organic component affords increased water retention and organic carbon levels, whilst low mineral sediment content gives rise to the low carbonate values.

The dramatic rise in pollen concentrations substantiates the claim that vegetation was growing in the immediate area of the site. The massive Chenopodiaceae pollen component suggests that this taxon was a major constituent of the local flora, and therefore the influence of saline conditions still prevailed. Despite increased vegetative productivity, the continued presence of *A. beccarii* infers that Es Colombar remained under direct tidal influence.

Low levels of T.A.P. input suggest that fully terrestrial conditions were some distance away. Such signals may arise from relatively high sedimentation rates which, when combined with higher local pollen inputs, produce low regional pollen proportions and concentrations. Saline-marsh vegetation can attain high rates of productivity (*e.g.* 2069 g/m^{-2}/yr.$^{-1}$, Vernberg 1993), whilst *P. australis* produces a persistent litter (Grime, Hodgson and Hunt 1988), which would sustain low pollen concentrations. Alternatively, local air flow conditions may have prevented extra-local pollen input. These conditions may arise through dense vegetation reducing mean wind speed, allowing pollen deposition prior to arrival at the site, or the predominance of strong on-shore breezes. Pollen is principally released during daylight hours in late spring and summer; when temperate, coastal regions experience a strong diurnal wind regime, in response to the differential thermal properties of land and sea masses. During the day, land masses radiate more heat than water bodies, thus driving an on-shore breeze, this situation is reversed at night (Barry and Chorley 1976). As a consequence, the pollen spectrum of inshore taxa will be under-represented in the profile, unless they are held in suspension to be deposited during nocturnal off-shore breezes.

The marked transition reflected in the lithological, geochemical and palynological records of the core, suggests that environmental conditions switched at 70 cm from a fully lagoonal system with *ex situ* derivation of sediments and pollen, to a semi-terrestrial lagoon system with sediments and pollen principally derived *in situ*. This transformation may occur through a variety of mechanisms, not least of which is the possibility that a transitory phase of the sedimentary record is missing. However, as no lithological evidence for post-depositional sedimentary disturbance exists, it is assumed that assemblages d and c share a common temporal boundary. A reduction in mean water levels is the probable explanation for this change in sedimentary conditions, although this may have arisen under a variety of environmental changes:

☆ There is substantial evidence for pronounced shifts in mean sea level in the western Mediterranean (*i.e.* Butzer and Cuerda 1962; Borrego, Morales and Pendón 1993; Zazo *et al.* 1994; Dubar and Anthony 1995; Table 7), against a trend of progressive rise throughout the Holocene (Figure 13). Progressive retreat of the N.W. European and Laurentide ice-sheets between 17 Ka-4 ka B.P. saw sea levels throughout the northern hemisphere rise to within a few metres of current sea levels (Fairbanks 1989). In the last 5000 years local variations become increasingly apparent, as sea levels fluctuated around current mean levels. Mallorcan sea levels fell approximately 2 m below current levels *ca.* 3600-1800 yr. B.P. (estimate based on a figure presented by Lowe and Walker 1984). It is also worthy to note that sea levels in the Gulf of Lions (300 km away) were 2 m above present between 5000-4000 yr. B.P. (Pirazolli 1991). The south east coast of Spain witnessed three peaks of Holocene sea level, at *ca.* 5100 yr. B.P., *ca.* 3500 yr. B.P. and *ca.* 2400 yr. B.P. (Zazo et al. 1993). Falling sea level in intervening periods could facilitate this phase of semi-terrestrialisation.

Zazo *et al.* (1994) note that the influx of Atlantic sea water into the Mediterranean occurs as a function of an evaporation-driven mechanism. Spatial disparity in the circulation of Atlantic waters results in regional sea level flux, as inferred from Almeria, southern Spain, between 3800-3200 yr. B.P. and 2800-800 yr. B.P. Temporal variations in the influence of this mechanism are guided by shifts in seasonal climate patterns. The spatial variability of this phenomena may have influenced local mean sea levels, although this is undocumented.

☆ Periodic diminuitions of freshwater input into the lagoon could also reduce mean water level. Such reductions may arise through several mechanisms, including differential discharge from source aquifers, which would allow variations in surface water levels. However, the influence of such a feature cannot be ascertained. Localised tectonic uplift could account for terrestrialisation; this cannot be discounted, but is unlikely since Mallorca is not situated over major fault systems.

Table 7. Proposed timing of events with possible bearing on terrestrialisation of S'Albufera evident in assemblage c.

	Eustatic features		Climatic features	Climatic/ Anthropogenic features
Dates of relative sea level rise (yr. B.P.)	Dates of relative sea level fall (yr. B.P.)	Dates of sea level flux (yr. B.P.)	Dates of arid intervals (yr. B.P.)	Dates of possible catchment disturbance (yr. B.P.)
7200-3600 (a)			7050-6650 (e)	
5100 (b)				
5000-4000 (c)			4450-4300 (e)	
3500 (b)	3600-1800 (a)	3800-3200 (d)	2900-2750 (e)	
2400 (b)		2800-800 (d)	1950-1750 (e)	2073-1475 (f)
				1152-750 (f)

From data presented by:

a Lowe and Walker (1984)
b Zazo *et al.* (1993)
c Pirazolli (1991)
d Zazo *et al.* (1994)
e Lamb *et al.* (1995)
f Shimwell *et al.* (1984 unpublished)

Periodic reductions in precipitation input, as proposed by Lamb *et al.* (1995), would reduce water levels in freshwater/brackish environments, allowing terrestrialisation. Century-scale arid periods in Morocco (Table 7), were considered to be part of continental-scale climatic shifts. Given the magnitude of these changes, believed to be linked to variation in north Atlantic sea-surface temperatures, it is entirely possible that comparable climatic flux could be evident in other suitably-sensitive Mediterranean sites (Lamb, Personal communication). It is likely that S'Albufera forms such a suitably-sensitive environment, given the shallow topographic gradient. Against such a gradient, even slight changes in mean water level will greatly change the position of land/water boundaries (Figure 14).

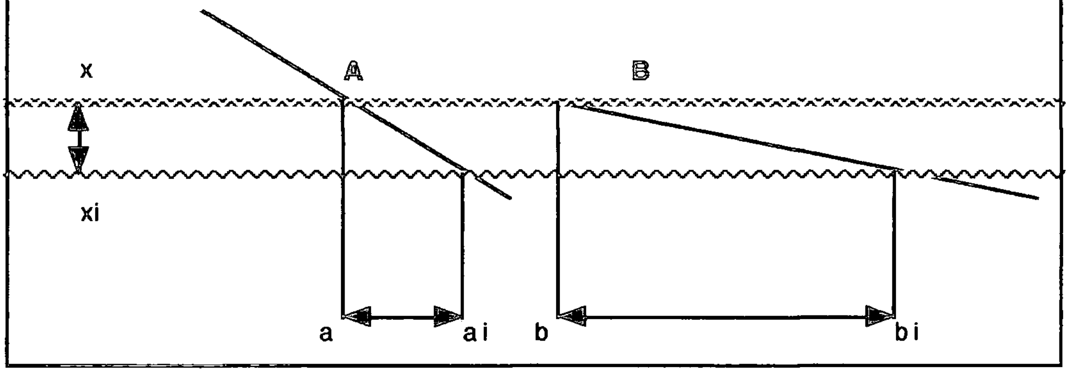
Upstream anthropogenic influences may also have reduced freshwater input. Such interference may be in the form of increased extraction during periods of urbanisation and agriculture, particularly once irrigation networks were established. Both the Roman and Moorish civilisations widely implemented irrigation networks across the Mediterranean region, including Mallorca (Hamshere *et al.* 1992 unpublished). Thus it is possible that noticeable diminuitions in freshwater input occurred during the Roman occupation from 2073- *ca.* 1475 yr. B.P., or subsequent periods of Moorish rule (*ca.* 1152-*ca.* 750 yr. B.P.) (Table 7).

Figure 14. Variation in areal inundation of coastal regions of varying topography in response to sea level flux

Sea level flux between x-xi is manifest in disparate responses from coasts of differing topographic gradient.

A: Steep coasts show relatively small changes in exposed area(a-ai)-an 'inelastic' response.

B: Coasts of low topographic gradient *i.e.* S'Albufera, show a relatively 'elastic' response (b-bi).



☆ Disturbance and removal of canopy vegetation, alongside progressive climate change throughout the Holocene across the Mediterranean in which seasonally arid conditions increasingly prevailed, may have reduced vegetative cover (Dubar and Anthony 1995). Consequent reductions in aggregate stability would have facilitated increased rates of erosion (Swank and Johnson 1994). Roberts (1991) reports that the lower reaches of many Mediterranean rivers contain deep alluvial deposits of historical age, known as the 'younger fill', which arose as a result of forest clearance at a catchment scale, and the subsequent breakdown of the meta-stable equilibria established during settled, agricultural periods. Depopulation resulted in the collapse of terraced agricultural systems, thus re-facilitating massive erosion. Settling of this sediment in the S'Albufera lagoon complex could act to reduce relative mean water level.

Removal of forest vegetation also serves to increase the hydrological response rate of a catchment (McCulloch and Robinson 1993). When combined with a Holocene Mediterranean precipitation hydrograph of increasing seasonality and intensity, this would facilitate increased floods of high sediment load in autumn and winter, and relatively low summer discharge. Consequently, the depositional environment of S'Albufera would receive high yields of sediment during rainy months, and low freshwater input during the dry season; giving a net relative decrease in mean water level. Such hydrological changes may also serve to disrupt existing drainage networks, creating shifts in sedimentation patterns. Increased sediment loads, resulting from increasing agricultural land use upstream during the Medieval period would have had similar effects as those described above.

c ii)

Given that the subdivisions of zone c were based solely on the palynological record, only pollen data will be considered in this section. The dramatic reduction in Chenopodiaceae pollen input, and increased contributions from Gramineae, Cyperaceae and T.A.P., may indicate a reduction in saline conditions, perhaps through a re-establishment of freshwater contributions to the system. However, progressive terrestrialisation, via a continuation of falling mean water levels, would also allow the apparent succession. Increasing T.A.P. suggests this is a feasible explanation, although values are still relatively low; possibly indicating sustained rapid sedimentation rates or continued effective isolation via a sea-breeze mechanism. The presence of *Alnus* and *Populus* pollen suggests high local water tables, although the low *Alnus* pollen sums may reflect regional input. Decreasing pollen concentrations suggest that sedimentation rates were greater than those observed in c iii.

c i)

The dramatic fall in pollen concentration, accompanied by a shift to pollen input increasingly dominated by the Chenopodiaceae, suggests a reversal of environmental conditions to a state similar to those evident in sub-assemblage c iii. That is to say that salinity re-asserts itself as a prime growth determinant, possibly in conjunction with a rising mean water level. Increasing salinity may serve to reduce local populations of Gramineae and Cyperaceae, since in marginal habitats *P. australis* shows a certain sensitivity to salinity (Mésleard *et al.* 1991). The reduction in extent and concentration of Chenopodiaceae pollen in relation to sub-assemblage c iii may be a feature of lower plant densities or further increases in sedimentation rate, as alluded to by the reduced concentrations of regional pollen taxa. Increasing sedimentation rates throughout zone c would arise through increased productivity per unit area, as canopy biomass increased.

Zone b (59 cm-22 cm)

The lithological transition at 59 cm is a broad a reversal of that found at 70 cm; organic deposits are rapidly replaced by dense clay sediments containing some organic fragments, suggesting a rapid rise in mean water level. Organic carbon content progressively decreases following this inundation, as the influence of local vegetation diminishes. Geochemical data alludes to a lower bulk density than in the underlying mineral horizons, as water values increase and carbonate levels diminish.

The lithological reversal is accompanied by pollen assemblages showing similar character to those of zone d. Grain concentration is relatively low, indicating poor preservation or low pollen deposition rates, since the shift from an organic to a mineral system, is likely to have reduced sedimentation rates. The high pollen concentrations observed at 24 cm may arise through a reduction in mineral sedimentation rates, although the disproportional increase in pollen from local taxa suggests that mean water levels temporarily retreated, allowing vegetation development closer to the site. Relatively high pollen percentage values for Chenopodiaceae, *Juniperus*, Gramineae and several ruderal herb taxa, indicate that local vegetation did not change significantly. Submergence of the site throughout this zone suggests that local pollen inputs are derived from peripheral marsh and lagoon vegetation some distance away. T.A.P. levels rise to a state comparable to assemblage d, again indicating that increased levels of extra-local or regional pollen are associated with aquatic sedimentation.

Zone a (22 cm-0 cm)

Dense clay sediments at the base of this zone show the aquatic depositional environment to persist up to the hiatus in the sediment between 9.5 cm-15.5 cm. This interval is likely to result from disturbance to the dense *Phragmites* root mat during coring. Above this void, the sediments show a higher organic content, including partially humified fragments of *P. australis* and other litter from recent vegetation. These sediments continue to the core surface. Leaching of organic colloids and some mixing of sediments has allowed staining and traces of organic material in the sediments below. Increased vegetative litter deposition facilitated higher organic carbon and extractable water components, whilst the diminished clay fraction is reflected in falling carbonate levels.

Sedimentary evidence suggests that the site was again colonised by semi-terrestrial, salt-tolerant marsh vegetation. This was facilitated by a reduction of mean water level, in the same manner as was described for zone c. However, the mechanism facilitating this change is proposed to be anthropogenic. The continuation of organic sediments with comparable pollen assemblages to the core surface indicates that since the reduction of water levels, environmental conditions have reached some form of equilibrium comparable to that observed at stages c iii and c i. For example, the local development of *Alnus* and *Populus* is inferred. This shift is likely to have occurred following drainage in 1856.

Pollen concentrations are an order of magnitude lower than in the comparable organic sediments of zone c. The vegetation of the two zones is likely to be similar, given the specific semi-terrestrialised marsh conditions, thus pollen production rates are likely to be comparable between the two sites. For this disparity to exist between sedimentary pollen concentrations, a change in pollen deposition or sedimentation rates is probably influential. Anthropogenic disturbance of *P. australis*, such as removal of flowering stems, may account for some of this disparity. However, it is proposed that compaction of the sediments in zone c by the overlying units facilitated much of this increased pollen concentration.

Amarador:

Zone e (446 cm-403 cm)

The basal sedimentary unit and overlying clays strongly resemble sediments in the comparable horizons of Es Colombar. The foraminiferal assemblage indicates a similar, brackish lagoon environment.

Whilst the small pollen sums do not warrant detailed comment, it is worthy to note that the low concentrations of Chenopodiaceae and Oleaceae pollen are comparable to those found in many of the later assemblages in the core. Low pollen concentrations are indicative of a relatively poor depositional environment; as occurs with distance from vegetation and inefficient pollen transfer across the water/atmosphere interface, or poor pollen preservation.

Zone d (403 cm-291 cm)

Relatively high concentrations of molluscan macrofossils within the homogenous clay sediments give high carbonate values, and possibly create pore spaces sufficient to allow relatively high extractable water levels. The steep gradient to the sedimentary boundary at 385 cm infers that the lagoon floor sloped.

Pollen input from Chenopodiaceae, Gramineae (*e.g. Phragmites australis*), *Populus*, *Alnus*, *Ranunculus* (*e.g. R. sceleratus*, *R. baudotii*) *Myriophyllum*, *Lemna* and *Potamogeton* indicates that local vegetation included a pronounced semi-aquatic component. Whilst *Rhamnus* pollen may typically infer maquis scrub vegetation, the *Rhamnus* pollen noted in this assemblage is probably derived from relatively hydrophytic species such *R. alaternus* and *R. ludovici-salvatoris*. The high sedimentary pollen concentrations of poorly preserved taxa suggest that the site was relatively close to pollen sources. Sedimentation rates may also be low, giving a high pollen:sediment ratio.

The pronounced T.A.P. component suggests that these sediments were deposited during the Holocene. Contributions from *Pinus*, *Quercus*, *Corylus*, *Alnus*, *Populus*, *Betula* and *Fagus* are evident. It is likely that much of this pollen was derived locally, since it is improbable that conditions have existed on Mallorca during the Holocene for the development of *Corylus*, *Fagus*, *Alnus*, *Populus*, and *Betula* at a landscape scale. Typically these taxa either require permanently high water tables (*Alnus*, *Populus*), or would not have been able to withstand high summer evapotranspirational demands (*Corylus*, *Fagus* and *Betula*). Gorges in the Sierra del Norte may have provided some localised sites for the development of these sub-humid taxa, and indeed may have acted as refugia during the Pleistocene, but the relatively high pollen contributions noted for these taxa suggests that pollen was derived locally. Even in the early Holocene, under a climatic regime less-seasonal that it is today (Roberts 1991), it is unlikely that these taxa could have survived in the lowland plains. The high water tables and relative humidity around S'Albufera may have facilitated an expansion of the range of these taxa out of the upland refugia.

High *Corylus* pollen concentrations may indicate a slightly wider distribution than for the other taxa; possibly via associations with *Quercus*, as a component of the sub-storey. Between 8000-4500 yr. B.P., heliophilous taxa such as *Corylus* became increasingly prevalent throughout the western Mediterranean, as woodland became progressively disturbed by anthropogenic activity (Oldfield 1964; Reille and Lowe 1993; Pérez-Obiol and Julià 1994). The high *Quercus* pollen values probably originate from regional sources-although some local contributions may be apparent-and indicate relatively high substrate stability and moisture availability.

The pronounced *Juniperus* pollen contribution suggests this taxon grew locally, since *Juniperus* often grows in sandy coastal Mediterranean environments (Stevenson 1984, 1985a, Stevenson and Moore 1988; Blamey and Grey-Wilson 1993). *Juniperus* currently occupies marginal environments across a wide latitudinal and altitudinal range; it was one of the first shrubs to colonise exposed sites in northern Europe following the deglaciation during the late-glacial (Grimes and Herbert 1989). *Juniperus* and *Artemisia* probably established in marginal coastal environments during the glacial period, and are observed in sediments of this age as a relic of late-glacial steppic vegetation.

Gramineae is totally absent from the assemblage at 300 cm, yet the presence of several ruderal herb taxa suggests that locally, the canopy was not completely closed. Given maximum Chenopodiaceae concentrations at this time, it is likely that local vegetation was dominated by halophytic, disturbed-substrate taxa. Pollen contributions from Gramineae in a lagoon-type environment are likely to be dominated by marsh grasses such as *P. australis*. Whilst the absence of Gramineae pollen is surprising, diminished pollen contributions are interpreted as signalling a reduction the extent of peripheral semi-aquatic beds of *P. australis*.

Zone c (291 cm-168 cm)

The discrete lithological unit, indicates a continuation of lagoon depositional conditions. Organic carbon concentrations are relatively high at 290 cm as a result of the partially humified fibrous ball of vegetative matter at this depth. This was identified as *Posidonia oceanica*, a marine angiosperm, the presence of which is another indicator of local marine influence.

The relatively high Ericales pollen input in the lowest extraction of this assemblage provides an interesting contrast to the underlying assemblages. Ten *Erica* species are currently found in the Mediterranean region, typically in association with open maquis scrub, heath or a woodland canopy (Blamey and Grey-Wilson 1993). The prevailing environmental conditions at this time suggest that *Erica terminalis* grew locally, since this species favours damp, calcareous substrates. Given the broad range of habitats colonised by Ericales, high pollen values cannot be used to infer specific environmental conditions.

Aside from the Ericales signal, pollen concentrations are low, with similar pollen assemblages as zone d, although the *Corylus* is less distinct. Growth conditions may be interpreted as being similar, although the site may have become further removed from local vegetation, probably via mid-Holocene sea level rise. Throughout the mid-Holocene, the increasingly seasonal nature of the Mediterranean climate influenced the distribution of sub-humid tree taxa, and may account for the decline in the *Corylus* signal.

The continuation of low pollen contributions from Gramineae suggest that beds of *P. australis* were restricted in extent, possibly by relatively rapid rates of sea level rise, or by intolerably saline conditions.

Zone b (168 cm-22 cm)

The rapid lithological sequences evident at the bottom of this zone result from a series of shifts in sediment supply or sedimentary source areas. Sedimentary conditions then became homogenous until, within the uppermost sediments, a rapid sequence of changes is evident. Prior to 38 cm all sediments appear to be lagoonal. Between 38 cm-35 cm, the deposits reflect an apparent increase in terrestrial input, with a discrete, relatively organic horizon. This suggests mean water level fell to the lowest level yet observed at Amarador. Potential mechanisms for this phenomenon are discussed above. Subsequent to this horizon, clay sediments-indicating a reversal to inundated conditions-are interrupted by a hiatus, created during coring by disturbance to the root zone of extant vegetation.

Geochemical analyses reveal that many of these sediments sustain a lower extractable water content than those in underlying units, perhaps as a function of relatively high bulk density. The reduction in organic carbon within the apparently organic horizon suggests that, within the clay sediments, organic compounds are humified, and thus not recorded visually. Such organics probably exist as colloidal leachates.

The continued pattern of low pollen concentration within this assemblage suggests sedimentary conditions were not conducive to pollen deposition or preservation. The absence of pollen (including *Eucalyptus* spike) in the extraction at 152 cm arises from errors introduced during pollen extraction.

Low pollen sums impose tentative discussions for the vegetation of this zone, however the re-occurrence of Gramineae pollen throughout the zone suggests that beds of *P. australis* increased in extent during this time, perhaps in response to a reduction in the rate of sea level rise. The increasing prevalence of pollen from aquatic taxa *e.g. Potamogeton* and *Lemna* in these assemblages, alongside notable contributions from *Populus* and Oleaceae, supports the notion of increasing dominance of marsh vegetation.

The discrete, apparently organic horizon between 38 cm-35 cm supports a slightly different pollen assemblage to adjacent extractions. However, the low pollen sum (35 grains) potentially places a high degree of error upon any interpretations.

Zone a (22 cm -0 cm)

Of the two lithological units evident, the upper horizon shows a higher organic component, derived from the litter of vegetation growing *in situ*. Carbonate values diminish in line with this shift to organic sediments, whilst the relatively low extractable water value provides an anomaly. This may arise through differential rates of post-extraction water retention between mineral and organic sediments. It is likely that substantial evaporation of extractable water took place from the organic sediments prior to experimental drying.

The subtle palynological changes within the unit may be an artifact of the relatively low pollen sum for the extraction at 20 cm. Composition of the uppermost pollen extractions reflect contemporaneous vegetation, although Gramineae appears to be underrepresented. This is surprising, since *P. australis* is anemophilous. Vegetation along a track adjacent to the site is of more terrestrial character, and this strip may act as the source of pollen from the Chenopodiaceae, Oleaceae, *Tamarix*, ruderal herb taxa and *Populus*. An established *P. alba* specimen was observed 35 m away from the site, and is likely to have provide the pollen evident in the extractions at 8 cm and 2 cm. This suggests that at least 8 cm of sediment have been deposited during the reproductive life of this specimen (<200 years, Grimes and Herbert 1989). It is probable that this particular *P. alba* individual, and hence vegetation reflected simultaneously in the pollen record, became established after drainage post-1856.

Comparison between cores:

Lithology

Both cores comprise dense clay sediments, deposited in a lagoonal environment. The lithological homogeneity of mineral units suggests that temporal and spatial changes in sedimentary conditions were small, bar transitions to the discrete, highly organic units, which reflect slight shifts in mean water level, catchment hydrology or precipitation regime. Drainage of the lagoonal complex after 1856 facilitated the colonisation of Es Colombar and Amarador by a hydrophytic community dominated by *Phragmites australis*. This shift from open water to extensive aquatic vegetation cover initiated the deposition of leaf litter, and hence the relatively organic surface horizons. Below these are mineral substrates laid down during the precursive lagoonal period.

Both cores indicate that on an earlier occasion, mean water levels fell sufficiently to allow the development of local vegetation, which produced an organic litter. This feature is evident at Es Colombar between 70 cm-59 cm and at Amarador between 38 cm-35 cm. The peripheral position of Es Colombar, and slightly lower water depth (above), account for a greater and perhaps earlier response to the environmental changes which triggered the reduction in mean water level. The formation of these organic horizons may have been synchronous, and occurred at different depths due to spatially disparate sedimentation rates. Alternatively, they may have been asynchronously deposited by localised variations in hydrology and sedimentation, most probably as a result of anthropogenic influences.

A discrete boundary marks the transition to an earlier period of relatively high mean water level. At 142 cm the Es Colombar core ends, at the interface between lagoonal clays and basal unit derived from a different sedimentary source. At a comparable depth (*ca.* 170 cm-*ca.* 140 cm), a rapid lithological sequence is also seen at Amarador, but aquatic clays continue to dominate. This suggests environmental changes are evident in both cores around this time, whilst the peripheral position of Es Colombar affords greater sensitivity to these stimuli.

Aquatic sediments continue at Amarador to a depth of 446 cm, whereupon the profile is terminated by sediments apparently similar to those underlying Es Colombar. However, lack of data renders any judgement placed on the nature of these horizons somewhat conjectured.

Geochemistry

In light of the lithological similarities, it is unsurprising to find comparable sedimentary geochemical signatures at both sites. Slight variations in the relative abundance of compounds arise through spatial and temporal disparity in sediment supply and characteristics such as deposition rate and bulk density.

The high water content of the cores is largely to be expected, given the contemporaneous aquatic environment. Variation in the water loss of the sediments will arise through differential rates of evaporation from the cores subsequent to coring. The high levels of inorganic carbon are also unsurprising, since the sediment was principally derived from a carbonate basin, whilst the rich molluscan fauna would also have enriched the concentration of carbonates in the core.

In the mineral horizons, organic carbon content is relatively low, in accordance with organic sediment supply rate. Organic content increases in those sediments associated with local vegetative litter production.

Pollen

Common principal and constituent taxa indicate that the local flora at each site varied little over the study period, and was broadly comparable. Lithological evidence, when interpreted with the typically low pollen concentrations, suggests that, for much of the time, the two sites were removed from their respective pollen catchments by a lagoon. Periodic reductions in mean water levels allowed the local establishment of semi-aquatic, salt-tolerant vegetation. This was more pronounced at Es Colombar, and possibly arose for a longer period, since a partial succession and subsequent regression of semi-terrestrial taxa is evident.

Pollen concentrations are much greater at Es Colombar, particularly in the organic band (zone c), probably as a consequence of increased rates of pollen deposition during this period. Peak pollen concentrations arise at Amarador during a mineral phase, and reflect a period of high arboreal pollen contributions and low sedimentation rate. This period is not evident in Es Colombar. Relatively high pollen input and taxon diversity at Es Colombar could arise through its peripheral position. Edge effects may be influential in determining pollen input from other, terrestrial habitat types. Pollen preservation is unlikely to have differed greatly between sites, unless active conditions preferentially increased grain attrition at one site. Disparities in geochemical state, whereby Es Colombar had a relatively acid-rich environment, giving greater pollen preservation. However, excess levels of carbonates in the sediments and marine water would buffer acid loadings. These features would be manifest in differential levels of indeterminable pollen between sites, which are evidently comparable (Figures 8, 11).

It is also important to consider the pollen sums of the respective assemblages in each core. Es Colombar has almost double the number of assemblages, which contain substantially more grains. This goes some way to explaining the increased diversity at Es Colombar, and strongly influences the outcome of any inter-core comparisons. However, in a study of this type, such discrepancies are unavoidable.

Foraminiferal Inspection

Ammonia beccarii was the only foram found, possibly as a function of low species diversity in hypersaline habitats (Basson and Murray 1995). Given the large numbers of *A. beccarii* found in most samples, strong environmental inferences can be made. Since the extraction and analyses of these samples were very basic, absence of *A. beccarii* may not be used to infer environmental shifts away from lagoon/marsh conditions.

Dating of the sediments

Attempts to date these cores may be conducted via a variety of mechanisms:

☆ Dates may be given to specific features which correspond to similar events dated in other projects in the region. This approach may be valid for estimating of the occurrence of organic horizons at S'Albufera, since they are discrete features, evident at both sites. The reduction in mean water level which initiated the production of these organic horizons may have arisen through a variety of mechanisms. Synchronous deposition of these sediments may have arisen under eustatic or climatic flux. Anthropogenic influences may also have facilitated synchronous deposition, but may have acted at sufficiently small scales to allow temporally-disjunct periods of litter formation. Three possible approximate dates are proposed for one or more of these horizons, based on data obtained in the western Mediterranean (Table 7):

Scenario 1: The earliest date for the formation of the relatively organic horizons is based on coincident diminished sea levels and relative aridity *ca.* 2800 yr. B.P. (Lowe and Walker 1984; Lamb *et al.* 1995).

Scenario 2: The second proposed date is based the coincidence of an arid phase and Roman occupation *ca.* 2100 yr. B.P. (Shimwell *et al.* 1984 unpublished; Lamb *et al.* 1995).

Scenario 3: The most recent proposed depositional period occurred during, or subsequent to, the Moorish occupation *ca.* 1150 yr. B.P. (Shimwell *et al.* 1984 unpublished).

☆ Dates based on mean sedimentation rates are not considered applicable, since insufficient data has been obtained in the Mediterranean region to provide adequate comparisons. Globally, mean sedimentation rates in comparable environments vary over almost two orders of magnitude (Table 8), and thus provide no real basis against which sedimentation rates at S'Albufera can be tested. Any errors in estimations based on this technique would be compounded by differential sedimentation rates during organic/mineral stages, and variation in subsequent compaction. Furthermore, constant mineral sedimentation rates cannot be assumed, since increasing anthropogenic influence has shown to increase sediment loads (Roberts 1991; Cooper and Brush 1993). For example, sedimentation rates in the Ebro delta have doubled in the past 2000 years (Nelson 1990).

Table 8. Observed sedimentation rates in several near-shore and tidal environments.

Sedimentation rate (mm yr.-1).	Study site	Reference
0.5-0.8	Chesapeake Bay, E. U.S.A.	Khan and Brush (1994)
0.8-5.3	Sado Marshes, Portugal	Soares de Albergaria Moreira (1994)
1.5-51.8	E. U.S.A. Marshes	Vernberg (1993)
1.8-8.0	Norfolk, U.K.	French and Spencer (1993)
ca. 11.0	Cardigan Bay, U.K.	Shi (1993)
6.2-7.0	Maine, U.S.A.	Anderson, Borns, Smith and Race (1992)
35.0-40.0	Severn Estuary, U.K.	French, Allen and Appleby (1994)

☆ A chronology is evident through the palynological record of the two cores. Both cores contain pollen from taxa prevalent in the western Mediterranean during the Holocene. Ideally, variations in regional pollen contributions would be used to correlate the two cores, and provide a reference to patterns evident in other western Mediterranean sites. However, shifts in the regional signals of taxa such as *Pinus* are not particularly pronounced, nor are they evident concurrently in the cores, possibly as a function of differential sedimentation rates.

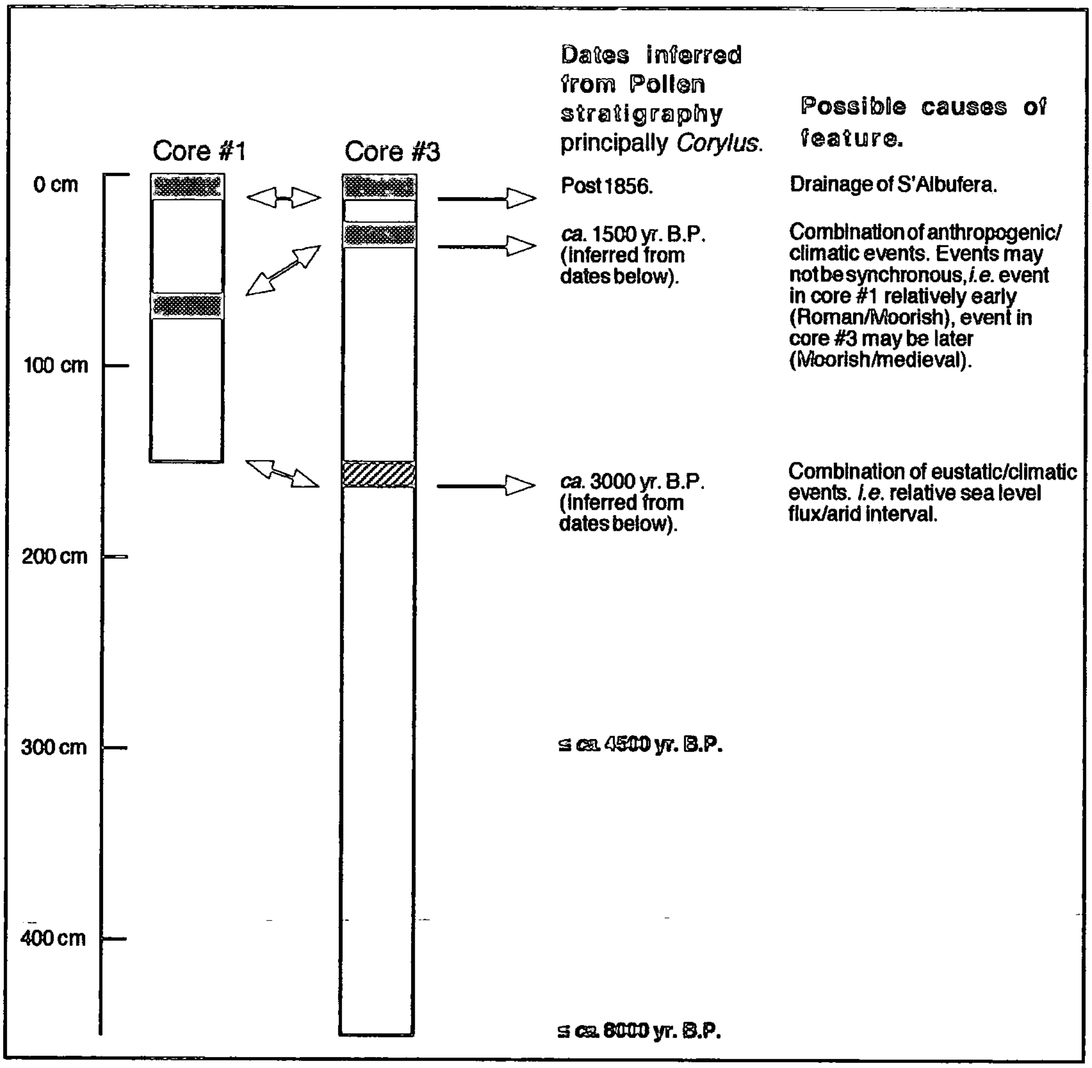
Differences in local pollen contributions between the cores may be used to infer dates, if they are sufficiently pronounced. For example, disparities in core length suggest that deposits at Amarador extend further into the Holocene than at Es Colombar. In the lower assemblages of Amarador, a strong local *Corylus* signal is evident, a feature not recorded at Es Colombar. Although the threshold at which *Corylus* contributions at Es Colombar curtail sufficiently to mark the end of the *Corylus* era is hard to establish, it is evident that the sediments below *ca.* 300 cm predate the lowest sediments at Es Colombar. *Corylus* was widespread throughout the region between 8000-4500 yr. B.P. (above). Subsequent to this, conditions arose which greatly reduced its distribution. Thus it transpires that whilst sediments at Amarador between 446 cm-*ca.* 300 cm were deposited before 4500 yr. B.P., and no later than *ca.* 8000 yr. B.P., the earliest sediments of Es Colombar postdate 4500 yr. B.P.

Dates extrapolated from this palynological framework are perhaps the most reliable, since the pollen record of this core is referenced to a regional vegetation history derived from several independent studies, in which the temporal scale is well established. The extrapolation of dates, for features of known approximate age in the overlying sediments, show a consistent conformity to a variety of events noted above for their potential influence on the landscape at S'Albufera (Figure 15).

Dating via the *Corylus* pollen signal shows the sediments at Amarador *ca.* 300 cm to be of mid-Holocene age. Subsequent extrapolation allows the overlying sediments-and the sediments of Es Colombar-to be placed into an approximate temporal framework. The rapid stratigraphy of sediments between 170 cm-140 cm at Amarador, and the base of Es Colombar are provisionally dated to *ca.* 3000 yr. B.P. Pronounced environmental perturbations have been noted for this time; it is proposed that eustatic regression (Lowe and Walker 1984) and/or an arid phase (Lamb *et al.* 1995) account for the rapid stratigraphy evident at Amarador *ca.* 2800 yr. B.P., via mechanisms discussed above. Subsequent transgression, perhaps associated with a restoration of precipitation conditions, allow the inundation and subsequent deposition of aquatic sediments at Es Colombar. Thus it is proposed that the lagoon at S'Albufera increased in extent through the action of these forcing agents.

Such extrapolation also provides approximate dates for the discrete organic horizons at between 2000-1000 yr. B.P. During this period, environmental flux can largely be attributed to human action; thus it is entirely possible that the two features are temporally disjunct, with the sediments between 70 cm-59 cm at Es Colombar predating those between 38 cm-35 cm at Amarador. The deposition of organic sediments is likely to date from local disturbance during Roman, Moorish or medieval times. Progressive anthropogenic influence through the historical period suggests formation during Moorish or Medieval periods. However, the influence of the Roman occupation should not be underestimated, particularly at Es Colombar, given its location. The Roman town of Pollentia (Alcudia) was also to the north of S'Albufera, so any influence would be more likely to be evident at this site. Amarador was cored at a less-accessible central location; marginal sites of poor access are unlikely to have been disturbed at the local scale until population or landuse pressures so determined, hence the apparently later period of semi-terrestrialisation.

Figure 15. Cross-core correlation and provisional chronology of sedimentary events at S'Albufera.



Dates inferred from Pollen stratigraphy principally *Corylus*.	Possible causes of feature.
Post 1856.	Drainage of S'Albufera.
ca. 1500 yr. B.P. (inferred from dates below).	Combination of anthropogenic/ climatic events. Events may not be synchronous, *i.e.* event in core #1 relatively early (Roman/Moorish), event in core #3 may be later (Moorish/medieval).
ca. 3000 yr. B.P. (inferred from dates below).	Combination of eustatic/climatic events. *i.e.* relative sea level flux/arid interval.
≤ ca. 4500 yr. B.P.	
≤ ca. 8000 yr. B.P.	

Chapter Five: Concluding remarks

It is proposed that S'Albufera has been a saline, aquatic depositional environment since at least the early-mid Holocene. The low topographic gradient at the site gives rise to an environment responsive to shifts in prevailing conditions. This is manifest in the apparent changes noted following drainage in 1856 and earlier periods of perturbation, including the inundations of Amarador *ca.* 8000 yr. B.P. and Es Colombar *ca.* 3000 yr. B.P. Local vegetation components remained virtually constant throughout the period studied, yet the relative position of these varied in response to fluctuating mean water level. As such, inundation level provided the primary constraint to local productivity. A combination of features, including low pollen sums and aquatic situation, obscured the nature and scale of regional forcing agents. Nevertheless, potential mechanisms of environmental flux have been identified where necessary.

Implications for further studies

The use of more advanced coring techniques, such as Mackereth and Livingstone samplers, may provide sediments of even greater age. The utilisation of physico-chemical or radiometric dating techniques would provide an absolute chronology.

Increased definition to the lithological and geochemical trends highlighted above may be gained by further studies of the physical and chemical properties of the sediments. Particle size distribution data may reveal trends in the hydrology and depositional environment of S'Albufera (*e.g.* Dubar and Anthony 1995). Sediment source area may be inferred from studies involving the aluminium concentration of the sediments (*e.g.* Siegel *et al.* 1995). Terrestrial sediments will be relatively rich in aluminium compounds, due to weathering of alumino-silicate parent materials. Base-rich conditions will ensure that at least some aluminium species remain insoluble (Marion *et al.* 1976), and thus available for analysis.

Despite time constraints, many salient vegetation characteristics were revealed by pollen analysis. Increasing the pollen sums within assemblages, and analysing more assemblages would increase the resolution of the evident patterns. This may reveal trends in vegetation, sedimentation and pollen source area which are unclear from the data presented here. In particular, regional trends may become more pronounced. However, further palynological work should first be evaluated against the potential benefits of other lines of evidence. The environmental and sedimentary features which lend themselves to the majority of pollen studies (*e.g.* Acidic, organic, terrestrial sediments rich in well-preserved pollen derived from local catchments) are not prevalent at S'Albufera. Thus, obtaining pollen data which provides more information than is evident here may prove relatively inefficient. A variety of other biological sources may be used to obtain environmental information. These could be used in conjunction with the patterns highlighted above to form a wider basis for environmental interpretation. Potential lines of evidence include diatoms, ostracods, charophytes and molluscs. Diatoms are expected to occur in these sediments, whilst the other lines are known to be abundant within the record. The composition of any of these assemblages would provide information concerning a wide variety of environmental factors, including water depth, hydrochemical signature, temperature, light, oxygen and nutrient availability. These inferences could be made to a higher level of accuracy than is evident from the pollen record, since many of the relevant species are stenotypic. The potential for such studies is introduced by Lowe and Walker (1984) and Berglund (1986). Further detail concerning diatom assemblages is provided by Cooper and Brush (1993) and Shennan *et al.* (1995), ostracod analyses are described by Holmes *et al.* (1995), whilst Martinez-Taberner and Moya (1991) and Souliemarsche (1993) address the potential of charophyte analyses.

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Appendices:

Appendix 1:

Pollen Preparation Protocol
(courtesy of the Environmental Research Centre, Durham).

PREPARATION PROTOCOL

Samples of lacustrine sediment will normally require steps 1 - 6 (including either 4 or 5 & 6), 8, 9 and 10 to be followed.

When preparing samples of peat that do not contain siliceous mineral materials, steps 4, 5 & 6 can be omitted.

Step 6 will only be necessary when the sediment contains large amounts of sulphide minerals. Step 2 can be omitted if the sediment is non-calcareous **and** exotic pollen tablets(*17*) are not being used. Step 9 can be omitted if staining of the pollen is not required.

1) Record the sample number, site, location and sediment type on one of the preparation sheets provided and/or in a preparation log book.

2)

   a) If the sediment is calcareous and/or if exotic pollen tablets(*17*) have been added, transfer sediment sample **plus** exotic pollen to a labelled 30-50ml centrifuge tube and slowly add *ca.* 10ml of 10% HCl (*2*). If at any time the tube threatens to froth over, reduce the foam using a squirt of acetone(*14*) (this step in the procedure MUST be always be performed away from any open flame). When the effervescence stops, place the tube in a boiling water-bath in a fume cupboard and stir until the effervescence again stops. Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). Decant the HCl (*2*) down the sink in the fume cupboard in running water.

      If the sediment is highly calcareous, it will be necessary to repeat this step with fresh 10% HCl(*2*) so as to ensure the removal of all carbonates. It is essential to remove all calcium carbonate at this stage if step 5 is to be used because otherwise insoluble calcium fluoride will be formed at that time.

   b) Wash the centrifugation residue with distilled water, centrifuge and decant; as in the case of all subsequent distilled water washes, balancing should be carried out using additional distilled water. Repeat at least twice.

3)

   a) If step 2 has been followed, then transfer the residue to a labelled boiling tube using 10% NaOH (*3*) and then add a further *ca.*10ml 10% NaOH (*3*).

      If step 2 has not been followed, then transfer the sediment sample **plus** exotic pollen suspension(*17*) to a labelled boiling tube using a 10% NaOH (*3*) and then add a further *ca.*10ml NaOH (*3*).

   b) Place the boiling tube in a boiling water bath in a fume cupboard for no more than 2 - 5 minutes, stirring occasionally. After boiling, record the colour of the supernatant as a measure of the degree of humification of the initial sample.

   c) If the sediment contains much coarse mineral material or organic debris, strain and wash through a fine sieve (*ca.*125-200µm), supported in a filter funnel, into a 30-50ml centrifuge tube. Wash the residue on the sieve thoroughly with a jet of distilled water. Centrifuge the material that passes through the sieve and decant; balancing should be carried out using distilled water.

Place the coarse residue retained upon the sieve in a labelled container (*e.g.*petri dish or vial) for later examination. Wash the seive, and the filter funnel used to support it, thoroughly between samples.

d) Wash the centrifugation residue with distilled water, centrifuge and decant. To wash the residue add ca. 30ml distilled water, cap the tube and agitate using the autovortex for about 15-20 seconds, further agitation is only necessary if lumps of residue are seen. Repeat until no trace of brown colour remains in the supernatant.

e) Wash the centrifugation residue with *ca.* 20ml 10% HCl(*2*). Check carefully for any signs of effervescence. If at any time the tube threatens to froth over, reduce the foam using a squirt of acetone(*14*) (this step in the procedure MUST be always be performed away from any open flame). If effervescence is detected then the sediment contains carbonate and step 2 must be carried out before proceeding any further. If no effervescence is detected then centrifuge and decant; balancing should be carried out using distilled water.

4) If the sediment contains much mineral matter, it must be treated either with saturated $ZnCl_2$ (*18*),this step, or with 60% HF (*4*), steps 5 & 6.

a) If the sediment contains a lot of fine clays wash over a 7μm monofilament nylon mesh.

OR

Add 20ml 5% $Na_4P_2O_7$ (*12*), warm in water bath, stir on the autovortex, centrifuge and decant. The very fine clays will stay in suspension and be poured off with the supernatant. Repeat this step as necessary. Wash with distilled water, centrifuge and decant.

b) Wash with 10% HCl (*2*), centrifuge and decant.

c) Add exactly 10ml $ZnCl_2$ (*18*), cap the tube, and mix thoroughly using the autovortex. Centrifuge for 15mins at 3000rpm, balancing should be carried out using water added to the centrifuge buckets. Do not add methanol. The pollen will float and therefore the supernatant should be poured into another labelled centrifuge tube. (Slight stirring of the surface layer helps to prevent the pollen adhering to the side of the tube but care must be taken not to disturb the inorganic residue.) Discard the residue.

d) Add 5ml 10% HCl (*2*) to the saved supernatant and then fill the tube with distilled water to 1cm from the top, cap and shake well. Centrifuge, the pollen will have sunk, check the supernatant is clear and decant into the waste $ZnCl_2$ vessel.

e) Wash the residue with distilled water. Go to step 7.

5)

** **Hydrofluoric acid (*4*) is extremely dangerous and requires special additional precautions. In the event of an accident, special first aid measures are required. Ensure that the precautions required for the use of HF are ALWAYS followed and that you are familiar with the first aid measures -see below.**

Prepare a large beaker of saturated sodium hydrogen carbonate (*13*) for use as a neutralising solution.

Either:

(i) Treat with hot HF(*4*) as follows:

Transfer the centrifugation residue to a labelled 30-50ml HF-resistant centrifuge tube (if a glass tube has been used for the earlier steps), or to a labelled crucible, using as little 10% HCl(*2*) as possible to wash the residue out of the tube.

In a fume cupboard, add *ca.*10-15ml of HF(*4*). Stir with a polyethylene rod and **either** place the centrifuge tube in a boiling water bath in a fume cupboard, **or else** place the nickel crucible on a sand bath in a fume cupboard, and allow the HF(*4*) to boil for between *ca.*30 minutes and 2 hours. Stir occasionally with a polyethylene rod.

Either remove the tube from the water bath, **or else** if a nickel crucible was used, allow the HF(*4*) to cool before pouring it into a labelled 30-50ml HF-resistant centrifuge tube. Add sufficient 95% methanol(*1*) to bring the level to within 2cm of the rim of the tube so as to reduce the specific gravity of the mixture. Stir with a polyethylene rod so as to mix well.

Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). Decant the HF(*4*) carefully into the neutralising solution and then down the sink in the fume cupboard.

If any silt or clay materials remain, repeat the procedure.

Or else:

(ii) Treat with cold HF(*4*) as follows:

Transfer the centrifugation residue to a labelled HF-resistant beaker using as little 10% HCl(*2*) as possible to wash the residue out of the tube.

In a fume cupboard, add *ca.* 25ml of HF(*4*). Stir with a polyethylene rod. Leave in the fume cupboard for at least 8 hours (usually overnight), stirring occasionally with a polyethylene rod.

Pour into a labelled 30-50ml HF-resistant centrifuge tube. Add sufficient 95% methanol(*1*) to bring the level to within 2cm of the rim of the tube so as to reduce the specific gravity of the mixture. Stir with a polyethylene rod so as to mix well.

Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). Decant the HF(*4*) carefully into the neutralising solution and then down the sink in the fume cupboard.

If any silt or clay materials remain, repeat the procedure.

6)

a) If required, wash the centrifugation residue back into a 30-50ml glass centrifuge tube using 10% HCl(*2*).

b) Half fill the centrifuge tube with 10%HCl(*2*) and place it in a boiling water bath in a fume cupboard for *ca.* 15 minutes so as to remove colloidal silicates and silicofluorides.

c) Cap the tube and centrifuge whilst hot; balancing should be carried out using distilled water added to the centrifuge bucket(s). Decant the HCl(*2*) carefully down the sink in the fume cupboard.

If much mineral material remains, repeat steps 5b and 5c one or more times. In general these steps should be continued until the supernatant loses any yellow colour.

7) N.B. - Unless the sediment contains large amounts of pyrite or related sulphide compounds such as hydrotroilite, melnikovite or marcasite (Vallentyne, 1963) then this step should be ommitted.

   a) In a fume cupboard, add *ca.* 10ml of 10% nitric acid (HNO_3)(*5*) to the centrifugation residue. Place the tube in a boiling water bath in a fume cupboard for no more than 2 minutes.

   b) Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). Decant the HNO_3 (*5*) carefully down the sink in the fume cupboard in running water.

8)

   a) Wash the centrifugation residue into a 13-15ml centrifuge tube using distilled water, centrifuge and decant. Wash once more with distilled water, centrifuge and decant.

   b) In a fume cupboard, add *ca.* 10ml of glacial acetic acid (CH_3COOH)(*6*) to the centrifugation residue, stir well. Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL**. Decant the CH_3COOH (*6*) carefully down the sink in the fume cupboard in running water.

   Repeat at least one further time so as to ensure that all water has been removed. Failure to adequately remove the water can lead to a dangerous tendency for the mixture to 'explode' at the next step.

   c) In a fume cupboard, add 9ml of acetic anhydride(*7*) followed by 1ml of concentrated sulphuric acid (H_2SO_4)(*8*)[2] to the centrifugation residue, stir well. Place the tube in boiling water bath in a fume cupboard for 2 minutes, stirring once after 1 minute. Remove the tube from the water bath. Add sufficient glacial acetic acid (CH_3COOH)(*6*) to fill the tube[3]. Stir well.

   Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL**. Decant carefully down the sink in the fume cupboard in running water.

   d) In a fume cupboard, add *ca.* 10ml of glacial acetic acid (CH_3COOH)(*6*) to the centrifugation residue, stir well. Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL**. Decant the (CH_3COOH)(*6*) carefully down the sink in the fume cupboard

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[2] Alternatively, if preferred sufficient of a 9:1 mixture of acetic anhydride(*7*) and concentrated sulphuric acid(*8*) to treat all of the samples being processed can be prepared in a dry measuring cylinder just before this step, and 10ml of the mixture added to each tube.

[3] The glacial acetic acid(*6*) effectively stops the acetolysis reaction because it is one of the products of the reaction and is now present in large excess.

in running water.

This removes soluble cellulose acetate products of acetolysis.

9) If staining of the pollen grains is required, then:

a) Wash the centrifugation residue with distilled water, centrifuge and decant.

b) Add *ca.* 9ml of distilled water and *ca.* 0·5 to 1ml of a 10% aqueous solution of sodium hydroxide(NaOH)(*3*) to the centrifugation residue in order to obtain the correct pH for subsequent staining. Stir well and test using indicator paper that the pH is *ca.* 7·0 (Faegri, 1936). If necessary the pH can be lowered by adding a few drops of 10% HCl(*2*). Centrifuge and decant; balancing should be carried out using distilled water.

c) Add *ca.* 10ml of distilled water to the centrifugation residue, stir well and then add a few drops of dilute aqueous safranin(*9*). Stir again, centrifuge and decant; balancing should be carried out using distilled water.

10)

a) In a fume cupboard, add *ca.* 10ml tertiary butyl alcohol(*10*) (TBA, 2-methylpropan-2-ol) to the centrifugation residue, stir well. Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL.** Decant into an excess of water in a beaker in the fume cupboard; discard the contents of this beaker by adding them slowly to a vigorous flow of water in the main sink.

b) Wash the centrifugation residue into a labelled vial using a **clean** Pasteur pipette. A second **clean** Pasteur pipette should be used to add to the centrifugation residue the minimal quantity of additional TBA(*10*) necessary to achieve this transfer. Stir well, place the vial into a centrifuge tube or bucket, cap the tube or bucket and gently centrifuge, bringing the centrifuge gradually up to 2000rpm and maintaining this speed for 3 - 5 minutes; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL.** Decant into an excess of water in a beaker in the fume cupboard; the supernatant should be drawn off with extreme care using a **clean** Pasteur pipette. Discard the contents of the beaker by adding them slowly to a vigorous flow of water in the main sink.

c) Using a **clean** Pasteur pipette that has had its fine tip removed if necessary, or a **clean**fine glass rod, add to the centrifugation residue a volume of silicone oil(*11*) (2000cs viscosity) equal to the volume of residue in the vial, stir well. Leave the vial uncorked in an oven at 50° - 60°C for *ca.* 12 - 24 hours so as to evaporate any residual TBA(*10*). Leave the vial uncorked for 3 - 4 days in a drawer before counting so as to ensure that all volatiles have evaporated.

If the sediment is rich in silt- and clay-size particles then the combination of sieving and sodium pyrophosphate (*12*) washes proposed by Cwynar *et al.* (1979) can be implemented as follows:

1) Between Steps 2 and 3:

In a fume cupboard, wash the centrifugation residue 3-5 times with a warm 5% aqueous solution of sodium pyrophosphate(*12*), stirring vigorously. Cap the tube and centrifuge to remove the finest particles; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL.** Decant into an excess of water in a beaker in the fume cupboard. (See Bates *et al.* (1978) for a discussion of the use of sodium pyrophosphate(*12*).)

2) Between Stages 7 and 8/9:

In a fume cupboard, suspend the centrifugation residue in a 5% aqueous solution of sodium pyrophosphate(*12*), stirring vigorously. Sieve under gravity through a 7cm diameter, 7µm mesh nylon screen (Cwynar *et al.*, 1979, Heusser and Stock, 1984).

When sieving is completed, wash the residue from the screen surface back into a 13-15ml centrifuge tube using distilled water. Cap the tube and centrifuge; balancing should be carried out using distilled water added to the centrifuge bucket(s). **DO NOT ADD 95% METHANOL.** Decant into an excess of water in a beaker in the fume cupboard.

Wash the centrifugation residue with distilled water to remove any traces of sodium pyrophosphate(*12*). Centrifuge and decant; balancing should be carried out using distilled water.

Upon completion of the preparation procedure, the coarse residues retained from stage 3c should be examined using a binocular microscope. Any plant macrofossils and/or other coarse debris present should be identified as far as possible and recorded.

Appendix 2:

Pollen count data (Es Colombar).

Pollen count data (Es Colombar).

	2 cm	6 cm	10 cm	20 cm	24 cm	32 cm	44 cm	60 cm	62 cm	64 cm	66 cm	68 cm	82 cm	98 cm	128 cm	140 cm
Pinus	7	39	4	20.5	28	28.5	26	13.5	16.5	24	26	3.5	11	13	23	3.5
Quercus	7	18	25	35	17	11	3	13	9	7	8	3	5	13	2	7
Corylus	*	*	6	5	1	*	*	2	1	*	*	*	*	*	*	2
Fagus	*	*	0	1	*	*	1	1	*	*	*	*	*	1	*	*
Carpinus	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	5	*	*	2	2	*	*	*	*	*	*	*	3	1	*
Populus	*	1	*	6	18	8	*	2	*	3	2	*	3	4	2	1
Alnus	1	*	*	2	*	*	*	*	*	*	1	*	*	*	*	*
Chenopodiaceae	37	37	44	58	22	17	12	45	28	23	33	137	1	2	5	26
Tamarix	2	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	3	*	5	4	1	*	*	1	1	*	*	*	*	*	*	2
Thymelaceae	1	*	*	5	*	*	*	*	*	*	*	*	*	*	*	*
Ericales	1	*	*	5	*	*	1	2	*	*	2	1	1	1	1	6
Juniperus	1	1	*	*	12	2	1	*	*	3	1	*	*	*	*	*
Oleaceae	9	12	11	17	12	6	3	9	6	5	6	4	2	14	12	1
Buxus	*	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*
Sambucus	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*
Rhamnus	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*
Ribes	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*
Vitis	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1
Gramineae	20	23	17	15	22	10	4	18	36	83	159	55	3	4	17	10
Cyperaceae	4	3	2	*	*	2	*	*	6	17	10	1	*	*	*	1
Comp. Liguliflorae	2	4	*	3	1	4	7	6	2	*	2	1	*	1	2	*
Compositae	4	*	2	2	1	*	*	3	1	*	2	2	*	*	*	*
Plantago	*	3	2	8	7	1	*	4	8	1	6	1	*	3	*	1
Caryophyllaceae	*	*	*	2	13	*	*	2	1	*	1	*	*	1	1	1
Rumex-type	*	*	*	*	*	*	*	*	*	*	*	*	*	2	*	4
Umbellifereae	1	*	1	1	*	*	*	1	1	1	2	1	*	*	*	*
Euphorbia	*	*	*	1	*	*	*	*	*	*	*	2	*	*	*	1
Marrubium	*	*	*	0	*	*	*	*	1	*	*	*	*	*	*	*
Leguminoseae	8	*	4	10	1	*	*	*	4	*	3	1	*	*	*	1
Myriophyllum	*	*	3	5	*	*	*	*	*	*	*	*	*	*	*	*
Potamogeton	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	1
Unknown	1	*	*	*	3	1	2	*	1	1	*	*	*	*	1	*
In. Concealed	15	5	17	2	*	1	*	8	*	5	6	2	5	13	*	*
In. Degraded	1	31	*	5	8	1	9	1	2	9	*	*	8	17	1	1
In. Sum	16	36	17	7	8	2	9	9	2	14	6	2	13	30	1	1
Tree Sum	15	63	36	69.5	66	49.5	30	31.5	26.5	34	37	6.5	19	34	28	13.5
Shrubs sum	54	50	60	94	48	25	17	56	35	31	43	142	4	17	18	36
Herbs sum	39	33	28	42	45	17	11	34	60	102	185	64	3	11	20	19
Aquatic sum	*	*	3	5	*	*	*	*	*	*	*	1	*	*	*	1
Unknown sum	1	*	*	*	3	1	2	0	1	1	*	*	*	*	1	*
Pollen sum	109	146	127	210.5	162.5	92.5	60	121.5	122.5	168	265	213.5	26	62	67	69.5

Appendix 3:

Pollen count data (Amarador).

Pollen count data (Amarador).

	2 cm	8cm	20 cm	32 cm	36 cm	80 cm	96 cm	128 cm	144 cm	152 cm	168 cm	198 cm	240 cm	260 cm	290 cm	300 cm	358 cm	390 cm	416 cm	444 cm
Pinus	8	22	3	10	*	1	1.5	5	*	*	1.5	11.5	13	5	9	5	28.5	27.5	1	2.5
Quercus	16	9	1	13	4	12	2	20	1	*	4	18	8	15	10	34	40	36	1	1
Corylus	*	*	*	*	1	*	*	3	*	*	*	5	*	*	2	30	4	7	4	2
Fagus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*
Ulmus	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*	*	*	*	*	*
Betula	*	*	*	1	*	2	1	*	*	*	*	*	*	*	2	2	4	5	*	*
Populus	3	3	*	4	*	2	1	*	*	*	*	*	*	*	1	5	*	10	*	*
Alnus	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	3	7	1	*	*
Chenopodiaceae	20	50	18	9	6	1	1	10	1	*	2	5	3	6	10	33	18	28	5	7
Tamarix	*	2	1	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Artemisia	2	2	1	6	1	*	*	2	*	*	*	1	*	*	2	1	4	4	*	*
Ericales	*	4	5	2	7	4	*	1	*	*	1	2	2	3	34	1	1	3	*	*
Juniperus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*	5	18	*	*
Oleaceae	7	14	4	12	5	6	4	17	1	*	4	9	4	3	13	7	2	1	*	3
Rhamnus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3	*	*	*	*
Ribes	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Gramineae	30	45	9	24	9	17	4	10	1	*	9	1	1	1	5	*	11	26	*	*
Cyperaceae	5	2	*	2	*	1	*	*	*	*	*	*	*	*	3	1	1	3	*	*
Comp. ligulif	3	29	6	3	1	1	*	*	*	*	1	*	*	*	*	5	1	*	*	*
Compositae	*	1	1	2	*	1	*	*	*	*	*	*	1	2	*	*	1	*	1	*
Plantago	1	1	*	3	*	*	*	4	*	*	1	3	*	2	2	7	1	3	*	*
Caryophyllaceae	3	*	*	*	*	*	*	1	*	*	1	4	*	1	1	1	7	*	*	*
Ranunculus	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1	*
Umbelliferae	*	3	*	1	*	*	*	*	*	*	*	1	*	*	*	*	1	1	*	*
Euphorbia	*	*	*	*	*	*	*	*	*	*	*	*	1	*	*	1	*	*	*	*
Urtica	*	*	*	*	*	*	*	1	*	*	*	*	1	*	*	*	*	*	*	*
Leguminosae	1	4	*	*	1	*	*	*	*	*	*	*	*	*	*	1	*	4	*	*
Equisetum	*	2	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*
Myriophyllum	*	*	*	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	1	*
Lemna	2	*	*	3	*	*	*	*	*	*	*	*	1	*	*	*	*	*	*	*
Potamogeton	*	2	*	*	*	5	*	1	*	*	*	*	*	*	1	2	*	*	*	*
Unknown	*	*	*	2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Id. Concealed	*	4	7	5	3	5	1	7	1	*	*	3	1	5	2	1	1	3	6	1
Id. Degraded	1	6	10	2	1	8	4	18	3	*	4	*	4	4	16	23	6	19	12	16
Id. Sum	1	10	17	7	4	13	5	25	4	*	4	3	5	9	18	24	7	22	18	17
Tree sum	27	34	4	28	5	17	5.5	29	1	*	5.5	34.5	21	21	24	79	83.5	87.5	6	5.5
Shrub sum	12	74	29	20	19	10	5	22	1	*	6	15	9	12	51	45	19	27	5	10
Herbs sum	40	87	16	35	11	20	4	15	1	*	11	5	5	6	10	16	16	37	2	*
Aquatic sum	2	2	*	3	*	5	*	1	*	*	*	*	1	*	1	*	*	*	1	*
unknown sum	*	*	*	2	*	*	*	*	*	*	*	2	*	*	*	*	*	*	*	*
Pollen sum	101	197	49	97	35	53	14.5	76	4	0	24.5	61.5	36	39	96	142	136.5	178.5	14	15.5

Appendix 4:

Moss polster data

Count and % data for moss polsters collected 20/3/95				
	20/3 #1-counts	20/3 #1-%	20/3 #2-counts	20/3 #2-%
Pinus	284.0	93.7	367.0	82.5
Quercus	6.0	2.0	3.0	0.7
Ericales	5.0	1.7	24.0	5.4
Phillyrea	*	*	6.0	1.3
Gramineae	*	*	6.0	1.3
Cyperaceae	*	*	1.0	0.2
Chenopodiaceae	*	*	1.0	0.2
Leguminoseae	*	*	6.0	1.3
Euphorbia	*	*	3.0	0.7
Unknown	6.0	2.0	2.0	0.4
Deteriorated	2.0	0.7	17.0	3.8
Concealed	0.0	0.0	9.0	2.0