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Palynological evidence for climatic change along the eastern Iberian Peninsula and Balearic Islands

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Resum

A partir de sis seqüències pol·líniques extretes al llarg del vessant mediterrani de la península Ibèrica i les illes Balears s'ha estudiat l'evolució del clima durant l'Holocè. Els paisatges mostren trets característics diferents en termes de latitud, determinats fonamentalment pel clima. El propòsit principal d'aquest treball és l'estudi de la història de la vegetació en l'àrea mediterrània occidental durant els darrers mil·lennis a partir de l'anàlisi pol·línica en sediments holocènics dels llocs seleccionats. Observant l'evolució de la concentració pol·línica tindrem una idea força precisa de la biomassa del paisatge. Això implica l'avaluació del ritme, l'abast i la taxa de desertificació a l'Europa sud-occidental en relació amb les tendències climàtiques naturals. Els canvis d'estructura i biomassa de la vegetació són generalment visibles a escala regional i estan en relació amb les crisis hidrològiques. La resposta que s'obté d'aquests canvis és ben diferent pel que fa a la recuperació del bosc depenent de la regió. Una tendència clara cap a la desforestació és visible en molts llocs de la península Ibèrica i les illes Balears a partir dels 5.000 BP.

Paraules clau: palinologia, Holocè, Llevant Península Ibèrica, Illes Balears, canvi climàtic

Abstract

Climate evolution during the Holocene was studied based on six pollen sequences extracted along the Mediterranean slope of the Iberian Peninsula and Balearic Islands. The climatic features of these landscapes differed as a function of latitude. The aim of the present work was to use this information to determine the history of the vegetation in the Western Mediterranean during the last millennia. The evolution of the pollen concentration precisely reflected the landscape biomass, which allowed the timing, profusion, and rate of desertification in southwestern Europe to be evaluated in relation to natural climatic trends. Changes in the structure and biomass of the vegetation were generally visible at a regional scale and occurred in relation to hydrological crises. The response elicited by these changes with respect to forest recovery differed depending on the region. A clear trend towards deforestation was visible in many sites along the Iberian Peninsula and Balearic Islands beginning at 5000 years BP.

Keywords: palynology, Holocene, eastern Iberian Peninsula, Balearic Islands, climate change

State of the art and objectives of the study

The landscapes of the eastern Iberian Peninsula and Balearic Islands are subject to climatic traits that differ as a function of latitude. In the south, the tree cover is reduced, giving much of the zone the appearance of semi-desert. Northern areas, by contrast, are often forested. The vegetation of the Mediterranean area is mainly affected by short-term or long-term climatic changes that determine rapid transformations in the aspect and potential of the region. In addition, the Mediterranean landscape is very vulnerable to sheet and gully erosion where the protective natural vegetation canopy is denuded. As a result, the shallow soil mantel is exposed to desiccation in the dry summer and to torrential rains in the winter. In this context, any small climatic change can induce a disarticulation of the natural landscape pattern.

Along the Iberian Peninsula, high mountains result in 'islands' of substantially different bioclimatic conditions that permit the co-existence of diverse ecosystems. A paleoecological approach to the study of these territories includes determination of the extent to which spatial variations in the vegetation are bioclimatically determined. Previous studies of the bioclimatic evolution of the Mediterranean area during the Holocene demonstrated important differences between the dynamics of the vegetation of this area and the established models for central and northern Europe. Between 6000 and 4000 years BP, transformations of great magnitude in the flora and vegetation were registered that conditioned the later evolution of the potentialities of the plant landscape.

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The principal aim of this work was to study the vegetation history in the West Mediterranean during the last millennia through pollen analysis of Holocene sediments from selected sites. The timing, extent, and progress of desertification in southwestern Europe were studied in relation to natural trends. The main objective was to determine the degree of variability in the structure and biomass of the region's vegetation during the Holocene. A tendency to decreasing biomass was observed in some areas of the Iberian Peninsula over the last five millennia. The changes have differed in extent and, among other factors, according to latitude. In some areas of the Iberian Peninsula, the changes have occurred abruptly.

Methods

Quaternary continental sedimentary deposits were studied. The origins of the deposits varied. On the one hand, the conditions of sedimentation determined by the most xeric Mediterranean environments made it necessary to concentrate sample collection to littoral and fluvial deposits (floodplain, marsh, and deltaic zones). On the other hand, samples were obtained from lakes of more humid climates in order to compare zones of different bioclimatic behaviors. Pollen analyses and radiocarbon dating were the principal methodologies. Sedimentary sequences recovered along the peninsular Mediterranean slope and Balearic islands (Fig. 1) evidenced the existence of important differences among them. The six examples described here were obtained along an important climatic gradient (from more than 1000 mm of average annual precipitation and an average annual temperature of less than 9ºC in the Pyrenees to data from the Almeria coast, where average annual precipitation is 300 mm and temperatures average about 18°C). Based on the sedimentary records, the values of the arboreal pollen concentration were directly related to biomass and to landscape forest cover. Pollen concentrations were calculated by the addition of a known quantity of *Lycopodium* spores during treatment [16]. These values are shown in Fig. 2.

Results and Discussion

In cores from the north (Pyrenees, Banyoles), the pollen spectra from glacial times were dominated by *Pinus*, *Artemisia*, and Poaceae. Later on, at the beginning of the late-glacial interstadial, the decrease in the pollen concentration was coincident with the percentages of arboreal pollen between 15000 and 14000 years BP [14, 10, 11], suggesting the existence of open and steppe-like landscapes. This phase corresponds to the very important presence of icebergs at low latitudes, which cooled the oceanic surface considerably. The classic late-glacial period Bølling-Allerød was marked by an invasion of *Pi-*

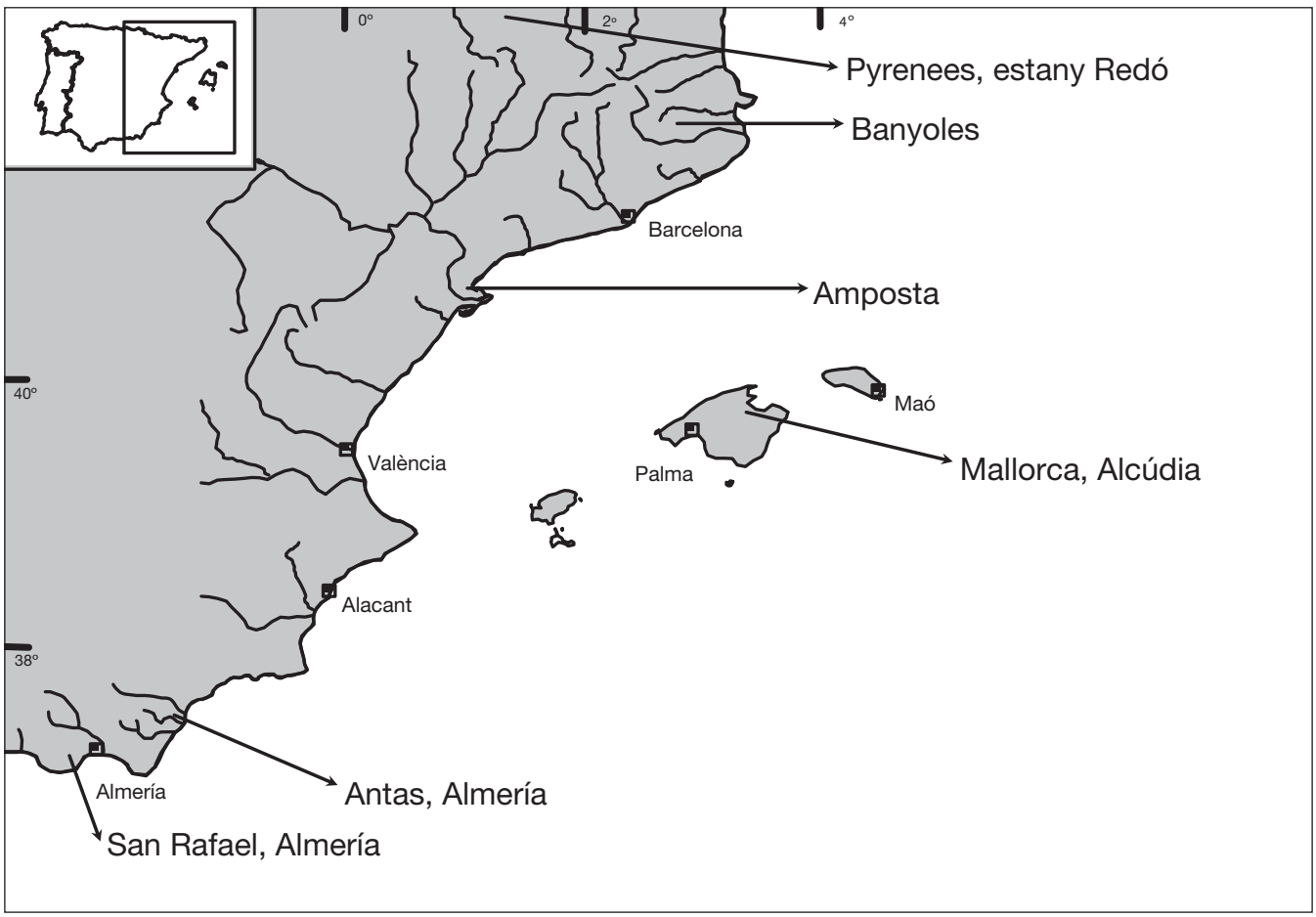

Figure 1. Location of the studied sites.

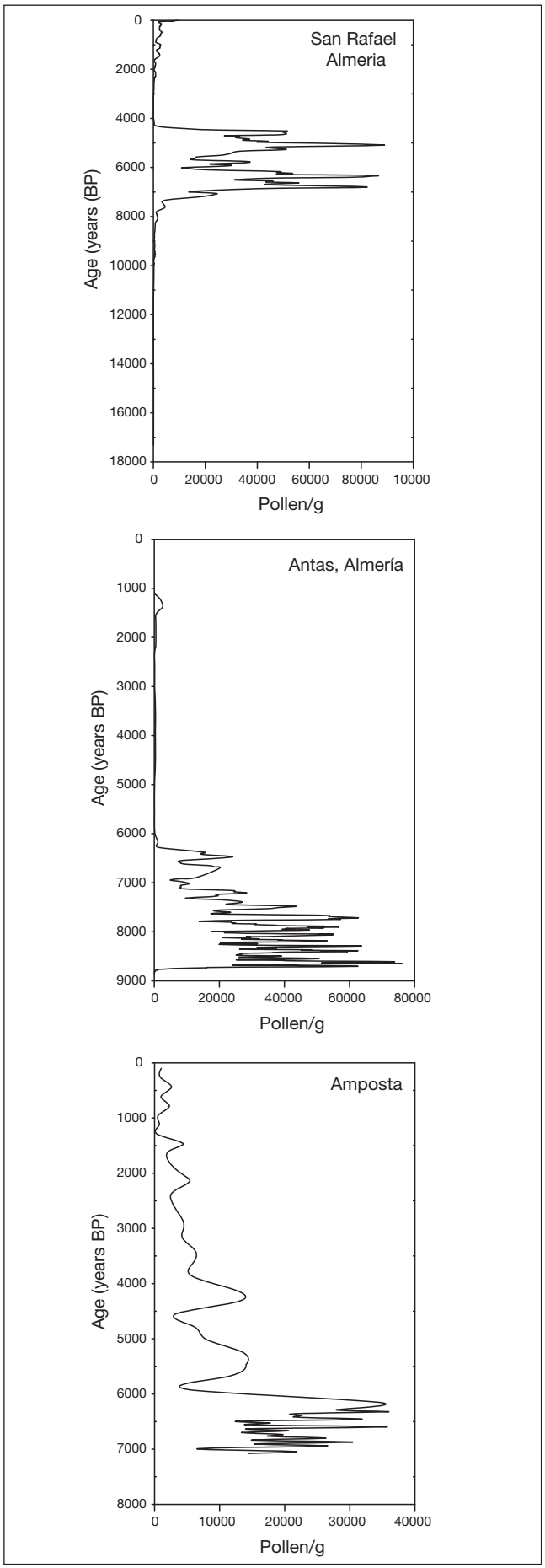

Figure 2. Evolution through time of pollen concentration.

nus, *Betula*, *Acer*, and *Juniperus*. Subsequently, there was an expansion of the herbaceous vegetation attributed to the Younger Dryas. The upper part of the sequences reflected the development of arboreal mesophilous vegetation (*Quercus*, *Corylus*, etc.). Toward 6000 years BP, *Abies* occupied the important extensions.

The core extracted in Amposta, in the lower Ebro valley, provided a sequence representative of the last 8000 years. During this time, trees have predominated, evolving the landscape toward mixed communities, mostly of deciduous and evergreen *Quercus* but also, initially, the strong presence of *Corylus*. In the pollen diagram of the Amposta, after a Holocene optimum climate had become established between 8000 and 6000 years BP, thermophilous taxa slowly replaced the most mesophilous ones. Biomass non-abruptly decreased from the mid-Holocene, in contrast to the sequence from Mallorca.

Samples from the Balearic Islands provided interesting results. Before 5000 years BP, the sequence was dominated by *Buxus* and *Corylus* (taxa no longer present on the island) and high values of *Juniperus*, *Ephedra*, and *Quercus*. During the upper part of the Holocene, the landscape changed, with an abrupt increment of the *Olea* curve and a strong decrease of *Buxus* and *Corylus*. Biomass notably declined. The reduction and disappearance of *Buxus* and *Corylus* from the fifth millennium BP was due to an important landscape disruption that caused a change in the vegetation structure, reflecting the substitution of mesophilous communities by a maquis dominated by *Olea.* The period coincided with the extinction of endemic animal species [1, 17]. Although this was probably the result of climatic changes [2, 13] that took place before human impact began, it was no doubt accelerated by human activity.

In the southeastern Iberian Peninsula, the main landscape change detected in the studied sequence (Almeria) was the alternation between steppe and shrub communities, with a remarkable similarity between the different episodes of each recorded type [8]. This pattern, clearly visible in the pollen sequences as well, was highly significant. It can be stated a priori that the physiognomy of the plant landscape is closely related to bioclimatic limitations, and that water availability is more of a deciding factor than temperature. Nonetheless, the results obtained from the pollen concentration values in zones that underwent severe aridification offer information that is essential to understanding environmental processes in those areas where the critical factor was the capacity for maintaining populations. Low pollen concentrations were generally coincident with periods during which the landscape opened up, when the dominant percentages correspond to non-arboreal taxa representative at local and regional scales. Phases of high pollen concentration appear to be related to percentages indicating a high degree of vegetation cover in the area, a decisive factor in the reduction of erosional processes. In the sequence studied, these maxima seem to be reached synchronously with the regional establishment of maquis, marked by the expansion of *Olea* and *Pistacia.* Evidence that Mediterranean vegetation with evergreen oaks, probably *Quercus coccifera* and *Q. ilex*, mixed with steppe and grassland plants was present already before the Holocene in southeastern Spain comes from the

sub-arid region of Almería [8]. This early reforestation dynamic suggests that mesophilous and thermophilous trees refugia were present in southeastern Spain. The absence of woodland formations in certain sectors of the Mediterranean lowlands in the Iberian Peninsula has often been interpreted as evidence for the existence of an open landscape basically due to human activity. The likelihood that maquis spread to constitute common natural formations in many places in Mediterranean Iberia during the first part of the Holocene is supported by the various pollen sequences studied in recent years. These suggested the non-existence of woodland formations beginning at the last interglacial period and continuing in that area to the present day owing to a constant water deficit.

Conclusions

Changes of vegetation structure are generally visible at a regional scale but often differ from region to region. For example, hydrological crises may alter the vegetation structure and biomass, followed by different recovery responses. Deforestation at many sites of the Iberian Peninsula probably occurred around 5000 BP.

In the Pyrenees [15], modern analogues of the pollen record indicate a higher continentality in the first part of the Holocene than in the second. They point to warmer summers associated with continentality, whereas winter temperatures may have been either warmer or colder than in the late Holocene. Furthermore, low winter temperatures were particularly probable before 7000 BP. This conclusion is not based on the evolution of biomass but can be deduced from the maintenance of the forest cover during the Holocene [9].

In the Balearic Islands, between 6000 and 4000 years BP, transformations of great magnitude in the flora and vegetation were registered. These conditioned the evolution of both the biomass and the landscape. Common vegetation patterns were distinguished in pollen diagrams from the same region, despite local floristic differences. Plant formations from the first part of the Holocene initiated a progressive environmental "Mediterranization", with an increment in seasonality [12, 13].

In the Amposta sequence, there was a general and progressive trend towards a decrease of biomass; at the same time, temporary variations were recorded. A change in the rainfall seasonality could be inferred from variations in the physiognomy of the dominant vegetation, from deciduous to evergreen (or vice versa). Romanization effects were clearly visible in the biomass curve. Appreciable changes in land management occurred only during the last few centuries [6], when the natural landscape and the biomass radically changed.

The available data suggest that the southern sector of the Mediterranean side of the Iberian Peninsula is characterized by shrub communities, with paleoenvironmental events deduced from the palynological study. It is evident that, during the coldest periods, some areas acted as refuges for thermophilous arboreal taxa and thus constituted foci for their expansion following the arrival of more favorable climatic conditions. In this context, new evidence indicates that littoral and sublittoral glacial refuges were present in the studied area. This same phenomenon could have occurred in other parts of the Mediterranean fringe, such as north of Palestine, where, at around 18000 years BP, very high values of *Olea* were recorded within a phase described as warm and humid [7]. Furthermore, the data also provide evidence for two phases, dominated by xerophilous taxa at the beginning and at the end of the Holocene. Thus, the beginning of the Holocene was most likely marked by xeric conditions, in which water availability was the key factor. The same phenomenon was inferred from the sequences of Navarrés [4, 5], where *Pinus* dominated the landscape until its replacement by *Quercus*, at ca. 6000 years BP, and from the Salines and Elx sequences, in which maxima of xerophilous arboreal taxa were present during the first half of the Holocene [3]. Pollen sequences from the southern Iberian Peninsula do not show clearly the development of human activities in the area, fundamentally because these would only constitute a single, low-intensity variable in the transformation of a vegetational landscape that principally responds to processes of aridification determined by global climatic change. The most characteristic feature of the evolution of the landscape on the coast of Almería during the Holocene consisted of two main phases, an earlier one characterized by a high degree of vegetational cover with the widespread presence of shrub communities, and a later one, from 5000 to 4500 years BP and onwards, marked by dramatic deforestation of the area. Before 4000 years BP, the maquis was a formation in equilibrium with the climate.

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About the author

Ramon Pérez i Obiol has wide experience not only in Tertiary and Quaternary paleoecology and paleoclimatology, but also on phytogeography, bioclimatology, vegetation analysis, and biostratigraphy. The geographical area covered by his research ranges from the Mediterranean region to the Pyrenees from where more than 60 localities have been cored and analysed. He has more than 50 articles in journals such as Quaternary Research, The Holocene, Pollen and Spores, Vegetation History and archaebotany and others. He has been involved in international coordination tasks such as the European Pollen Database (EPD) and Past Global Changes (PAGES). In addition to many national projects, he has actively participated in international projects funded by the European Union. Among them: "Past climatic change in Europe and the paleoclimatology of last glacial-interglacial cycle" (EV 4C-OO11-E(T), "Global changes over the last 30000 years" (EPOCH 0004-EDB), "Palynological study on desertification in south-western Europe: Timing, Natural Trends and Human Impact" (EV5V-CT910027),"Characterization of the aridity processes on Mediterranean Europe. Protection and management guidelines". (Ariduseuromed ENV4-CT95-0062), "Dynamics and Biodiversity of forest tree populations; linking genetic, Paleogenetic and Plant Historical approaches" (FOSSILVA EVK2-1999-00244. Degree in Biological Sciences in 1982 and Doctor in Biology in 1987. He is working at the laboratory of botany in the Fac. de Biociències of the Autonomous University of Barcelona . At present, he is Professor of Vegetal Biology and his research, in the last 25 years has been focused in palaeopalynology.