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Dialectic with climatic interpretations of Late-Quaternary vegetation history in Mediterranean Spain

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Abstract

The preferred views of the vegetation history of Mediterranean Spain still rely upon the few pollen sequences that fit into the north-European climatic stratigraphy. However, these sequences represent only a small fraction of the variation observed in the pollen-stratigraphical patterns across the region for the period since the last glacial maximum. Here I contend that traditional deterministic views of vegetation-climate response are not satisfactory to explain the observed patterns. A particular state of the vegetation may appear determined by its biotic history rather than by the abiotic site properties. The role of fire disturbance in shaping Mediterranean vegetation has been also underestimated in palaeoecological research, and disregarded in floristic-phytosociological and other equilibrial models. In a contingent picture of vegetation dynamics, subtle differences in initial conditions during full glacial and lateglacial times, would have tended to cascade and affect the outcome of post-glacial events, so that it is statistically improbable to duplicate the exact sequence of vegetation types for a particular site. Phenomena such as fire disturbance, hervibory, catastrophic events, deforestation, and competitive interactions would be contingent while remaining compatible with the determinism of the climate system.

Introduction

Palaeoecologists have searched for general principles of vegetation responses to past climatic variation, but the challenge has not been easily met because there is no steadfast relation between vegetation and climate. Two major strands of research highlight that dynamic equilibrium may be a reasonable approximation for the responses of the broadest continental-scale vegetation patterns to orbitally-induced climatic changes (Prentice, 1986), and the difficulty to devise tests to distinguish between dispersal processes and climate as factors limiting range limits in the past (Bennett, 1992; Davis, 1994). The debate is not over whether climate change influences vegetation dynamics, but over contending models of vegetation change for its tempo and mode. Few will deny that climate is a major influence at the Milankovitch scale (Bennett, 1990, 1997), but no consensus exists on whether vegetation dynamics is determined primarily by climatic variation, biotic interactions, or by random, albeit fortuitous, historical accident.

The growing confidence that, on time scales of thousands of years, climate is the major determinant of plant distributions, has encouraged the application of isopoll mapping and transfer functions to pollen data sets to reveal regional variation in late Quaternary climates (Guiot *et al.*, 1993; Cheddadi *et al.*, 1998; Prentice & Webb, 1998). In principle, similar attempts for the Mediterranean region of Spain (Fig. 1) cannot be equally successful, because the geographic coverage of suitable sites for pollen analysis is sparse, most records are fragmentary, and chronological control is insufficient. However, the situation with this region is further problematical because while a basic outline of Late-Quaternary vegetation developments in the Eurosiberian region of Spain is becoming available (Allen *et al.*, 1996; Ramil-Rego *et al.*, 1998), the picture depicted by the network of pollen diagrams from the Mediterranean region of Spain is more and more puzzling as we gain information (Martínez-Atienza, 1999; Carrión *et al.*, 2000a). It is questionable whether the development of pollen data sets will be able to provide similar insights into environmental change across Mediterranean Iberia. Glacial and periglacial processes provoked particular situations with northern European vegetation (Birks, 1986), and concepts developed from research in these regions may not be directly applicable in southern latitudes,

Fig. 1. Location of the main pollen sequences referred in this paper, and geographic coverage of Mediterranean and Eurosiberian regions in the Iberian Peninsula. Shaded areas correspond to the main mountain systems.

where floras might have remained relatively stationary, and where biotic interactions among existing populations may be of exceptional importance (Bennett & Willis, 1995). Here, I will address this issue for the period since the last glacial maximum, 18,000 yr BP to present. Rather than giving an over-view of the available pollen sequences, my intention is to take a critical look at what generalizations are possible and why it is not feasible to make many.

Components of a climaticist paradigm

The interpretation of pollen-stratigraphical changes in the Spanish literature on Quaternary palaeoecology results from a peculiar conjunction of influences. First, the north European conceptual framework weights at the chronostratigraphical level of discussion. Palynological stages are usually scrutinized in search of correlation with northern-latitude chrono- and biozones (Ruiz-Zapata *et al.*, 1997; López-Sáez & López-García, 1999). Special emphasis has been placed on the Spanish counterparts of last-glacial interestadials (Dupré, 1988; Carrión, 1992; Burjachs & Julià, 1994). A second influence derives from scholastic tradition, which has remained strong in botany. In particular, studies based on the floristic-phytosociological approach have been a central feature of Spanish vegetation science for most of this century and a large body of information has accumulated (Peinado & Rivas-Martínez, 1987; Rivas-Martínez, 1990). Vegetation patterns are explained in terms of their relationships with site variables, in particular climate and soils. Accordingly, fluctuations of vegetation since the last glacial maximum are expected to owe to direct influence of climate, at least until the inception of cultural landscapes during the last millennia (Barbero *et al.*, 1990).

Under the scope of a climaticist paradigm, it is not surprising that our preferred views of the vegetation history of Mediterranean Spain rely upon the few pollen sequences that fit into the north-

European climatic stratigraphy, principally Padul (Pons & Reille, 1988), Banyoles (Pérez-Obiol & Julià, 1994), and, to a lesser extent, Quintanar de la Sierra (Peñalba, 1994; Peñalba *et al.*, 1997) (Fig. 1). These sequences set out the "coherent story of positive outcomes" (Fig. 2), that deserve being included in the databases for quantitative estimates of climatic variation (e.g. Peyron *et al.*, 1998).

It is generally accepted that, on a global scale, about 18,000 years ago, temperatures and precipitations reached their minimum values, and north European landscapes were dominated by treeless tundra and prairie-steppe (Kutzbach *et al.*, 1998). Forest vegetation refuged in southern Europe (Bennett *et al.*, 1991) and particular regions of central Europe (Willis *et al.*, 2000). The arrival of the Lateglacial period (c. 14,000-10,000 yr BP) involved spread of first *Pinus, Juniperus,* and *Betula*, and then *Quercus* from southern European localities. The Younger Dryas cold spell interrupted this trend for several centuries between 11,000 and 10,000 yr BP. The onset of the Holocene implied range expansions of mesothermophytes (*Corylus, Alnus, Fraxinus, Ulmus, Acer, Abies, Fagus, Quercus*). By about 6000 years ago the ice caps would have reached their present limits, and most European forests their maximum extension. According to this picture, pollen diagrams from Mediterranean Spain are expected to show most of the following characteristics: (i) presence of mesothermophilous taxa during full glacial stages, (ii) oak pollen increases since lateglacial period, with the earliest occurrences in southernmost regions, (ii) evidence for the Younger Dryas cold spell in the form of expansion of xerophytes, (iii) mesophyte maxima during the first Holocene millennia. Divergences from this basic pattern will tend to be considered as result of site constraints or regional climate heterogeneity (e.g. Ramil-Rego *et al.*, 1998).

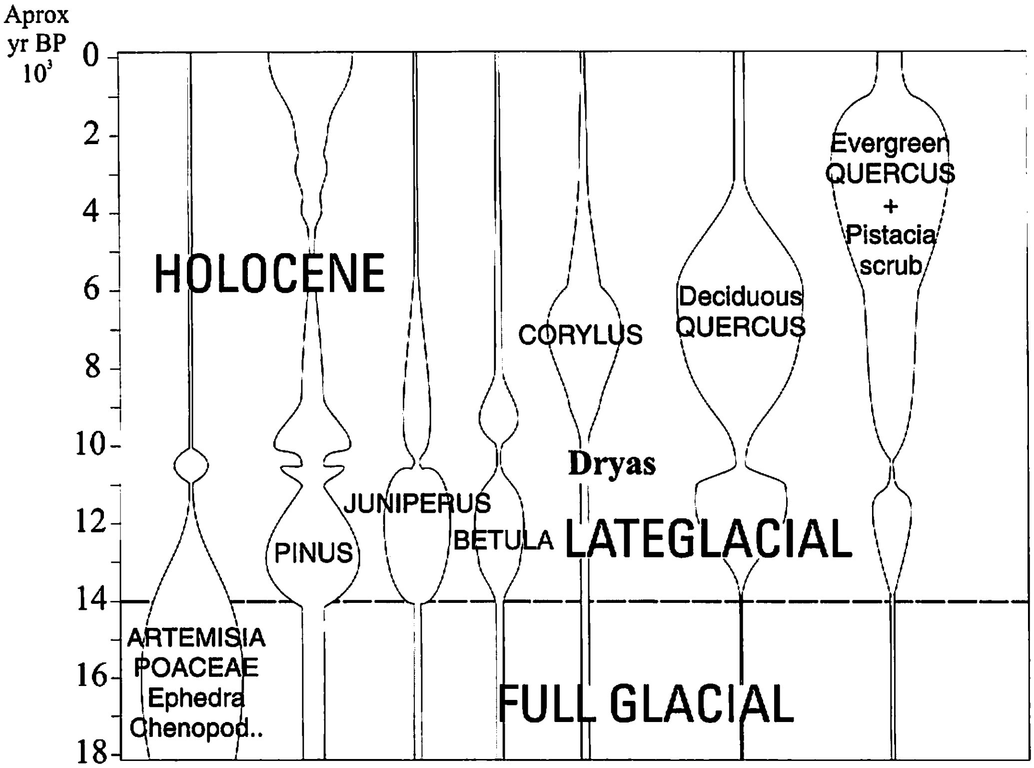

Fig. 2. The conventional wisdom envisages millennial-scale pollen-stratigraphical changes as determined by climatic changes, with temporal lags not spanning beyond the centurial scale and largely caused by differences in migrational rates. This prevailing view is principally supported by vegetational developments inferred from the pollen sequences of Padul (Pons & Reille, 1988), Banyoles (Pérez-Obiol & Julià, 1994), and Quintanar de la Sierra (Peñalba, 1994).

The importance of unexpected sequences

The sequences mentioned above provide insight into only a minute fraction of the huge variation observed in vegetation patterns of the Mediterranean region of Iberia (Dupré, 1988; Yll & Pérez-Obiol, 1992; Riera, 1993; Carrión *et al.*, 1995a; Franco *et al.*, 1997; van der Knaap & van Leeuwen, 1997; Yll *et al.*, 1997; Dupré *et al.*, 1998; Dorado *et al.*, 1999; Sánchez-Goñi & Hannon, 1999; Pantaleón-Cano *et al.*, 1999; Carrión *et al.*, 1999a, 2000a; Valero-Garcés *et al.*, 2000). By discussing three pollen sequences that show "unexpected trajectories", I will contend the viewpoint that climate is just a piece in the puzzling system of mechanisms exerting control on vegetation change in the region, even at the millennial scale.

The pollen record of Navarrés (39° 06`N, 0° 41`W, 225 m asl) shows vegetation developments in the southern valleys of the Iberian System from c. 30,900 to 3160 yr BP (Fig. 3) (Carrión & Dupré, 1997; Carrión & van Geel, 1999). Pine forests dominated the glacial landscape, and there is evidence for a full glacial expansion of *Pinus pinaster, Quercus faginea, Quercus rotundifolia*, and *Erica arborea* at about 30,210-27,890 yr BP. A slight decline in *Pinus* parallels the last expansion of *Artemisia* and *Ephedra nebrodensis* at about 10,340 yr BP. Pine forests resisted invasion until c. 5900 yr BP, even though oaks and other temperate trees occurred in the region from several thousands before (Badal *et al.*, 1994; González-Sampériz, 1998). At first, two major influences may have shaped these patterns: a prevailing dry climate during the first half of the Holocene, and the intervention of mechanisms of forest inertia. Both influences are not mutually exclusive, but they can be explanatory in their own right. The variation of macro- and microcharcoal throughout the core demonstrates that pine forests were only replaced by evergreen-oak scrub after local fire disturbance (Carrión *et al.*, 1999b; Carrión *et al.*, 2000b). The increases of anthropogenic indicators such as *Plantago* occur after a this major shift in the relative abundances of *Pinus* and *Quercus* (Fig. 3). In sum, the sequence is explicable by (i) millennial-scale inertia of the established full-glacial pine forests, (ii) threshold response of local forests to increased fire frequency and virulence, (iii) competitively-mediated invasion of pine forests by oak scrub after disturbance and establishment of a new ecological structure. Interestingly, slight climatic changes within the pleniglacial provoked a more sensitive vegetation response than major climate fluctuations inherent to the establishment of the present interglacial.

The pollen sequence of Villaverde (38° 48`N, 2° 22' W, 870 m asl) can be used to establish the vegetation history of the plains at the north of the Segura Mountains of south-central Spain from c. 8390 to 1230 yr BP (Fig. 4) (Carrión *et al.*, in press). The area represents boundary conditions for semi-arid, plateau and mountain vegetation. *Pinus* is dominant from c. 8400 to 5140 yr BP, although there is moderate invasion of the catchment area by deciduous *Quercus*, and other mesothermophilous taxa such as *Fraxinus, Betula*, and *Pistacia* ever since 6670 yr BP. This invasion could be in part shaped by competitive adjustments after arrival of these taxa to the study area, probably under increased moisture availability. The positive correlation between microcharcoal, *Pinus*, xerophytes (*Artemisia, Ephedra*, Chenopodiaceae, Lamiaceae), and *Juniperus* suggests a relationship between fire disturbance, vegetation and climate for the whole sequence (Carrión et al., *in press*). It is, however, noticeable that pines remained dominant for more than a millennium even though climate had become more humid, and there was a rich pool of available potential free colonists. The ulterior abrupt shift towards deciduous *Quercus* dominance, estimated to occur within c.10-33 years, could be a threshold response ultimately mediated by climate. Deciduous oaks, being shade tolerant species, might have invaded closed stands of pines quite rapidly.

A change towards dominance by evergreen *Quercus* communities is observed in Villaverde within the mid Holocene over a period of 300-400 years. This change can be viewed as the consequence of competitive interactions following a trend of increased aridity, which would have been critically manifested in the pollen record at c. 3240, 2650, 2260, and 1680 yr BP. This climatic trend can be inferred from declines of mesophilous vegetation and expansions of xerophytes, *Juniperus* and *Pinus*, as well as from forest depletions and/or expansions of *Artemisia* in other pollen sequences of Spain (Riera, 1993; Burjachs *et al.*, 1997; Yll *et al.*, 1997; Pantaleón-Cano, 1997). The arid tendency from mid to late Holocene is also supported by palaeoanthracological information relative to wood anatomy (Terral and Arnold-Simard, 1996), geomorphological evidence of badlands (Wise *et al.*,

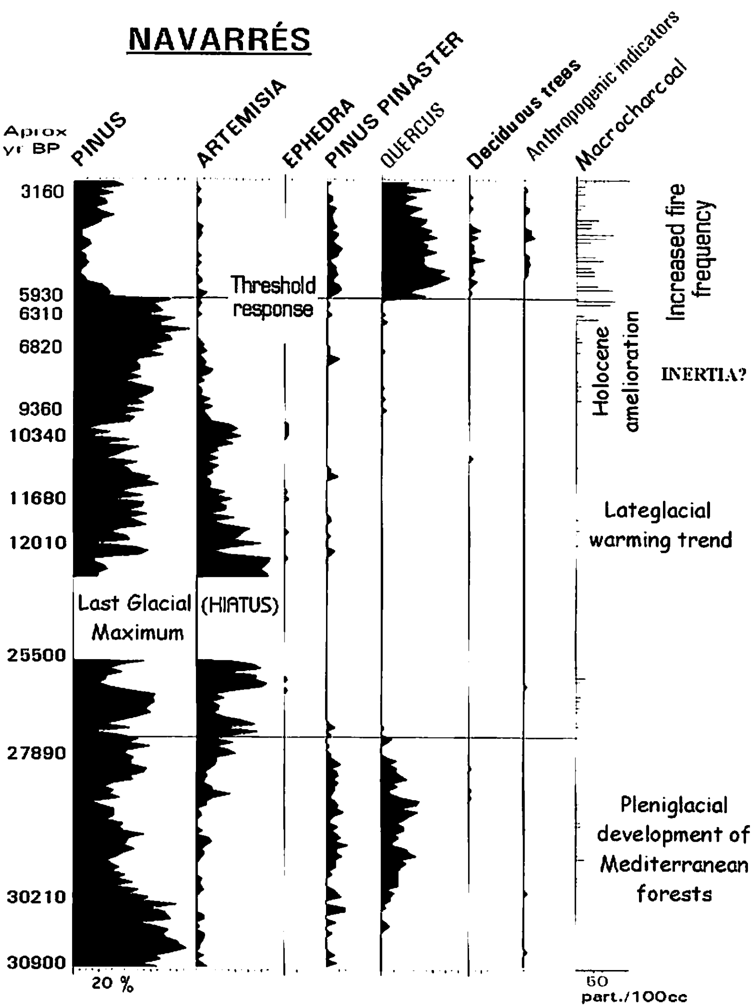

Fig. 3. Navarrés pollen sequence (redrawn from Carrión & van Geel, 1999). Established full-glacial pine forests resist competition by oaks despite the lateglacial and postglacial climate ameliorations. Mid-Holocene invasion by oaks is coherent with threshold response of local forests to increased fire virulence. Ages are quoted in uncalibrated radiocarbon years BP.

1982), and important changes in the hydrological regimes of north African lakes (Gasse, 2000). However, while independent evidence sets out the most pronounced aridity crises at around 4500 yr BP and 3500 yr BP, the last spread of *Pinus* which brought about a permanent modification of the ecosystem, does not occur until c. 1680 yr BP. The fact that pine peaks since c. 3240 yr BP to c. 1680 yr BP are preceded by charcoal increases, envisage a fire disturbance-mediated invasion of mixed and evergreen oaks forests by *Pinus*, which agrees with simulation experiments predicting changes in the relative abundance of *Q. rotundifolia and P. halepensis* with changes in the fire recurrence (Pausas, 1999).

Climate may have exerted long-term control of the species pool in Villaverde. However, initiating factors and the inertia of established tree populations, as well as migrational processes interconnected with competition adjustments, have been responsible for important time lags in the response of local vegetation to climate amelioration from early to mid Holocene (Fig. 4). Fire disturbance would have been a major factor shaping interspecific relationships and vegetation change from c. 4500 yr BP onwards. It has been demonstrated by numerical analyses that there are no two identical phases throughout the sequence (Carrión *et al.*, in press): the sequence begins with pollen spectra dominated by *Pinus*, then moves through a

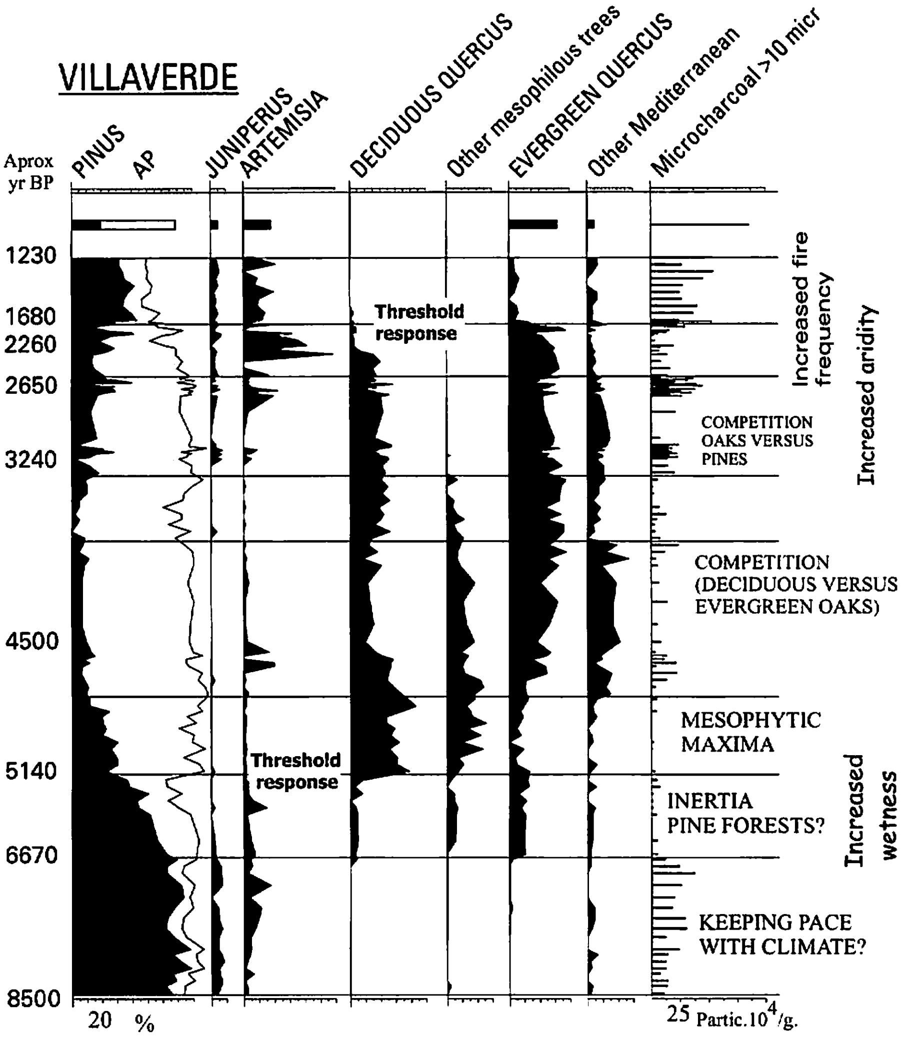

Fig. 4. Villaverde pollen sequence (redrawn from Carrión *et al.*, in press). Initiating factors and the inertia of established tree populations, as well as migrational processes interconnected with competition adjustments, have been responsible for important time lags in the response of local vegetation to climate changes from early to mid Holocene. Fire disturbance shapes interspecific relationships and vegetation change from c. 4500 yr BP onwards. Ages are quoted in uncalibrated radiocarbon years BP.

mesophilous/deciduous *Quercus* phase towards spectra dominated by evergreen *Quercus*, and finally to the modern xerophytic-dominated spectra. Vegetation has been changing continually, never returning back to any intermediate state, so that it appears that every stage is contingent.

Although the pollen sequence of San Rafael (36° 20'N, 2° 12'W, 10 m asl) has not been studied in such temporal resolution as those described above, it still shows important divergences in relation with the patterns observed in Padul (Pons & Reille, 1988) (Fig. 5). This sequence demonstrates that temperate trees and Mediterranean scrub persisted in the southeastern littoral during full glacial times, without any palynological evidence of the Younger Dryas xerophytization of vegetation (Pantaleón-Cano, 1997). In contrast, *Artemisia* increases from lateglacial to early Holocene. The optima of deciduous trees and Mediterranean scrub (c. 7500-4500 yr BP) occur later than mesocratic early-Holocene phase of forest development in north-west Europe (Birks, 1986), and there is no record of any lateglacial expansion of *Quercus*.

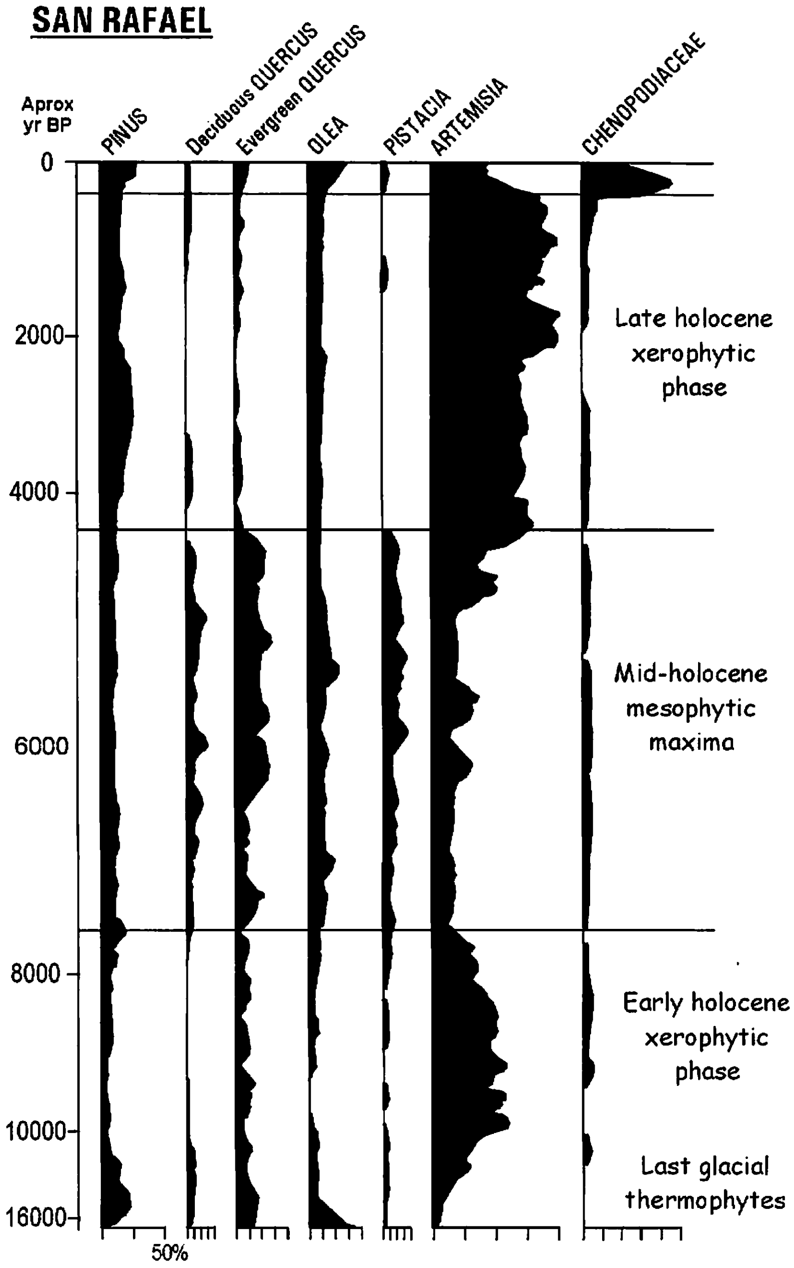

Fig. 5. San Rafael pollen sequence (redrawn from Pantaleón-Cano, 1997). Temperate trees and Mediterranean scrub persisted in the southeastern littoral during full glacial times. There is no evidence of Younger Dryas xerophytization. This sequence shows out-of-phase relationships in trends of mesophytic and xerophytic developments with respect to other European, Mediterranean, and southeastern Spanish pollen records. Ages are quoted in uncalibrated radiocarbon years BP.

San Rafael is just one of the many pollen records of Mediterranean Iberia that show out-of-phase relationships in trends of mesophytic and xerophytic developments. In fact, within the semi-arid southeastern province (Fig. 1), the patterns and timing of vegetation stages differ notably in San Rafael, Antas, Roquetas de Mar (Pantaleón-Cano, 1997), Elx, Salines (Burjachs *et al.*, 1997), Algarrobo (Carrión *et al.*, 1995b), Villena (Yll *et al.*, unpublished), and the Alborán offshore pollen sequences (Targarona, 1997). Physiographic het erogeneity could explain the occurrence of different palaeo-vegetation types and moderate time lags, but provided a primary climatic control, there should be certain overlap in the timing as well as in the palaeoclimatic significance of major events. Plausibly, post-glacial developments of vegetation were influenced by the composition and structure of lateglacial plant communities. This hypothesis may explain the early-Holocene prevailence of pine forests in areas where pines featured lateglacial landscapes, which include not only high- and mid-altitude mountain zones (Andrade, 1994; Ruiz-Zapata *et al.*, 1997; García-Antón *et al.*, 1997; Franco *et al.*, 1998; Carrión & van Geel, 1999; Sánchez-Goñi & Hannon, 1999; Stevenson, 2000), but also coastal territories and interior platforms (Dupré, 1988; García-Antón *et al.*, 1995; Carrión *et al.*, 2000a). The influence of historical factors is also noticeable in the early-Holocene developments of oak forests in the southernmost Betics (Pons & Reille, 1988), southwestern lowlands and western peninsular mountains (Hooghiemstra *et al.*, 1992; Carrión *et al.*, 2000c; van der Knaap & van Leeuwen, 1997; Stevenson *et al.*, 1999), north-eastern coast and pre-Pyrenees region (Riera, 1993; Burjachs, 1994; Pérez-Obiol & Julià, 1994), and maritime Atlantic coasts of Spain and Portugal (Ramil-Rego *et al.*, 1998). Due to the complex distribution and composition of forests during the last glaciation (Bennett *et al.*, 1991; Peñalba, 1994), it cannot be expected a simple postglacial picture of vegetation developments. It is worth questioning whether problems with correlation of pollen records from southern and central Italy (see Magri & Sadori 1999, for discussion) are not at least in part the consequence of similar processes.

Implications for current vegetation models

Pre-settlement vegetation in the sequences of Navarrés (Fig. 3), Villaverde (Fig. 4), San Rafael (Fig. 5), and a number of other sites (García-Antón *et al.*, 1997; Franco *et al.*, 1998), differ from site-specific potential natural vegetation established by floristic-phytosociological models (Peinado & Rivas-Martínez, 1987; Peinado *et al.*, 1992). There has been a great deal of uncertainty caused by the circularity of environment-vegetation correlation inherent in this approach. Concepts such as the potential natural vegetation are little crucial in the light of palaeoecological information of Iberia because current vegetation cannot be conceived out of the reach of human interference. Yet, studies with pollen data sets verify that individual taxa often migrate and change in abundance independently of one another, so that vegetation assemblages appear and disappear (Davis, 1994; Webb, 1987). This lack of integrity of plant communities questions the paradigm that vegetation is in balance with prevailing climatic conditions at any point in time. An important consequence that emerges for plant ecologists is that there is little reason to believe that any kind of stability has been achieved with the present vegetation pattern. Equilibrial models have failed to take into account the role of fire, herbivory, and other disturbances in determining vegetation structure, composition and distribution.

Remarks about the anthropogenic argument

As opposed to climate, human disturbance has been suggested as a major control of vegetation change in Spain and other Mediterranean areas during the last 4500 years or more (Barbero *et al.*, 1990; Reille & Pons, 1992; Stevenson & Harrison, 1992), but pollen evidence for these activities, macrocharcoal and independent archaeological remains, is not uniform within the region. Anthropogenic pollen indicators in Navarrés occur since Neolithic installation at c. 5500 yr BP (Fig. 3), while they are absent from the pollen record of Villaverde prior to c. 2000 BP (Fig. 4). Pollen sequences in mountain regions of the interior such as Cañada de la Cruz fail to provide pollen evidence of human activities until the last centuries (Carrión, unpublished). Wildwood of Iberian interior areas would have retreated considerably later (Dorado *et al.*, 1999; Carrión *et al.*, in press) than in Levant and Andalusia (Dupré & Renault-Miskovsky, 1990; Badal *et al.*, 1994; Bernabeu *et al.*, 1993). This conforms with the view that settlement was uneven and still sparse in wide territories of central Spain during the Bronze Age, while prehistoric hunting communities of the Iberian periphery had adopted a more sedentary pattern of resource ever since the Neolithic (Butzer, 19898). It is clear that the intensity and timing of human impact on vegetation varied from one part of Mediterranean Spain to another. In consequence, the interpretation of pollen-stratigraphical changes as result of local human disturbance may be speculative if due account is not taken of the spatial scale of the impact.

Towards a contingent palaeoecology

It has been ruled among Quaternary palaeoecologists that we should first establish the facts of vegetation history by elaboration of a network of regional pollen diagrams, and then, at some future time when the bulk of accumulated information becomes sufficiently dense, move to theories and explanations. Too busy with the details of pollen stratigraphies, we have certainly had a peculiar interest in emphasizing facts over theories. Generally too, we have emphasized changes over states, and trends and correlations over peculiarities and out-of-phase relationships. Moreover, pollen-stratigraphical changes are principally viewed as intrinsic, gradual and determined by the physical properties of the system. It is nevertheless worth stressing that (i) the vast majority of pollen sequences in Mediterranean Spain appear not to show persistent trends through time or correlation with major events of global scale, (ii) pollen changes may be episodic and abrupt, that is to occur on the time scales of decades to centuries, (iii) pollen records may show millennial-scale complacency to continental-scale climate change, (iv) a particular state of the vegetation may appear determined by its biotic history rather than by the abiotic site properties, (v) the role of fire disturbance in shaping Mediterranean vegetation has been underestimated in palaeoecological research, and (vi) deterministic and statistical explanations are often not satisfactory to explain the patterns observed.

Ritchie (1986) anticipated that the subject of vegetation-climate responses in palaeoecology would not produce any unifying principles, because this subject is made up of multiple relationships controlled by multiple causes operating at varying scales of time and space. In the same line of reasoning, Bennett & Willis (1995) postulated that internal processes of forest dynamics, including competition among existing species, and interactions between existing species and potential invading species, have been the dominant influence on the pattern of change of forested systems during the Holocene. Even at the orbital frequencies of precession and obliquity, there has been recently demonstrated that internally driven nonlinear responses of the climate system may be at least as important as external forcing in driving terrestrial vegetation responses (Willis *et al.*, 1999). The topic appears more and more complicated over the last few years, perhaps because vegetation and climate are basically complex systems where contingency is an important feature, simply like at any level of the biological history.

It is thus worth questioning whether there are not different ways of explaining the patterns we observe in the pollen records. In particular, in addition to considering the deterministic features of the palaeo-ecosystem we might try to assess the unpredictable and possibly chaotic aspects of its behaviour. We can therefore consider full glacial and lateglacial as initial states from which vegetation developed into post-glacial types. Subtle differences in starting conditions would have tended to cascade and affect the outcome of post-glacial events, so that it is statistically improbable to duplicate the exact sequence of vegetation types.

In this context, the nature and frequency of vegetation change cannot be ruled. For change would occur every time that a particular stress impacted the vegetation beyond its capacity to absorb without substantial modification. Vegetation changes could be frequent and inherent to a particular system, as could they appear concentrated in rare events in other situations. This scenario is still not contradictory with the fact that vegetation stages may reiterate through time because, even considering future events to be contingent on past events, vegetation cannot avoid the consequences of physical processes and laws. Phenomena such as fire disturbance, herbivory, pathogens, catastrophic events, deforestation, arrival of new competitors, etc,... would be contingent while remaining compatible with the determinism of the climate system. The conclusion that emerges is that vegetation change involves dialectic, a tension between random and non-random forces.

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