*MANUSCRIT ACCEPTAT*

**Testing micro-regional variability in the Holocene shaping of high mountain cultural landscapes: a palaeoenvironmental case-study in the eastern Pyrenees**

Ana Ejarque ; Yannick Miras ; Santiago Riera ; Josep Maria Palet ; Hector A. Orengo

Per citar aquest document:

Aquest arxiu PDF conté el manuscrit acceptat per a la seva publicació.

## Abstract

Previous research acknowledges the ancient and complex land-use history of European mountainous areas, which are characterised by a remarkable regional variability in terms of human practices and patterns of occupation during the Holocene. However, the combined palaeoenvironmental and archaeological study of highland human management at a micro-regional scale remains a largely unexplored research field, especially in the Pyrenees. A combined pollen, stomata, non-pollen palynomorphs (NPPs) and macrocharcoal study was carried out at three nearby alpine and subalpine peat basins from a relatively small territory (ca.1700 ha) at the Madriu valley (Andorra, eastern Pyrenees), following a fine spatial-resolution strategy. The purpose was to test the suitability of high altitudinal palaeoecological sequences when reconstructing past small-scale land-use variability. The palaeoecological results of those peat records are compared and further integrated with archaeological local data, and together underline the marked complexity of high mountain land-use system over the Holocene period. Main phases of micro-regional land-use and landscape variability can be distinguished from the middle Neolithic to the early Bronze Age and from the Roman Period to the Modern Era. Conversely, several phases of homogeneous landscape management are distinguishable during the early Neolithic, and from the late Bronze to the late Iron Age. Results drawn from this study show that landscape variability is not necessarily connected to topographic or climatic parameters, and underline the role of social, economical and cultural parameters in the land-use organisation and the landscape shaping of high mountain spaces since Prehistory.

## Keywords

## 1. Introduction

High mountain European areas, for a long time considered marginal and risky spaces, constrained by severe climatic conditions and extreme topography, are acknowledged today as cultural landscapes. This new concept of European mountainous areas results from different archaeological and palaeoenvironmental studies which have revealed significant evidence of highland human occupation and landscape management that can be traced back to the Mesolithic period (Biagi and Nandris, 1994; Galop, 1998; Mazier et al., 2009; Moe and Hjelle, 1999; Oeggl and Wahlmüller, 1993; Palet et al., 2007; Rendu, 2003; Walsh, 2005).

These studies show that high mountain human occupation was an ancient and complex one. Besides, the comparison of different palaeoenvironmental and archaeological records has underlined that management of the Pyrenean ranges, rather than being homogeneous was characterised by regional variability in terms of human practices and patterns of occupation during the Holocene (Galop, 2005; Galop and Jalut, 1994; Miras et al., 2007; Palet et al., in press; Ejarque et al., 2009; Riera et al., 2009). Former multi-profile and high spatial-resolution palaeoenvironmental studies have indeed proved to be useful when it comes to characterising land-use variability in upland environments at a regional scale (Davies and Tipping, 2004; Davies, 2007). The combined palaeoenvironmental and archaeological study of Pyrenean highland management at a high spatial resolution has also been attempted (Galop, 1998; Rendu, 2003). Nevertheless, the micro-regional study combining multiple cores and archaeological records within a single valley remains a largely unexplored research field. This is especially remarkable in the Spanish central and eastern Pyrenees, where palynological research (Catalan et al., 2001; Gómez and Esteban, 1993; Montserrat, 1992; Pla and Catalan, 2005; Pèlachs, 2004; Pèlachs et al., 2009) has been mainly conducted towards the reconstruction of changes in regional vegetation from the analysis of a single pollen record.

Based on the premise that local scale case studies are the most suitable approach to analysing human–environment interactions (Dearing et al., 2006), particularly in upland environments (Davies, 2007), this paper aims to explore the existence of micro-regional, i.e. small-scale, variability in human management of high mountain spaces by following a high spatial-resolution and multi-proxy research strategy.

When attempting to study small-scale variability using pollen analyses from high altitudinal sites, the over-representation of extra-local and regional taxa in pollen assemblages becomes a remarkable shortcoming in the reconstruction of local alpine vegetation. This is mainly due to the predominance of low pollen producers within alpine grasslands and the uphill transport of regional pollen by wind currents (Cañellas-Boltà et al., 2009; Court-Picon et al., 2005; Oeggl, 1994; Ortu et al., 2006; Pardoe, 2001). Nonetheless, former studies have shown that local pollen production remains an important component of the pollen rain in small-sized upland basins, which are prone to display patchiness of local landscape throughout time (Davies and Tipping, 2004; Mazier et al., 2009). In this respect, small peat basins ≤ 1 ha (ca. 50–60 m diameter) have been selected in this study in order to emphasize the local pollen signal and detect site-to-site landscape

variation (Sugita, 1994). Moreover, this study combines high resolution pollen analyses with other biological proxies providing more local information such as stomata, non-pollen palynomorphs (NPPs), and macrocharcoal charred particles (Carcaillet et al., 2001; MacDonald, 2001; van Geel and Aptroot, 2006; Whitlock and Larsen, 2001). Archaeological data from the Madriu valley (Palet et al., 2007; Orengo, 2007) will also be used to assess palaeoenvironmental results at a local scale.

This study was performed as a part of an integrated palaeoenvironmental and archaeological research program which aims to understand the long-term shaping of the Madriu–Perafita–Claror valley, a high mountain cultural landscape included in the UNESCO World Heritage List. Extensive surveying, excavation and radiocarbon dating have revealed the existence of 400 archaeological structures which range from the early Neolithic to the modern era and include pastoral huts, livestock enclosures, milking structures, charcoal mounds and kilns (Palet et al., 2007; Orengo, 2007). The distribution of these archaeological structures suggests a complex spatial organisation of the valley's land-use during the past (Palet et al., in press; Riera et al., 2009). This palaeoecological study was carried out following a micro-regional strategy. Three nearby and small size peat basins were selected at different altitudes and landscape settings of the main Madriu valley. In doing so, this paper aims to test the suitability of high altitudinal pollen sequences to reconstruct past micro-regional land-use variability.

## 2. Study area and sites description

The Madriu–Perafita–Claror valley is located in southeast Andorra (eastern Pyrenees) and it is formed by the main Madriu valley and the Perafita–Claror valley (Fig. 1). The Madriu valley follows an NW–SE orientation and is characterised by a rough relief and a pronounced altitudinal range from 1050 to 2905 m a.s.l. Given its location in the southern basin of the eastern Pyrenees, the climate of this region is largely influenced by both Mediterranean and oceanic climatic conditions (Esteban et al., 2009). A mean annual rainfall of 1003.6 mm per year and a mean annual temperature of 7.7 °C have been recorded at 1600 m a.s.l. (Folch, 1984). The area sits on a siliceous bedrock mainly shaped by glacial and periglacial activity (Mases et al., 2005). This micro-regional study will focus on the high altitudinal spaces of the Madriu valley, from 2100 to 2700 m a.s.l., covering a reduced area of ca. 1700 ha. Alpine grasslands from the *Caricetalia curvulae* plant community expand throughout the southern slope from 2400 m a.s.l. Timberline oscillates between 2300 and 2400 m a.s.l. and below this level, *Pinus uncinata* woodland dominates. Subalpine forest varies from xerophilous pine woodland with *Juniperus communis ssp nana* in the southern slope to dense mesophilous pine woodland with *Rhododendron ferrugineum* in the northern slope (Carreras et al., 2003).
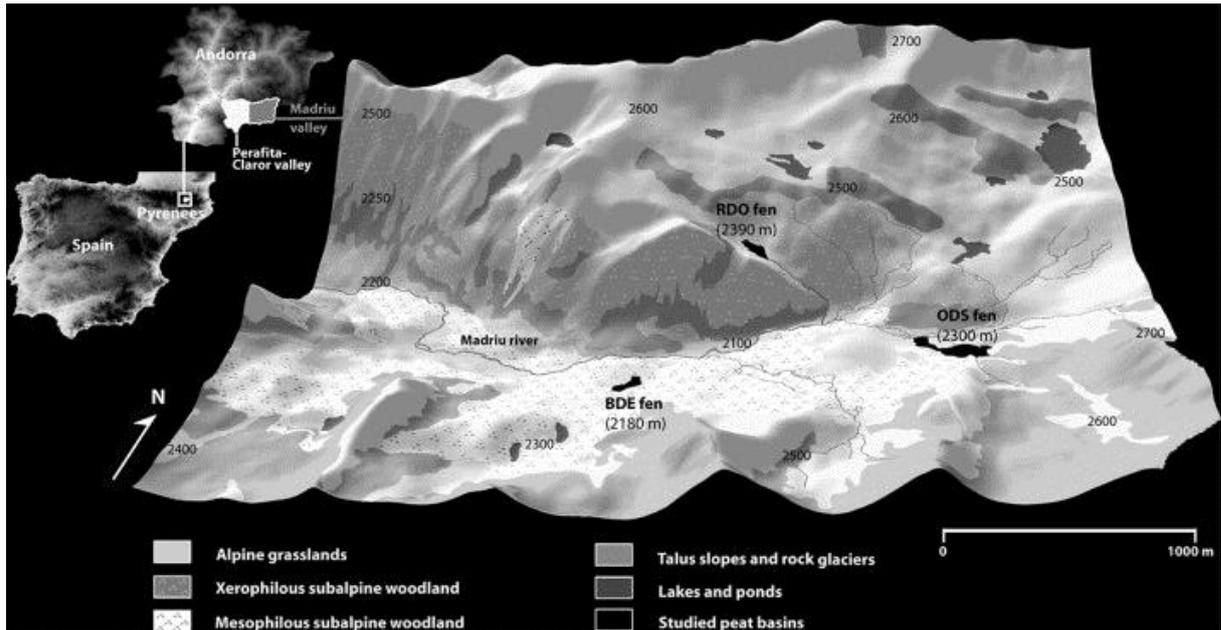
1. Download high-res image (283KB)
2. Download full-size image

Fig. 1. Vegetation map of the Madriu valley's study area showing the location of the three studied peat sequences.

Two new peat sequences, located in distinctive vegetation settings within this mosaic landscape, are presented and compared to the previously published Bosc dels Estanyons fen (Miras et al., 2007).

The Riu dels Orris fen (42° 29′ 20″ N; 1° 38′ 14″ E), hereinafter RDO, is located at 2390 m a.s.l. in the alpine belt of the southern slope of the Madriu valley. The fen occupies a small elongated glacial rock-basin of ca. 0.8 ha. Surrounded by alpine grasslands, RDO is a black sedge acidic fen set on the tree limit of the subalpine pine woodland.

The Orris de Setut fen (42° 28′ 57″ N; 1° 39′ 1″ E), hereinafter ODS, is located at 2300 m a.s.l. on the easternmost part of the main basin formed by the Madriu river. Delimited by two glacial moraines, this black sedge acidic fen of ca. 1.2 ha is set within the alpine grasslands on the timberline. Whilst previous pollen analyses were performed at ODS (Esteban, 1994), they were not radiocarbon dated. New coring of the fen was carried out in order to perform an accurately – dated multi-proxy palaeoenvironmental study.

The Bosc dels Estanyons fen (42° 28′ 49″ N; 1° 37′ 45″), hereinafter BDE, is located at 2180 m a.s.l. in the subalpine belt of the northern slope of the Madriu valley. Delimited by a glacial moraine, this small fen of ca. 0.7 ha is surrounded by subalpine pine woodland and it is set below the timberline.

## 3. Material and methods

In September 2005, coring was carried out in the RDO and ODS fens using a 50 cm × 5 cm "Russian" corer. A 200 cm-long core was extracted from the southernmost edge of the RDO fen and a 67 cm-long core was obtained from the centre of the ODS fen. Samples were taken at intervals of 4 cm at RDO and of 2 cm at ODS for pollen, stomata, NPP and macrocharcoal particles analysis. Besides, sampling at 1 cm intervals was undertaken between 18 and 36 cm at RDO in order to more precisely define human activity from the Iron Age to the late Antiquity.

Samples were prepared using standard procedures for pollen analysis (Faegri and Iversen, 1989). The samples were soaked in 10% KOH and then sieved through a 200 μm mesh sieve to retrieve macrocharcoal particles (Whitlock and Larsen, 2001).

*Lycopodium clavatum* spore tablets were added in order to calculate particle accumulation rates (Stockmarr, 1971). Pollen, NPP and conifer stomata counting was performed using a Zeiss Axioscop microscope at 500× magnification and macrocharcoal particles >200 μm were counted using a Zeiss Stemi microscope at 80× magnification. Pollen, NPP and stomata identification followed published illustrations and keys (Faegri and Iversen, 1989; Hansen, 1995; Moore et al., 1991; Punt et al., 1976–2009; Reille, 1992; van Geel, 2001; van Geel and Aptroot, 2006), and the pollen reference collection at the Catalan Institute of Classical Archaeology. Minimum pollen counts of 700 dry land pollen grains per sample were made. Pollen and NPP relative values were calculated as a percentage of total land pollen (TLP) excluding Cyperaceae, fern spores and aquatic plants. The apophytes summary curve displays pollen taxa indicative of anthropogenic impact (Behre, 1981), including those underlined by studies on modern pollen assemblages performed in mountainous environments (Court-Picon et al., 2005; Mazier et al., 2009). Diagrams were plotted using the C2 program (Juggins, 1991) and Pollen Assemblage Zones (PAZ) were established using CONISS with minor modifications (Grimm, 1987).

A total of 9 $^{14}$C AMS dating measurements on 1 cm-thick peat samples (5 from the RDO profile and 4 from the ODS profile) were performed by Beta Analytic Inc (Miami, USA) and the Poznań Radiocarbon Laboratory. Dates were calibrated using CALIB 5.0.2 (Reimer et al., 2004).

Similar sampling and analytical methods have been performed in the BDE fen and they are presented in Miras et al. (2007).

## 4. Results

### 4.1. Dating

Radiocarbon dates for the RDO and ODS fens are shown in Table 1. Age–depth models for both sequences were obtained by plotting calibrated radiocarbon dates against depth using linear interpolation between adjacent pairs of dates (Fig. 2). Radiocarbon results at RDO and ODS support continuous sedimentation that

covers the last 8000 and 3700 years respectively. This allows for a proper comparison with the BDE fen from the early Neolithic onwards (Miras et al., 2007). On the other hand, the low sedimentation rates for the last 1000 years in all the sequences only allow for a general discussion on the Medieval and Modern periods.

Table 1. AMS radiocarbon results from the RDO and ODS fens. Dates have been calibrated using CALIB 5.0 (Reimer et al., 2004).

| Core | Laboratory reference | Depth (cm) | Conventional ag ($^{14}$C yr BP) | Calibrated age (2 σ) (cal. yr BC/AD) | Mean age values (2 σ) used in the chronological model |
|---|---|---|---|---|---|
| RDO | Beta-246717 | 14 | 1230 ± 40 | 684–887 AD | 785 ± 101 AD |
| RDO | Beta-250084 | 26 | 1730 ± 40 | 224–412 AD | 318 ± 94 AD |
| RDO | Poz-25566 | 41 | 2650 ± 40 | 898–783 BC | 840 ± 57 BC |
| RDO | Poz-24486 | 81 | 4850 ± 40 | 3708–3527 BC | 3617 ± 90 BC |
| RDO | Poz-24523 | 171 | 6565 ± 35 | 5611–5476 BC | 5543 ± 67 BC |
| ODS | Beta-256861 | 25 | 890 ± 40 | 1035–1219 AD | 1127 ± 92 AD |
| ODS | Poz-28988 | 38 | 1875 ± 30 | 70–224 AD | 147 ± 77 AD |
| ODS | Beta-247793 | 49 | 2320 ± 40 | 511–213 BC | 362 ± 149 BC |
| ODS | Poz-13712 | 66 | 3330 ± 35 | 1728–1520 AD | 1624 ± 104 BC |
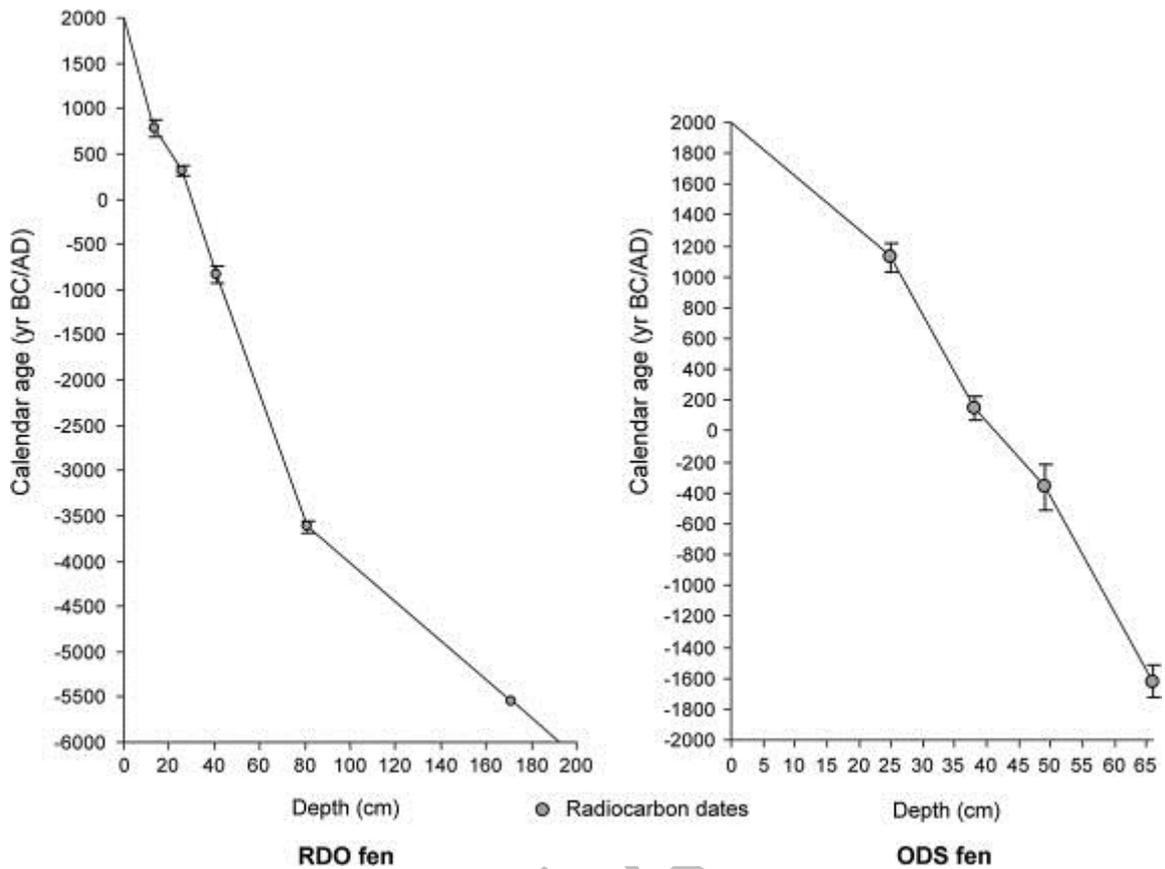
Fig. 2. Age–depth models of the RDO and ODS fens constructed with calibrated radiocarbon dates.

## 4.2. RDO pollen, NPP and macrocharcoal results

Two PAZs and six subzones have been distinguished at the RDO sequence (Figs. 3 and 4) and are described as follows.
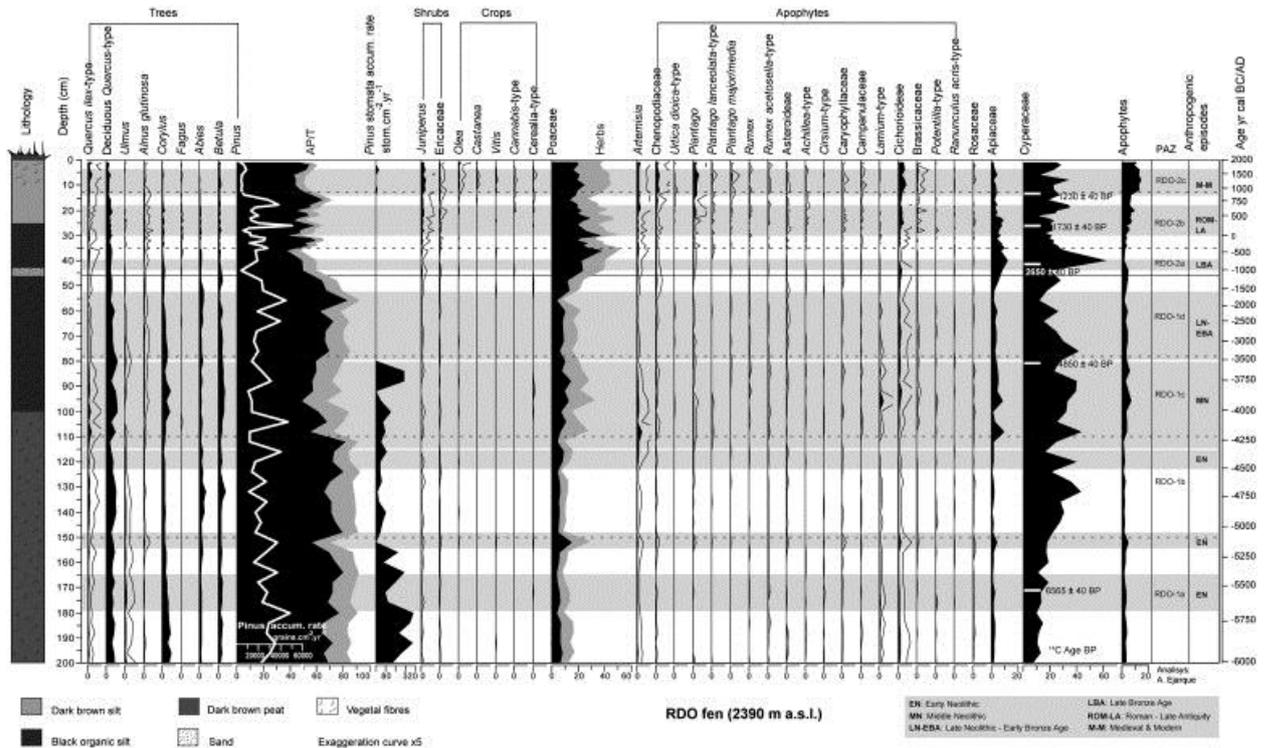
1. Download high-res image (910KB)
2. Download full-size image

Fig. 3. Main pollen percentages and *Pinus* stomata accumulation rates diagram of the RDO fen. The white line within the *Pinus* percentage curve represents *Pinus* accumulation rates. Grey-shaded areas stress those anthropogenic episodes mentioned in the discussion.
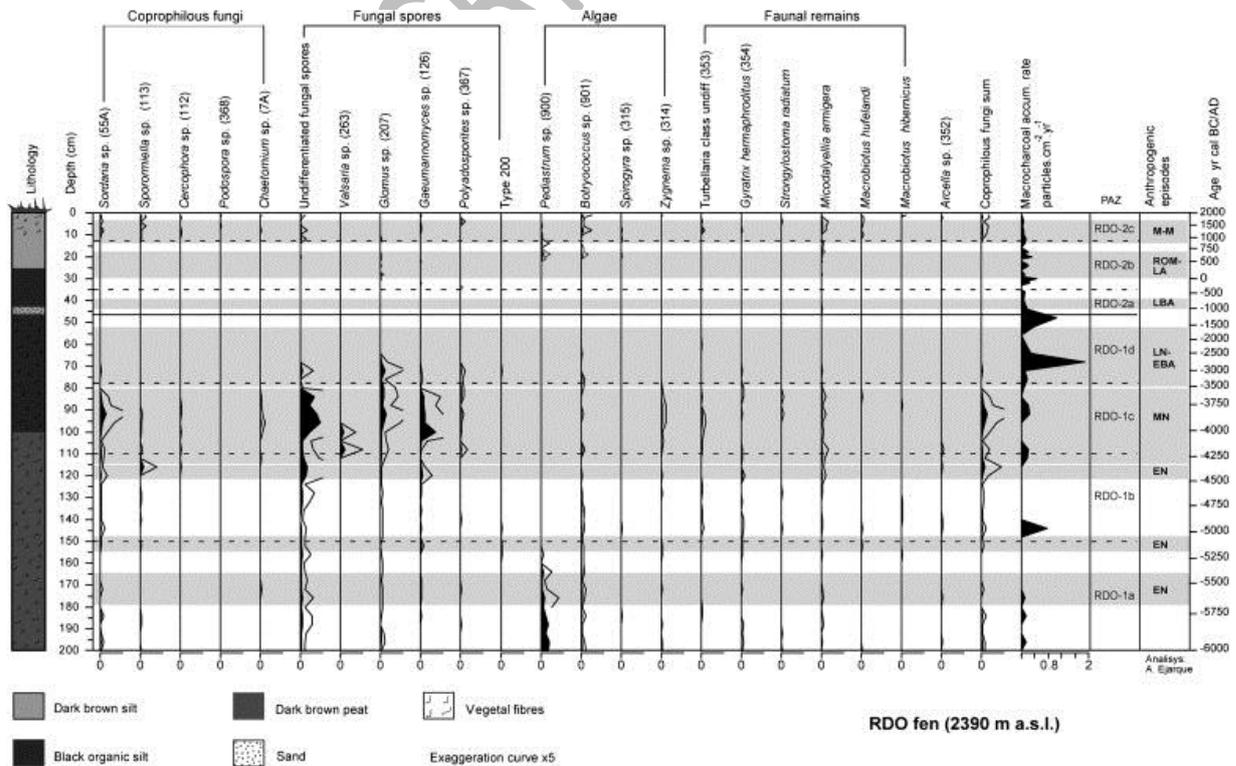


1. Download high-res image (690KB)

2. Download full-size image

Fig. 4. Main NPP taxa and macrocharcoal diagram of the RDO fen. NPP values are expressed in percentages, while macrocharcoal are shown in accumulation rates.

*RDO-1a (200–150 cm)*. High percentages of AP are recorded in this zone. *Pinus* pollen values show an oscillating pattern, while *Pinus* stomata show high accumulation rates with significant retreats at the middle and the upper part of the zone. A peak of herbs appears at the end of the zone, partly reflecting an increase in Poaceae within an episode of AP reduction. A moderate increase in apophytes is recorded at the middle and upper part of the zone, together with the first notations of Cerealia-type. Most NPP values are low, with the occasional recording of coprophilous fungi and the continuous presence of *Pediastrum* sp. and *Botryococcus* sp. Macrocharcoal particles are occasionally registered.

*RDO-1b (150–110 cm)*. Most arboreal pollen expands, mainly *Pinus*. Whilst herb pollen falls, a slight recovery is witnessed at the upper part of the zone. Some apophytes i.e. *Plantago major/media*, *Rumex acetosella*-type, Asteroideae, *Achillea*-type or *Potentilla*-type, are recorded at the upper part of the zone while Cyperaceae values increase. Among NPP, *Pediastrum* sp. disappears while peaks of *Sordaria* sp. and *Sporormiella* sp. and the first notations of *Cercophora* sp. are evidenced at the upper part of the zone.

*RDO-1c (110–78 cm)*. A significant decline of *Pinus* percentages and the recording of low accumulation rates are noticeable, while *Pinus* stomata disappear at the upper part. *Quercus ilex*-type, deciduous *Quercus*-type, *Alnus*, *Corylus*, and *Betula* increase while *Fagus* first appears. Herbs expand, especially Poaceae, *Artemisia* and Apiaceae,.A general increase in apophytes is recorded, with a higher representation of *Plantago*, *Plantago lanceolata*-type, *R. acetosella*-type, *Lamium*-type, Brassicaceae and Cichoroideae. Cerealia-type is occasionally present in the middle of the zone. *Sordaria* sp. rises, *Sporormiella* sp. and *Cercophora* sp. are recorded, and a peak of *Chaetomium* sp. and the increase in other fungal spores- i.e. *Glomus* sp., *Gaeumannomyces* sp., and *Polyadosporites* sp., as well as *Zygnema* sp. and oocytes of the Turbellaria flatworm is evidenced. The sporadic occurrence of macrocharcoal particles is present.

*RDO-1d (78–46 cm)*. While the presence of deciduous *Quercus*-type, *Corylus*, *Ulmus* and *Betula* declines, *Abies* and *Pinus* show an increasing trend, which is further demonstrated in the *Pinus* accumulation rates. Herbs, most apophytes and Cyperaceae recede. There is a general retreat of most fungal spores and coprophilous fungi disappear. Peaks of macrocharcoal can be found at the middle and the upper part of the zone.

*RDO-2a (46–35 cm)*. *Pinus* percentages and accumulation rates fall, while *Abies* recedes and a continuous curve of *Fagus* and *Juniperus* begins. Herbs increase with the significant rise of Poaceae and Cyperaceae.

*RDO-2b (35–13 cm)*. *Pinus* shows an oscillating pattern along the zone, with three recovery phases followed by three retreats. This trend is also evidenced in the *Pinus* accumulation rate curve. Increase in herbs occurs within the recessive

episodes of *Pinus*, while *Juniperus* and Ericaceae rise along the zone. Apophytes expand and some crops such as *Olea*, Cerealia-type, and *Cannabis*-type show a higher representation. Cyperaceae retreat while the renewal of the algae *Pediastrum* sp., *Botryococcus* sp. and *Spyrogyra* sp., and of oocytes of the Turbellaria class is found.

*RDO-2c (13–0 cm)*. This zone records the retreat of AP, with the exception of *Q. ilex*-type. *Pinus* recede while *Pinus* stomata are eventually registered along the zone. Shrubs, especially *Juniperus*, and herbs expand, together with most apophytes and all crops. Dung fungal spores reappear while *Macrobiotus* oocytes are recorded. Macrocharcoal values disappear at the uppermost part of the zone.

## 4.3. ODS pollen, NPP and macrocharcoal results

Two PAZs and four subzones have been distinguished at the ODS sequence (Fig. 5).
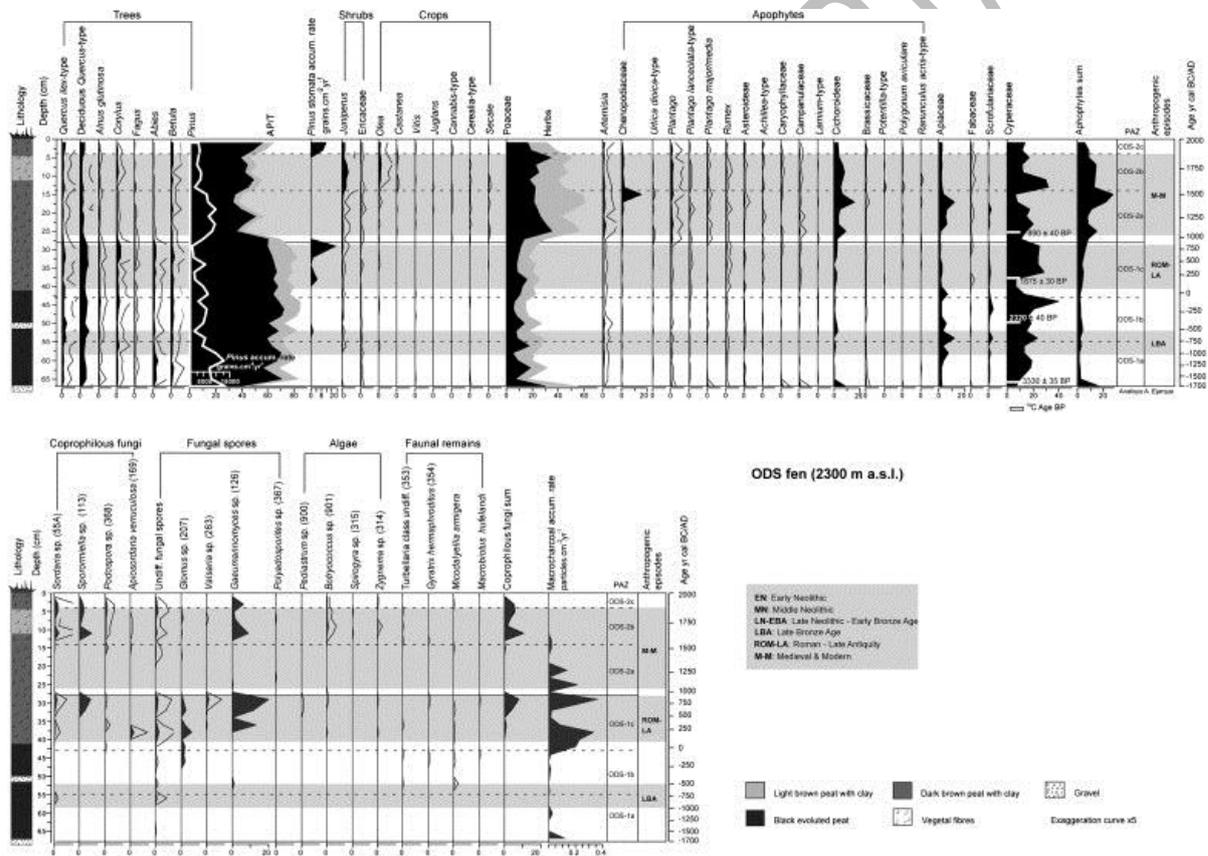


1. Download high-res image (912KB)
2. Download full-size image

Fig. 5. Selected pollen taxa and *Pinus* stomata and NPP and macrocharcoal diagrams of the ODS fen, Pollen and NPP values are expressed in percentages, while stomata and macrocharcoal are shown in accumulation rates.

*ODS-1a (67–55 cm)*. *Pinus*, *Fagus*, *Abies* and *Betula* recede at the uppermost part of the zone. Herbs show an increase at the middle and upper part of the zone, coinciding with a higher representation of *Juniperus*. Apophytes are occasionally

recorded while NPP values remain low, with the sporadic occurrence of *Sordaria* sp. and undifferentiated fungal spores at the uppermost part of the zone.

*ODS-1b (55–43 cm)*. AP and *Pinus* percentages show maximum values, while *Corylus* and *Q. ilex*-type retreat. Minimum values of herbs at the upper part of the zone are mainly due to the decreasing presence of Poaceae, *Artemisia*, Apiaceae and Cichoroideae, while Cyperaceae reaches its maximum values. *Glomus* sp. rises at the upper part of the zone and oocytes of the Turbellaria class are recorded.

*ODS-1c (43–28 cm)*. *Pinus* values remain stable while *Pinus* stomata occur along the zone and *Corylus* and *Alnus* slightly expand. Herbs increase, especially Poaceae, while some ruderal taxa such a *Plantago*, *P. lanceolata*-type, *Rumex* and Campanulaceae rise. Cyperaceae fell in the lower part of the zone to ultimately recover. Coprophilous fungi extend, with the increase of *Sordaria* sp. and the first recording of *Podospora* sp., *Apiosordaria verruculosa* and *Sporormiella* sp. Among other fungal spores, *Gaeumannomyces* sp. rise and some algae such as *Pediastrum* sp., *Botryococcus* sp. and *Zygnema* sp. are first documented. Finally, macrocharcoal particles reach their highest values.

*ODS-2a (28–14 cm)*. A significant drop of AP and the increase in herbs constitute the main features. *Pinus* percentages fall and *Pinus* stomata disappear. Poaceae reaches its highest values and Cichoroideae and Apiaceae rise. Most apophytes increase and *Olea*, *Vitis* and *Secale* crops are more continuously reported. Coprophilous fungi disappear and macrocharcoal is more scarcely recorded.

*ODS-2b (14–4 cm)*. AP and *Pinus* percentage values recover whereas Poaceae show a moderate retreat and *Juniperus* rises. Among crops, *Olea* values rise and *Castanea* is better represented. A renewal of coprophilous fungi is evidenced, together with the rise of *Gaeumannomyces* sp., *Glomus* sp. and some algae, i.e. *Botryococcus* sp. and *Zygnema* sp.

*ODS-2c (4–0 cm)*. This zone shows the recovery of AP and the reappearance of *Pinus* stomata. The retreat of most herbs, apophytes and most crops is otherwise evidenced.

## 5. Discussion

Following, RDO and ODS results will be compared with those of the BDE fen (Miras et al., 2007). A simplified diagram of the BDE fen has been included (Fig. 6) and Fig. 7 shows simplified diagrams of the studied sites. In order to detect small-scale landscape variability, discussion will mainly focus in the changes of the taxa located at high altitudinal spaces of the valley where fens are.
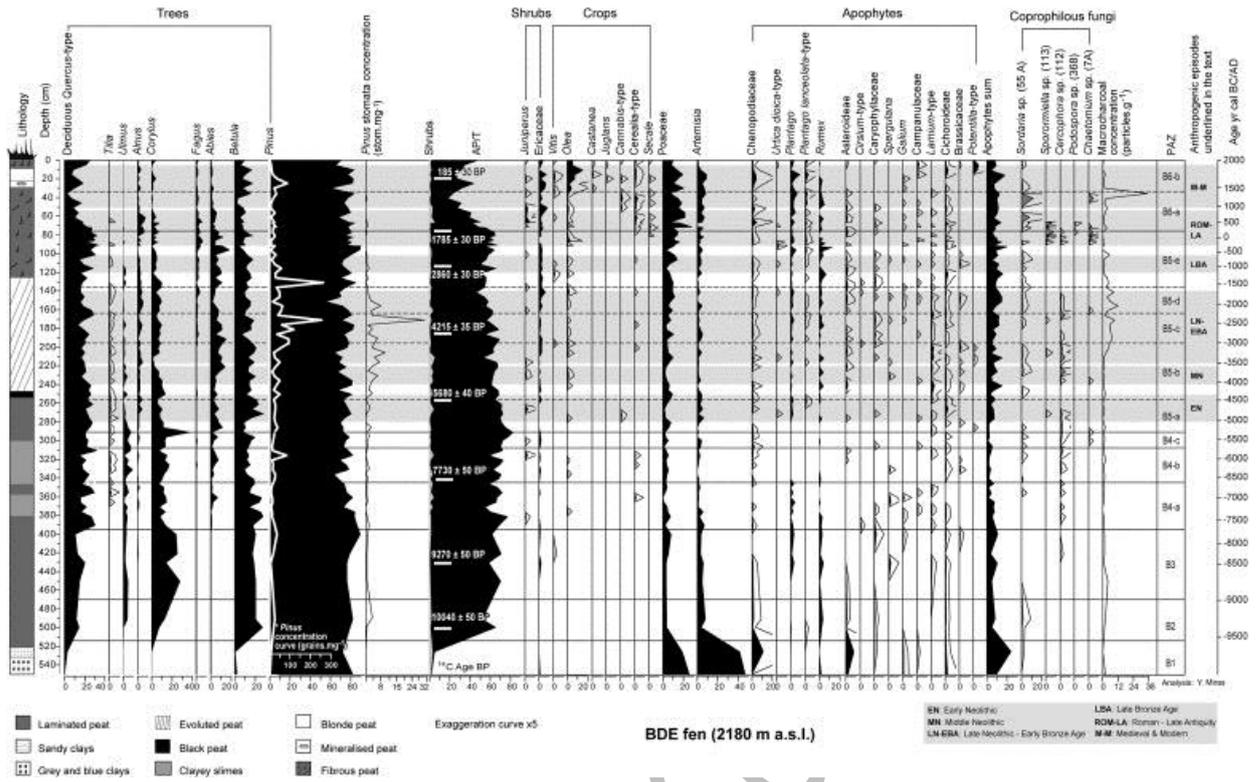
1. Download high-res image (1MB)
2. Download full-size image

Fig. 6. Simplified diagram of the BDE fen with main pollen and coprophilous fungi percentages and stomata and macrocharcoal concentration values (modified from Miras et al. (2007, in press)). The white line within the *Pinus* percentage curve represents *Pinus* concentration values per milligram of dry sediment.
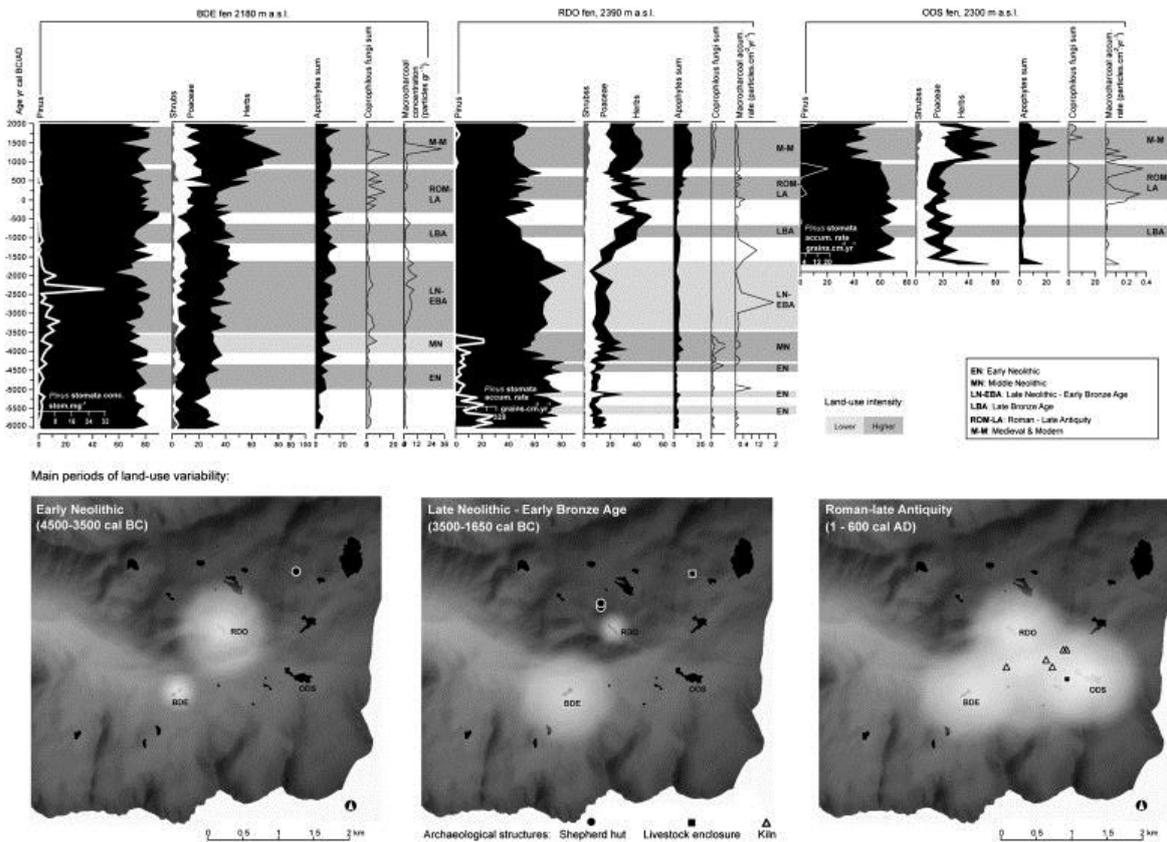
Fig. 7. Simplified diagrams of the BDE, RDO and ODS fens plotted against mean calibrated ages. Grey-shaded areas show the main land-use phases mentioned in the text. Maps display the three periods of main land-use variability and the location of archaeological structures from each period. The size of the white-shaded circles indicates the intensity of human impact as deduced from each peat basin.

## 5.1. Early and middle Neolithic (from ca. 6000 to ca. 3500 cal BC; RDO-1a/b/c, B-4b/c, B-5a)

During the early Neolithic, from ca. 6000 to ca. 4300 cal BC, the high levels of *Pinus*, the presence of pine stomata and the low values of herbs at both RDO (2390 m a.s.l.) and BDE fen (2180 m a.s.l) reveal the existence of a forested landscape at the Madriu valley. The occurrence of pine stomata confirms the local presence of subalpine woodland at both sites (MacDonald, 2001), and places timberline position above 2390 m a.s.l. Equally, the dominance of a *Quercetum mixtum* woodland at lower altitudes is displayed at BDE during this period (Miras et al., 2007), and the expansion of the *Abies* woodland within the montane belt from ca. 5200 cal BC is coincident in time at both sequences with that observed in the eastern Pyrenees (Guiter et al., 2005). At the RDO fen, the expansion of Cyperaceae and the disappearance of *Pediastrum* sp. from 5000 cal BC indicate sedge colonisation of the basin.

Three turning points at the RDO fen should be pointed out within the local predominance of pine woodland. The first two occur from ca. 5650 to ca. 5480 cal

BC and at ca. 5130 cal BC (RDO-1a), as indicated by a slight decline of *Pinus* percentages, the drop of *Pinus* stomata and an increase of herbaceous pollen. All this suggests the existence of eventual and moderate woodland openings at the vicinity of the fen which, on the basis of the pollen signal, became more intense during the second episode. However, despite the decline of pine stomata, they remain present throughout this period. This suggests that the landscape openings were not extensive but resulted instead in an open pine forest in the surroundings of the watershed. The recording of some apophytes and the occasional presence of the coprophilous fungi *Sordaria* sp. and *Sporormiella* sp. (Davis and Shafer, 2006; van Geel and Aptroot, 2006) suggest the presence of herbivores and moderate human pressure in such open woodland areas on which it is difficult to be precise, given the weakness of the pollen and NPP signal. Together with the enhanced human and animal presence, cold climatic conditions recorded in the central Pyrenees between ca. 6450 and ca. 5050 cal BC (Pla and Catalan, 2005) might indeed have benefited the formation of a clear forest at a high altitude during this early stage of the early Neolithic. The availability of sources of water and wet meadows probably turned peat basins as RDO into highly attractive areas for grazing. The existence of human farming activities at a lower altitude has been also proved through the recording of the first notations of Cerealia-type at the RDO fen at ca. 5550 and ca. 5130 cal BC. Human and livestock presence in highland deforested areas as well as early agricultural evidence at the lower valleys have been documented in the southern French Alps since 5200 cal BC (Court-Picon, 2007), while grazing activities and forest disturbances have been reported in mid-mountain areas in the western Pyrenees (Galop, 2006).

The last shifting period that needs to be underlined at the RDO fen ranges from ca. 4500 to ca. 4350 cal BC (RDO-1b). At this time, the retreat of *Pinus* percentage and the rise of herb taxa, especially Poaceae, indicate the progress of alpine grasslands within cleared pine woodland. The recording of *P. major/media*, *R. acetosella*-type, Asteroideae, *Achillea*-type or *Potentilla*-type, some reported either as local grazing indicators (Mazier et al., 2009) or connected to grazed spaces (Court-Picon et al., 2005) in European mountain areas- suggest the existence of grazing activities in the vicinity of the fen. Local grazing during the aforementioned period is suggested by the presence the coprophilous fungi *Sordaria* sp., *Sporormiella* sp. and *Cercophora* sp. (Blackford and Innes, 2006; Davis and Shafer, 2006; van Geel and Aptroot, 2006). Signals of pine woodland retreat, as evidenced by the reduction of pine stomata, proliferation of herbs and a larger and more heterogeneous assemblage of apophytes are also reported at the BDE fen (2180 m a.s.l.) from ca. 5050 to ca. 4350 cal BC (B-5a) (Miras et al., 2007). These data support the human occupation and the extension of grazing in both slopes of the alpine and the subalpine belt of the Madriu valley, facts that are further confirmed by the recording of a pastoral hut located at 2530 m a.s.l. and radiocarbon dated to 4481 ± 112 cal BC (Palet et al., in press). This is consistent with the development of early Neolithic husbandry practices in the nearby Balma de la Margineda shelter (Andorra, 970 m a.s.l.), where the presence of domesticated sheep and goats are archaeologically reported from the first half of the 6th millennium cal BC (Geddès, 1995).

The middle Neolithic, from ca. 4350 to ca. 3500 cal BC, appears to be a threshold period in the landscape shaping of the alpine areas of the Madriu valley. At the RDO fen (RDO-1c), the sharp decline of *Pinus* percentages during this period suggests pinewood clearings which are accompanied by the spread of more diversified alpine meadows, mainly formed by Poaceae but also by *Artemisia*, Cichoroideae and rich tall herbs such as Apiaceae. The rise and more consistent recording of nitrophilous and ruderal taxa such as *Urtica dioica*-type, *P. lanceolata*-type, *Rumex*, Asteroideae, *Cirsium*-type, *Lamium*-type, Brassicaceae or *Potentilla*-type, some of them regarded as local grazing indicators in Pyrenean areas (Mazier et al., 2009), are indicative of a more intense grazing pressure on the alpine pastures. The increase of *Sordaria* sp., the obligate cophrophilous fungi *Sporormiella* sp. and the more consistent recording of *Cercophora* sp. and *Chaetomium* sp. ratify herbivore grazing on the fen, whereas the recording of macrocharcoal suggests the existence of occasional local fire events (Carcaillet et al., 2001) probably linked to human activity. The simultaneous increase of *Glomus* sp. may be related to erosion processes caused by woodland clearances, animal trampling and the occurrence of fires in the watershed surroundings (Marinova and Atanassova, 2006; van Geel et al., 2003). The maximum values of undifferentiated fungal spores and a higher consistency in the recording of oocytes of Turbellaria and of *Polyadosporites* sp. (367) suggest the existence of more eutrophic conditions and higher organic matter decomposition in the fen (Carrión and Navarro, 2002; Haas, 1996) possibly related to local grazing pressure. Finally, the disappearance of *Pinus* stomata around ca. 3500 cal BC suggests a lowering of the timberline in the vicinity of RDO fen as the ultimate consequence of the grazing pressure evidenced during this period. The sporadic presence or absence of pine stomata along the following RDO pollen zones indicate that the tree line would never again reach the 2390 m a.s.l. at this zone, thus leaving the fen above the timberline position as it is located today.

On the contrary, a different landscape setting can be observed in the northern slope of the valley. The BDE fen (B-5b) records a moderate recovery in the pine woodland, stressed by the rising values of pine stomata and the decline in herbs, whereas a slight reduction of human pressure is indicated by a less abundant assemblage of apophytes. However, local grazing pressure within this wooded environment does not disappear, as inferred from the recording of *Cercophora* sp., *Sordaria* sp. and *Chaetomium* sp. (Blackford and Innes, 2006; van Geel and Aptroot, 2006). This period shows marked small-scale land-use variability at the Madriu valley between a highly grazed and cleared southern alpine slope and a wooded northern subalpine one that resulted from lower human pressure (Fig. 7).

Highland human occupation is otherwise reported between 3790 and 4100 cal BC in nearby mid-mountain Andorran areas, at the Tomba del Segudet (Ordino, 1324 m a.s.l.) and the Feixa del Moro archaeological sites (Juberri, 1335 m a.s.l.) (Llovera, 1986; Yáñez et al., 2002). In other eastern Pyrenean areas, the extension of grazing activities towards high altitudinal spaces during the middle Neolithic has been also documented in either pollen (Galop, 2006; Jalut, 1974) or archaeological records (Rendu, 2003). Nevertheless, this study shows that differences in the intensity and landscape management of highland spaces occurred at a micro-regional scale during the middle Neolithic. The first signs of

land-use variability in the Madriu valley consisted of considerable grazing pressure, as well as the lowering of the timberline at the alpine belt and lesser human pressure at the subalpine belt (Fig. 7). By contrast, a more homogeneous land-use system and impact on vegetation is observed during the early Neolithic in the three studied records.

## 5.2. Late Neolithic and early Bronze Age (from ca. 3500 to ca. 1650 cal BC; RDO-1d, B-5b/c/d)

At the RDO fen, the slight retreat of Poaceae and other herbs, together with a lesser recording of apophytes as well as the disappearance of coprophilous fungi may reflect lower grazing pressure in the basin during this period. This would allow a moderate pine woodland recovery in this alpine environment, as shown by the increase of both *Pinus* percentages and its accumulation rates. Nonetheless, the peak of macrocharcoal indicates that fire events took place near the fen, while grazing activities are archaeologically reported at a higher altitude. Further on, two shepherd huts and one livestock enclosure dated between 2400 and 2160 cal BC (Palet et al., in press) have been documented at 2530 m a.s.l., thus pointing to the upper alpine grasslands as the focus of grazing activities during the late Neolithic and the early Bronze Age.

However, pollen record at the BDE fen reveal that human pressure was not only limited to the upper alpine belt but also comprehended the subalpine belt at ca. 2180 m a.s.l. In this respect, the increase of grazing pressure is supported through the overall progress of herbs, apophytes and the presence of coprophilous fungi, whereas woodland clearances are revealed by the decrease of *Pinus* percentages and its concentration values. Such woodland clearances were probably favoured by the use of fire, as suggested by the significant increase of macrocharcoal particles at BDE during this period. Two main periods of human activity interbedded by a period of woodland recovery are recorded at ca. 3500–3000 cal BC and at ca. 2200–1650 cal BC.

All these data underlines a new phase of micro-regional landscape variability in the Madriu valley. The surroundings of the RDO fen were less frequently grazed, which lead to a woodland recovery at ca. 2390 m a.s.l., while grazing would focus in the upper areas of the alpine belt and in the subalpine belt where the use of fire favoured pine woodland clearances (Fig. 7). The development of a landscape organisation of high altitudinal spaces during this period is the result of a complex land-use system which reveals the high adaptability of prehistoric societies to the management of highland environments.

The late Neolithic–early Bronze Age can be, thus, considered as a threshold period in the land-use exploitation of high mountain areas. This is further confirmed in other south-eastern Pyrenean areas, where increased human occupation, the intensification of pastoral and burning activities and the first timberline lowering at high altitudes can be proven since ca. 3300 cal BC (Galop, 1998, 2006).

### 5.3. Middle Bronze Age and late Iron Age (from ca. 1650 to ca. 300 cal BC; RDO-1d, RDO-2a, ODS-1a/b, B-5e, B-6a)

At the RDO fen, the decline of *Pinus* percentages and its accumulation rates from ca. 1650 cal BC, together with the proliferation of Poaceae and other herbs, indicates a marked landscape opening at the alpine belt of the Madriu valley. The mild occurrence of apophytes and the absence of coprophilous fungi at the beginning of this woodland retreat do not support grazing activities as the main factor that caused such landscape opening. The increase of *Juniperus* and herbs such as *Artemisia*, Cichoroideae and Chenopodiaceae may actually suggest the extension of grasslands and heliophilous shrubs during this period. In this sense, certain consideration has to be taken into account for the cooling climate from ca. 2550 to ca. 1150 cal BC (Pla and Catalan, 2005) that could have constrained pine pollen production and benefited the extension of alpine grasslands. In this respect, the decline in summer temperature has been acknowledged as a key factor affecting tree pollen production and timberline shifts at high altitudes (Kofler et al., 2005). However, the fact that such colder conditions took place far earlier than the documented drop in *Pinus* at RDO does not provide the basis for a strictly climatic explanation for the origin of said woodland retreat.

On the other hand, from ca. 1050 cal BC the renewal of most apophytes at RDO underlines renewed human activities on a persistently open landscape. From this point to ca. 700 cal BC landscape clearings would progress towards lower altitudes. Thus, at the ODS fen (2300 m a.s.l.), the retreat of *Pinus*, together with the increase in herbs and the onset of the *Juniperus* curve, indicate the existence of woodland clearings and the settling of a shrubby cover. Besides, the renewal of some apophytes such as *P. lanceolata*-type, *Plantago major/media*, *Rumex* or Asteroideae, and the occurrence of *Sordaria* sp. may suggest the use of such cleared areas for grazing purposes. A similar pattern is evidenced at BDE (B-5e), showing some retreating of *Pinus* percentage, the moderate increment of apophytes and the occurrence of *Sordaria* sp. from ca. 1200 cal BC. Such woodland opening may be attributed to the spread of grazing activities along this highland landscape during the late Bronze Age. Finally, during the Iron Age, from ca. 700 to ca. 400 cal BC the gradual increase of *Pinus* concentration rates at both the RDO and ODS fens, and the recovery of *Pinus* percentages at BDE reflect a general woodland regeneration in the valley. Thus, similar land-uses and landscape dynamics prevail in the valley along this period.

### 5.4. Roman Period, late Antiquity and early Middle ages (from ca. 300 cal BC to ca. 800 cal AD; RDO-2b, ODS-1b/c, B-5e, B-6a)

At the BDE fen, the drop of *Pinus* percentages and stomata concomitant to the proliferation of Poaceae indicate the existence of woodland clearances and the extension of grasslands at the subalpine belt from ca. 300 cal BC. The increase of most apophytes and the significant rise of *Sporormiella* sp., together with other dung-related fungi such as *Cercophora* sp., *Podospora* sp. or *Chaetomium* sp. (Blackford and Innes, 2006; Davis and Shafer, 2006; van Geel and Aptroot, 2006), prove the local presence of livestock in the fen from the 2nd century cal BC through to the 5th century cal AD.

From the 1st to the 5th century cal AD, a more significant grazing pressure is documented in the Madriu valley where grazing activities have been recorded at the highest altitudes. In this respect, at the ODS fen (2300 m a.s.l.), the onset and progress of coprophilous fungi such as *Sordaria* sp., *Podospora* sp. and *A. verruculosa* and the rise of apophytes suggest local grazing activities, whereas the boost of macrocharcoal makes evident the existence of frequent fire activities on the watershed. The increase in herbs and Poaceae indicate the anthropogenic favouring of open spaces, whereas the stability of *Pinus* percentages and the recording of pine stomata stress the local presence of rather stable local woodland. This fact suggests that grazing activities focused mainly on the fen pastures and, rather than causing widespread woodland clearances, resulted in a patchy grazed forest at 2300 m a.s.l. This land-use pattern would presumably be related to a more stable human occupation of the fen area, as demonstrated by the reporting of a close livestock enclosure dated to 14 ± 60 cal AD (Fig. 7) (Palet et al., in press; Riera et al., 2009). Besides, the grazing exploitation of both ODS and BDE at this moment reflects the Roman use of fens as wet pastures within the subalpine woodland.

On the other hand, at the RDO fen (2390 m a.s.l.), the decline of *Pinus* together with a rise in Poaceae between the 1st and the 5th century cal AD suggests the existence pine woodland clearances and grassland expansion similar to that encountered at lower altitudes at the BDE fen. The moderate increase of some apophytes and the absence of coprophilous fungi at the RDO fen suggest a low local grazing pressure on the fen and raise doubts about the preponderance of grazing in the woodland recession. In this sense, the reporting of kilns – probably related to rosin production-nearby the RDO and BDE sequences dated between the 2nd and 7th century cal AD (Palet et al., in press; Riera et al., 2009) reveals the existence of other local activities which also contributed to woodland clearance (Fig. 7). Charcoal analysis carried out in one of the kilns ratifies the use of pine wood fuel (Euba, 2009) and strengthens the role of existing tree felling activities in the woodland retreat observed at both fens. The local coexistence of a wide range of human activities including grazing, burning and forest management during Roman era led to a complex mosaic of highland vegetation types. Moreover, the decline of montane mixed forest and the expansion of cropping activities, which are especially evidenced at BDE, indicate that Roman land management was not just restricted to the highest areas but also included the lower montane belts and foothills. This land-use system that integrated the entire mountain altitudinal range contrasts with that observed in the Pyrenees and southern Alps, where Roman management focuses preferably in mid-mountain areas rather than in highlands (Court-Picon, 2007; Galop, 2005; Walsh, 2005). Moreover, despite the fact that regional variability in Roman management of mountainous areas has already been stressed in the Pyrenees (Galop, 2005), this case-study shows that Roman land-use variability was not merely restricted to a regional scale, but was also formulated at a micro-regional level (Fig. 7).

During the Roman period a highly heterogeneous landscape arises. An open environment can be found in the alpine and subalpine belt in relation to both grazing and forestry activities. On the other hand, a different landscape management is recorded at the ODS fen, at 2300 m a.s.l., where grazing, burning

and pastoral occupation are carried out within a clear but still forested local landscape ([Fig. 7](#)).

During the late Antiquity-early Middle age transition, from ca. 500 to ca. 800 cal AD, at BDE, new *Pinus* pollen and stomata retreat, followed by a peak in apophytes and of *Sordaria* sp., suggest the continuation of an open grazed landscape on the watershed. Equally, at the ODS fen, the significant renewal of coprophilous fungi, together with a higher representation of some ruderal and nitrophilous herbs and the increase of macrocharcoal indicate the existence of a higher grazing pressure and frequent fire activities on the peat basin. The stability of *Pinus* percentages and the uninterrupted record of pine stomata suggest that such activities took place on the watershed within patchy pinewood. All these data point to the continuation of grazing pressure at the subalpine belt up to 2300 m a.s.l. Nonetheless, the recovery of *Pinus* percentage and the pollen accumulation rates together with a slight retreat of apophytes at the RDO fen from the 7th century AD suggest lower human pressure at the alpine belt. This period, thus, highlights a new phase of land-use variability in the valley.

## 5.5. Middle ages and modern times (from ca. 800 cal AD to modern times; RDO-2c, ODS-2a/b/c, B-6a/b)

From ca. 800 cal AD the pronounced decline of *Pinus* at the RDO fen, together with the rise in herbs, most apophytes and the renewal of coprophilous fungi, provide evidence of woodland retreat and the extension of alpine grasslands at high altitudes. Local grazing exploitation is also apparent on the watershed with the recording of two shepherd huts dated to the mid 10th century cal AD ([Palet, 2008](#)). From the 10th, and more remarkably, from the 14th century onwards, ODS and, to a lesser extend, BDE, the retreat of *Pinus* pollen and stomata is registered, while the increase of herbs results in the expansion of alpine grasslands towards the subalpine belt. The marked increase in apophytes and coprophilous fungi corroborate the constitution of a largely grazed landscape in the valley. In fact, grazing activities have been confirmed archaeologically as having carried out between the 14th and the 18th century ([Palet et al., 2007](#)) related to the well documented late Medieval and Modern transhumance practices in the Andorran valleys ([Codina, 2005](#)). However, different lands-uses also developed, as shown by the recording of multiple charcoal mounds in the northern slope of the subalpine belt of the Madriu valley dated to the modern period and which reflect local charcoal production related to iron forge activities ([Palet et al., 2007; Euba, 2009](#)). This is consistent with the ultimate pine woodland recovery at the BDE fen during this period. Besides, the land-use management of lower belts is attested with the general decline of mixed montane woodland and the expansion of arable crops such as olive, chestnut, vineyard, hemp and cereals from the late Medieval period. Extension of medieval and modern grazing at a high altitude and the expansion of arable activities at a lower altitude have been otherwise encountered in the pollen and the archaeological record of nearby Pyrenean areas ([Ejarque et al., 2009; Galop, 1998; Rendu, 2003](#)).

The preponderance of grazing in a largely open landscape and the concurrent charcoal production in a wooded northern slope of the subalpine belt ratifies the

existence of a complex landscape management and discloses the last micro-regional variability during this period.

## 6. Conclusion

The comparison of three nearby palaeoenvironmental sequences in the Madriu valley, together with the integrated use of archaeological data, has revealed the existence of remarkable variability in the human management of high mountain environments since the Neolithic.

These results show that during some periods, such as the middle Neolithic or late Antiquity, landscape variability responds to the existence of human pressure in relation to topographic features, i.e. altitude and slope orientation. Nonetheless, the complex mosaic landscape usage which arises from the late Neolithic to the early Bronze Age and, most remarkably, during the Roman and Medieval periods does not merely follow topographic parameters, but rather responds to the spatial fragmentation of land-uses and the complementary human exploitation of mountainous resources.

The fact that human management in the Madriu valley was not strictly linked to altitudinal and slope orientation parameters questions the suitability of a climatic/temperature gradient as the main factor triggering human land-use at a high altitude. The results from this paper stress the weight of social, economical and cultural parameters in the land-use organisation and the landscape shaping of high mountain spaces since the Prehistory.

The study of NPP, conifer stomata and macrocharcoal has aided in confirming the local nature of some pollen disturbances and characterising the nature of some anthropogenic impacts occurred within the watersheds, particularly the ones involving woodland clearances, grazing practices or fire disturbances. Archaeological data have equally proved to be priceless when assessing local human occupation and the distinctive nature of highland land-use practices. The combination of palaeoenvironmental and archaeological proxies has thus helped to overcome some interpretation constraints of upland pollen assemblages, and offers meaningful insights into the scale and nature of high mountain land-uses.

This paper demonstrates that high mountain pollen sequences are sensitive to micro-regional landscape change and that they constitute valuable palaeoenvironmental records for the analysis of small-scale land-use if fine spatial-resolution pollen analyses are conducted. When analysing the human shaping of highland cultural landscapes the spatial organisation of the land-use may actually limit the adequacy of mountain palaeoenvironmental reconstructions based on single pollen records. This paper points to combined palaeoenvironmental multi-proxy records and archaeological studies through high spatial resolution at a micro-regional scale as the most suitable research strategy for the study of human mountain management and landscape change during the Holocene.

## Acknowledgements

## References

- Behre, 1981
  K.E. Behre**The interpretation of anthropogenic indicators in pollen diagrams**
  Pollen et Spores, 13 (1981), pp. 225-245
- Biagi and Nandris, 1994
  P. Biagi, J. Nandris (Eds.), Highland Zone Exploitation in Southern Europe, Monografie di 'Natura Bresciana', 20 (1994)
- Blackford and Innes, 2006
  J.J. Blackford, J.B. Innes**Linking current environments and processes to fungal spore assemblages: surface NPM data from woodland environments**
  Review of Palaeobotany and Palynology, 141 (2006), pp. 179-187
  ArticlePDF (624KB)
- Carcaillet et al., 2001
  C. Carcaillet, M. Bouvier, B. Fréchette, A.C. Larouche, P.J.H. Richard**Comparison of pollen-slide and sieving methods in lacustrine charcoal analyses for local and regional fire history**
  The Holocene, 11 (2001), pp. 467-476
- Carreras et al., 2003
  J. Carreras, E. Carrillo, A. Ferré, J.M. Ninot**Mapa Digital Dels Hàbitats D'Andorra (MDHA), Escala 1: 25.000**
  Centre de Biodiversitat, Institut d'Estudis Andorrans, Andorra (2003)
- Carrión and Navarro, 2002
  J.S. Carrión, C. Navarro**Cryptogam spores and other non-pollen microfossils as sources of palaeoecological information: case-studies from Spain**
  Annales Botanici Fennici, 39 (2002), pp. 1-14
- Catalan et al., 2001
  J. Catalan, R. Pérez-Obiol, S. Pla**Canvis climàtics a Aigüestortes durant els darrers 15.000 anys**
  M. Aniz (Ed.), V Jornades sobre Recerca al Parc Nacional d'Aigüestortes i Estany de Sant Maurici, Lleida (2001), pp. 45-51
- Cañellas-Boltà et al., 2009
  N. Cañellas-Boltà, V. Rull, J. Vigo, A. Mercadé**Modern pollen–vegetation relationships along an altitudinal transect in the central Pyrenees (southwestern Europe)**
  The Holocene, 19 (8) (2009), pp. 1185-1200
- Codina, 2005
  O. Codina**De Fer et de Laine. Les Vallées Andorranes du VXIe au XIXe Siècle**
  Presses Universitaires de Perpignan, , Perpignan (2005)
- Court-Picon, 2007
  Court-Picon M., 2007. Mise en Place du Paysage dans un Milieu de Moyenne et Haute Montagne du Tardiglaciaire a l'Époque Actuelle: Analyse du Signal Palynologique en Champsaur (Hautes-Alpes, France) à l'Interface des Dynamiques

Naturelles et des Dynamiques Sociales. Unpublished Ph.D thesis, Université de Franche-Comté.

- Court-Picon et al., 2005
  M. Court-Picon, A. Buttler, J.L. de Beaulieu**Modern pollen-vegetation relationships in the Champsaur valley (French Alps) and their potential in the interpretation of fossil pollen records of past cultural landscapes**
  Review of Palaeobotany and Palynology, 135 (2005), pp. 13-39
  ArticlePDF (459KB)
- Davies, 2007
  A.L. Davies**Upland agriculture and environmental risk: a new model of upland land-use based on high spatial-resolution palynological data from West Affric, NW Scotland**
  Journal of Archaeological Science, 34 (2007), pp. 2053-2063
  ArticlePDF (493KB)
- Davis and Shafer, 2006
  O.K. Davis, D. Shafer**Sporormiella fungal spores, a palynological mean of detecting herbivore density**
  Palaeogeography, Palaeoclimatology, Palaeoecology, 237 (2006), pp. 40-50
  ArticlePDF (786KB)
- Davies and Tipping, 2004
  A.L. Davies, R. Tipping**Sensing small-scale human activity in the palaeoecological record: fine spatial resolution pollen analyses from West Glen Affric, northern Scotland**
  The Holocene, 14 (2004), pp. 233-245
- Dearing et al., 2006
  J.A. Dearing, R.W. Battarbee, R. Dikau, I. Larocque, F. Oldfied**Human–environment interactions: learning from the past**
  Regional Environmental Change, 6 (2006), pp. 115-123
- Ejarque et al., 2009
  A. Ejarque, R. Julià, S. Riera, J.M. Palet, H.A. Orengo, Y. Miras, C. Cascón**Tracing the history of highland human management in the Eastern Pre-Pyrenees: an interdisciplinary palaeoenvironmental study at the Pradell fen**
  Spain. The Holocene, 19 (8) (2009), pp. 1241-1255
- Esteban, 1994
  A. Esteban**Primeres dades sobre l'evolució de la vegetació a la Vall del Madriu durant l'Holocé superior**
  Annals 1994 de l'Institut d'Estudis Andorrans (1994), pp. 63-78
- Euba, 2009
  I. Euba**Explotación de los resursos forestales desde el Neolítico hasta la época moderna en los valles de La Vansa-sierra del Cadí (Alt Urgell) y del Madriu (Andorra). Anàlisis antracológico de estructuras altimontanas. Documenta 9**
  Institut Català d'Arqueologia Clàssica, Tarragona (2009)
- Esteban et al., 2009
  P. Esteban, M. Ninyerola, M. Prohom**Spatial modelling of air temperature and precipitation for Andorra (Pyrenees) from daily circulation patterns**
  Theoretical and Applied Climatology, 96 (2009), pp. 43-56
- Faegri and Iversen, 1989
  K. Faegri, J. Iversen**Textbook of Pollen Analysis**
  (fourth ed.), The Blackburn Press, New Jersey (1989)
- Folch, 1984
  R. Folch**El Patrimoni Natural D'Andorra. Els Sistemes Naturals Andorrans I Llur Utilització**
  (second ed.), Ketres editora, Barcelona (1984)
- Galop, 1998

D. Galop**La Forêt, l'Homme et le Troupeau dans les Pyrénées. 6000 Ans d'Histoire de l'Environnement entre Garonne et Méditerranée. Contribution Palynologique**
GEODE-Laboratoire d'écologie terrestre-Framespa, Toulouse (1998)

- Galop, 2005
Galop, D., 2005. Les transformations de l'environnement pyrénéen durant l'Antiquité: l'état de la question à la lumière des données polliniques. In: V.V.A.A., L'Aquitaine et l'Hispanie Septentrionale à l'Époque Julio-Claudienne. Organisation et Exploitaton des Espaces Provinciaux. IVe Colloque Aquitania, 317–327.

- Galop, 2006
D. Galop**La conquête de la montagne Pyrénéenne au Néolithique. Chronologie, rythmes et transformations des paysages à partir des données polliniques**
J. Guilaine (Ed.), Populations Néolithiques et Environnement, Editions Errance, Paris (2006), pp. 279-295

- Galop and Jalut, 1994
D. Galop, G. Jalut**Differential human impact and vegetation history in two adjacent Pyrenean valleys in the Ariège basin, southern France, from 3000 BP to the present**
Vegetation History and Archaeobotany, 3 (1994), pp. 225-244

- Geddès, 1995
D. Geddès**La fauna mesolítica i neolítica de la Balma de la Margineda**
J. Guilaine, M. Martzluff (Eds.), Les excavacions a la Balma de la Margineda (1979–1991), volume 2, Edicions del Govern d'Andorra, Andorra (1995), pp. 83-891

- Gómez and Esteban, 1993
A. Gómez, A. Esteban**Análisis polínico de la turbera de la Feixa (La Màniga, Cerdanya, 2.150nbsp;m). Evolución del paisaje**
M.P. Fumanal, J. Bernabeu (Eds.), Estudios sobre Cuaternario. Medios sedimentarios. Cambios ambientales. Hábitat humano, Universitat de València, Valencia (1993), pp. 185-190

- Grimm, 1987
E. Grimm**CONISS: a Fortan 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares**
Computers and Geosciences, 13 (1987), pp. 13-35
ArticlePDF (1MB)

- Guiter et al., 2005
F. Guiter, V. Andrieu-Ponel, G. Digerfeldt, M. Reille, J.L. de Beaulieu, P. Ponel**Vegetation history and lake-level changes from the Younger Dryas to the present in the Eastern Pyrenees (France): pollen, plant macrofossils and lithostratigraphy from Lake Racou (2000nbsp;m a.s.l.)**
Vegetation History and Archaeobotany, 14 (2005), pp. 99-118

- van Geel, 2001
B. van Geel**Non-pollen palynomorphs**
J.P. Smol, H.J.B. Birks, W.M. Last (Eds.), Tracking Environmental Change Using Lake Sediments Terrestrial, Algal and Silicaceaous Indicators, Vol. 3, Kluwer Academic Publishers, Dordrecht (2001), pp. 99-119

- van Geel and Aptroot, 2006
B. van Geel, A. Aptroot**Fossil ascomycetes in Quaternary deposits**
Nova Hedwigia, 82 (2006), pp. 313-329

- van Geel et al., 2003
B. van Geel, J. Buurman, O. Brinkkemper, J. Schelvis, A. Aptroot, G. van Reenen, T. Hakbijl**Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi**
Journal of Archaeological Science, 30 (2003), pp. 873-883
ArticlePDF (690KB)

- Haas, 1996
  J.N. Haas**Neorhabdocoela oocytes – palaeoecological indicators found in pollen preparations from Holocene freshwater lake sediments**
  Review of Palaeobotany Palynology, 91 (1996), pp. 371-382
  ArticlePDF (947KB)
- Hansen, 1995
  B.C.S. Hansen**Conifer stomate analysis as a paleoecological tool: an example from the Hudson Bay lowlands**
  Canadian Journal of Botany, 73 (1995), pp. 244-252
- Jalut, 1974
  G. Jalut**Évolution de la Végétation et Variations Climatiques durant les Quinze Derniers Millenaires dans l'Extremité Orientale des Pyrénées**
  Université Paul Sabatier, Toulouse (1974)
- Juggins, 1991
  S. Juggins**C2 Data Analysis Vs.1.4.2**
  University of Newcastle, Newcastle (1991)
- Kofler et al., 2005
  W. Kofler, V. Krapf, W. Oberhuber, S. Bortenschlager**Vegetation responses to the 8200 cal. BP cold event and to long-term climatic changes in the Eastern Alps: possible influence of solar activity and North Atlantic freshwater pulses**
  The Holocene, 15 (6) (2005), pp. 779-788
- Llovera, 1986
  X. Llovera**La Feixa del Moro (Juberri) i el Neolític Mig – Recent a Andorra**
  Tribuna d'Arqueologia, 1985–1986 (1986), pp. 15-24
- MacDonald, 2001
  G.M. MacDonald**Conifer stomata**
  J.P. Smol, H.J.B. Birks, W.M. Last (Eds.), Tracking Environmental Change Using Lake Sediments, Terrestrial, Algal, and Siliceous Indicators, Vol. 3, Kluwer Academic Publishers, Dordrecht (2001), pp. 33-47
- Marinova and Atanassova, 2006
  E. Marinova, J. Atanassova**Anthropogenic impact on vegetation and environment during the Bronze Age in the area of lake Durankulak, NE Bulgaria: pollen, microscopic charcoal, non-pollen palynomorphs and plant macrofossils**
  Review of Palaeobotany and Palynology, 141 (2006), pp. 165-178
  ArticlePDF (1MB)
- Mases et al., 2005
  M. Mases, M. González, N. Gallego**Memòria del Mapa Geomorfològic d'Andorra 1:50.000. Centre de recerca en Ciències de la Terra (CRECIT)**
  Institut d'Estudis Andorrans, Sant Julià de Lòria (2005)
- Mazier et al., 2009
  F. Mazier, D. Galop, M.J. Gaillard, C. Rendu, C. Cugny, A. Legaz, O. Peyron, A. Buttler**Multidisciplinary approach to reconstructing local pastoral activities – an example from the Pyrenean Mountains (Pays Basque)**
  The Holocene, 19 (2009), pp. 171-188
- Miras et al., 2007
  Y. Miras, A. Ejarque, S. Riera, J.M. Palet, H.A. Orengo, I. Euba**Dynamique holocène de la végétation et occupation des Pyrénées andorranes depuis le Néolithique ancien, d'après l'analyse pollinique de la tourbière de Bosc dels Estanyons (2180nbsp;m, Vall del Madriu, Andorre)**
  Comptes Rendus Palevol, 6 (2007), pp. 291-300
  ArticlePDF (839KB)
- Moe and Hjelle, 1999

D. Moe, K.L. Hjelle**Mesolithic human adaptation to changing alpine/subalpine vegetation in the Central and Eastern Alps based on vegetational historical study from Val Febbraro, Spluga Valley (Italy)**
Universitätsforsch Prähist Archäol, 55 (1999), pp. 207-214

- Montserrat, 1992
  J. Montserrat**Evolución Glaciar y Postglaciar del Clima y la Vegetación en la Vertiente Sur del Pirineo: Estudio Palinológico**
  Monografías del Instituto Pirenaico de Ecología 6, Zaragoza (1992)

- Moore et al., 1991
  P.D. Moore, J.A. Webb, M.E. Collinson**Pollen Analysis**
  (second ed.), Blackwell Scientific Publications, Oxford (1991)

- Oeggl, 1994
  K. Oeggl**The Palynological record of human impact on highland zone ecosystems**
  P. Biagi, J. Nandris (Eds.), Highland Zone Exploitation in Southern Europe, 20, Monografie di 'Natura Bresciana' (1994), pp. 107-122

- Oeggl and Wahlmüller, 1993
  K. Oeggl, N. Wahlmüller**Vegetation and climate history of a high alpine mesolithic camp site in the Eastern Alps**
  Preistoria Alpina, 28 (1993), pp. 71-82

- Orengo, 2007
  H.A. Orengo**Informe de les Intervencions Arqueològiques a la Vall de Perafita (Escaldes-Engordany, Andorra)**
  Àrea de Recerca Històrica del Govern d'Andorra, Andorra (2007)

- Ortu et al., 2006
  E. Ortu, S. Brewer, O. Peyron**Pollen-inferred palaeoclimate reconstructions in mountain areas: problems and perspectives**
  Journal of Quaternary Science, 21 (6) (2006), pp. 615-627

- Palet, 2008
  J.M. Palet**Memòria de les Intervencions Arqueològiques a la Vall del Madriu (Andorra)**
  Àrea de Recerca Històrica del Govern d'Andorra, Andorra (2008)

- Palet et al., 2007
  J.M. Palet, A. Ejarque, Y. Miras, S. Riera, I. Euba, H.A. Orengo**Formes d'ocupació d'alta muntanya a la vall de la Vansa (Serra del Cadí-alt Urgell) i a la vall del Madriu-Perafita-Claror (Andorra): estudi diacrònic de paisatges culturals pirinencs**
  Tribuna d'Arqueologia 2006–2007 (2007), pp. 229-253

- Palet et al., in press
  Palet, J.M., Orengo., H.A., Ejarque, A., Euba, I., Miras, Y., Riera, S., Formas de paisaje de montaña y ocupación del territorio en los Pirineos orientales en época romana: estudios pluridisciplinares en el valle del Madriu–Perafita–Claror (Andorra) y en la Sierra del Cadí (Cataluña). In: Proceedings of the 17th International Congress of Classical Archaeology (Roma 22–26 Septiembre 2008). Bollettino di Archeologia On-line, in press.

- Pardoe, 2001
  H.S. Pardoe**The representation of taxa in surface pollen spectra on alpine and sub-alpine glacier forelands in southern Norway**
  Review of Palaeobotany and Palynology, 117 (2001), pp. 63-78
  ArticlePDF (183KB)

- Pèlachs, 2004
  Pèlachs, A., 2004. Deu Mil Anys de Geohistòria Ambiental al Pirineu Central Català. Aplicació de Tècniques Paleogeogràfiques per a l'Estudi del Territori i el Paisatge a

la Coma de Burg i a la Vallferrera. Ph.D thesis, Universitat Autònoma de Barcelona. http://www.tdx.cesca.es/TDX-0119105-162806/#documents, 2 June 2009.

- Pèlachs et al., 2009
  A. Pèlachs, R. Pérez-Obiol, M. Ninyerola, J. Nadal**Landscape dynamics of Abies and Fagus in the southern Pyrenees during the last 2200 years as a result of anthropogenic impacts**
  Review of Palaeobotany and Palynology, 156 (2009), pp. 337-349
  ArticlePDF (1MB)
- Pla and Catalan, 2005
  S. Pla, J. Catalan**Chrysophyte cysts from lake sediments reveal the submillennial winter/spring climate variability in the northwestern Mediterranean region throughout the Holocene**
  Climate Dynamics, 24 (2005), pp. 263-278
- Punt et al., 1976–2009
  W. Punt, S. Blackmore, P. Hoen, P. Stafford (Eds.), The Northwest European Pollen Flora, Vol. I–IX, Elsevier, Amsterdam (1976–2009)
- Reille, 1992
  M. Reille**Pollen et Spores d'Europe et d'Afrique du Nord**
  Laboratoire de Botanique historique et Palynologie, Université d'Aix-Marseille III (1992)
- Reimer et al., 2004
  P.J. Reimer, M.G.L. Baillie, E. Bard, A. Bayliss, J.W. Beck, C.J.H. Bertrand, P.G. Blackwell, C.E. Buck, G.S. Burr, K.B. Cutler, P.E. Damon, R.L. Edwards, R.G. Fairbanks, M. Friedrich, T.P. Guilderson, A.G. Hogg, K.A. Hughen, B. Kromer, G. McCormac, S. Manning, C.B. Ramsey, R.W. Reimer, S. Remmele, J.R. Southon, M. Stuiver, S. Talamo, F.W. Taylor, J. van der Plicht, C.E. Weyhenmeyer**IntCal04 terrestrial radiocarbon age calibration, 26–0nbsp;ka BP**
  Radiocarbon, 46 (2004), pp. 1029-1058
- Rendu, 2003
  C. Rendu**La Montagne d'Enveig. Une Estive Pyrénéenne dans la Longue Durée**
  Trabucaire, Canet (2003)
- Riera et al., 2009
  S. Riera, J.M. Palet, A. Ejarque, H.A. Orengo, R. Julià, A. Currás**Variabilite Climatique, Occupation du Sol et Paysage en Espagne de l'Age du Fer a l'Epoque Medievale: Integration des Donnees Paleoenvironnementales et d'Archeologie du Paysage**
  E. Hermon (Ed.), Société et Climats dans l'Empire Romain, Editoriale Scientifico de Naples (2009), pp. 251-280
- Stockmarr, 1971
  J. Stockmarr**Tablets with spores used in absolute pollen analysis**
  Pollen et spores, 13 (1971), pp. 615-621
- Sugita, 1994
  S. Sugita**Pollen Representation of Vegetation in Quaternary Sediments: Theory and Method in Patchy Vegetation**
  Journal of Ecology, 82 (4) (1994), pp. 881-897
- Walsh, 2005
  K. Walsh**Risk and marginality at high altitudes: new interpretations from fieldwork on the Faravel Plateau, Hautes–Alpes**
  Antiquity, 79 (304) (2005), pp. 289-305
- Whitlock and Larsen, 2001
  C. Whitlock, C. Larsen**Charcoal as a fire proxy**
  J.P. Smol, H.J.B. Birks, W.M. Last (Eds.), Tracking Environmental Change Using Lake Sediments, Terrestrial, Algal, and Siliceous Indicators, Vol. 3, Kluwer Academic Publishers, Dordrecht (2001), pp. 75-97

- Yáñez et al., 2002
  C. Yáñez, A. Malgosa, F. Burjachs, N. Díaz, C. García, J. Juan, J. Matamala**El món funerari al final del V mil·lenni a Andorra: la tomba de Segudet (Ordino)**
  Cypsela, 14 (2002), pp. 175-194