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Isabelle Jouffroy-Bapicot, B. Vannière, Emilie Gauthier, Hervé Richard, Fabrice Monna, et al.. 7000 years of vegetation history and land-use changes in the Morvan Mountains (France): a regional synthesis.. *The Holocene*, 2013, 23 (12), pp.1888-1902. 10.1177/0959683613508161 . hal-01291972

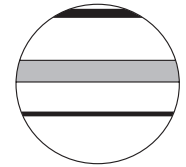
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Submitted on 7 May 2020

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7000 years of vegetation history and land-use changes in the Morvan Mountains (France): A regional synthesis

Isabelle Jouffroy-Bapicot,¹ Boris Vannière,¹ Émilie Gauthier,¹ Hervé Richard,¹ Fabrice Monna² and Christophe Petit³

Abstract

This paper aims to reconstruct the vegetation history of a middle mountain – the Morvan (Burgundy, France) – since the Neolithic (i.e. 7000 years). The results of palynological and non-pollen palynomorphs (NPPs) analysis performed on 10 peat cores document the main phases of human agro-pastoral practices and natural resources management which drove the formation of the cultural landscape of the Morvan Massif over time. To document the history of human activities at a regional scale, particular attention was given to the determination, the characterization and the graphical depiction of phases of human impact. Both the quantification of the impact of human pressure and the chronological uncertainty of the different phases identified by pollen and NPP analysis were taken into account. This study reveals a clear human presence during periods that were formerly poorly documented, such as the onset of the Neolithic period, the Bronze Age, the early Iron Age and the early Middle Ages. It also sheds new light over periods for which there is better archaeological and historical knowledge, such as the widespread occupation of the massif in the late Iron Age, the cultivation of chestnut from the 11th to the 16th century and the impact of modern firewood exploitation on the forest.

Keywords

Burgundy (France), coprophilous fungi, human impact, middle mountain, mid–late Holocene, pollen

Received 22 May 2013; revised manuscript accepted 5 August 2013

Introduction

Multiproxy palaeoecological investigations carried out during the last decades illustrated the complex interrelations between natural and human forcing, which drove ecological dynamics during the mid- and late Holocene (Berghlund, 2003; Dearing, 2006). These analyses, related to archaeological and historical knowledge, are of primary importance to our understanding of the formation of European cultural landscape. Throughout these studies, the regional scale (in the sense of a natural region) has appeared as the most suitable spatial scale for understanding the complex interplay of human history, land-use and climate variations (Dearing et al., 2006). In this context, European middle and high mountains are areas of primary importance (e.g. in the Alps: Court-Picon et al. (2006), Gauthier and Richard (2009), Moe et al. (2007) and Tinner et al. (2003); in the Jura: Gauthier and Richard (2007) and Magny et al. (2008); in the French Massif Central: Miras et al. (2004) and Miras et al. (2011) and in the Pyrenees: Ejarque et al. (2010), Miras et al. (2010) and Rius et al. (2009)). Mostly because of these studies, mountain regions are no longer considered as marginal zones but have shown original land uses over time that are strongly connected to the exploitation of local resources such as wood and metalliferous ore deposits. Furthermore, mountainous environments have the advantage of combining an abundance of natural archives suitable for palaeoecological investigations and sensitivity to climatic and/or anthropogenic forcing. However, despite the increase in recent multiproxy studies concerning the micro-regional scale in European mountainous environments linking palaeoecology, archaeology and history (Curras et al., 2012; Ejarque et al., 2009; Miras et al., 2011; Rius et al., 2011; Roepke et al., 2011), scientific

papers focusing on a long-term regional approach based on several sequences remain scarce.

The Morvan Massif, a small middle mountain in central France, is well adapted to the study of landscape dynamics processes at the regional scale. From a geomorphological and a biogeographical point of view, it is characterized by a homogeneity of environmental conditions over a restricted area (c. 1500 km²). Furthermore, peat deposits spread throughout the massif provide the opportunity to investigate pollen records, and hence to document vegetation dynamics. Two periods of supra-regional importance marked the local history. The first one took place during the 1st century BC, with the presence of one of the greatest *oppidum* of the Celtic world, Bibracte, a major economic and political centre (Dhennequin et al., 2008). The second one occurred much later, when the Morvan Forest supplied Paris with firewood during modern times (Vigreux, 1994). The goal of this paper is to investigate how these well-known periods are part of an evolution

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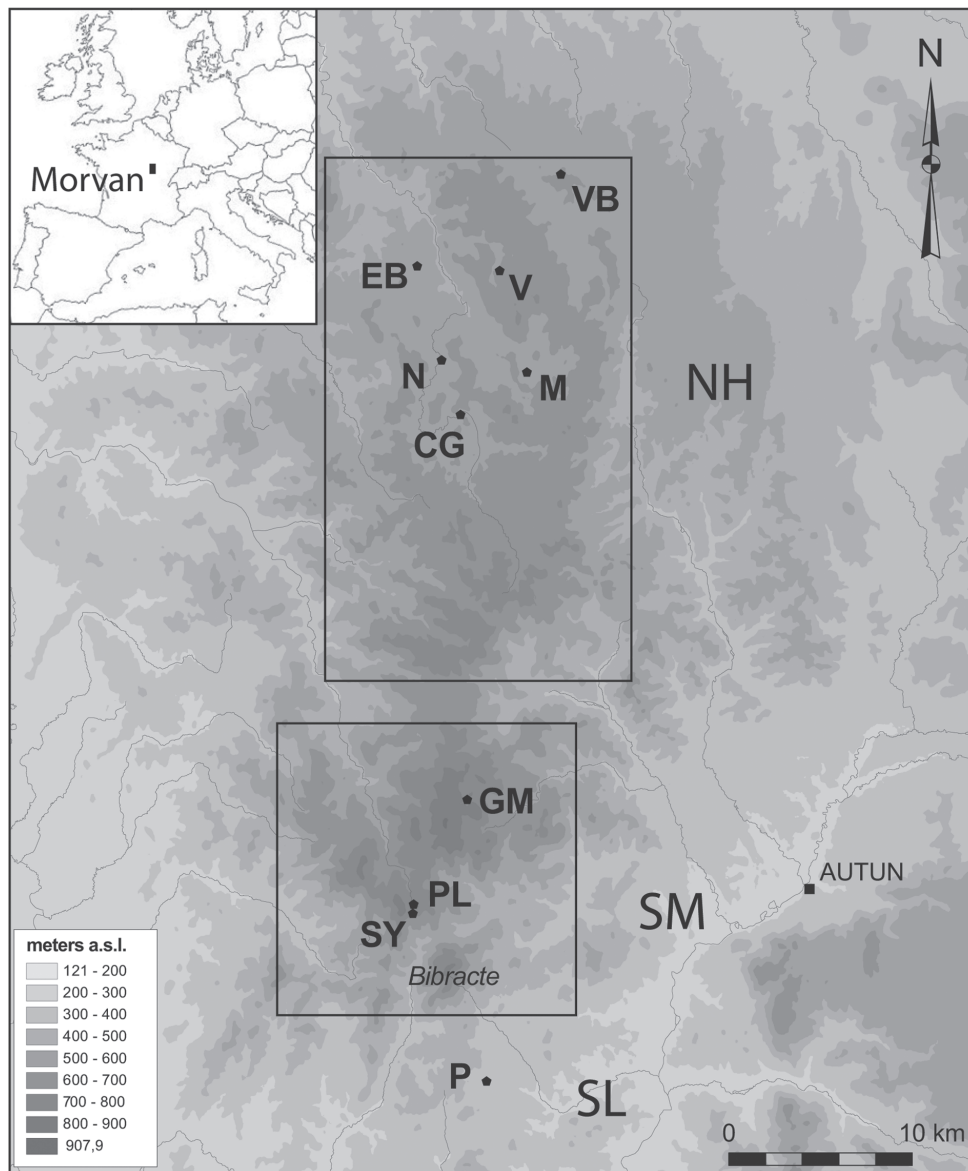


Figure 1. Study area: location of the Morvan Massif and peatlands analysed in the northern hills (NH), the southern mountains (SM) and the southern slope (SL).

VB: Vergy-des-Brûlons; EB: Etang Bouquin; V: Le Vernay; N: Nataloup; M: Montbé; CG: Champ Gazon; GM: Grand-Montarnu; PL: Port-des-Lamberts; SY: Sources de l'Yonne; P: Poil.

over the long term. It also aims to evaluate the role of poorly documented practices, especially breeding and cultivation, in the formation of the cultural landscape of the Morvan Massif, as well as the role of climate forcing. To achieve this goal, we attempted to quantify the impact of human pressure on the environment using the results of pollen analyses as well as coprophilous fungal spores identified through the study of non-pollen palynomorphs (NPPs). Finally, we explored a new kind of graphical depiction which allows comparison between different sequences in the area, while taking into account the chronological uncertainty inferred by radiocarbon dating.

The study area

The Morvan Massif, located in the north/centre of France (Burgundy), is the northern extension of the French Massif Central. The bedrock is mainly granitic, with volcano-sedimentary formations (conglomerates and rhyolite) on the southern part (Ricordel et al., 2007). In the north (northern hills), the topography is smooth, with low altitudes ranging between 450 and 550 m a.s.l.,

while they are higher in the southern part (southern mountains), from 700 to 900 m a.s.l. (Figure 1). The climate is typical of submontane areas, marked by wet conditions with precipitations of more than 1000 mm in the most elevated zones, and a low average annual temperature of about 9°C. Influences of an Atlantic climate are found on the western part, while influences of a continental climate dominate in the east.

The whole massif is crosscut by several microgranitic and quartz veins in which abundant polymetallic mineralization (Pb, Zn, Ag) is present (Gourault, 1999; Marcoux, 1986). Textual and field evidence indicates the exploitation of fluorine, barite and lead during the 20th century. Geomorphological anomalies, such as wide trenches and gullies, found throughout the massif also suggest ancient mining. During the last decade, palaeoenvironmental investigations, combining geochemical and palynological analysis on peat cores, provided indirect clues for local metallurgical activities as early as the Bronze Age (*c.* 1300 cal. BC) and during the Iron Age (*c.* 200–50 cal. BC; Jouffroy-Bapicot, 2007; Jouffroy-Bapicot et al., 2008; Monna et al., 2004). Furthermore, recent excavations at Mont-Beuvray provided the first

Table 1. Sites location and description: altitudes a.s.l., type of the peatlands according to Charman (2002).

| Code | Name | Altitude above sea level | Geographical setting | Type of peatland |
|------|--------------------|--------------------------|------------------------|-------------------------------|
| VB | Verny-des-Brûlons | 565 m | 47° 19'04"N/04°07'22"E | Pond border mire ^a |
| EB | Etang Bouquin | 540 m | 47° 16'17"N/04°01'23"E | Pond border mire ^a |
| LV | Le Vernay | 590 m | 47° 15'43"N/04°04'45"E | Blanket mire |
| N | Nataloup | 515 m | 47° 13'39"N/04°02'07"E | Valley mire |
| M | Montbé | 562 m | 47° 12'53"N/04°06'25"E | Blanket mire |
| CG | Champ Gazon | 585 m | 47° 12'12"N/04°02'55"E | Blanket mire |
| GM | Grand-Montarnu | 770 m | 47°00'41"N/04°03'12"E | Sloping mire |
| PL | Port-des-Lamberts | 710 m | 46°57'39"N/04°00'38"E | Sloping mire |
| SY | Sources de l'Yonne | 740 m | 46°57'23"N/04°00'36"E | Sloping mire |
| P | Poil | 420 m | 46°53'33"N/04°02'03"E | Basin mire |

^aIn both cases, the peat deposit is older than the artificial pond.

archaeological evidence of Prehistoric mining in the Morvan dated to about the 1st century BC (Cauuet and Tamas, 2008).

Soils on the granitic and/or volcanic substrate have moderate to strong acidity (Quantin, 2004). Agricultural lands are rare, and at present, the landscape is dominated by forests and meadows. More precisely, 48% of the area is forested (Zakin et al., 2007): roughly half by natural deciduous forest with common beech (*Fagus sylvatica*) and sessile oak (*Quercus petraea*), and half with coniferous plantations (*Abies* sp., *Pseudotsuga menziesii*, *Picea abies*; Fedoroff et al., 2005). Since the 1960s, the cultivation of Christmas trees has increased in the Morvan in an attempt to diversify agricultural activities. Forestry and breeding are the main economic activities, and rural depopulation has been important over the last five decades.

The history of human occupation in the Morvan Massif is unevenly documented over time and space. Published archaeological data are scarce and archaeological investigations are rare, with the exception of the Aeduan *oppidum* of Bibracte, established on Mont-Beuvray, one of the highest points of the Morvan Massif. This Celtic hill fort was occupied during the 1st and 2nd centuries BC and, according to Caesar, who wrote his famous narrative of the Gallic War there (Julius Caesar, *De Bello Gallico*, books 1–8), was one of the greatest and richest towns in Gaul. After the Roman conquest, the *oppidum* was gradually abandoned in favour of a new town founded by the Emperor Augustus, Augustodunum, nowadays known as Autun (Rebourg, 1991). Unlike the late Celtic period, the Prehistoric, the Roman and the Mediaeval human occupations of the Morvan are not well documented with the exception of some recent papers dealing with archaeological data provided by old excavations and surveys (Martineau et al. (2011) for the Neolithic and Chevrier (2002) for the Bronze Age). Finally, the socio-economic history of the massif in modern times, from the 16th to the early 20th century, when the timber floating industry of Morvan supplied Paris with firewood, is well-known (Benoit et al., 2004; Poux et al., 2011; Vigreux, 1994).

Materials and methods

Fieldwork and sites

There are no natural lakes on the Morvan Massif, but several peat deposits representing suitable natural archives for palaeoenvironmental investigations. Their potential was little exploited before 2000, and only some old palynological analyses, with or without radiometric dating, were done (Lemée, 1951; Richard, 1996). All the known peat deposits of the Morvan Massif were investigated for this study. Only those with more than 1 m of sediments were cored, using a Russian corer (GYK-type). In all, 10 fossil pollen sequences from the Morvan were analysed. From north to south, we studied six cores in the northern hills (NH), three cores in the

southern mountains (SM) and one core on the southern slope (SL; Figure 1 and Table 1). Only the part of the cores concerning the last 7 kys, from the Neolithic to the present, is discussed in this paper; a complete analysis of the sequences with an older chronology can be found in Jouffroy-Bapicot (2010).

Radiocarbon dates

Three to seven radiocarbon dates per core were performed, depending on the depth and the timespan, representing a total of 46 dating. These dates were calibrated with IntCal09, and the age–depth models were done with CLAM (Blaauw, 2010). The smooth spline function was used when the studied core or a section of a core contained at least four dates, and the interpolated function was preferred when less than four dates were available. Radiocarbon dates and calibrations are reported in Table 2. Age–depth models and simplified lithology are shown for each sequence in Figure 2. Sediments mainly consist of homogenous peat, especially sphagnum-peat, except at Poil (P) where it is sedge-peat. According to the pollen data and the radiocarbon dating in the sequences of Grand-Montarnu and Le Vernay, two sedimentary hiatuses, not visible in the lithology, appear. The upper part of the core performed at Le Vernay has no radiometric dating and will not be used to reconstruct vegetation history.

Pollen and NPP analyses

The samples for pollen and NPP analyses were routinely taken at intervals of 4 cm, but for the most compacted section-parts, subsampling was taken at intervals of 2 cm or 1 cm in order to refine time resolution analysis. Samples were prepared according to standard techniques for pollen analysis (Faegri and Iversen, 1989). Pollen grains were identified with the aid of keys (Beug, 2004; Moore et al., 1991), photographs (Reille, 1992) and reference to the modern pollen-type slide collection of the Chrono-environment Laboratory of Besançon. Nomenclature follows Beug (2004). In addition to pollen analysis, NPPs were identified and counted according to Van Geel classifications (Van Geel, 2001; Van Geel et al., 1981, 1983, 1989). The focus here is on fungal remains commonly used as dung indicators, which give a new reliable data set to characterize pastoral phases in different kinds of environments (e.g. Baker et al., 2013; Cugny et al., 2010; Ejarque et al., 2010; Gauthier et al., 2010; Miede et al., 2009; Mighall et al., 2006; Van Geel and Aptroot, 2006; Yeloff et al., 2007).

Pollen percentages are based on the sum of pollen of dry-ground vascular plants, total land pollen (TLP) sum exceeding 500 grains. Fern spores, aquatic plants, Cyperaceae and *Alnus* (whose impressive proportions along the diagrams suggest the development of these species in the wetlands) were excluded from the TLP (except at the site of Etang de Bouquin for the Cyperaceae and the site of Poil for *Alnus*, where these taxa percentages remain

Table 2. Radiocarbon dates (AMS ^{14}C dating).

| Site code and depth (cm) | Material | Lab code | Age uncalibrated BP | Cal. BC–AD (2 sigma) |
|--------------------------|----------------------|------------------|---------------------|---------------------------|
| PL 34-38 | Peat | LY-10941 | Modern | |
| PL 77-79 | Peat | LY-10942 | 1070 ± 50 | 784–1015 cal. AD |
| PL 97-99 | Peat | LY-10943 | 1460 ± 60 | 435–665 cal. AD |
| PL 126-128 | Peat | LY-10944 | 2480 ± 40 | 768–415 cal. BC |
| PL 163-165 | Peat | LY-10945 | 3117 ± 54 | 1497–1264 cal. BC |
| SY 45,5-46,5 | Peat | Erl-11298 | 706 ± 35 | 1230–1388 cal. AD |
| SY 54,5-55,5 | Peat | Erl-11297 | 1006 ± 37 | 905–1154 cal. AD |
| SY 82-83 | Seeds | Erl-11296 | 2059 ± 47 | 194 cal. BC to 48 cal. AD |
| SY 109,5-110,5 | Wood | Erl-11295 | 2341 ± 41 | 723-235 cal. BC |
| GM 14-15 | Peat | Poz-13091 | 730 ± 30 | 1225–1296 cal. AD |
| GM 18-20 | Peat | Poz-20338 | 1365 ± 30 | 613–760 cal. AD |
| GM 23-24 | Peat | Poz-20289 | 1845 ± 30 | 86–238 cal. AD |
| GM 35,5-36 | Peat | Poz-13160 | 2920 ± 40 | 1259–1007 cal. BC |
| GM 56-58 | Peat | Poz-20339 | 3375 ± 30 | 1745–1540 cal. BC |
| GM 61,5-62,5 | Peat | Poz-13094 | 4290 ± 40 | 3030–2870 cal. BC |
| GM 80-81 | Peat | Poz-13093 | 5750 ± 40 | 4710–4490 cal. BC |
| P 64-66 | Wood | Erl-11294 | 447 ± 35 | 1410–1612 cal. AD |
| P 134-135 | Peat | Erl-11293 | 1311 ± 40 | 648–776 cal. AD |
| P 173,5-175 | Seeds | Erl-11292 | 1547 ± 36 | 426–591 cal. AD |
| M 56-57 | Peat | Poz-26581 | 1880 ± 35 | 61–227 cal. AD |
| M 80-81 | Macro remains | Poz-26604 | 2190 ± 35 | 371–171 cal. BC |
| M 112-113 | Macro remains | Poz-26582 | 2410 ± 40 | 748–396 cal. BC |
| M 125,5-126,5 | Macro remains | Poz-26605 | 2720 ± 30 | 916–811 cal. BC |
| M 168-169 | Peat | Poz-26583 | 3485 ± 35 | 1894–1693 cal. BC |
| <i>M 179-180</i> | <i>Macro remains</i> | <i>Poz-26606</i> | <i>3045 ± 35</i> | <i>1409–1212 cal. BC</i> |
| V 53-54 | Peat | Poz-18740 | 3390 ± 35 | 1861–1540 cal. BC |
| V 77-78 | Peat | Poz-17990 | 4055 ± 35 | 2846–2474 cal. BC |
| V 109-110 | Peat | Poz-20340 | 5225 ± 35 | 4224–3962 cal. BC |
| V 141-142 | Peat | Poz-18742 | 5990 ± 50 | 5000–4729 cal. BC |
| CG 61-62 | Peat | Poz-2685 | 2295 ± 45 | 475–203 cal. BC |
| CG 97-95 | Peat | Ly-2463 (Poz) | 2805 ± 45 | 1109–836 cal. BC |
| CG 165-166 | Peat | Poz-21627 | 3660 ± 35 | 2137–1941 cal. BC |
| CG 197,5-199 | Charcoal | Poz-21628 | 4120 ± 35 | 2869–2577 cal. BC |
| CG 223,5-224,5 | Peat | Poz-21629 | 4415 ± 35 | 3320–2917 cal. BC |
| CG 269-270 | Peat | Poz-22896 | 4850 ± 40 | 3706–3528 cal. BC |
| CG 296,5-297,5 | Peat | Poz-22893 | 5710 ± 40 | 4680–4449 cal. BC |
| N 64-65 | Charcoal | Poz-18739 | 1680 ± 30 | 258–423 cal. AD |
| N 85-86 | Charcoal | Poz-18647 | 2405 ± 35 | 745–396 cal. BC |
| N 114-115 | Charcoal | Poz-18648 | 3830 ± 35 | 2456–2150 cal. BC |
| N 134-135 | Macro remains | Poz-24016 | 4130 ± 35 | 2870–2581 cal. BC |
| EB 38,5-39,5 | Macro remains | Poz-26573 | 210 ± 35 | 1641–1964 cal. AD |
| EB 85-86 | Macro remains | Poz-26575 | 370 ± 35 | 1447–1634 cal. AD |
| EB 121-122 | Peat | Poz-26729 | 2040 ± 35 | 163 cal. BC to 49 cal. AD |
| VB 37,5-38,5 | Peat | Poz-13030 | 695 ± 30 | 1260–1390 cal. AD |
| VB 68-70 | Charcoal | Poz-12013 | 2300 ± 30 | 402–235 cal. BC |
| VB 76-77 | Peat | Poz-20364 | 3695 ± 35 | 2200–1970 cal. BC |

AMS: accelerator mass spectrometry; Poz: Poznan Radiocarbon laboratory – Poland; Erl: AMS ^{14}C -Labor Erlangen – Germany; LY: Centre des Sciences de la Terre à Lyon – France.

One date was rejected at the base of the Montbé peat deposit core (in italic) because it displays age reversal and it is not coherent with pollen spectra.

moderate). Relative values of pollen and NPPs were calculated as a percentage of the TLP using *Tilia*, and the pollen diagrams were constructed with TGView (Grimm, 1991–1993).

Direct and indirect indicators of human impact were selected. Direct indicators of human disturbances consist of anthropochores pollen, including the following:

- *Introduced and cultivated trees*: Chestnut (*Castanea sativa*) and walnut (*Juglans regia*);
- *Cultivated herbs*. Cereals (*Cereal*-type grains with a minimum diameter of 42 μm and a minimum diameter pore + annulus >10 μm (Beug, 2004; Tweddle et al.,

2005)), buckwheat (*Fagopyrum*) and hemp (*Cannabis sativa*). All the Cannabinaceae pollen grains are identified here as *Cannabis*-type because of the convergence of the following clues: (1) all the diameters of the pollen grain were >28 μm , (2) they appear after AD 500 and (3) common hop (*Humulus lupulus*), whose pollen grain can be confused with hemp, is absent from the Morvan Massif (Bardet et al., 2008);

- *Archaeophyte weeds*. *Centaurea cyanus*, *Papaver rhoeas*-type and *Polygonum aviculare*-type (Brun, 2011; Brun et al., 2007);

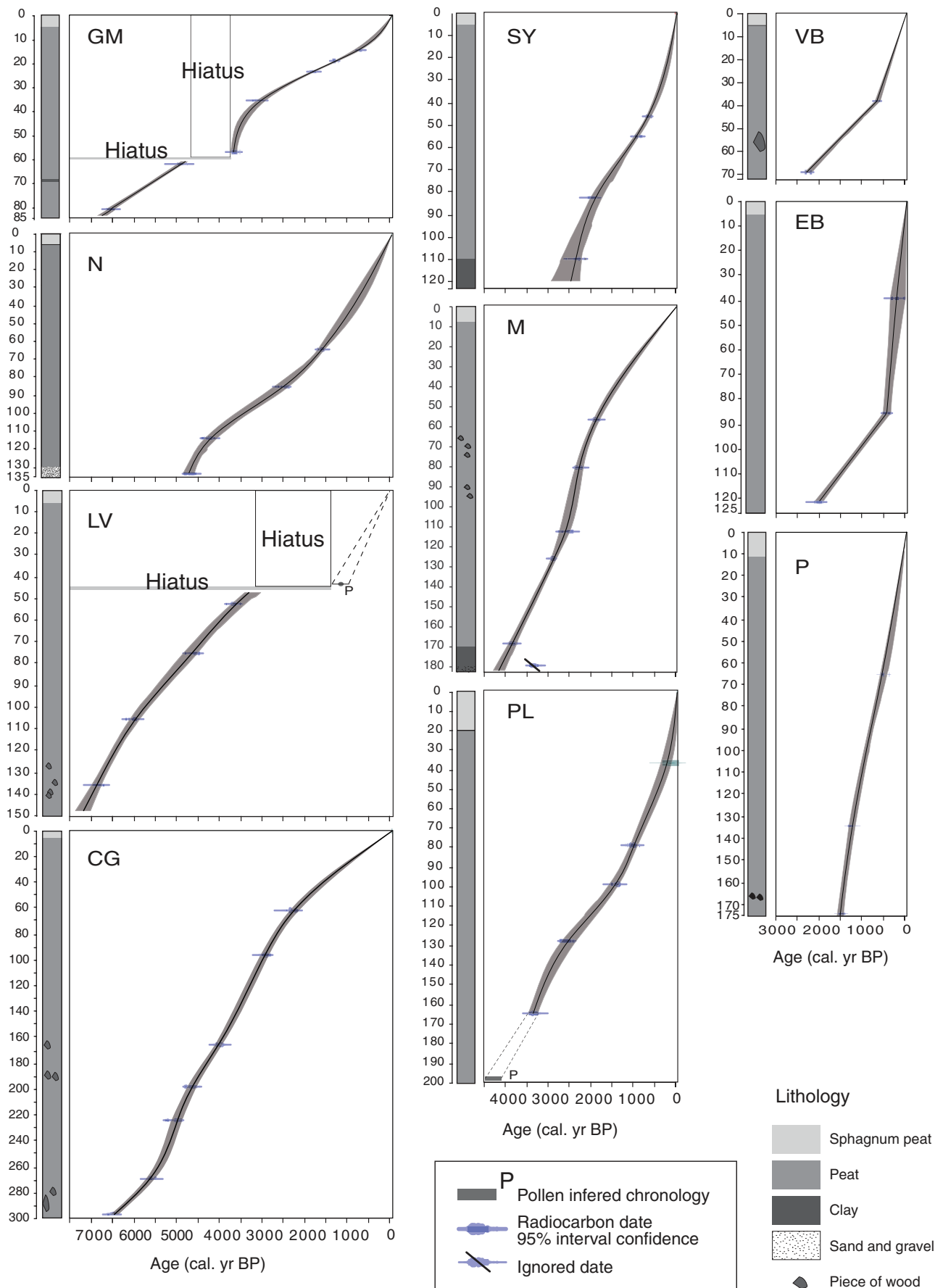


Figure 2. Lithology and age–depth models of the 10 peat cores performed in Morvan, in the northern hills (NH), the southern mountains (SM) and the southern slope (SL). VB: Vergy-des-Brûlons; EB: Etang Bouquin; V: Le Vernay; N: Nataloup; M: Montbé; CG: Champ Gazon; GM: Grand-Montarnu; PL: Port-des-Lamberts; SY: Sources de l'Yonne; P: Poil.

Table 3. Presence of ruderal taxa found in the Morvan's pollen spectra before the Neolithic (7000 cal. BP): ' ' = absent; 'l' = rare; 'X' = present.

| Ruderal taxa | Grand-Montarnu | Le Vernay | Champ Gazon | Nataloup | Etang de Bouquin | Verny des Brûlons |
|-----------------------------|----------------|-----------|-------------|----------|------------------|-------------------|
| <i>Plantago lanceolata</i> | | | | | | |
| <i>Plantago major/media</i> | | | | | | |
| Urticaceae | | | | | | |
| Chenopodiaceae | | | | | | |
| <i>Rumex</i> | x | x | x | | | |
| Rubiaceae | x | x | | x | | |
| <i>Artemisia</i> | x | x | x | x | x | |

- *Ascospores of the coprophile fungal genera Sporormiella.* Recent papers indicate that *Sporormiella* (HdV 113) is the most reliable indicator for documenting pastoral history during the mid- to late Holocene in different areas (Baker et al., 2013).

Indirect indicators of human disturbances consist of the following:

- *Apophytes pollen, including ruderal, heliophilous and meadow taxa.* This group includes taxa commonly used as anthropogenic indicators (Behre, 1981): *Plantago lanceolata*-type, *Plantago major/media*-type, *Urtica*, Chenopodiaceae, *Rumex acetosella*-type, Rubiaceae and *Artemisia*. Some of these taxa were considered here as better indicators than others because they are absent or very rare in pollen spectra before the Neolithic (Table 3, according to Jouffroy-Bapicot (2010)). Other taxa underlined by recent studies on modern assemblages conducted in mountainous areas (Brun, 2011; Brun et al., 2007; Court-Picon et al., 2005, 2006; Mazier et al., 2009; Miras, 2009) were added: *Potentilla*-type, Caryophyllaceae, *Melampyrum*, Compositae, Fabaceae, *Epilobium*, *Echium* and *Scrophularia*-type.
- *Fungal ascospores of Sordaria sp. (HdV 55a) and Cercophora sp. (HdV 112).* These coprophilous fungi are common in the sequences but as indicators of pastoralism, they are not as specific as *Sporormiella* sp., because they are not strictly linked to the dung of herbivores, although they are also saprophytic (Baker et al., 2013).

Anthropogenic impact phases (AIPs) were established from the pollen diagrams by a stratigraphically constrained cluster analysis using constrained incremental sums of squares (CONISS), a function of TGView. The cluster analysis was based on direct and indirect anthropogenic indicators as listed above (pollen and fungal spores), and also included trees, shrubs and Poaceae because they reflect wood clearance that may be related to an anthropogenic origin. Pollen and NPP diagrams are shown in Figure 3.

The degree of perceived human impact was estimated for each AIP by totalling the semi-quantitative scores related to (1) the arboreal pollen/non-arboreal pollen (AP/NAP) ratios, expressing the openness of the landscape, (2) the direct indicators and (3) the indirect indicators. Guidelines for scoring are reported in Table 4. Note that the direct indicators present higher scores than the others which may also be driven by natural dynamics. AIP values do not quantify agro-pastoral pressure and/or woodland openness. However, they offer an element of comparison of the changes in

the palaeoecological perception of anthropization, site by site, in the perspective of a regional synthesis.

The quantifications of the anthropogenic impact of the AIP are shown on a chronological scale using the age-model data provided by CLAM (Figure 4). This graphic representation offers the opportunity to compare the anthropogenic impact site by site and, at the same time, to show the margins of the chronological uncertainty (confidence intervals at 95%) of each AIP. It also allows a comparison of the trends of human impact at the regional scale with the regional chrono-cultural chronology and the climate dynamics in Western Europe provided by independent climate proxies.

Results, vegetation dynamics

Neolithic (c. 7000–4300 cal. BP to c. 5000–2300 cal. BC)

(Figure 3 – Grand-Montarnu: AIP-2 to AIP-5, Le Vernay: AIP-2 to AIP-8 – 7000–4300 cal. BP, Champ Gazon: AIP-1 to AIP-6 and Nataloup: AIP-1 and AIP-2)

Three sequences provide information about the timespan corresponding to the early and middle Neolithic (c. 7000–5200 cal. BP): Grand-Montarnu in the SM (GM-2 and GM-3) and Le Vernay and Champ Gazon in the NH (V-2 to V-5 and CG-1 and CG-2). All of these sequences are characterized by AP values that remain high but irregular, and by the appearance of anthropochore pollen grains. The presence of anthropogenic indicators is not continuous. Several phases alternate, characterized by more or less anthropochore and/or apophyte pollen associated or not with a decrease in AP pollen. Some of them registered a stronger decrease in AP and an increasing curve of Poaceae and/or apophytes. These are associated with the appearance and the increase in *Sordaria* and *Cercophora* spores (GM second part of V-2, V-3 and V-4). From c. 5500 cal. BC on, distinct trends characterize the two parts of the Morvan Massif. In the SM, at Grand-Montarnu (GM-4 and GM-5), cultivated and ruderal taxa disappear and other apophytes recede, despite the rise of Poaceae. In the NH, at Champ Gazon, the presence of the apophytes 'strong indicators' is continuous and *Sordaria* spores appear (CG-3 and GM-4); at Le Vernay, where anthropogenic indicators are constant until c. 6200 cal. BP (V-5 and V-6), an increasing presence of anthropochores and apophytes is registered from 5000 to 4000 cal. BP (V-6, V-7 and V-8). Then, from c. 4500 cal. BP on, a decrease is already registered at Le Vernay (V: end of AIP-8 and beginning of AIP-9). At Nataloup, where the onset of peat accumulation occurs somewhat earlier (N-1 and first half of N-2), anthropogenic indicators are scarce. One exception to this regional scheme is recorded at Champ Gazon where all indicators increase (CG-6).

Bronze Age and Iron Age (c. 4300–2000 cal. BP to 2300–50 cal. BC)

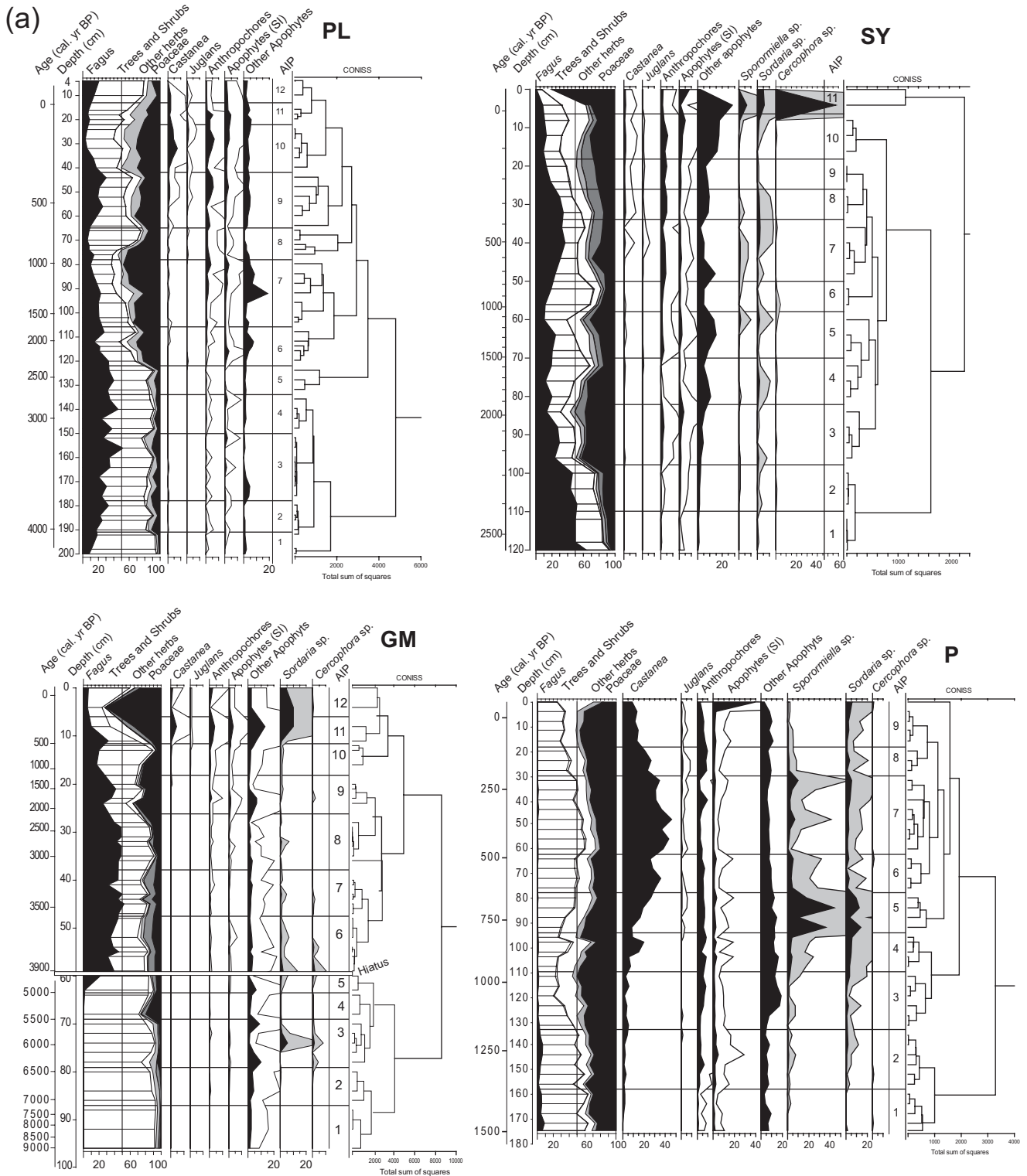
(Figure 3 – Grand-Montarnu: AIP-6 to AIP-8, Port-des-Lamberts: AIP-1 to AIP-6, Sources de l'Yonne: AIP-1 to AIP-3, Le Vernay: AIP-9 to AIP-11, Champ Gazon: AIP-7 to AIP-14, Nataloup: AIP-2 to AIP-4, Verny-des-Brûlons: AIP-1 and Montbé: AIP-1 to AIP-6)

Five sequences provide palaeoecological information about the Bronze Age in the Morvan (4300–2800 cal. BP). In the SM, the beginning of this period corresponds to the onset of peat accumulation in the Port-des-Lamberts, and in the Grand-Montarnu sequence, approximately one millennium is lacking, from 4500 to 3500 cal. BP, because of a hiatus in peat accumulation (Figures 2

and 3a). In the NH, Champ Gazon and Nataloup document all the period, and peat accumulation initiates around 4000 cal. BP in Montbé. A durable hiatus interrupts the sequence of Le Vernay around 3500 cal. BP (Figure 2).

On the whole, at the beginning of this period, in the SM as in the NH, the AP pollen is dominant with values up to 80% of the TLP sum. *Fagus* became the main arboreal pollen in the area (PL-1 and PL-2, N-2, CG-7, V-9 and M-1). However, the arboreal pollen/total pollen (AP/T) curves are irregular in the SM, whereas agro-pastoral indicators remain low and intermittent everywhere.

During middle Bronze Age and the beginning of late Bronze Age (c. 3600–3000 cal. BP), the AP curve, and especially the *Fagus* percentages, rise in Montbé (M-3), and anthropochores disappear at the end of the period. The increase of AP is especially strong at Champ Gazon, up to 95% (CG-8 to CG-10), while anthropochores disappear evenly from c. 3500–3200 cal. BP. At Nataloup, the crop indicators are constant and the AP curve decreases slightly (N-3). At the end of the period, the presence of agro-pastoral indicators increases anew at Champ Gazon (CG-11) even if the forest canopy remains strong. In the SM, the anthropogenic



(Figure 3 Continued)

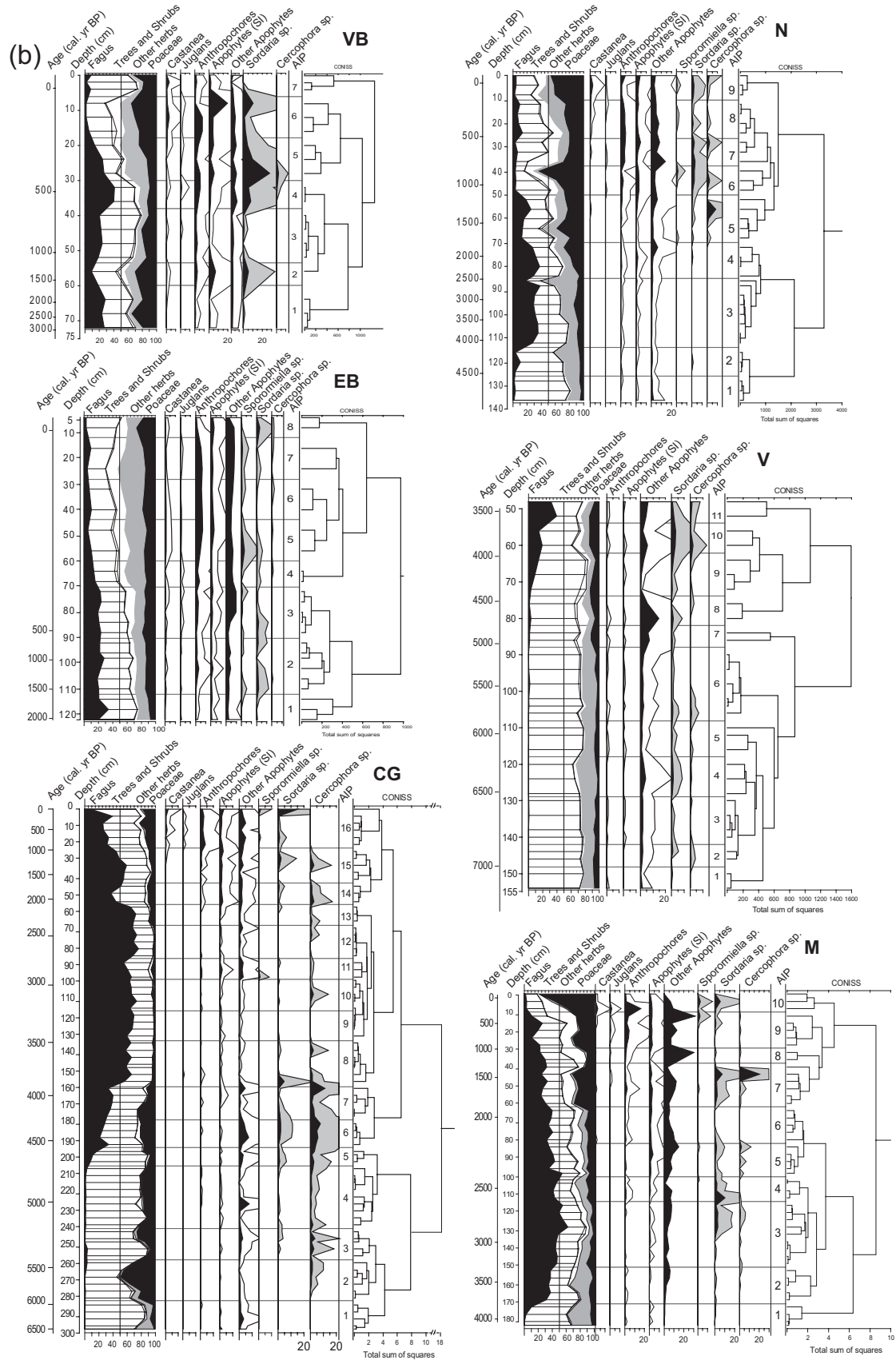


Figure 3. Pollen diagrams with selected taxa (pollen and coprophilous fungi) and cumulative curves related to human impact on vegetation. ‘Anthropochores’ cumulative curve contains herbaceous direct indicators; ‘apophytes (SI)’ cumulative curve contains strong indicators displayed in Table 2 and ‘other apophytes’ cumulative curve contains other apophytes displayed in Table 2. Hollow curves for pollen and grey curves for fungal spores are exaggerated 6x. (a) Three sequences from the southern mountain (SM) and one sequence from the southern slope (SL). As the study of Port-des-Lamberts was performed some years before the others, NPPs have not been considered there. The values of AIP have been calculated according to pollen taxa only. (b) Six sequences from the northern hills (NH). GM: Grand-Montarnu; PL: Port-des-Lamberts; SY: Sources de l’Yonne; P: Poil; VB: Vergy-des-Brûlons; EB: Etang Bouquin; LV: Le Vernay; N: Nataloup; M: Montbé; CG: Champ Gazan; AIP: anthropogenic impact phase.

Table 4. Pollen and NPP inferred degree of human impact for each AIP in the 10 diagrams.

| | | | | | | | | | | | | | | | | | | | | | | | | | |
|-----------------|-----------------|---|---|---|----|----|----|---|---|----|----|-----------------|-----------------|----|----|----|-------------|-----------------|---|---|---|---|----|----|----|
| NH | M - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | N - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | |
| | Open. | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | Open. | 0 | 0 | 1 | 1 | 2 | 3 | 3 | 2 | 1 | | | | |
| | Direct I. | 1 | 1 | 0 | 2 | 0 | 2 | 2 | 2 | 4 | 2 | Direct I. | 2 | 0 | 2 | 2 | 2 | 2 | 4 | 4 | 4 | | | | |
| | Indirect I. | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 1 | 2 | 2 | Indirect I. | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 2 | | | | |
| | Total | 3 | 3 | 2 | 5 | 3 | 4 | 6 | 5 | 8 | 7 | Total | 3 | 1 | 4 | 4 | 5 | 7 | 8 | 7 | 7 | | | | |
| | CG - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | VB - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Open. | 0 | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | Open. | 1 | 2 | 0 | 1 | 2 | 2 | 0 | |
| Direct I. | 0 | 0 | 0 | 2 | 0 | 2 | 2 | 2 | 0 | 2 | 2 | 0 | 0 | 2 | 2 | 4 | Direct I. | 2 | 2 | 2 | 2 | 2 | 4 | 2 | |
| Indirect I. | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | Indirect I. | 1 | 2 | 1 | 2 | 2 | 1 | 1 | |
| Total | 1 | 3 | 2 | 4 | 2 | 5 | 4 | 3 | 1 | 3 | 4 | 1 | 2 | 5 | 5 | 7 | Total | 4 | 6 | 3 | 5 | 6 | 7 | 3 | |
| V - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | EB - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | | | | | |
| Open. | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | Open. | 0 | 1 | 1 | 2 | 2 | 2 | 2 | 1 | | | | | |
| Direct I. | 0 | 0 | 2 | 0 | 2 | 2 | 2 | 2 | 0 | 1 | 1 | Direct I. | 2 | 2 | 2 | 2 | 4 | 4 | 4 | 2 | | | | | |
| Indirect I. | 0 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 1 | 2 | 1 | Indirect | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | | | | | |
| Total | 0 | 1 | 3 | 3 | 3 | 3 | 4 | 5 | 1 | 4 | 2 | Total | 3 | 4 | 5 | 5 | 8 | 7 | 8 | 4 | | | | | |
| SM | PL - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | GM - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| | Open. | 0 | 1 | 1 | 0 | 1 | 2 | 2 | 2 | 1 | 2 | 0 | Open. | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 2 | 1 | 2 | 0 |
| | Direct I. | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 2 | 4 | 4 | 2 | Direct I. | 0 | 2 | 2 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 4 | 2 |
| | Indirect I. | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | Indirect I. | 0 | 1 | 1 | 1 | 1 | 2 | 1 | 1 | 0 | 1 | 2 | 1 |
| Total | 3 | 4 | 4 | 3 | 4 | 6 | 8 | 5 | 7 | 8 | 3 | Total | 0 | 4 | 4 | 2 | 1 | 5 | 4 | 3 | 4 | 4 | 8 | 3 | |
| SY - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | | | | | | | | | | | | | | |
| Open. | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 1 | 2 | 2 | 2 | | | | | | | | | | | | | | |
| Direct I. | 0 | 2 | 4 | 0 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | | | | | | | | | | | | | | |
| Indirect I. | 1 | 1 | 2 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | | | | | | | | | | | | | | |
| Total | 2 | 4 | 8 | 3 | 7 | 6 | 6 | 7 | 8 | 8 | 8 | | | | | | | | | | | | | | |
| SL | P - AIP | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | | | | | | | | | | | | | | | |
| | Open. | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | | | | | | | | | | | | | |
| | Direct I. | 2 | 4 | 4 | 4 | 8 | 8 | 8 | 4 | 4 | | | | | | | | | | | | | | | |
| | Indirect I. | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | | | | | | | | | | | | | | | |
| Total | 5 | 7 | 8 | 8 | 12 | 12 | 12 | 8 | 8 | | | | | | | | | | | | | | | | |

Values attributed to Direct Anthropogenic Indicators:

0– Absent; 2 – Discrete; 4 – Present; 8 – Abundant

Values attributed to Indirect Anthropogenic Indicators:

0– Absent; 1 – Discrete; 2 – Present; 3 – Abundant

Values attributed to openness, according to the AP/NAP ratio:

0– None; 1 – Slight; 2 – Important; 3 – Very important

impact is moderate, but a clear decrease in the *Fagus* curve is registered at Port-des-Lamberts (PL-transition AIP-3 to AIP-4).

During the early Iron Age (3500–2400 cal. BP), pollen and fungal human indicators are present but scarce, with a high AP/T ratio and low percentages of apophytes and anthropochores. This is obvious in the SM at Grand-Montarnu, Port-des-Lamberts (GM: middle part of AIP-8 and PL: second half AIP-4 and AIP-5) and in the sequence of Sources de l'Yonne that begin at around 2600 cal. BP (SY-1), and in the NH at Champ Gazon where anthropochores disappear anew (CG-12). The same situation characterizes Nataloup, except a punctual but strong fall of *Fagus* percentages around 2500 cal. BP (N: end of AIP-3). In Montbé, at the same time, a more important and long-lasting impact is highlighted by a *Fagus* curve below 50% and increasing percentages of anthropochores, apophytes and *Sordaria* spores (M-4). During the second Iron Age (2400–1900 cal. BP), a concordant and strong anthropogenic impact can be observed for the first time throughout all the diagrams (PL: first half of AIP-6 and SY-2 and SY-3, GM: second half of AIP-8, VB: second half of AIP-1, N: end of AIP-4, CG: transition AIP-13/AIP-14, M-6 and N: first

half of AIP-5). This is especially obvious in the SM, in the two peat deposit located in the vicinity of the Yonne Springs, Port-des-Lamberts and Sources de l'Yonne (PL-6 and SY-3). This anthropogenic impact combines different pollen and fungal agro-pastoral indicators and woodland openness, and increases until the beginning of the following period. *Castanea* appears for the first time.

Roman period (c. 2000–1500 cal. BP to c. 50 cal. BC to 500 cal. AD)

(Figure 3: Grand-Montarnu: AIP-9, Port-des-Lamberts: AIP-6 and AIP-7, Sources de l'Yonne: AIP-4, Champ Gazon: AIP-14 and AIP-15, Nataloup: AIP-4, Verny-des-Brûlons: AIP-1, Montbé: AIP-1 to AIP-6 and Etang Bouquin: AIP-1)

Roman time is characterized by contrasting situations throughout the Morvan Massif. In the SM, the Roman impact grows slightly compared to the late Iron Age on the sequence of Grand-Montarnu where the AP curve clearly decreases (GM: upper part of AIP-8 and AIP-9), and in Port-des-Lamberts (PL: upper part of AIP-6 and beginning of AIP-7) where crop indicators increase.

On the contrary, in the Sources de l'Yonne (SY-4), crop indicators totally disappear and grazing indicators remain low. Beech pollen percentages remain stable even if the AP pollen percentages increase (due to *Salix* – willow, *Corylus* – hazelnut and *Quercus* – oak, which are not represented on the anthropogenic synthetic diagrams, but can be found in Jouffroy-Bapicot (2010)).

In the NH, the Roman period is characterized by an anthropogenic impact that is comparable to those of the late Iron Age, or that increases (EB-1, VB-2, N-4, CG-14, M-7). Each diagram shows a decrease in AP mainly driven by the decrease of *Fagus*.

The perception of human activities and occupation is also contrasted at the end of the period, during the late Antiquity (3rd and 4th centuries AD). For example, in the NH, a decreasing trend in crop indicators is observed at Nataloup (N-5), despite the continuous decrease of the AP curve. On the contrary, at Champ Gazon (CG-first sample of AIP 5), the *Fagus* rise again, whereas crop and grazing indicators persist. During this period, and to a lesser extent during the whole Roman period, the detailed timing of vegetation changes must be considered with caution because the time resolutions of the available sequences are unequal, and are in some case very low (e.g. VB-2).

The Middle Ages (c. 1500–500 cal. BP to c. 500–1500 cal. AD)

(Figure 3 – Grand-Montarnu: AIP-10, Port-des-Lamberts: AIP-7 to AIP-9, Sources de l'Yonne: AIP-5 to AIP-7, Poil: AIP-1 to AIP-6, Champ Gazon: AIP-15 and AIP-16, Nataloup: AIP-5 to AIP-7, Verny-des-Brûlons: AIP-3 and AIP-4, Montbé: AIP-7 to AIP-9 and Etang Bouquin: AIP-2)

Almost all the sequences from the Morvan Massif record the impact of human settlement during the first part of the Mediaeval period (1500–1000 cal. BP). In the SM, the transition between the late Antiquity and the early Middle Ages is related to an increasing presence of anthropochores and apophytes pollen (PL-7 and SY-5). Slightly later, an increase of coprophilous fungi is also recorded at SY and correlates with a decrease of AP below 50%. In the NH, agro-pastoral indicators rise and the openness of woodland occurs later: around 1200 cal. BP at Champ Gazon (CG: upper part of AIP-15), Nataloup (N-6) and Montbé (M: transition AIP-8/AIP-9). On the contrary, the AP/T percentages remain steady at Etang Bouquin (EB-4) and increase at Verny-des-Brûlons (VB-4). Then, during the second part of the Middle Ages (classic and late Middle Ages 950–500 cal. BP), the presence of human indicators is steady or increasing in the NH. The rise of the AP values in the peat deposit from the SM (GM-10, PL-8 and SY-6) is due to *Betula* percentages increase (Jouffroy-Bapicot, 2010).

The onset of peat accumulation begins around 1500 cal. BP on the southern slope of the massif at the little sedge-fen of Poil. Pollen analyses give a detailed evolution of vegetation during the Middle Ages (P: AIP-1 to AIP-3), showing an increasing impact of agro-pastoral activities. Percentages of *Fagus* pollen are much lower here than in other sequences. Pollen and fungal remains indicate agro-pastoral pressure, and the percentages of crop pollen reach 8% at the end of the AIP P3. While only some occurrences of *Castanea* pollen appear on the diagrams from the Morvan Massif since the 1st century AD, the presence of this taxa at Poil is continuous, with low but increasing percentages. From c. the 11th to 15th century, agro-pastoral indicators reach a maximum by combining anthropochores pollen grains and a large amount of coprophilous fungi, particularly *Sporormiella* and *Sordaria*. The percentages are high, with a maximum of 40% of the TLP sum in AIP P-5.

Modern times (c. 500 cal. BP to present to c. 1500 cal. AD to present)

(Figure 3 – Grand-Montarnu: AIP 11 and AIP-12, Port-des-Lamberts: AIP-9 to AIP-12, Sources de l'Yonne: AIP-7 to AIP-11, Poil: AIP-7 to AIP-9, Champ Gazon: AIP-16, Nataloup: AIP-8 and AIP-9, Verny-des-Brûlons: AIP-4 to AIP-7; Montbé: AIP-9 and AIP-10 and Etang Bouquin: AIP-3 to AIP-8)

As mentioned above, even if this period is unevenly documented by the pollen spectra (three samples during this timespan at Champ Gazon versus 16 samples at Poil), a decreasing trend of arboreal pollen is noted at the scale of the massif. A gradual and permanent decline in the forest cover begins during the 16th century and persists until the 19th century. The AP curves drop below 50% of the TLP sum almost everywhere on the massif. The decrease is especially strong in the SM (GM-11, PL-10, SY-8) and in the extreme northern part of the massif (VB-5, EB-4). It is less important elsewhere in the NH, at Nataloup and Montbé (N-8, M-9), and moreover at Champ Gazon, where the percentages of arboreal pollen, particularly of *Fagus* pollen, remain high, evoking a wooded zone persisting around the peat deposit (CG-16). The agro-pastoral indicators remain stable or show a moderate increase (GM-11, CG-14). Cultivated trees, *Juglans* and especially *Castanea*, increase everywhere. The percentages of chestnut tree remain moderate in SM as in NH, but they reach a maximum during the 16th century in the SL, with more than 40% of the TLP sum (P-7). Later, the curve decreases regularly, from the end of the 16th century to the present-day. In the Morvan Massif, from north to south, the anthropogenic impact reaches maximum values during the 17th and 18th centuries, especially due to the dramatic decrease in *Fagus*. The upper parts of the diagrams show an overall decrease in crop indicators, and the arboreal pollen increases anew. Some sites still have fungal and pollen indicators of pastoralism: Nataloup and Montbé in the NH (N-9 and M-10) and Sources de l'Yonne in the SM (SY-11). These peat deposits and their close surroundings are currently used for cattle grazing. Overall, arboreal pollen increases again with percentages of *Pinus* and *Picea* that are higher than ever during the studied period.

Discussion

Discriminating local versus regional impacts

The comparison of the 10 diagrams and of the time series compiled in Figure 4 makes it possible to observe the spatio-temporal variability of human impact at the regional scale. Some events, recorded at one single site, are absent from others located at only a few kilometres. For example, it is obvious in the NH during late Bronze Age (Figures 3 and 4). This pinpointed the very local palaeoecological information provided by each small peat deposit (Sugita, 1998). However, some trends at the scale of the massif, or at the SM versus NH scale, are notable and will be detailed below. The sequence located on the southern slope (Poil) has a more marginal situation than the others. The magnitude of human impact during historic times is obviously higher than on the rest of the massif, the beech/oak forest is not noticeable and land uses seem different. This singular pollen diagram evidences the homogeneity of the others. It is worth mentioning that on the Morvan Massif, the woodland remains important throughout time, characterized by a beech/oak forest and a moderate agro-pastoral impact.

One limit of this approach is the chronological control. Despite the number of radiocarbon dating, the compaction of some peat cores does not allow us to detail the reconstruction. Because of the discrepancy of time resolution between each sequence, some decennial or multidecennial events recorded by one core might

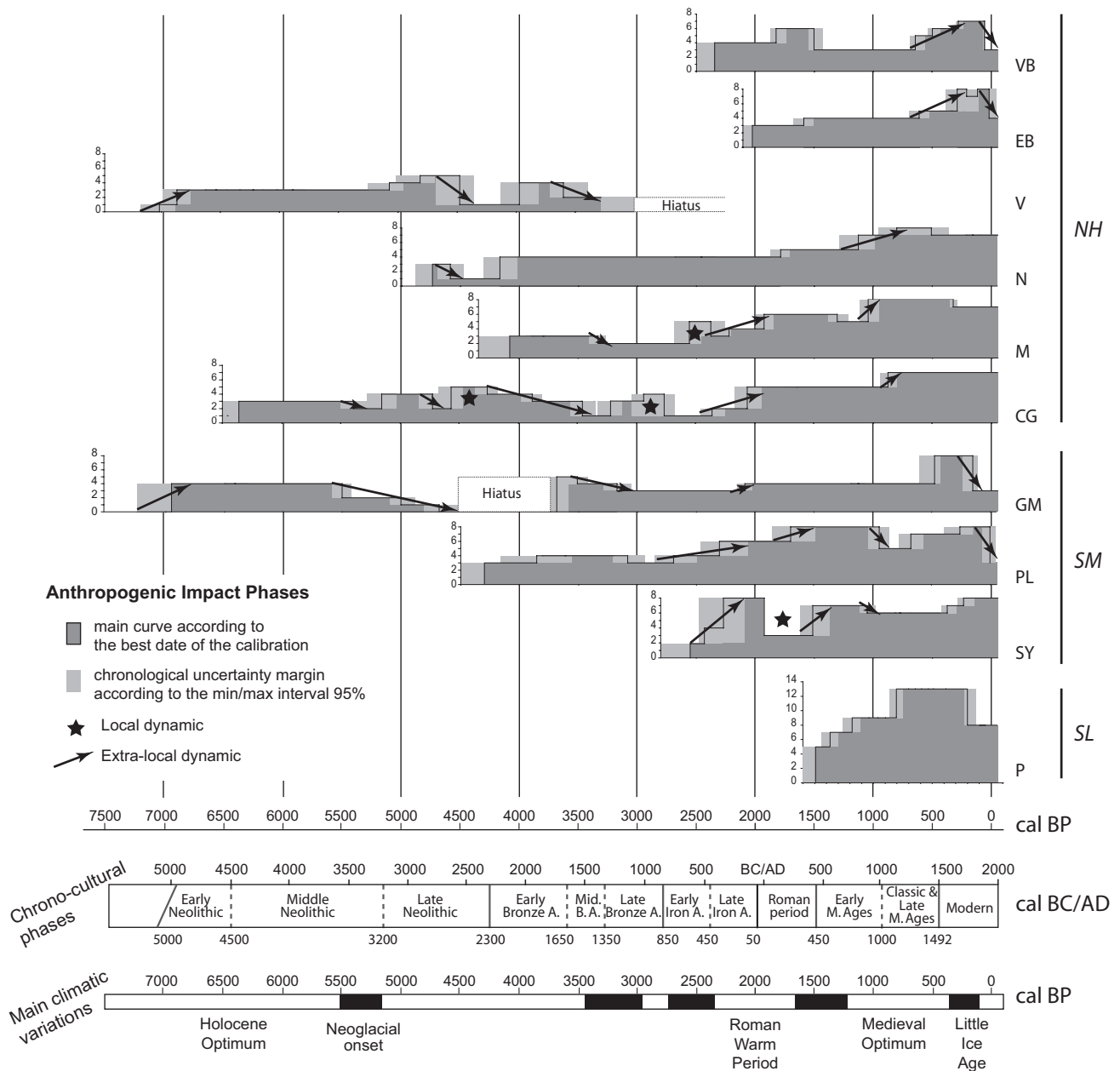


Figure 4. Human impact on the vegetation of the Morvan Massif during 7000 years. Chronological representation of the AIP quantifications from the 10 pollen diagrams. The main climatic variations of the mid-late Holocene are depicted in the following: Büntgen et al. (2011), Joerin et al. (2006, 2008) and Magny (2004). In black: colder and wetter phases. NH: northern hills; SM: southern mountains; SL: southern slope; VB: Verny-des-Brûlons; EB: Etang Bouquin; LV: Le Vernay; N: Nataloup; M: Montbé; CG: Champ Gazon; GM: Grand-Montarnu; PL: Port-des-Lamberts; SY: Sources de l'Yonne; P: Poil.

not appear in others. However, some trends are clear and allow the identification of key phases in the vegetation history of the massif that may be related to human pressure and that can be compared to major Holocene climate dynamics.

The main features of the vegetation history

Signs of human impact appear from the beginning of the early Neolithic. These impacts are moderate, with values from 3 to 4 (Figure 4). They are sparse, short-lived and generally without significant openings in the woodland. The palaeoecological data illustrate a widespread but moderate and scattered agro-pastoral impact during the middle Neolithic, followed by a transition towards a concentration of human impact around one site in the late Neolithic, the bog of Champ Gazon. The only well-known

archaeological site from the late Neolithic and the early Bronze Age in the Morvan Massif is located 3 km from the peat deposit (Martineau et al., 2011). This observation is consistent with a spatial analysis of archaeological data at the Burgundy scale, which concludes in a territorial concentration during the late Neolithic (Pillot et al., 2013).

The presence of pastoral activities in the vicinity of the peat deposits during Prehistory remains unclear. Ecological changes at the peatland scale are obvious (e.g. at Champ Gazon), but the role of human society cannot be clearly associated because of the lack of robust local indicators of grazing, namely, the ascospores of *Sporormiella* (Baker et al., 2013). In the Morvan Massif, the genera *Sordaria* and *Cercophora* are the most common coprophilous fungi, and they coincide with, or lag slightly behind, the first human disturbances recorded by pollen analysis (Jouffroy-Bapicot, 2010). But these fungi are associated with decaying

wood as well as dung. In recent studies performed in peat deposits from different geographical areas, *Cercophora* and *Sordaria* are mentioned during the initial phases of anthropization, for example, in Greenland (Schofield and Edwards, 2011) or in the north of Spain (Ejarque et al., 2010; Lopez-Merino et al., 2010; Mighall et al., 2006). Different interpretations are suggested by the authors: wild herbivores, domestic livestock, decaying wood and/or leaves on the substrate. In testing modern samples in the Morvan, a large amount of these genera have been found (1) in the dung of highland cattle grazing at the present time in peaty meadows, (2) in moss pollsters collected in the grazing area (Jouffroy-Bapicot, 2010) and (3) in the upper part of the studied sequences where cattle are grazing nowadays. Nevertheless, in modern samples, these genera are always associated with *Sporormiella*. Even if fungal associations dominated by *Cercophora* and/or *Sordaria* seem evenly linked to human disturbances, further studies are needed to better understand their significance, and more generally, the significance of assemblages of coprophilous fungi ascospores without *Sporormiella*, and to assess the extent to which they could be related to grazing pressure.

Studies combining palynology and geochemical analyses on 3 of the 10 sequences from the Morvan Massif have underlined the attractive role of mining resources during the Metal Ages (Jouffroy-Bapicot et al., 2008; Monna et al., 2004). Atmospheric metallic micro-pollutants have been found as early as the early Bronze Age/middle Bronze Age or late Bronze Age at different places in the SM (c. 1600–900 cal. BC). During the Bronze Age, these activities led to localized and moderate impacts on woodland, and agro-pastoral indicators remain moderate on the whole.

Later, during the early Iron Age, a period poorly documented by archaeology, the presence of human activities is highlighted by geochemical clues of metallurgical activities in the vicinity of Grand-Montarnu, and pollen and fungal agro-pastoral indicators throughout the massif. Anthropogenic impact as well as metallic pollutions increase during the late Iron Age, and reach a maximum during the two last centuries BC. This period corresponds to the Aeduan period and the occupation of Bibracte, where metal working is well-known (Guillaumet and Dhennequin, 2008). In addition to archaeological knowledge, palaeoecological studies highlight both the regional scale of this human pressure dynamic, as shown in Figure 4, and the presence of agro-pastoral activities, even in the highest part of the massif. Recent archaeological surveys in the close vicinity of the Yonne's springs resulted in the discovery of a large settlement (80 ha), probably connected to the oppidum of Bibracte, and characterized by a short occupation between 50 and 20 BC (Haupt et al., 2007). The palaeoecological data show that the construction of the agglomeration took place in a previously wide open area, related to agro-pastoral activities.

Palaeoecological data suggest that the Roman conquest led to a reorganization of land uses. On the whole, agro-pastoral pressure remains moderate in the massif, while a decrease in woodland pollen occurred during at least the 3 first centuries AD, and could be more sustainable around some sites (e.g. Nataloup in the NH and Port-des-Lamberts in the SM), until the late Antiquity. Beech is then the main species affected by woodland exploitation. In the SM, after the abandonment of both the oppidum of Bibracte and the agglomeration around the Yonne's springs, archaeology has attested to a religious presence in the area, but nearby agro-pastoral activities are no longer registered by pollen and NPPs.

Considering the lack of archaeological data concerning the early Middle Ages, human impact, as early as the 5th century AD in the SM, is surprisingly strong during this period. The early Middle Ages seem to be a new phase of agro-pastoral expansion at the scale of the massif. This period is known for cold and high moisture climate, which may offer poor conditions for agriculture, and for socio-economic instability induced by the migration

of Germanic peoples (Büntgen et al., 2011). In the Jura Mountain, for example, this period clearly corresponds to a rural abandonment and forest return (Gauthier, 2004; Gauthier and Richard, 2007). The Morvan, as well as other places on the edge of the French Massif Central (Miras, 2004), seems to be less affected, perhaps because it is located further from the main migration roads, and/or because Atlantic climatic influences, combined with lower altitudes, attenuated the cooling effect compared to the Jura and Alps mountains. Human pressure during the following Mediaeval period (11th to 15th centuries) appears in the continuation of the early Middle Ages, evoking an early formation of agricultural territories in the Morvan. From the Middle Ages on, major monastic centres are located in north Morvan, namely, Vézelay and the abbey of la Pierre-qui-Vire. Nevertheless, the lack of recent published data about this topic did not permit to consider their role in the human land use in the NH. Deposits of atmospheric micro-pollutants, recorded in the southern and the northern part of the massif, may be due to a new mining and metal working phase operated on a regional scale. However, the influence of a supra-regional pollution must be taken into account for this period as well (Jouffroy-Bapicot et al., 2008).

The palynological data indicate the cultivation of chestnut trees on the southern slope probably since the early Mediaeval period. Later, chestnut production seems to have an important part in Mediaeval and modern land use in south Morvan. The cultivation of chestnut for food supply was well-known in the Morvan during the 19th century, and it is known that the thin and acidic soils of the Morvan are, in general, not suitable for cereal cultivation. The pollen data indicate that in this part of the Morvan, as elsewhere in Western Europe according to historical (Pitte, 1986) and palynological (Conedera et al., 2004) data, the cultivation of chestnut flourished from the 11th to the 16th century. The high range of *Castanea* percentages (from 10% to 40%), during at least four centuries, attests to the cultivation of chestnut trees in orchards, probably for the production of staple foods. Crop cultivation and/or breeding were also locally important during this period. In addition to the high percentages of cultivated plants, the palaeoecological analysis evidences a large amount of coprophilous fungi. The quantities are much higher than those found in other samples, even those of the same sequence. This might not be due to a variation of concentration because the age–depth model suggests a regular accumulation rate. Soil amendment in the watershed could also explain the quantity of dung-related fungal spores, especially when the proximity of cultivated fields is shown by taxa such as *Centaurea cyanus* (Jouffroy-Bapicot, 2010), a weed which is a strong local indicator of cultivation (Brun, 2011).

At the end of the 16th century, the development of the timber floating industry in the Morvan Massif and its flood transport to Paris sustainably promoted woodland at the expense of agricultural land (Poux et al., 2011). It is also worth mentioning the activity was a key phase in the formation of the Morvan landscape. The dramatic decrease in beech observed throughout the pollen records does not necessarily attest to a completely deforested landscape but rather depredated woodland. Beech trees, coppiced to produce firewood for Paris may have had a very low pollen production. The long-term exploitation of the beech forest drove palaeoecological changes from the 18th to the early 20th century, but it does not seem to have been homogenous at the regional scale. It appears stronger in the SM than in the NH, except in the vicinity of the ponds used for floating (EB and VB). These two sites had a very similar palaeoecological history for at least the last five centuries, probably related to their role in the floating process.

In the upper part of the diagrams, pollen spectra from the past 70 years show a decrease in human pressure on landscape, which is, at least in part, in concordance with the historical trend

of depopulation of the Morvan. A rural exodus began in the mid-20th century. Modern pollen spectra illustrate the current woodland extensively replanted after the collapse of the firewood activity around 1900. The woodland which covers roughly one half of the massif at present is mainly an artificial forest. Trees planted are mainly coniferous trees, indigenous but rare species such as spruce, or introduced species, mainly Douglas-fir and larch. All of them have very low pollen productivity and dispersion. Moreover, these species are often young cutting, that is, before flowering, such as Christmas trees. This current situation demonstrates the problem of perceiving some type of land use based only on pollen analysis, such as forest management.

Climate drivers as favouring or limiting factors

The comparison of anthropogenic pressure with the main phases of climate changes, resumed from independent proxies such as lake-level fluctuations (Magny, 2004), tree-ring series (Büntgen et al., 2011) or glacier fluctuations (Joerin et al., 2006, 2008) in Figure 4, emphasizes the extent to which climate drivers acted as favouring or limiting factors in human history. Pre- and Protohistoric agro-pastoral societies are potentially sensitive to climate change. In the Morvan, the decrease of anthropogenic indicators during the middle Neolithic in the SM coincides with the Neoglacial onset. However, the same trend is not obvious in the NH. Moreover, just one core provides information here, with a low time resolution, and it is difficult to make a direct link with the cooler and moister climate. The decrease in human pressure during the middle Bronze Age, a cool and moist phase corresponding to an abandonment of lacustrine habitats in the Jura and the Alps (Magny, 2004; Magny et al., 2007), is more obvious at the scale of the Morvan Massif. Nevertheless, the absence of a robust archaeological data set implies a cautious interpretation in terms of the settlement of the whole massif: the decrease in anthropogenic indicators in the diagrams may also reflect a decrease in the attractiveness of the area surrounding the wetlands rather than a decline in human pressure at the regional scale.

The increasing human impact during the late Iron Age and the Roman period in the Morvan is in keeping with the middle European trend which coincides with a wetter and warmer climate (Büntgen et al., 2011). Moreover, sociocultural conditions may also be of primary importance at this time. For example, it has been shown that the attractiveness of the Morvan is also due to its mineral resources. This activity is less impacted by climate drivers than agriculture.

The impact of the 'Little Ice Age' on the Morvan Massif is not clear, probably mainly because of the specific land use prevalent on the massif at that time. The exploitation of firewood relegated agro-pastoral activities to a marginal activity. Moreover, the timber floating industry in the Morvan strongly depended on socio-economic drivers: it began because of the depredation of woodland near Paris, and the end of the activity is related to the preference for coal as heating fuel.

Finally, it is worth mentioning that the period during which the cultivation of chestnut tress flourished on the southern slope of the massif coincided with the Mediaeval Climate Optimum. Favourable climate conditions may have facilitated this cultivation, which was at the edge of the known chestnut production area during the late Middle Ages and modern times (Conedera et al., 2004; Pitte, 1986).

Conclusion

The palaeoecological investigations performed on 10 cores from the Morvan Massif add to our knowledge of human history in this middle mountain area. They reveal a clear human presence during

periods that were formerly poorly documented, such as the onset of the Neolithic period, the Bronze Age, the early Iron Age and the early Middle Ages. They also provide new data about better known periods such as the widespread occupation of the massif in the late Iron Age; the importance of chestnut cultivation, probably in orchards, on the southern slope of the massif from the 11th to the 16th century; or the impact of modern firewood exploitation on the forest. In this kind of environment, palaeoecological studies offer the opportunity to obtain information about human history when archaeological and historical data are scarce and/or difficult to obtain. The quantification of human impact allowed a site-by-site comparison, and the identification of regional and intra-regional trends, which is not possible or more uncertain when palaeoecological information comes from a single core. The human land-use pattern during the last seven millennia is typical of middle mountain areas. Acidic and thin soils are not suitable to the development of widespread agriculture, so that periods such as the late Neolithic, the Roman period and the 20th century are marginal. In contrast, the major phases are related to the exploitation of natural resources, such as minerals during the Metal Ages or wood during the modern times.

Acknowledgements

This work was carried out as part of the programme 'Environnement du Mont-Beuvray' of the European archaeological Centre of Mont-Beuvray, Bibracte (Burgundy, France). We thank all the persons involved in this programme, especially B. Forel and J-P. Guillaumet, and the 'Bibracte team', especially V. Guichard (General Director) and P. Paris (Archaeologist, assistant to the scientific director). We gratefully thank the two anonymous reviewers for their valuable comments and suggestions on the manuscript.

Funding

This research was also partly supported by the ACI Tepaneo programme of the CNRS, co-headed by R. Martineau, B. Vannière and M. Gabillot.

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