# Quantitative reconstruction of climatic variations during the Bronze and early Iron ages based on pollen and lake-level data in the NW Alps, France

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## Abstract


Vegetation and lake-level data from the archaeological site of Tresserve, on the eastern shore of Lake Le Bourget (Savoie, France), are used to provide quantitative estimates of climatic variables over the period 4000–2300 cal BP in the northern French Pre-Alps, and to examine the possible impact of climatic changes on societies of the Bronze and early Iron Ages. The results obtained indicate that phases of higher lake level at 3500–3100 and 2750–2350 cal BP coincided with major climate reversals in the North Atlantic area. In west-central Europe, they were marked by cooler and wetter conditions. These two successive events may have affected ancient agricultural communities in west-central Europe by provoking harvest failures, more particularly due to increasing precipitation during the growing season. However, archaeological data in the region of Franche-Comté (Jura Mountains, eastern France) show a general expansion of population density from the middle Bronze Age to the early Iron Age. This suggests a relative emancipation of proto-historic societies from climatic conditions, probably in relation to the spread of new modes of social and economic organisation.


## 1. Introduction

In addition to influences of climatic variations, the evolution of the environment during the second half of the Holocene appears to be characterised by an increasing impact of human societies on natural landscapes. After the expansion of a new subsistence strategy based on farming and animal breeding during the Neolithic, the diffusion of the metallurgy and its associated technological efficiency marks a second step towards a possible increase in anthropogenic disturbances of the natural environment. However, despite this general context of economic and technical advances, recent investigations have suggested that Bronze Age societies in Central Europe were relatively sensitive to the climatic variations which punctuated the late Holocene (Tinner et al., 2003; Zolitschka et al., 2003). In the middle 20th century, German archaeologists pointed to apparent synchronisms between a climatic reversal at the Subboreal–Subatlantic transition and the cultural transition from the Bronze to the Iron Ages (Smolla, 1954; see also Millotte, 1963 and references therein). The general abandonment of lake-dwellings during the middle and at the end of Bronze Age to the north of the Alps (Magny, 1993) appears as another print of climate on Bronze Ages societies. This may support the hypothesis of possible strong influences of climatic conditions on human cultural evolution during protohistoric times in Western Europe.

However, while multiple Holocene climate records have been established in Central Europe from various archives (Haas et al., 1998; Schmidt et al., 2002; Heiri et al., 2003; Zolitschka et al., 2003; Magny, 2004; Nicolussi et al., 2005), quantitative reconstructions of seasonal changes in both temperature and precipitation are still rare. However, such seasonally resolved quantitative records are nevertheless needed for a better understanding of possible links between variations in the climate and the history of societies during the Bronze and early Iron Ages. As a contribution to these quantitative investigations, this paper presents a reconstruction of temperature and precipitation changes based on the modern analogue method using both pollen and lake-level data obtained at Tresserve, an archaeological site on the south-eastern shore of Lake Le Bourget in the northern French Pre-Alps.

## 2. Study site and methods

Lake Le Bourget (45°45′N–5°55′E) is a 18-km-long narrow and over-deepened basin of glacial origin. It is located at an altitude of 231.5 m in the northern French Pre-Alps (Fig. 1). The lake area is ca. 44.6 $km^2$ and the maximum depth reaches 150 m. Its catchment area covers 550 $km^2$ with a maximal elevation at 1845 m a.s.l. However, during major flooding events of the Rhone River (a catchment of 4000 $km^2$ culminating at 4807 m a.s.l.), the outlet of the lake functioned as an inlet and sometimes provoked catastrophic flooding before recent arrangements to regulate lake-level fluctuations (Chapron et al., 2005). The lake is fed by seasonal rain and snow melting. The climate of the area can be defined as temperate. The mean annual temperature is ca. 12 °C, in the coldest month 3 °C and in the warmest month 21 °C. Annual precipitation reaches ca. 1150 mm. Deciduous forests with *Alnus*, *Quercus* and *Corylus* dominate areas below 700 m a.s.l., while *Fagus* and *Abies* dominate the montane belt (700–1500 m a.s.l.). *Picea abies* and *Pinus uncinata* characterise the subalpine forests above 1500 m a.s.l. The Holocene deposits of Lake Le Bourget are mainly composed of sand (detrital input from the catchment area) and authigenic carbonate lake marl.

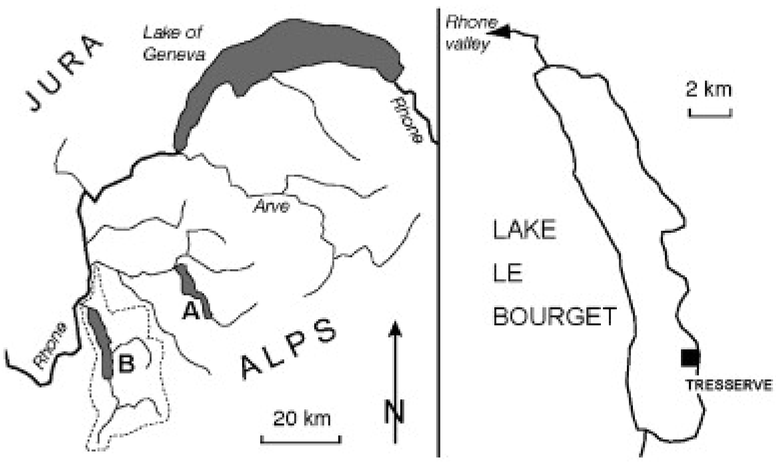

Fig. 1. Geographical location of site Tresserve, Lake Le Bourget, in the north-western French Pre-Alps. Broken line: catchment area of Lake Le Bourget without flooding from the Rhone river: (A) Lake Annecy, (B) Lake Le Bourget.

Recent subaquatic archaeological investigations at Tresserve, on the littoral platform along the south-eastern shore of the lake have discovered remains of late Bronze Age lake-dwellings (Marguet, 1995; Marguet and Billaud, 1997; Billaud, 2006; Billaud and Marguet, 2006). The chronology is based on (AMS) radiocarbon dates from terrestrial plant macrofossils and on tree-ring dates from wooden posts found in archaeological layers and corresponding to parts of Bronze Age houses. The radiocarbon dates were calibrated using IntCal 5 (Stuiver et al., 1998). Cores have been taken for pollen and sediment analysis. This paper presents results obtained from core 5 (Fig. 2).

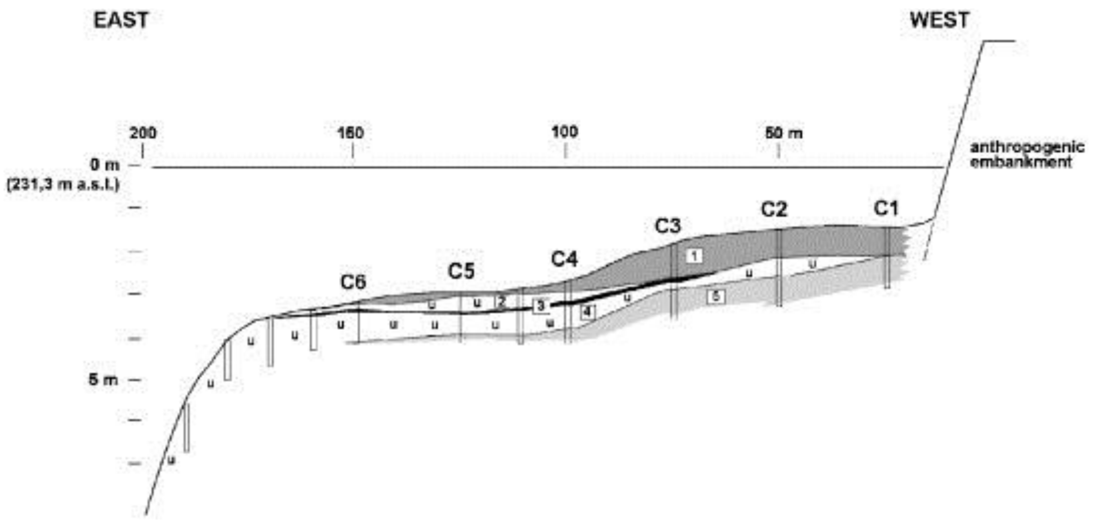


Fig. 2. Stratigraphic section established at Tresserve with the location of cores 5 and 6. The vertical bars correspond to sediment cores.

Samples for pollen analysis were treated by acetolysis and HCl. They show excellent preservation and high concentration of pollen and spores. Usually, a sum of at least 500 pollen grains was counted in each sample. The results of the counts are presented in a simplified percentage pollen diagram (Fig. 3). All arboreal and non-arboreal pollen is included in the basic pollen sum, while spores are excluded.

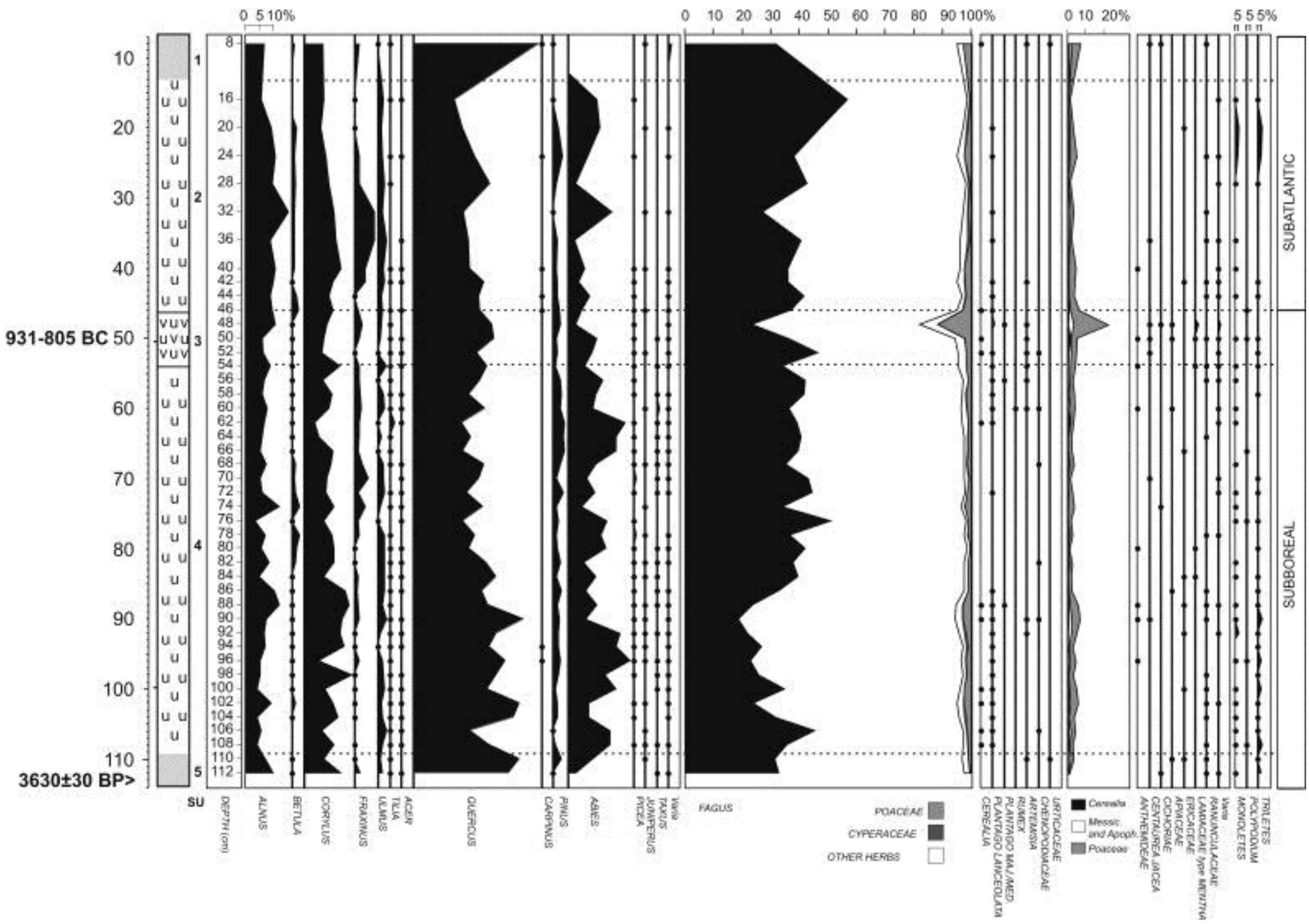


Fig. 3. Simplified pollen diagram of core 5. SU: sediment units.

The lake-level fluctuations were reconstructed using a specific method developed by Magny, 1998, Magny, 2004 and Magny, 2006. It is based on multiple lines of evidence, including changes in sediment texture, lithology, and the relative frequency of various carbonate concretion morphotypes of biochemical origin. Each morphotype shows a specific spatial distribution from the shore to the extremity of the littoral platform, with the successive domination of oncolites (nearshore areas with shallow water and high-energy environment), cauliflower-like forms (littoral platform), plate-like concretions (encrustations of leaves from the Potamogetonion and Nymphaeion belts), and finally tube-like concretions (stem encrustations from the Characeae belt on the platform slope). The reconstruction of a curve of relative changes in lake level is based on the ratio between the total scores of indicators of low lake-level conditions (e.g. oncolites, cauliflower-type carbonate concretions) and those of high lake-level conditions (e.g. plates and tubes) (Magny, 2006).

The quantitative estimate of climatic parameters from pollen and lake-level data is based on a model developed by Guiot et al. (1993) and Cheddadi et al. (1997) to refine the palaeoclimatic reconstruction based only on pollen data. The method has been extensively described in Magny et al. (2001). The principle is to find, for each fossil pollen assemblage, several similar modern pollen spectra (modern analogues). This approach relies on the degree of similarity (or distance) between fossil assemblages and spectra from a modern reference pollen data base, including more than 1300 European surface pollen samples from which 8–10 modern analogues are selected. The climate of these analogues is averaged to provide an estimate of the fossil assemblage climate.

However, problems arise when reconstructing past precipitation because, in Europe, the moisture of the growing season is rarely the main limiting factor for vegetation on a regional scale and modern analogues tend to span a wide range of precipitation estimates. As pointed out by Guiot et al. (1993), lake-level records can provide a complementary source of information on precipitation changes. They offer an additional constraint for pollen-based quantitative reconstruction of climatic parameters. Analogues giving a climate that was incompatible with the lake-level status were rejected. Thus, the climate reconstruction is based only on those analogues coherent with lake levels (Guiot et al., 1993).

## 3. Results

Fig. 2 presents the sediment sequence observed at Tresserve. Five main lithological units may be distinguished.

> At the top, a sand layer (unit 1). This corresponds to detritic input associated to medieval and modern anthropogenic deforestation of surrounding areas, and/or perturbations in sedimentation linked to recent regulation of lake level.
>
> Two carbonate lake-marl layers (units 2 and 4) separated by an anthropogenic organic layer (unit 3) composed of the remains of a late Bronze Age village tree-ring dated to 931–805 BC. The lower part of unit 4 in cores 3 and 1 has been radiocarbon dated to 3475±50 and 3450±45 BP, respectively (Table 1, Fig. 2).

Table 1. Radiocarbon dates obtained from the sediment sequence of Tresserve

| Core | Sediment unit | Tree–ring (in BC) radiocarbon (in BP) age | Calibrated age (1 sigma) | Calibrated age (2 sigmas) | Laboratory | Material |
|---|---|---|---|---|---|---|
| Core 5 (47–54 cm) | US 3 | 931–805 BC | | | Archeolabs | |
| Core 3 | US 4 | 3450±45 BP | 1875–169 cal BC | 1883–1637 cal BC | ARC 2236 | Wood |
| Core 1 | US 4 | 3475±50 BP | 1880–1693 cal BC | 1920–1644 cal BC | ARC 2238 | Wood |
| Core 5 (112 cm) | US 5 | 3630±30 BP | 2031–1942 cal BC | 2127–1888 cal BC | VERA 2760 | Twig |

Radiocarbon ages have been calibrated using Calib.5 (Stuiver et al. (1998).

At the base, a sand layer (unit 5). The upper part of unit 5 has been radiocarbon dated to 3630±30 BP (Table 1).

### 3.1. Vegetation and lake-level changes

The results of pollen and sediment analysis from core 5 are presented in Figs. 3 and 4. The main features of vegetation history are consistent with regional pollen stratigraphy of the late Holocene as established for the northern French Pre-Alps (Beaulieu (de) et al., 1994). Sediments of units 5–3 accumulated during the Subboreal pollen zone characterised by the domination of *Quercus* and *Fagus*, while the representation of *Abies* ranges from 7% to 22%. Above level 88 cm, an expansion of *Fagus* correlates with a decrease in *Quercus* and a stronger representation of *Fraxinus*, which attains 5% at level 70 cm. Except for level 48 cm characterised by a peak in Poaceae (archaeological layer), the pollen diagram does not show strong human impact on vegetation. *Plantago lanceolata* is present regularly between levels 108 and 88 cm and levels 62 and 44 cm, where *Cerealia* displays an irregular representation. Above 46 cm, the deposits accumulated during the Subatlantic pollen zone and give evidence of nearly similar landscapes. *Fraxinus* slightly develops between levels 42 and 32 cm and reaches ca. 6%. The uppermost levels (20, 16 and 8 cm) probably reflect anthropogenic disturbances of the vegetation with correlative large variations in the representation of *Quercus* and *Fagus*. In core 6 (50 m away from core 5, Fig. 2), the continuous presence of *Juglans* observed in unit 1 suggests that unit 2 was deposited before the Roman period (Magny and Richard, 1985) and only documents the early Subatlantic pollen zone equivalent to the Iron Age.

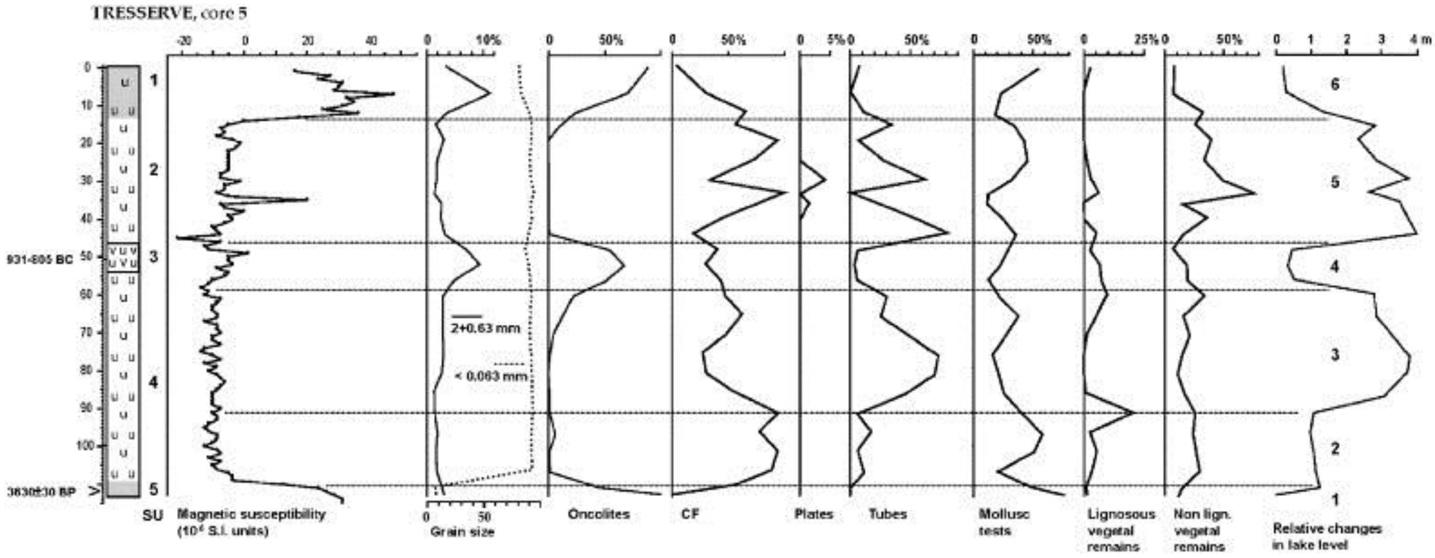


Fig. 4. Sedimentological diagram of core 5. SU: sediment units. The six successive phases of relative lake-level changes refer to Table 2.

Table 2 summarises the 6 successive lake-level phases distinguished from the sediment analysis (Fig. 4). Considering the water-level fluctuations before modern times, peaks in oncolites mark major phases of low lake level at ca. 3800 cal BP and 931–805 BC.

Table 2. Sedimentological and lithologic markers used to reconstruct past variations in the water table at Tresserve

| **Sediment unit** | **Sedimentological and lithologic markers** | **Lake level phases** | |
|---|---|---|---|
| | | **Lower** | **Higher** |
| 1 | Coarser texture, development of oncolites, small peaks of plate and tube concretion | 6 | |
| 2 | Finer texture, absence of oncolites alteration of peaks of tube concreations and CF | | 5 |
| 3 | Coarser texture, maximum of oncolites | 4 | |
| 4 | Decrease in CF, peak of tube concretions | | 3 |
| 4 | Decrease in oncolites, maximum of CF, slight development of tube concretions finer texture | | 2 |
| 5 | Oncolite maximum, coarse texture (deposition of sand) | 1 | |

CF: cauliflower-type concretions.

### 3.2. Quantitative reconstruction of climatic variables

Seven climatic variables have been reconstructed (Rouèche, 2005): total annual precipitation (PANN), summer precipitation (PSUM), winter precipitation (PWIN), mean annual temperature (TANN), mean annual temperature of the coldest month (MTCO) and the warmest month (MTWA), and the growing degree days (GDD5, i.e. the sum of daily temperatures above 5 °C). Due to relatively strong human impact on the vegetation evidenced by pollen data, levels 20, 16 and 8 cm of the sediment sequence have been not used for quantitative reconstructions of climatic parameters.

Fig. 5 presents the pollen and lake-level-based estimates of climatic variables obtained at Tresserve for the Bronze and early Iron Ages using the best analogue method (Guiot et al., 1993). Generally, the phases of higher lake level (3 and 5) correspond to decreasing MTCO and TANN, and increasing PANN and PSUM. The major phases of lower lake level (1–2 and 4), coincided with the opposite processes. The magnitude of the changes reaches ca. 0.8 °C for TANN, 1–1.2 °C for MTCO, 70–100 mm for PANN, and 50–70 mm for PSUM. Unclear oscillation may be recognised from the PWIN curve. The MTWA and GDD5 curves give evidence of oscillations, which, although not statistically significant, are consistent with the information provided by the MTCO and TANN curves, i.e. a coincidence of high lake-level conditions with a decrease in MTWA by ca 1 °C and in GDD5 by ca 200 days with a temperature greater than 5 °C.

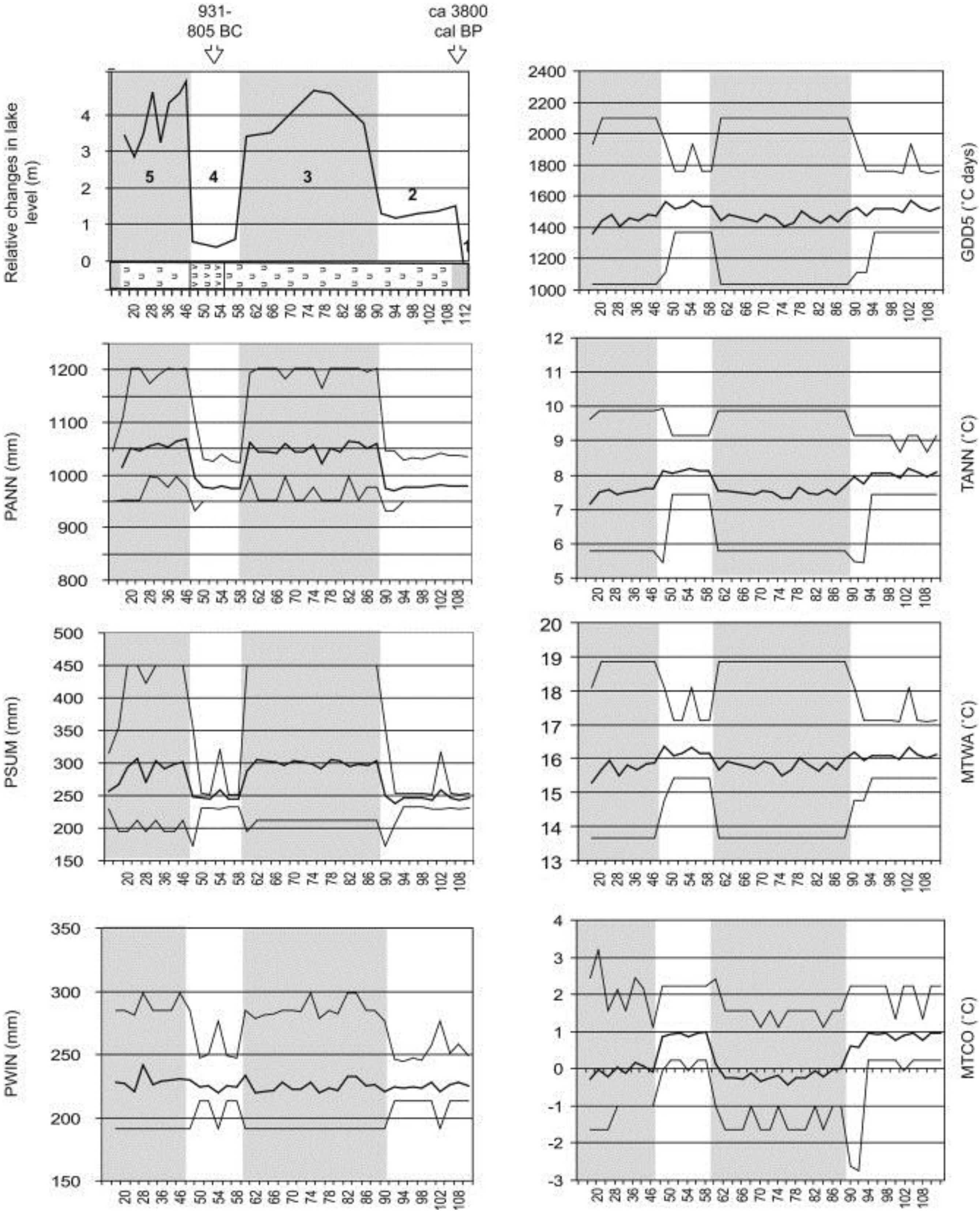


Fig. 5. Climatic parameters with confidence interval reconstructed from core 5 (Rouèche, 2005). MTWA: mean temperature of the warmest month, MTCO: mean temperature of the coldest month, TANN: mean annual temperature, GDD5: growing

degrees above 5 °C×days, PANN: annual precipitation, PWIN: winter precipitation, PSUM: summer precipitation.

## 4. Discussion and conclusions

The vegetation and lake-level changes reconstructed at Tresserve, Lake Le Bourget, and their translation into quantitative climatic variables, offer the opportunity to examine the climatic variations which punctuated the Bronze and early Iron Ages in eastern France. The palaeohydrological changes recognised at Tresserve appear fully consistent with the regional pattern established for west-central Europe with phases of higher lake levels at 3500–3100 and 2750–2350 cal BP (and the correlative abandonment of lake-dwellings at ca. 1500 and 800 BC, i.e. 3450 and 2750 cal BP; Magny, 1993 and Magny, 2004; Magny et al., 2007) in relation to solar-forced climatic oscillations (van Geel et al., 1996; van Geel and Magny, 2002; Magny, 2004 and Magny, 2006). Using a combination of seismic investigations and sediment cores from the profundal zone of Lake Le Bourget, Chapron et al. (2005) identified a period of enhanced Rhone River flooding activity at ca. 2800 cal BP, synchronous with glacier advances in the Mont Blanc massif (Deline and Orombelli, 2005). Cooler and/or wetter climate conditions may have also favoured the expansion of *Fagus* observed above level 88 cm in the Tresserve pollen record and *Fraxinus* at levels 70 and 36–32 cm (Fig. 3).

van Geel et al. (1996) have shown that the climate cooling at ca. 2800 cal BP was a global event, which affected various regions in both hemispheres. The climate reversal dated to ca. 3500 cal BP and marked by higher lake-level conditions in west-central Europe also seems to be a major climatic oscillation. While it coincided with a maximum in the residual atmospheric $^{14}C$ content (Stuiver et al., 1998) and in the Greenland $^{10}Be$ record (Bond et al., 2001), it also appears synchronous with an IRD event in the North Atlantic Ocean (Bond et al., 2001), a decrease in sea surface temperature of the Norwegian Sea (Birks and Koç, 2002; Calvo et al., 2002), a change in the North Atlantic Ocean circulation (Hall et al., 2004), a glacier advance in Iceland (Jiang et al., 2002) and in the Swiss and the Austrian Alps (Patzelt, 1977; Zoller, 1977; Haas et al., 1998), a decline in tree-limit in Austrian Alps (Nicolussi et al., 2005), and a reinforcement of humidity in mires and of discharge in rivers of England (Hughes et al., 2000; Macklin and Lewin, 2002). Moreover, a well marked climate cooling dated to 3500–3300 cal BP in Antarctica (Noon et al., 2003) suggests that the 3500 cal BP event may have affected both hemispheres.

When considering the quantitative estimates of seasonal changes in temperature and precipitation (Fig. 5), they appear consistent with environmental changes observed in west-central Europe: temperature cooling and increasing precipitation at ca. 3500 and 2800 cal BP may explain higher lake levels in the Jura Mountains and on the Swiss Plateau, and glacier advances and decline in tree-limit in the Alps. They are also consistent with values estimated from other proxies (Bortenschlager, 1977; Patzelt, 1985; Grafenstein (von) et al., 1994; Haas et al., 1998).

In regard to the possible impact of climate oscillations on Bronze and Iron Age communities, the Tresserve palaeoclimatic record suggests an influence of the climate not just for the location of their villages, but also on their socio-economic equilibrium. Phases of cooler and wetter climatic conditions may have provoked harvest failures, more particularly due to wetter summers. In agreement with the quantitative estimates of climatic variables reconstructed in this study, Tinner et al. (2003) have also pointed to the fact that, during climate reversals, an increase in precipitation probably had a more decisive impact than a temperature decrease on former settlements in marginal elevated areas like the Alps. Likewise, in Germany, Zolitschka et al. (2003) observed that from the Bronze Age to the Migration period, there are reasons to assume that, at least within the margin of error in the dating methods used, a coincidence appears between phases of unfavourable climatic conditions (cool and moist) and a decrease in human activities.

However, archaeological data collected in the Jura region (eastern France) invites to rule out an excessive deterministic view of human history, at least from a regional point of view (Gauthier, 2001). Fig. 6 presents curves based on the chronological distribution of archaeological sites recognised in the region of Franche-Comté from the mid-Neolithic to the early Iron Age (Pétrequin et al., 2005). The left-hand curve includes all sites while the right-hand curve excludes sites in humid areas such as lake shores and karstic caves. A comparison of these archaeological data with the regional pattern of climate changes as reflected by lake-level fluctuations, indicates a stronger impact of climatic conditions on prehistoric societies during the Neolithic, especially at ca. 5500 and 4850 cal BP, than during the Bronze and early Iron Ages. The curve including sites in humid areas, more sensitive to changes in climate conditions, also shows marked variations, which mainly reflect the development of late Bronze Age lake-dwellings and their abandonment at ca. 2800 cal BP. However, the right-hand curve, which excludes sites in humid areas, shows a general trend toward an increasing population density from 3500 to 2400 cal BP. This is in agreement with increasing anthropogenic disturbances observed in regional pollen diagram for the same period (Richard, 1994 and Richard, 1995; Richard and Gauthier, 2007). In contrast, the period 4200–3500 cal BP appears characterised by a general decrease in population density, which cannot be simply attributed to a climatic reversal which was limited to 4150–3950 cal BP. Such observations invite caution when proposing general interpretations from single sites and suggest progress in the relative emancipation of protohistoric societies from climatic conditions. Such progress probably reflects the spread of new modes of social and economic organisation (Pétrequin et al., 2005).

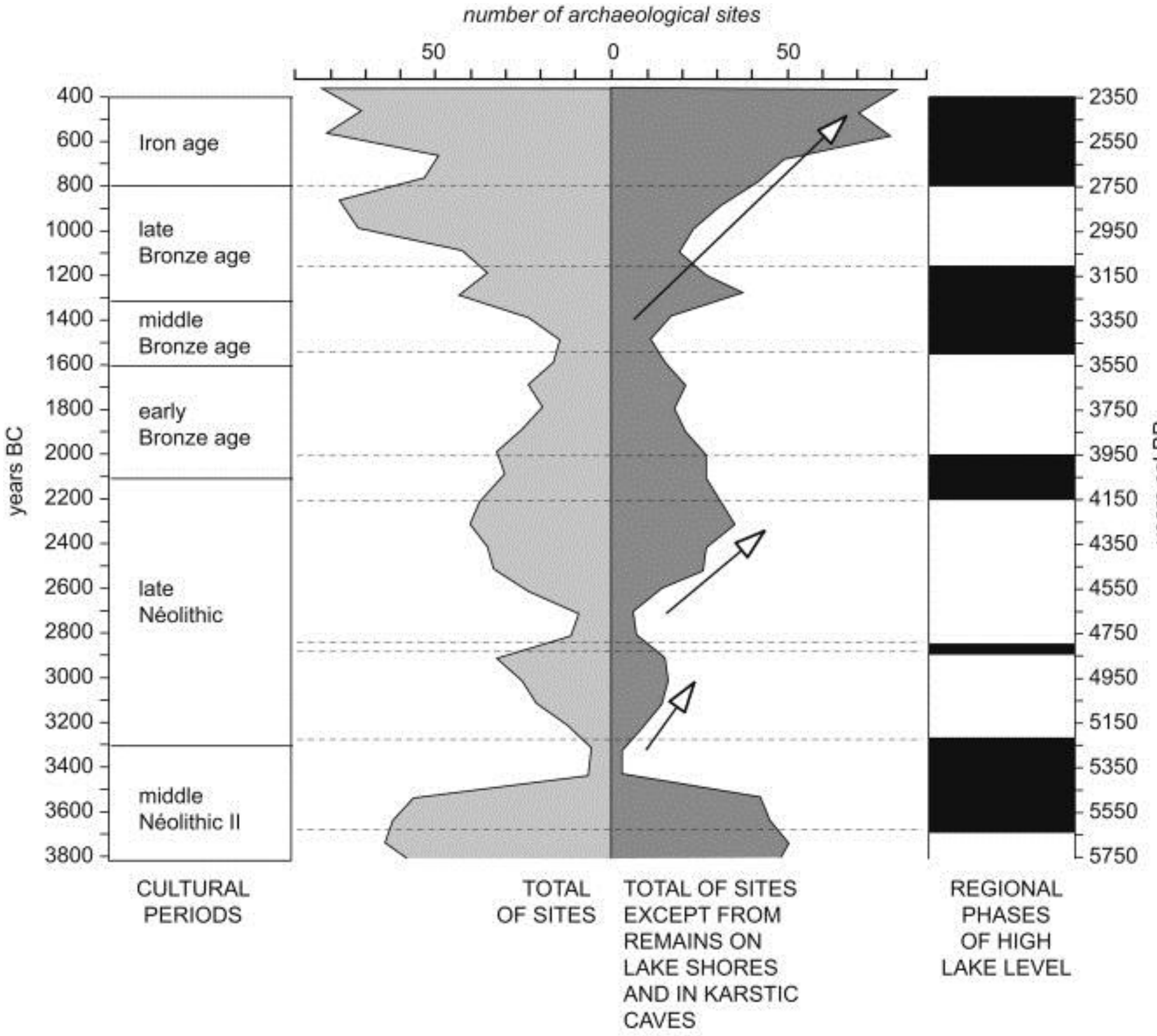


Fig. 6. Comparison between the regional pattern of variations in climate as reflected by lake-level fluctuations (Magny, 2004 and Magny, 2006) and changes in population density inferred from the number of archaeological sites in the region Franche-Comté, eastern France (Pétrequin et al., 2005). The left-hand curve includes all sites while the right-hand curve excludes sites in humid areas such as lake shores and karstic caves.

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