British late glacial and Holocene climatic history reconstructed from land snail assemblages

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ABSTRACT

We present a high-resolution record from a late glacial–Holocene land-snail succession from southeast England. Temperature estimates, derived from the best analogue technique, indicate a cooling trend, between 14 500 and 12 600 calendar years before present (cal yr B.P.) of 4 °C in summer and 8 °C in winter preceding the Younger Dryas event. The intense warming following the Younger Dryas stadial corresponds to increasing values of the same magnitude in 600 yr. A cooling event, weaker than the Younger Dryas, of 1 °C in both seasons is recorded between 8000 and 8500 cal yr B.P. These reconstructions from a European Holocene continental sequence are in agreement with fluctuations already described in North Atlantic and Mediterranean cores, ice cores, and African and Tibetan lake records.

INTRODUCTION

Late glacial marine records indicate a two-step deglaciation punctuated by the cold Younger Dryas event (~10 000–11 000 ^{14}C yr B.P. or 11 500–12 500 cal yr B.P.) culminating in the present-day climate (Bard and Broecker, 1992; Duplessy et al., 1981; Fairbanks, 1989; Ruddiman and McIntyre, 1981). However, high-resolution continental studies indicate the occurrence of significant climatic changes in the early and late Holocene (Alley et al., 1997; Chappellaz et al., 1993; Dalfes et al., 1997; Gasse and Van Campo, 1994; Johnsen et al., 1992).

The results of the Greenland ice core studies lead many to interpret these events as global phenomena. The cooling event recorded in the early Holocene is indicated in Greenland by a strong decrease in the methane signal and by other independent climate indices (Alley et al., 1997). In a survey of different published proxy data that could be related to this particular event, Alley et al. (1997) presented worldwide records except for temperate western Europe. Here we present temperature estimates reconstructed from the analysis of a British Holocene mollusk sequence.

MATERIAL AND METHODS

Holywell Coombe is a dry valley cut into chalk escarpment near Folkestone, Kent, in southeast England (lat 51.15°N, long 0.13°E, 50 m above sea level) (Fig. 1). This is the type locality for a mollusk zonation of the late glacial and Holocene (Kerney, 1977) A series of 180 boreholes were cored near the British terminal of the tunnel connecting southeastern England and northern France. The data from the new investigations have enabled refinement of the stratigraphic scheme, as shells of land snails occur in quantity throughout the sequence (Preece, 1998). They provide a detailed mollusk succession from the beginning of the late glacial until the present day. The late-glacial assemblages are dominated by species of open country and marsh, but shade-intolerant species are replaced by a succession of woodland species during the early part of the Holocene. Following forest clearances during the Neolithic and Bronze Age (5000–3000 yr B.P.), these closed forest communities show a reversion to grassland assemblages, with only minor indications of scrub (Fig. 2). A detailed chronology for this succession is provided by a series of radiocarbon dates, many measured by accelerator mass spectrometry (AMS), obtained from charcoal and wood remains from key layers (Fig. 2).

Among the main limiting factors constraining the growth of the terrestrial snails, temperature is most important (Goodfriend, 1986; Rousseau, 1989). Eggs and embryos can endure less extreme temperature than can adults. Most of the identified species at Holywell Coombe exhibit biennial growth. A prolonged duration of extreme low temperature would considerably limit the development of specialized populations. Thermal sensitivity is determined for decreasing temperatures

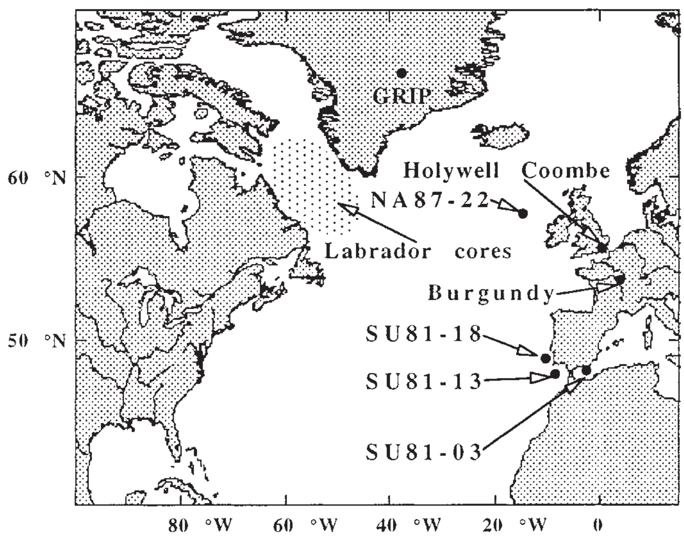

Figure 1. Location of several records mentioned in text.

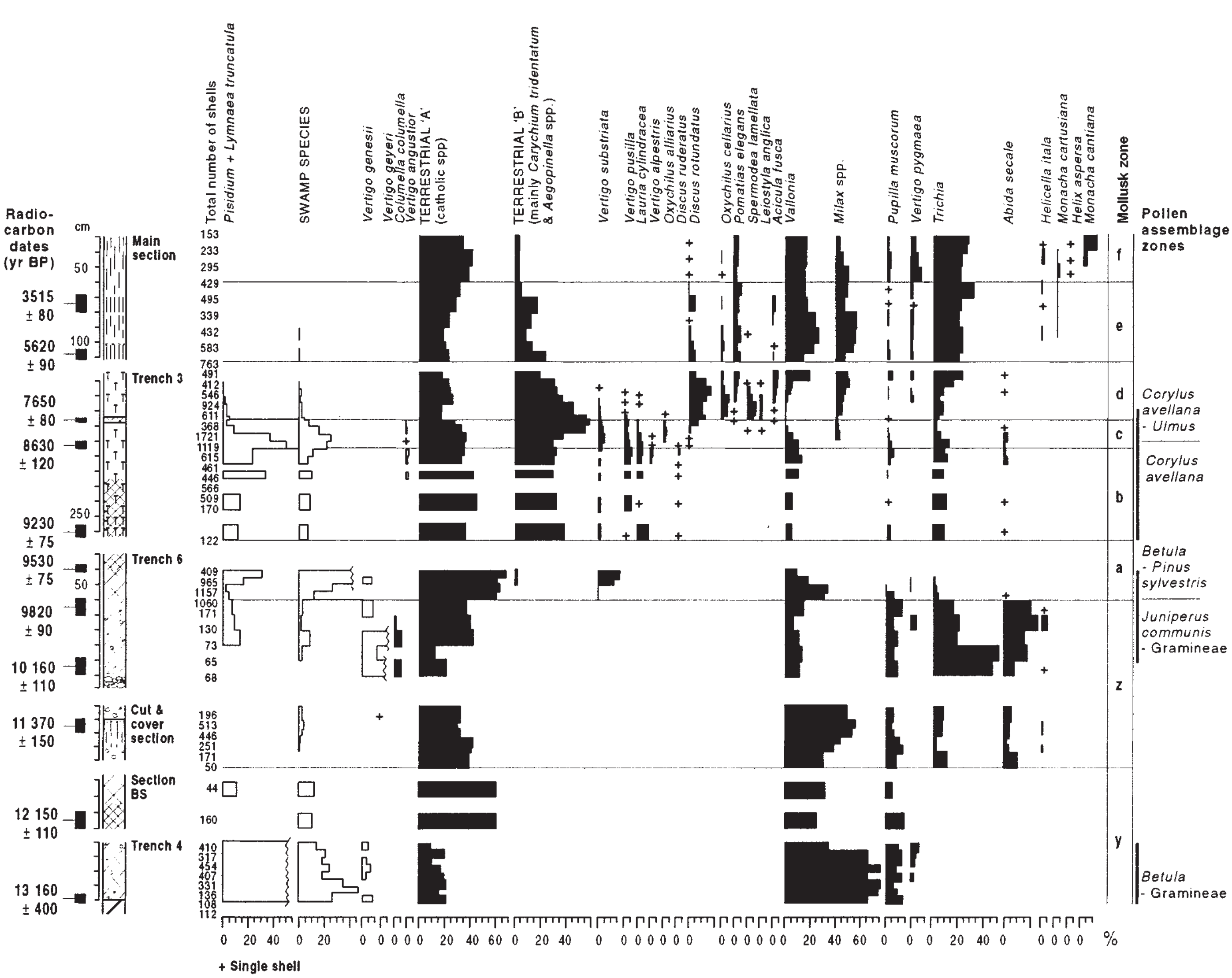

Figure 2. Summary diagram of the molluscan succession at Holywell Coombe. The correlation of mollusk and pollen zones is shown on the right and the radiocarbon chronology appears on the left. For the sake of simplicity, several terrestrial species have been grouped into ecological categories A and B. Those in group A are essentially catholic species of wide tolerance, living in open ground, marshes, and woodland. Those in group B are more critical in their requirements, being most common in deciduous woods and similar well-shaded places. Swamp species include the obligatory hygrophiles (from Preece, 1998).

by the onset of the freezing of tissues, and for increasing temperatures by the initiation of cell coagulation, although the relative importance of these factors varies from one species to another. Furthermore, when the cold season arrives, terrestrial snails retract into their shells and hibernate from four to six months. Their respiratory systems, cardiac rhythms, and oxygen consumption decrease during hibernation, but do not cease. The total water loss can reach 20%, and the oxygen content is minimum in February when growth stops (Chevalier, 1982; Rousseau et al., 1994). The temperature values reconstructed correspond to February and August, which are two particularly sensitive periods for snail development. The modern assemblages, which provide the basis for the analogue comparisons, came from samples of top soil/leaf litter from which snails were identified and counted. These assemblages were sampled on a transect from northern Scandinavia to southern France, and they therefore encompass a wide range of vegetation. For the fossil succession, temperature estimates, using the analogue procedure, were calculated for 49 successive assemblages and 58 different species, as all the identified species still live in Europe (Kerney and Cameron, 1979). The procedure uses correspondence analyses to select the species and the statistical factors which explain the general variance of the data set, and multiple stepwise regressions are used to calculate the estimates (Rousseau, 1991; Rousseau et al., 1994).

RESULTS AND DISCUSSION

The error estimates are of 2.94 and 2.8 °C for the coldest and warmest months, respectively, somewhat lower than those obtained from beetle assemblages (Atkinson et al., 1987). The reconstructions indicate four main climate intervals (Fig. 3). The first interval corresponds to a cooling trend following the Bolling interstadial, the first step of the last deglaciation (Duplessy et al., 1981). For both months, the temperature estimates indicate a cooling trend: 8 °C in winter and 4.5 °C in summer. This trend is not linear and shows several oscillations. The second interval corresponds to the Younger Dryas stadial, for which the temperature estimates vary between –6 °C and –5 °C in winter and 15.5 °C and 16.5 °C in summer. This trend is similar to estimates calculated from beetle assemblages sampled in parallel (Coope in Preece and Bridgland, 1998). This cold interval is followed by a strong and rapid warming that lasted for no more than 600 yr, according to the ^{14}C dates available. The temperature estimates return to values that existed in the early Bolling. The fourth interval corresponds to the Boreal to Subatlantic chronozones. It shows different trends in the reconstructions; a cooling of 1 °C between 8630 ± 120 and 7650 ± 80 yr B.P. After this short interval, the low sampling resolution indicates that the summer temperature increased slightly to remain stable at around 19 °C. On the contrary, the winter temperature remains at the low value obtained during the mid-Holocene cold event.

These reconstructions for the 13 000–7500 yr B.P. interval are similar to other reconstructions derived from beetle studies (Atkinson et al., 1987) in Britain. However, the temperature estimates also indicate a cooling event after the Younger Dryas at around 8000 yr B.P. Converting the ^{14}C dates into calendar years (Stuiver and Reimer, 1993), this cooling of 1 °C appears to be contemporaneous with the event identified in the methane record in the Greenland GRIP ice core, which is a global signal (Blunier et al., 1995; Chappellaz et al., 1993), and in other independent signals from the United States Greenland Ice Sheet Project (GISP2) ice core (Alley et al., 1997) and in the oxygen signal of four Greenland ice cores (Johnsen et al., 1992).

The comparison of the mollusk reconstructions with methane and oxygen records of the European Greenland Ice Core Project (GRIP) (Fig. 4) shows that between 14 500 and 11 500 cal yr B.P., the temperature estimates follow the oxygen variations. They clearly indicate a cooling, whereas the methane signal shows a warming trend ending with the sudden and strong decrease in methane content. Although the warming following the Younger Dryas is well expressed in the four curves, the temperature estimates show a relatively stable interval, as does the methane. In contrast, the oxygen corresponds to an increase in wetland extent that may be associated with a warming trend. The 8200 cal yr B.P. cold event corresponds to a 1 °C cooling in the temperature estimates, and around 1‰ in the oxygen or around 200 parts per billion by volume (ppbv) in the methane records. The species that are characteristic of swamp conditions indicate a strong reduction of the moisture supply during that cold interval in Holywell Coombe (Preece, 1998). This agrees with the classic interpretation of the decreasing CH_4 values being related to a reduction in its production by wetlands due to a strong weakening of the African and Asian monsoons, leading to drier conditions (Alley et al., 1997; Chappellaz et al., 1993; Gasse and Van Campo, 1994).

In other Northern Hemisphere records, there is a similar climatic event (Fig. 1). The oxygen record and the salinity estimates in North Atlantic cores SU81-18 and NA 87-22 indicate significant minimum values at around 8000 cal yr B.P. (Duplessy et al., 1992). In the Labrador Sea, a minimum in the CO_2 production in the basin is recorded at around the same time (Hillaire-Marcel et al., 1994). Another mollusk sequence in France shows a contemporaneous cooling of 1 °C in both winter and summer associated with dry conditions, as at Holywell Coombe (Rousseau et al., 1993; Rousseau et al., 1994). In the western Mediterranean, pollen analyses of marine cores also indicate the occurrence of a cold and dry climatic event, indicated by a strong reduction in the oak pollen and an increase in *Artemisia* (Parra, 1994). At another scale, other proxies indicate the record of this event in Africa and in the Tibetan plateau (Gasse and Van Campo, 1994). Complementary to the methane, CO_2 shows a sharp variation at that time (Neftel et al., 1988) in the Antarctic Byrd ice core that is possibly related to changes of circulation in the high-latitude ocean. Closer to Europe, the Laurentide ice sheet, and more precisely the timing of its collapse, provides some key information. It is assumed that between 8400 yr B.P. and

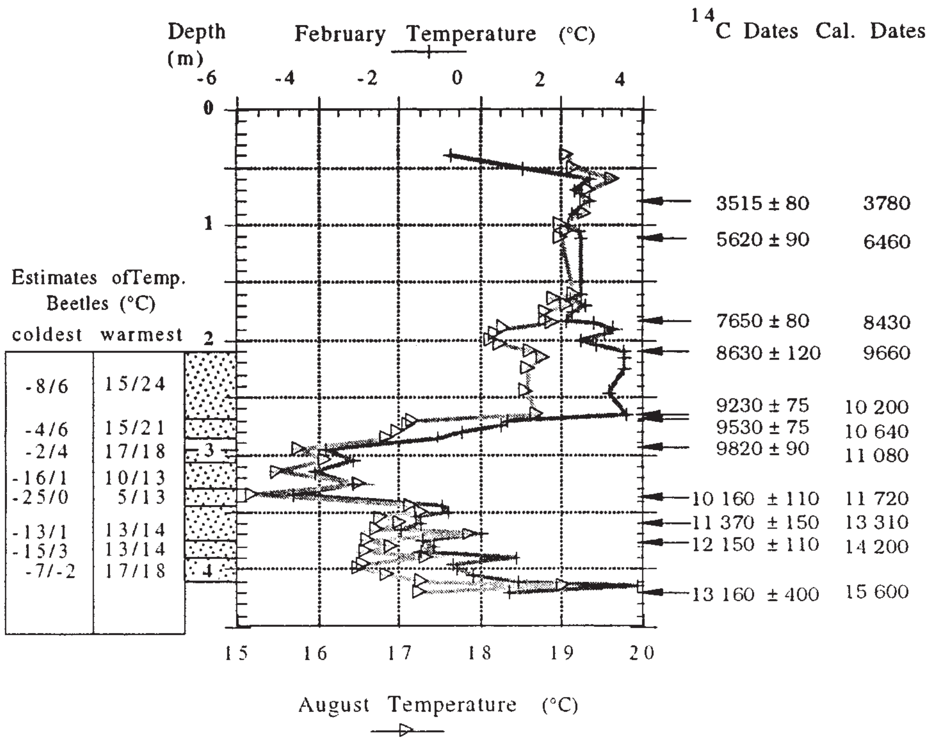

Figure 3. Estimates of February and August temperatures from mollusk assemblages at Holywell Coombe. Indication of estimates for warmest and coldest month from beetle assemblages using mutual climatic range procedure sampled in parallel. Beetle samples are represented by gray boxes. Dates are expressed in ^{14}C yr B.P. and in calendar age. Present mean temperatures for February and August are 4.5 and 16 °C, respectively. Apparent cooling after 5000 yr B.P. results from forest clearance, which produces an increase in grassland snails, as already observed in France by Rousseau et al. (1994).

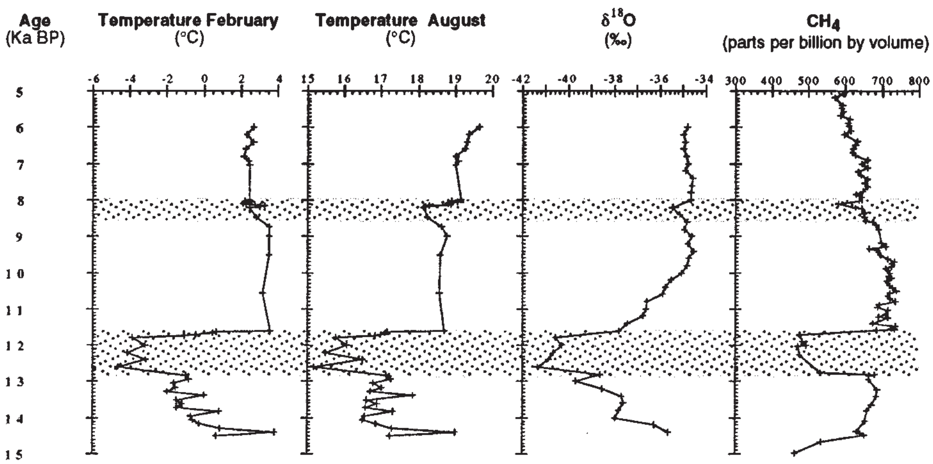

Figure 4. Comparison of mollusk estimates with $\delta^{18}O$ (Johnsen et al., 1992) and methane (Blunier et al., 1995; Chappellaz et al., 1993) records in the Greenland Ice Core Project (GRIP) ice core.

7900 yr B.P., the Cochrane lobe surged into Lake Ojibway and the Hudson Bay ice dome collapsed (Hardy, 1977), accompanied by a northward drainage of 1.2×10^5 km^3 of fresh water from the southern glacial lakes Agassiz and Ojibway (de Vernal et al., 1997). Such input of cold fresh water into the North Atlantic is thus detected by reduced salinity and low sea-surface temperatures (SST) down to the latitude of Portugal (Duplessy et al., 1992). This seems to have shut down or weakened the thermohaline circulation in a way similar to when massive iceberg discharges invaded the North Atlantic during full glacial conditions (Bond and Lotti, 1995; Broecker, 1994).

A shutdown or slowdown of the thermohaline circulation at 8200 cal yr B.P., reducing the heat transport to the high latitudes and leading to cold conditions over both the North Atlantic and the neighboring European continent, seems to be the best possible explanation for the 8200 cal yr B.P. event recorded at Holywell Coombe. This interpretation is in agreement with the results of the Ammersee deep lake study by von Grafenstein et al. (1998). Such a hypothesis was already proposed by Alley et al. (1997), Keigwin and Jones (1995), and Street-Perrot and Perrot (1990) to explain climate events apparently contemporaneous with the cooling at 8 ka in Holywell Coombe.

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