Temperature oscillations over the last 10,000 years in western Europe estimated from terrestrial mollusc assemblages

DENIS-DIDIER ROUSSEAU, NICOLE LIMONDIN, FRÉDÉRIC MAGNIN AND JEAN-JACQUES PUISSEGUR

BOREAS

Rousseau, D.-D., Limondin, N., Magnin, F. & Puisségur, J.-J. 1994 (March): Temperature oscillations over the last 10,000 years in western Europe estimated from terrestrial mollusc assemblages. *Boreas*, Vol. 23, pp. 66–73. Oslo. ISSN 0300-9483.

Snail assemblages are used to estimate February and August temperatures during the past 10,000 years in western Europe. We find that a strong warming occurred after the Younger Dryas event, followed by several rapid cooling and warming events. These observations are in agreement with insect and pollen proxy data from the European continent and with estimates of sea-surface temperature from the North Atlantic Ocean as well as with fluctuations of glaciers in western Norway. This study also confirms that terrestrial molluscs can provide reliable climatic data in conjunction with other proxy data.

Denis-Didier Rousseau, URA CNRS 327, Université Montpellier II, place Eugène Bataillon, 34095 Montpellier, France and Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964 USA; Nicole Limondin, UPR CNRS 7557, Laboratoire de Chrono-écologie, 16 route de Gray, 25030 Besançon cedex, France; Frédéric Magnin, URA CNRS 903, Université Aix-Marseille II, Institut de Géographie, 29 avenue Robert Schuman, 13621 Aix-en-Provence cedex, France; Jean-Jacques Puisségur, Hauteroche, 21150 Les Laumes, France; 30 October, 1992 (revised 9th July, 1993).

Numerous records from the Atlantic Ocean (Duplessy *et al.* 1992; Lehman & Keigwin 1992; Bond *et al.* 1992) and the Greenland ice sheet (Oeschger & Arquit 1991; Johnsen *et al.* 1992) provide a basis for comparison with proxy data from continental sequences in Europe. Those regions seem directly climatically connected, according to Broecker's (1990) theory of the salt conveyor belt. Up to now, the terrestrial data have mainly come from pollen and insect remains found in lacustrine deposits or peat bogs. In other types of environments, molluscs have been shown to yield good ecological and climatic information that can be correlated with biological, physical or chemical climatic signals (Rousseau 1991, 1992; Rousseau *et al.* 1993; Rousseau & Puisségur 1990; Goodfriend 1988, 1991). The purpose of this paper is to present temperature estimates for February and August based on molluscan assemblages from a well-dated composite sequence in Burgundy, France, and to compare the results with independent regional climate data.

Methods and material

Terrestrial molluscs provide environmental information that can be deduced using multivariate analyses (Rousseau 1987, 1990). Molluscan studies have provided quantitative reconstructions of past temperature changes in western Europe using an analogue procedure (Rousseau 1990, 1991; Magnin 1992). Mollusc assemblages collected in samples of about 10 kg of sediment were washed and sieved to extract the shells. The taxa were identified and counted for broken shells applying Lozek's (1964) method.

The modern set of molluscan assemblages corresponds to samples of top soils from which mollusc species were all identified and counted. These modern molluscan assemblages are distributed from northern Scandinavia to southern France (Fig. 1) and correspond to a wide range of vegetation, from high latitude tundra to deciduous temperate mid-latitude forests (Fig. 2). The best modern analogues of the fossil assemblages are selected from the modern database by using the squared chord distance method (Overpeck *et al.* 1985). The meterological data are taken from a compilation of modern measured values averaged over thirty years (Wernstedt 1972), and from local stations (same time interval) close to modern sampling sites.

The molluscan data set is analyzed using the correspondence analysis (Benzecri & Benzecri 1980). Each element (row or column) I is represented in a J dimensional space by its coordinates on each J variable (kij; and $\Sigma kij = ki$), but is also allocated a weight ($= ki/k$, $k = \Sigma ki$, $\Sigma k = 1$). For example, three assemblages yield the following countings for three species a, b, c:

assemblage 1: $a = 2 - b = 4 - c = 8 - ki = 14$,
assemblage 2: $a = 4, - b = 8 - c = 16 - ki = 28$,
assemblage 3: $a = 3 - b = 10 - c = 0 - ki = 13; k = 55$.

The coordinates (kij) of each assemblage will be 2/14, 4/14 and 8/14 for the first two and 3/13, 10/13 and 0 for the third. The weight will be 14/55, 28/55 and 13/55.

As this procedure can be used for both rows and columns, superimposable factors are yielded (reference axes of the hyperspace) that allow the simulta-

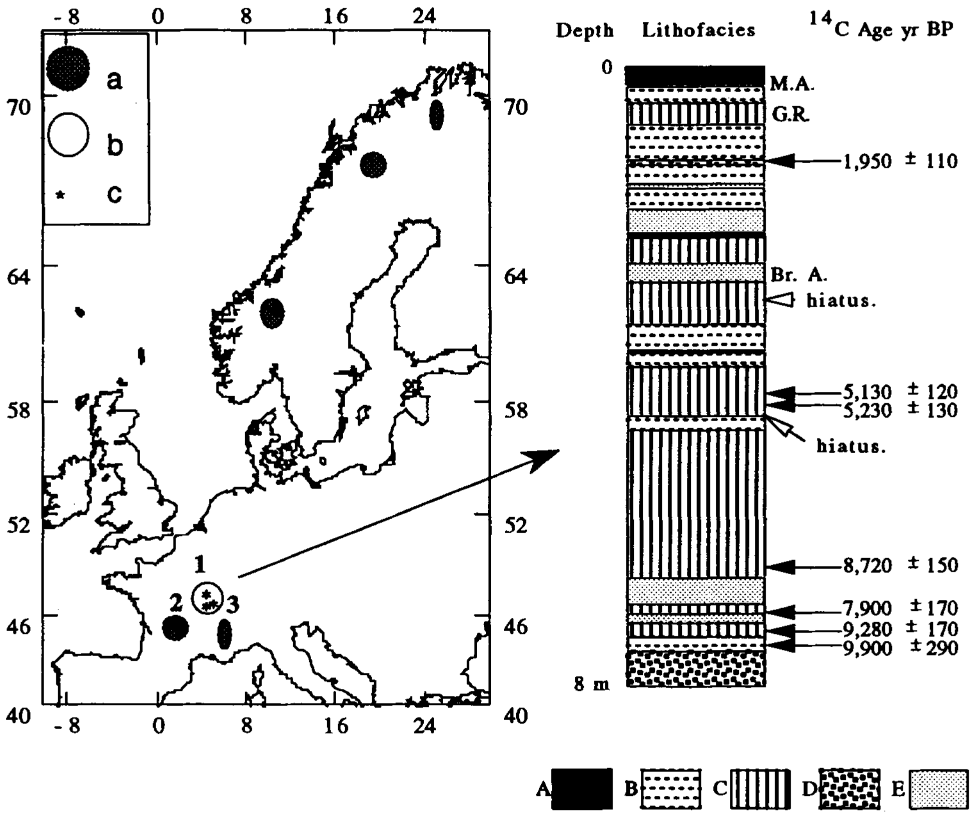
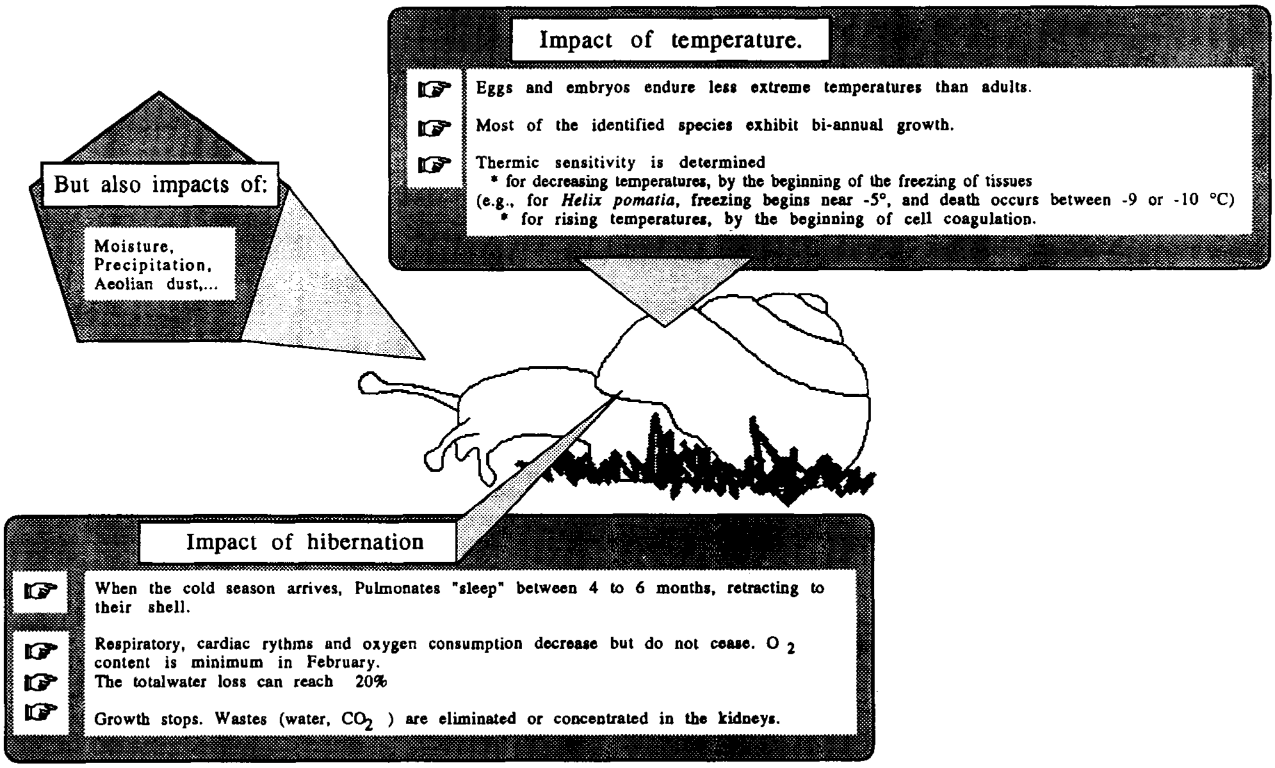


Fig. 1. Location map of (a, b) the modern snail analogue assemblages used for the estimates of palaeotemperatures, and of (c) the fossil sequences. 1: Molesmes, 2: Beaume-lès-Créancey, 3: Clenay. Lithostratigraphic column: (A) present soil, (B) Clay, (C), (D) indurated tufa, (E) unindurated tufa. M.A. Middle Age, G.R. Gallo-Roman, Br. A. Bronze Age archeological remains.



Impact of temperature.

- Eggs and embryos endure less extreme temperatures than adults.
- Most of the identified species exhibit bi-annual growth.
- Thermic sensitivity is determined
  - for decreasing temperatures, by the beginning of the freezing of tissues (e.g., for *Helix pomatia*, freezing begins near -5°, and death occurs between -9 or -10 °C)
  - for rising temperatures, by the beginning of cell coagulation.

But also impacts of:

Moisture, Precipitation, Aeolian dust,...

Impact of hibernation

- When the cold season arrives, Pulmonates "sleep" between 4 to 6 months, retracting to their shell.
- Respiratory, cardiac rythms and oxygen consumption decrease but do not cease. O_2 content is minimum in February.
- The totalwater loss can reach 20%
- Growth stops. Wastes (water, CO_2) are eliminated or concentrated in the kidneys.

Fig. 2. Main limiting factors constraining the growth of terrestrial molluscs.

neous plotting of both variables and individuals (rows). For our analysis, the mollusc species are columns, and molluscan assemblages, corresponding to a single stratigraphical level, are rows. To avoid too much disturbance in the variability, the data are coded following an abundance class principle (Rousseau 1987).

Correspondence analysis is applied in two steps. The first allows the selection of species which primarily influence the variance of the total data set. If all the species had equal influence on the variance, their contribution would be equal to $1/p$, p representing the total number of species. The selection of predominant species is made using the first seven axes, which usually explain about 50% of the general variability. Species which do not show a high contribution to the variability of the first seven axes are thereby eliminated. The second correspondence analysis (second step of our investigation) is then applied to the reduced data set. Generally, the first 24 factors explain about 90% of the total variance. Stepwise multiple regression between the modern temperature values, used as dependent variables, and loadings of the modern assemblages on these first axes determine the equations of the transfer functions to be applied to the fossil assemblages. The retained coefficients correspond to the highest multiple correlation and the lowest standard error. The analysis of the residuals (real values-estimated values) provides a basis on which to accept or reject the results. Plotting the residuals against the reconstructed values, the scatter plot must show a shape corresponding to a horizontal band if all the conditions necessary for the use of the regression are to be met (Scherrer 1984).

The fossil data come from three ^{14}C dated stratigraphic sequences from the valley bottom in the Burgundy, France. A composite stratigraphy based on these three sites which consists of 42 molluscan assemblages covering the last 10,000 years has been proposed by Rousseau *et al.* 1993 (Fig. 1). All the fossil species analyzed in this Holocene set still exist in assemblages identical to those living during the Pleistocene. The advantage of correspondence analysis is that the modern ecology and distribution of the mollusc species can be used to interpret precisely the general variability of the Holocene data set.

A previous study of this sequence (Rousseau *et al.* 1993) shows that the molluscan assemblages recorded climate events which are in agreement with the classical European Holocene chronostratigraphy. Two steps in Termination I were suggested to occur after the Younger Dryas could event, in agreement with the chronology proposed by Mix & Ruddiman (1985): Termination Ib between 10,000 and 9000 and Ic between 8000 and 6000 years. Termination Ia preceding the Younger Dryas, was however absent from the record. The purpose of the present paper is to provide temperature estimates for the Holocene based on snail assemblages.

Results

Correspondence analysis is first made on a data set comprising 96 species (see list in Table 1) and 132 assemblages (present and fossil). The theoretical contribution of the columns (species) to the variability is then $1/96 = 0.010$. Species with values lower than the threshold on the first seven factors that explain 44.41% of the total variance are eliminated from the data set (Table 1).

The reduced data set comprises 52 columns (species) and 132 rows (assemblages). Using the transfer function procedure for molluscs developed by Rousseau (1991), the first 24 factors are retained. They explain 87.54% of the total variance of the data set. Stepwise regression is then applied to the coordinates of the modern assemblages (total number – fossil number: $132 - 142 = 90$). The largest part of the variance of each predicted variable (February and August temperature) was obtained with partial F ratios equal to 4.

February mean temperature: among the 24 factors, six were seleted (Table 2). The transfer function has a high standard error of estimate of 2.18°C and a multiple correlation coefficient of 0.93.

August mean temperature: the standard error of estimates is lower than that of February temperature, 1.31°C, with a multiple correlation coefficient equal to 0.91. Seven factors were selected among the 24 (Table 2).

The equations determined for February and August estimates respectively are indicated in Table 2. The plots of residuals are random, suggesting that the assumptions underlying the application of regression analysis are not violated.

Application of the transfer functions

The composite Burgundian sequence has been time calibrated in accordance with the northwest European chronostratigraphy (Mangerud *et al.* 1974) using ^{14}C dates on organic matter by biostratigraphy and sedimentology. The correspondence between our radiometric dates and the Holocene chronology forms the basis of the proposed time-scale of the sequence (Rousseau *et al.* 1993).

The temperature estimates for the past 10,000 years in Burgundy are plotted, taking into account the stratigraphic position of their corresponding fossil assemblage (Fig. 3). The two main stratigraphic hiatuses previously recognized (Rousseau *et al.* 1993) are also shown. The temperature estimates show less variation relative to present values than those obtained for the pleniglacial interval, i.e. stage 2 (Rousseau 1991; Magnin 1992). At the base of the sequence, the estimates indicate that the Younger Dryas cold event was followed, at 9900 BP, by a rapid warming (Fig. 3). February and August values rose to 1.5 and 17.2°C (Table 3). Cold conditions occurred after this warm

Table 1. List of the species used as variables in the first correspondence analysis. Contributions higher than the theoretical value (10) of the species to the general variability on the first seven factors (F1-F7). The values are expressed in thousands. Variables eliminated for the second analysis are indicated in italics.

Name	F1	F2	F3	F4	F5	F6	F7
Pomatia elegans	42	14	285	25	–	–	–
Acicula dupuyi	18	–	119	99	–	27	–
Carychium minimum	55	287	363	34	31	32	12
Carychium tridentatum	–	*162*	*19*	–	*51*	–	–
Succinea oblonga	–	32	28	–	41	18	11
Succinea putris	48	193	517	24	–	20	–
Succinea sp.	30	–	–	31	–	55	128
Oxyloma pfeifferi	–	–	–	–	*149*	–	–
Azeca goodalli	–	*36*	*48*	–	*82*	–	–
Cochlicopa lubrica	652	–	14	34	31	53	76
Cochlicopa lubricella	25	40	–	–	11	–	11
Columella edentula	50	20	–	– 47	71	45	
Columella columella	455	176	20	3641	–	–	245
Truncatellina cylindrica	114	288	29	–	145	–	11
Vertigo pusilla	–	*37*	–	*– 50*	*11*	–	
Vertigo antivertigo	59	155	744	14	–	–	–
Vertigo substriata	–	*18*	*11*	–	*27*	–	–
Vertigo pygmaea	58	70	145	–	516	17	–
Vertigo moulinsiana	28	106	140	17	75	11	–
Vertigo genesii	333	12	535	2239	–	1246	–
Vertigo alpestris	*11*	–	–	–	*49*	*209*	–
Vertigo angustior	*24*	*73*	*303*	–	–	–	–
Orcula doliolum	*12*	–	*75*	*11*	–	–	–
Pagodulina pagodula	–	–	*108*	*14*	–	–	–
Abida secale	293	994	201	13	571	–	–
Pupilla muscorum	120	142	15	–	751	18	–
Vallonia costata	99	60	68	–	279	43	–
Vallonia pulchella	11	–	129	–	812	27	16
Vallonia enniensis	*32*	*53*	*500*	–	–	–	–
Vallonia excentrica	*65*	*115*	–	–	*266*	–	–
Acicula aculeata	–	*39*	*139*	–	*54*	–	–
Chondrula tridens	*16*	*37*	–	–	*58*	–	–
Ena montana	–	*11*	*21*	–	–	–	–
Ena obscura	23	–	191	20	16	17	–
Punctum pygmaeum	–	–	–	*17*	–	–	–
Discus ruderatus	235	113	101	368	–	22	229
Discus rotundatus	–	*159*	*229*	–	*87*	–	–
Vitrina pellucida	1085	631	268	819	14	41	1535
Vitrea subrimata	52	195	23	–	544	–	–
Vitrea crystallina	–	*162*	*27*	–	*127*	–	–
Vitrea contracta	*40*	–	*115*	–	–	–	–
Nesovitrea hammonis	83	44	114	47	–	–	–
Aegopinella pura	–	42	245	11	127	–	–
Aegopinella nitidula	–	*131*	*77*	–	*89*	–	–
Aegopinella minor	–	52	–	11	14	27	–
Oxychilus cellarius	39	–	299	47	–	58	–
Oxychilus sp	–	95	–	16	98	31	–
Zonitoides nitidus	41	201	279	26	54	27	–
Euconulus fulvus	10007	38	53	–	48	34	797
Cecilioides acicula	*146*	*138*	–	–	*401*	–	–
Cochlodina laminata	17	–	334	38	50	51	–
Macrogastra ventricosa	–	–	–	–	–	–	–
Macrogastra rolphii	11	–	268	34	18	48	–
Clausilia parvula	228	607	103	–	231	–	–
Clausilia bidentata	16	16	223	16	32	22	–
Clausilia dubia	–	–	–	–	–	–	–
Clausilia sp.	–	–	–	–	*36*	–	–
Clausilia sylv	–	*37*	–	–	*24*	*25*	–
Bradybaena fruticum	–	*23*	–	–	*16*	–	–
Candidula unifasciata	*91*	*182*	–	–	*368*	–	–
Hellicella itala	144	259	11	–	504	–	–
Hellicella sp.	28	75	15	–	58	–	–
Trochoidea geyeri	110	399	100	–	684	–	–
Monacha cartusiana	–	–	–	*– 42*	–	–	

Table 1. (Contd.)

Name	F1	F2	F3	F4	F5	F6	F7
Perforatella incarnata	–	–	*38*	–	–	–	–
Hygromia cinctella	–	–	–	–	–	–	–
Trichia hispida	23	39	35	–	102	–	–
Euomphalia strigella	–	–	–	–	–	–	–
Helicodonta obvoluta	–	–	*90*	–	*42*	*11*	–
Arianta arbustorum	90	23	14	268	–	503	–
Helicigona lapicida	–	*14*	*67*	–	*35*	–	–
Cepaea hortensis	–	–	*138*	*17*	–	*16*	–
Cepaea sp.	–	*53*	–	–	*20*	–	–
Helix pomatia	–	–	*22*	–	*16*	–	–
Aegopinella nitens	–	–	95	15	12	25	–
Cochlostoma obscurum	36	–	351	52	45	76	–
Macrogastra lineolata	–	–	–	–	–	–	–
Cepaea nemoralis	–	–	–	–	–	–	–
Cochlostoma septemspirale	133	52	276	47	–	37	–
Pupilla triplicata	184	762	202	14	257	–	–
Zebrina detrita	–	–	–	–	–	–	–
Chondrina avenacea	*13*	*41*	–	–	–	–	–
Pyramidula rupestris	155	663	207	23	1391	–	18
Helix aspersa	–	–	–	–	–	–	–
Theba plebeia	13	–	66	10	–	14	–
Phenacolimax major	56	28	37	–	41	–	–
Lauria cylindracea	–	–	–	–	*31*	–	–
Limax sp.	–	*85*	*53*	–	–	–	–
Vitrea sp.	–	–	–	–	14	–	–
Nesovitrea petronella	1693	742	256	534	40	311	138
Deroceras agreste	30	–	40	209	–	433	–
Vertigo modesta	766	398	225	887	47	5369	–
Vertigo lilljeborgi	351	120	13	76	–	143	1793
Euconulus alderi	101	30	–	20	11	–	270
Vertigo ronnebyensis	145	60	25	78	–	99	4478
Vertigo geyeri	*63*	*21*	–	–	–	*530*	–
% of variance explained	11.1	8.99	6.21	5.17	4.7	4.41	3.51

Table 2. Statistics of transfer functions.

	Temperature (°C)	
	February	August
Multiple correlation coefficient	0.93	0.91
Standard error of estimates	2.18	1.31
Intercept	1.5	17.21
F1	−3.66	−1.61
F2	−3.25	−2.15
F3	0.77	0.84
F4	0.80	0.44
F5	−2.09	−1.71
F15	1.62	0.86
F21		0.49

event during the Boreal chronozone (9000–8000 BP). The temperature estimates for that time go down to 3.5°C below present in February and 3°C in August (Fig. 3). A rapid warming, close to 2°C, took place just after 8000 BP. This warm interval lasted uninterrupted until almost 6000 BP and corresponds to the Atlantic chronozone. At the end of this interval an abrupt and small decrease in temperature is indicated, marked mainly during winter (Fig. 3). A new cold fluctuation is recorded after the first stratigraphic hiatus at around 5000 BP, with temperatures approximately 3°C less than present-day values for February and August (Fig. 3; Table 3). This event is immediately followed by a new rapid warming of at least 2°C. The interval from 3000 to 2000 BP shows small fluctuations in temperature after the second hiatus (Fig. 3). Estimates for August show values around 2000 BP similar to today (Fig. 3). Both February and August reconstructions show cool values at around 3000 BP (Fig. 3). The reconstructed values for the interval 2000 to around 1000 BP are not taken into account, as they reflect the effect of human impact on the environment in the studied area (Rousseau *et al.* 1993).

Discussion

The trends in the estimates from snail assemblages are in agreement with other proxy data. Temperature estimates from British insect (Coleoptera) assemblages show that an interval as warm as today immediately succeeded the Younger Dryas cold event, and was

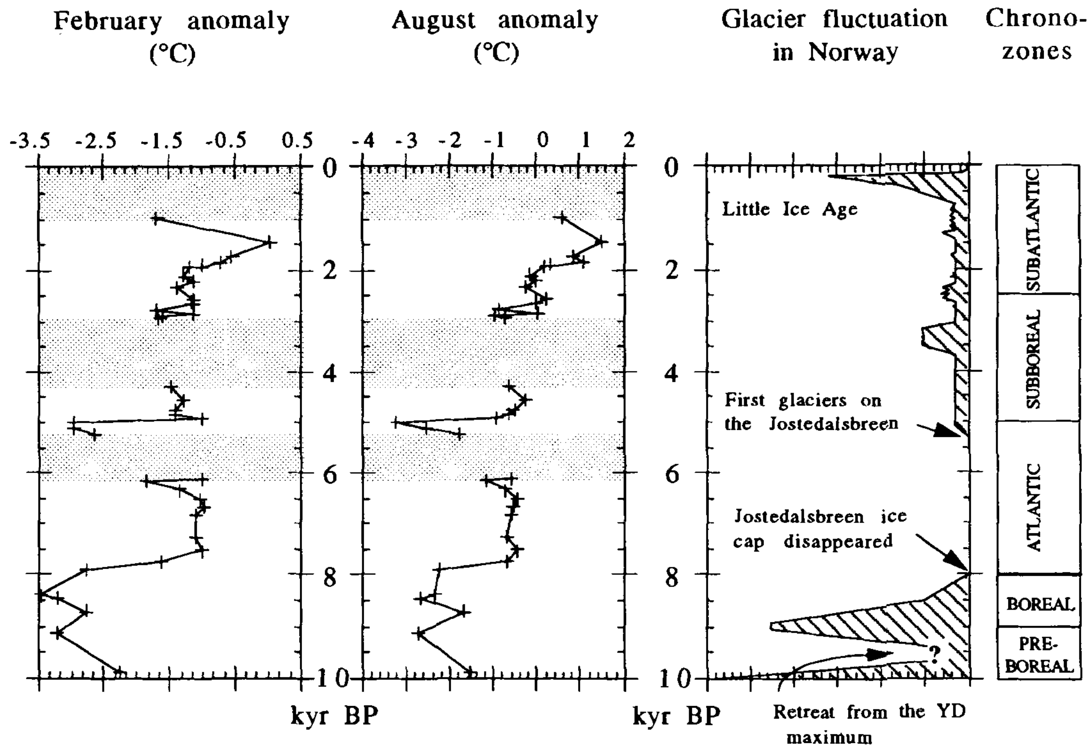


Fig. 3. Reconstructed February and August average temperatures in France expressed as deviations from the modern value. Grey areas correspond to stratigraphic hiatuses previously recognized (Rousseau *et al.* 1993). Fluctuations of Norwegian glaciers (Nesje *et al.* 1991) are also shown.

followed by short cold phases (Atkinson *et al.* 1987; Coope 1987). Estimates based on molluscs also indicate a significant warming, by comparison with values reconstructed for stage 2 in the Achenheim sequence (negative anomalies between −12.7 and −4.2°C in February and −5.3 and −2.7°C in August during the interval lasting from 24,000 to 12,000 BP) which corresponds to late Glacial maximum conditions (Rousseau 1991). This rapid warming, also recorded in Greenland ice cores (Johnsen *et al.* 1992; Taylor *et al.* 1993) has been recognized in both the Antartic ice sheet (Jouzel *et al.* 1987) and in Southern Ocean (Charles & Fairbanks 1992) cores. This appears to be a global event which is part of the complex Termination I interval, and corresponds to the second major freshwater pulse into the Atlantic Ocean (Fairbanks 1989). Reconstructions from pollen data provide composite proxy data from numerous European localities (Guiot 1987, 1990; Huntley 1990; Pons *et al.* 1987). These studies are mainly centered on the Termination interval. Pons *et al.* (1987), however, show similar general trends to our results with cold fluctuations at around 5000 BP in the annual temperature.

These independent interpretations of terrestrial records are also in agreement with marine records from the Norwegian Sea (Lehman & Keigwin 1992), in which the variation in the percentage of the sinistrally coiled *Neogloboquadrina pachyderma* is used to define climatic fluctuations during the last deglaciation. A rapid but short warming of estimated sea-surface temperature occurred after the Younger Dryas cold event, and was immediately followed by a Preboreal cold oscillation (Lehman & Keigwin 1992). Sea-surface temperature then seems to have remained relatively constant from 8800 BP until the present. Moreover, August anomalies from our reconstruction range in the same interval, about 4°C, as do sea summer temperature estimates from core NA 87-22 located off the Rockall Plateau in the North Atlantic (Duplessy *et al.* 1992).

Indirect estimates from geological and paleoecological analyses of lake sediments and terrestrial deposits in western Norway show several glacier fluctuations of the Jostedalsbreen ice cap during the Holocene (Nesje & Kvamme 1991; Nesje *et al.* 1991; Fig. 3). First a district retreat from the Younger Dryas maximum is recorded during the Preboreal. This short warm interval was immediately followed by a new advance of the glaciers between 9500 and 8000 BP, with a maximum at around 9000 BP (Fig. 3). Then, between 8000 and 5000 BP, the ice cap disappeared. The glaciers reappeared just before 5000 BP (Fig. 3). Peaks for extension of glaciers are then recorded between 3000 and 4000 BP, and especially during the Little Ice Age

Table 3. Mean calculated February and August temperatures based on molluscan data from French Holocene sequences. Abbreviations used: MO for Molesmes, B for Beaume-lès-Créancey, CL for Clenay (Fig. 1). Ages come from Rousseau *et al.* (1993) and have been interpolated between ^{14}C dates. Modern February and August temperatures are respectively 3.8° and 18.8°C at Molesmes, 2.8°C and 17.8°C at Beaume-lés-Crèancey, and 3.6°C and 18.6°C at Clenay. The ^{14}C date of sample MO4 was used for the time scale of the sequence even if, because of too few terrestrial mollusc individuals, the assemblage itself was not used for the reconstruction.

Mollusc assemblages	February	August	Age (× 1000 yrs)	^{14}C dates
M015	2.12	19.38	0.99	
B + 20	2.84	19.28	1.45	
B + 19	2.26	18.63	1.75	
B + 18	2.08	18.85	1.85	
B + 17	1.79	18.11	1.92	
B + 16	1.62	18.00	1.95	1950 ± 110 BP
B + 15	1.53	17.67	2.11	
B + 14	1.66	17.80	2.20	
B + 13	1.43	17.54	2.35	
B + 12	1.68	18.01	2.58	
B + 10	1.64	17.80	2.63	
B + 9	1.66	17.78	2.67	
B + 8	1.12	16.95	2.76	
B + 7	1.67	17.85	2.85	
B + 6	1.19	16.85	2.89	
B + 5	1.15	17.06	2.94	
			Hiatus	
B + 4	1.33	17.16	4.28	
B + 3	1.51	17.56	4.54	
B + 2	1.38	17.29	4.76	
B + 1	1.38	17.19	4.85	
B − 1	1.81	16.90	4.93	
MO11	0.84	15.60	5.02	
MO10	0.84	16.27	5.13	5130 ± 120 BP
MO9	1.15	17.05	5.23	5230 ± 130 BP
			Hiatus	
B − 5	1.79	17.23	6.10	
B − 6	0.96	16.65	6.17	
B − 7	1.46	17.09	6.33	
B − 8	1.78	17.35	6.50	
B − 9	1.83	17.28	6.67	
B − 10	1.70	17.20	6.83	
B − 11	1.71	17.12	7.27	
B − 12	1.80	17.34	7.52	
B − 13	1.17	17.11	7.73	
CL15	0.85	16.35	7.90	7900 ± 170 BP
MO8	0.34	16.47	8.40	
MO7	0.60	16.15	8.45	
MO6	1.05	17.12	8.72	8720 ± 150 BP
MO5	0.59	16.10	9.12	
MO4				9280 ± 170 BP
MO3	1.54	17.25	9.90	9900 ± 290 BP

(Nesje & Kvamme 1991). The re-appearance of glaciers just before 5000 BP implies a sufficient supply in moisture and cool temperatures. This event is in agreement with the small cooling phase determined from mollusc estimates.

Our results demonstrate the complexity of the temperature variation during the past 10,000 years. These observations are also in agreement with the Holocene δ^{18}O fluctuations recorded from the Greenland ice sheet (Oeschger & Arquit 1991; Johnsen *et al.* 1992). The Greenland ice record shows climatic oscillations superimposed on the deglacial trend, the complex Friesland oscillation, following the Younger Dryas, and followed by the so-called climatic optimum.

One can question these interpretations, arguing about the size of standard errors, and if strictly considering these standard errors several oscillations would in fact disappear. But does this mean that they are not real? The comparison of our results with other independent and different proxy data give us confidence, and our purpose is to show general trends in changes of the past environments during the Holocene, and how the molluscan assemblages recorded them.

Conclusions

The quantitative reconstructions of temperature from molluscan communities has been shown to be generally successful in loess environments. The results presented here indicate the usefulness of, records provided by snail communities in another environmental context, and for the relatively short time interval of the Holocene.

The succession of the reconstructed events, as recorded by the molluscs, follows the classical West European framework. After the cold Younger Dryas event, alternating warm and cool events occur just before the climatic optimum of the classical literature (the Atlantic chronozone). These results are in agreement with temperature estimates based on Coleoptera from the British Isles, but disagree with the COHMAP (1988) and other reconstructions indicating warmer summers than today.

Acknowledgements. – We thank Joyce Gavin, H. J. Birks, George Kukla and an anonymous reviewer for fruitful comments. This work is contribution CNRS-INSU-DBT No. 679, and contribution ISEM No. 94-005, to CEC-EPOCH. We also received support from an NSF-CNRS fellowship (DDR).

References

Atkinson, T. C., Briffa, K. R. & Coope, G. R. 1987: Seasonal temperatures in Britain during the past 22,000 years, reconstructed using beetle remains. *Nature 325*, 587–592.

Benzecri, J. P. & Benzecri, F. 1980: *Pratique de l'analyse des données*. Dunod, Paris.

Bond, G., Heinrich, H., Broecker, W. S., Labeyrie, L., McManus, J., Andrews, J., Huon, S., Ruediger, J., Clasen, S., Simet, C., Tedesco, K., Klas, Bonani, G. & Ivy, S. 1992: Evidence for massive discharges of icebergs into the North Atlantic ocean during the last glacial period. *Nature 360*, 245–249.

Broecker, W. S. 1990: Salinity history of the northern Atlantic during the last deglaciation. *Paleoceanography 5*, 459–467.

Charles, C. D. & Fairbanks, R. G. 1992: Evidence from southern Ocean sediments for the effect of North Atlantic deep-water flux on climate. *Nature 355*, 416–419.

COHMAP members 1988: Climatic changes of the last 18,000 years: observations and model simulations. *Science 241*, 1043–1052.

Coope, G. R. 1987: Fossil beetle assemblages as evidence for sudden and intense climatic changes in the British Isles during the last 45,000 years. *In* Berger, W. H. & Labeyrie, L. D. (eds.): *Abrupt Climatic Change*, 147–150. Reidel, Dordrecht.

Duplessy, J. C., Labeyrie, L., Arnold, M., Paterne, M. Duprat, J. & Weering, T. C. E. van 1992: Changes in surface salinity of the North Atlantic Ocean during the last deglaciation. *Nature 358*, 485–487.

Fairbanks, R. G. 1989: A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature 342*, 637–642.

Goodfriend, G. A. 1988: Mid-Holocene rainfall in the Negev desert from ^{13}C of land snail shell and organic matter. *Nature 333*, 757–760.

Goodfriend, G. A. 1991: Patterns of racemization and epimerization of amino acids in land snails shells over the course of the Holocene. *Geochimica et Cosmochimica Acta 55*, 293–302.

Guiot, J. 1987: Late Quaternary climatic change in France estimated from multivariate pollen time series. *Quaternary Research 28*, 100–118.

Guiot, J. 1990: Methodology of the last climatic cycle reconstruction from pollen data. *In* Rousseau, D. D. (ed.): Methods for the study of stratigraphical records. *Palaeogeography, Palaeoclimatology, Palaeoecology 80*, 49–69.

Huntley, B. 1990: European post-glacial forests: compositional changes in response to climatic change. *Journal of Vegetation Science 1*, 507–518.

Johnsen, S. J., Clausen, H. B., Dansgaard, W., Fuhrer, K., Gundestrup, N., Hammer, C. U., Iversen, P., Jouzel, J., Stauffer, B. & Steffensen, J. P. 1992: Irregular glacial interstadials recorded in a new Greenland ice core. *Nature 359*, 311–313.

Jouzel, J., Lorius, C., Petit, J. R., Genthon, C., Barkov, N. I., Kotlyakov, V. M. & Petrov, V. M. 1987: Vostok ice core: a continuous isotope temperature record over the last climatic cycle (160,000 years). *Nature 329*, 403–408.

Lehman, S. J. & Keigwin, L. D. 1992: Sudden changes in North Atlantic circulation during the last deglaciation. *Nature 356*, 757–762.

Lozek, V. 1964: Quartärmollusken der Tschechoslowakei. *Rozpravy Ustredniho Ustavu Geologickeho 31*, 1–374.

Magnin, F. 1992: Variations de température en Provence pendant le Pleistocène supérieur (stades isotopiques 2 et 3) estimées d'après l'analyse d'associations de gastropodes terrestres. *Comptes Rendus Académie des Sciences, ser. II 315*, 231–327.

Mangerud, J., Andersen, S. T., Berglund, B. E. & Donner, J. J. 1974: Quaternary stratigraphy of Norden, a proposal for terminology and classification. *Boreas 3*, 109–128.

Mix, A. C. & Ruddiman, W. F. 1985: Structure and timing of the last deglaciation: oxygen-isotope evidence: *Quaternary Science Reviews 4*, 59–108.

Nesje, A. & Kvamme, M. 1991: Holocene glacier and climate variations in western Norway: evidence for early Holocene glacier demise and multiple Neoglacial events. *Geology 19*, 610–612.

Nesje, A., Kvamme, M., Rye, N. & Løvlie, R. 1991: Holocene glacial and climate history of the Jostedalsbreen region, western Norway: evidence from lake sediments and terrestrial deposits. *Quaternary Science Reviews 10*, 87–114.

Oeschger, H. & Arquit, A. 1991: Resolving abrupt and high frequency global changes in the ice-core record. *In* Bradley, R. S. (ed): *Global Changes of the Past*, 175–200. UCAR, Office for Interdisciplinary Earth Studies, Boulder, CO.

Overpeck, J. T., Webb III, T. & Prentice, I. C. 1985: Quantitative interpretation of fossil pollen spectra: dissimilarity coefficients and the method of modern analogs. *Quaternary Research 23*, 87–108.

Pons, A., Beaulieu, J. L. de, Guiot, J. & Reille, M. 1987: The Younger Dryas in southwestern Europe: an abrupt climatic change as evidenced from pollen records. *In* Berger, W. H. & Labeyrie, L. D. (eds.): *Abrupt Climatic Change*, 195–208. Reidel, Dordrecht.

Rousseau, D. D. 1987: Paleoclimatology of the Achenheim series (middle and upper Pleistocene, Alsace, France). A malacological analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology 59*, 293–314.

Rousseau, D. D. 1990: Statistical analyses of loess molluscs for paleoecological reconstructions. *Quaternary International 7/8*, 81–89.

Rousseau, D. D. 1991: Climatic transfer function from Quaternary molluscs in European loess deposits. *Quaternary Research 35*, 195–209.

Rousseau, D. D. 1992: Terrestrial molluscs as indicators of global aeolian dust fluxes during glacial stages. *Boreas 21*, 105–109.

Rousseau, D. D. & Puisségur, J. J. 1990: A 350,000 years climatic record from the loess sequence of Achenheim, Alsace, France. *Boreas 19*, 203–216.

Rousseau, D. D., Limondin, N. & Puisségur, J. J. 1993: Holocene environmental signals from mollusc assemblages in Burgundy (France). *Quaternary Research 40*, 237–253.

Scherrer, B. 1984: *Biostatistique*. 850 pp. Gaëtan Morin éditeur, Chicoutimi.

Taylor, K. C., Lamorey, G. W., Doyle, G. A., Alley, R. B., Grootes, P. M. & Mayewski, P. A. 1993: The 'flickering switch' of late Pleistocene climate change. *Nature 361*, 432–436.

Wernstedt, F. L. 1972: *World Climatic Data*. 522 pp. Climatic Data Press, Lemont.