ELSEVIER

Palaeogeography, Palaeoclimatology, Palaeoecology 128 (1997) 187–206

PALAEO

Rodents and climate. 1. A model for estimating past temperatures using arvicolids (Mammalia: Rodentia)

Sophie Montuire[a], Jacques Michaux[b], Serge Legendre[a,*], Jean-Pierre Aguilar[a]

[a] *Institut des Sciences de l'Evolution—U.R.A. 327 du C.N.R.S., 34095 Montpellier, Cédex 5, France*
[b] *Laboratoire de Paléontologie des Vertébrés, E.P.H.E., 34095 Montpellier, Cédex 5, France*
Université Montpellier II, Place Eugène-Bataillon, 34095 Montpellier, Cédex 5, France

Received 26 October 1994; revision 15 May 1995; accepted 15 May 1996

Abstract

Analysis of 253 extant mammalian local faunas shows that the number of arvicoline species in each fauna is related to temperature parameters. The very high correlation allows us to propose a method to estimate the temperature for fossil faunas bearing arvicoline species from temperate areas. To illustrate this method, mean annual temperatures were estimated for Late Pleistocene Hungarian localities and for a sequence from the Baume de Gigny (Jura, France). These were compared with results obtained by other techniques (multivariate analysis of rodent associations and synthetic analysis of pollen, faunal, and sedimentological data).

Keywords: Rodentia; Arvicolinae; diversity; climate; temperature; estimation

1. Introduction

Over the last few decades, significant endeavour has been made in determining the characteristics of past climates. In the continental domain, studies have been realized using approaches dealing with geochemical data (e.g. Buchardt, 1978), with palaeosol analysis (see, for example: Retallack, 1992), with vegetal data such as pollen and plant remains (e.g., Collinson et al., 1981; Guiot, 1990; Hubbard and Boulter, 1983; Ollivier-Pierre et al., 1988; Pantic, 1986), or with animal data such as coleopterans (e.g. Atkinson et al., 1986), molluscs (e.g., Rousseau, 1987, 1991; Rousseau and Puisségur, 1990; Rousseau et al., 1992), or vertebrates, mainly mammals (Aguilar and Michaux, 1990; Chaline and Brochet, 1989; Daams and Van der Meulen, 1984; Janis, 1984; Legendre, 1987, 1989; Van der Meulen and Daams, 1992; Michaux et al., 1996).

Mammals have been used as climatic indicators since a long time by reference to related extant groups (see: Aguilar et al., in press; Legendre, 1989). Rodents have particularly been useful to reconstruct past climates: for example murines (e.g., Aguilar et al., in press; Michaux, 1971; Montuire, 1994), and arvicolines (e.g., Chaline, 1972; Chaline and Brochet, 1989; Chaline et al., 1995; Horácek, 1990).

Combining the palaeoecological analysis of mammalian communities with the relationships between the extant faunal structure and climate

* Corresponding author.

PII S0031-0182(96)00038-7

(Legendre et al., in prep.), as well as between biodiversity dynamics and climatic changes during the late Tertiary and the Quaternary (Aguilar et al., in press; Montuire, 1994, 1995), a quantification of the climatic parameters has been attempted. Results on arvicoline diversity and climatic parameters, such as temperatures, are presented in this study.

2. The Arvicolinae

The oldest arvicolines are recorded in Western Europe as early as the latest Late Miocene (Fejfar and Heinrich, 1986, 1990; Repenning et al., 1990). An age of 5.5 m.y. has been estimated for the radiation of these rodents (in the stratigraphical context adopted here, the base of the Pliocene is around 5.2 m.y.).

In fact, the presence of arvicolines as early as the Late Miocene cannot be excluded: a few faunal elements recently collected bear evidence of their presence in the late Late Miocene locality of Castelnou 3 in Southern France (Aguilar et al., 1991). It must however be noted that the quality of the datings and correlations is rather poor.

Data concerning the Eastern and Western part of the United States demonstrate the presence of arvicolines as early as the Late Miocene (Repenning, 1987; Repenning et al., 1990) while these rodents are not recorded in China before the Early Pliocene (Repenning et al., 1990; Zheng and Li, 1990). The oldest representatives of the arvicolines in western Transbaikalia are recorded slightly later than in Europe (Repenning et al., 1990).

Musser and Carleton (1993) recognize 143 living arvicoline species. Among them, 99 are known in the Old World, mainly from Eurasia but 1 in Africa, and 40 in the New World. Only 4 species have a holarctic distribution, one of these, the muskrat *Ondatra zibethicus*, having been introduced in a great part of the Old World for fur and having returned in the wild.

The definition of the subfamily Arvicolinae follows Musser and Carleton (1993).

3. Material

In order to analyze the structure of the body weight distribution of species in mammalian communities with the cenogram method (Legendre, 1986, 1989; Valverde, 1964, 1967), a database on extant local faunas has been built. These data are used to develop a taxon-free method using mammals to quantify climatic parameters (Legendre et al., 1991, Legendre et al., *in prep.*). A first method has been proposed which follows the observations of Misonne (1969) on the murine geographical distribution. This method was applied to estimate temperatures and rainfall during the Pliocene in Southwestern Europe (Aguilar et al., in press). Whereas the Murinae are basically distributed over the palaeotropical realm, the Arvicolinae have a very large distribution in the temperate regions of both the Old and the New World. Thus, the same approach as for the Murinae has been undertaken for the Arvicolinae.

Based on bibliographical data on their extant distribution, the number of arvicoline species has been determined for each locality. One locality roughly covers an area ranging from 100 km^2 to a maximum of 10,000 km^2, but 400 km^2 to 2500 km^2 on average. The presence of one species in a specified area (the locality) was the only criterion taken into account without any consideration on its biotope preferences. This was done with two reasons. The first reason is to reproduce the conditions involved during the formation of a fossil locality where the sediments could trap species living at the vicinity and another part of the fossil fauna would result from the activity of various predators living in that area. The second reason is to avoid circular reasoning which could occur when environments are deduced from the ecological affinities of fossil species, that should not be exactly similar to those of extant relatives used as reference.

A total of 253 faunas have been compiled for the Palearctic and Nearctic realms (Fig. 1). Thus, all the Holarctic domain has been covered including North Saharian regions from Africa (Morocco, Algeria, Libya) where arvicolines are now generally absent, although one species (*Microtus irani*) is still present in Cyrenaica (Libya). Faunas without Arvicolinae have been retained to obtain data concerning the climatic limit of the subfamily distribution (location marked with a star in Fig. 1). The list of all the faunas, with their

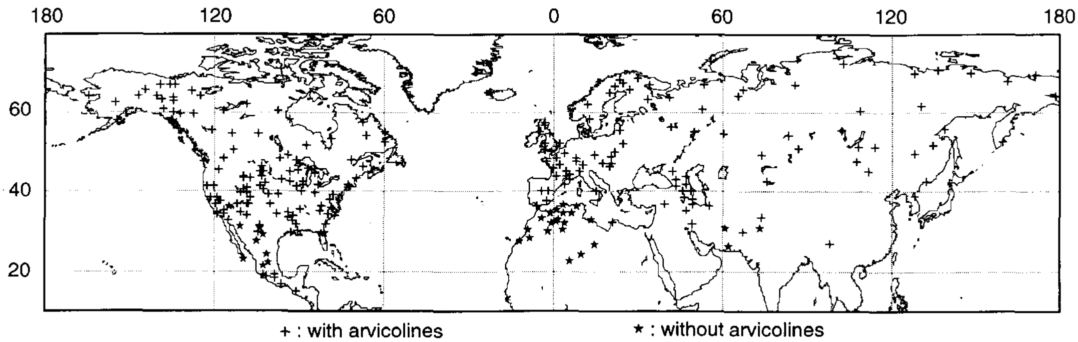

Fig. 1. Geographical distribution of the extant faunas used in this study.

geographical location and bibliographic references, is given in Tables 1 and 2.

For each fauna, temperature parameters have been determined with the meteorological data compiled in Wernstedt (1972). The temperature parameters used are: mean annual daily temperature, mean daily temperature of the coldest month, and mean daily temperature of the warmest month. These data are also given in Tables 1 and 2.

4. Method

The relationship between climatic parameters and arvicoline diversity has been analyzed using linear regression. For an overview on the various regression techniques, and for a discussion on the choice of the regression models to use, the reader is referred to specialized treatises such as those of Campbell (1989), Edwards (1984), Scherrer (1984), Sokal and Rohlf (1981), Tomassone et al. (1983), and Weisberg (1985).

To describe the relationship, without any assumption on causality between two variables both measured with statistical errors, type II regression models must be used. Moreover, while the two variables, here temperature and species number, are not measured in the same units, a method allowing standardization has been choosen: the reduced major axis (see: Sokal and Rohlf, 1981).

To use this relationship to estimate climatic parameters, a type I regression model must be used. In this model, the variable used for estimation is considered to be known without statistical error. The least square regression technique has thus been applied, with the number of arvicoline species as independent variable, and the climatic parameter as dependent variable of the model. Statistical errors are associated with these estimations and can be calculated (see, for example: Scherrer, 1984; Sokal and Rohlf, 1981).

To test the validity of the model based on the data, a randomization method has been used, the bootstrap technique (see, for example: Manly, 1991). The bootstrap method consists of resampling a random population of n individuals from the original sample, which includes n individuals. The individual which has been drawn is put back in the original sample. Calculations on the data from the theoretical populations are then run. In any case, the basic assumption of this method is that the original sample reflects the reality of the condition tested.

A computer program has been prepared by one of us (SL) to run the various calculations of this study.

5. Results

Figs. 2–4 are scatter diagrams of the basic data from the various extant faunas, and the results of the calculations using the reduced major axis on the 253 faunas are given in Table 3.

As illustrated by Figs. 2–4, the relationship between temperature and number of arvicoline species is very high. The correlation is the highest

Table 1
List (Part 1) of extant faunas used in this study, with their geographical position, the mean annual daily temperature (Ann.), the mean daily temperature of the coldest (Min.) and warmest (Max.) months, the number of species of Arvicolinae, and the bibliographical references for the arvicolid data. Temperature data from Wernstedt (1972)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
ASIA–EUROPE							
Armenia							
Araks sector	39.00 N	45.30 E	13.8	0.9	25.8	4	Vereshchagin, 1967
Sevan subdistrict	40.30 N	45.00 E	5.2	−5.4	15.8	3	Vereshchagin, 1967
Austria							
Neusiedlersee	47.40 N	16.40 E	9.8	−2.1	20.5	6	Bauer, 1960
Azerbaijan							
Kura subdistrict	40.30 N	48.00 E	4.6	2.2	26.4	2	Vereshchagin, 1967
Burma							
Northern Kachin Province	27.20 N	97.25 E	19.2	11.1	24.7	2	Ellerman, 1961a, Ellerman, 1961b
Czech Republic							
Cesky les	49.50 N	13.35 E	7.9	−2.6	17.9	6	Hurka, 1978
Finland							
Pallas Ounastunturin NP	68.00 N	24.00 E	−2.0	−13.1	11.6	9	Niethammer and Krapp, 1982
Rovaniemi	66.35 N	26.00 E	0.5	−13.0	15.1	8	Niethammer and Krapp, 1982
France							
Armorique	48.20 N	3.30 W	11.0	5.0	16.5	5	Fayard, 1984
Camargues	43.25 N	4.50 E	15.3	7.8	23.5	3	Fayard, 1984
Cévennes	44.20 N	3.40 E	8.0	1.0	17.0	4	Fayard, 1984
Colmar	48.10 N	7.30 E	10.5	1.0	19.5	5	Fayard, 1984
Landes de Gascogne	44.30 N	0.35 E	13.8	7.0	20.5	4	Fayard, 1984
Livradois – Forez	45.30 N	3.50 E	8.0	0.0	16.0	6	Fayard, 1984
Marais poitevin	46.20 N	1.00 W	12.5	6.0	19.5	5	Fayard, 1984
Nord-Pas-de-Calais	50.20 N	3.00 E	10.0	3.5	17.2	5	Fayard, 1984
Normandie-Maine	48.50 N	0.30 E	10.7	4.0	17.5	4	Fayard, 1984
Sologne	47.30 N	1.20 E	10.5	3.5	19.0	5	Fayard, 1984
Vercors	44.50 N	5.10 E	7.4	−0.9	16.2	5	Fayard, 1984
Vosges du Nord	48.50 N	7.10 E	9.5	1.2	18.0	5	Fayard, 1984
Georgia							
Greater Caucasus subdistrict	43.40 N	42.30 E	0.8	−7.4	9.3	8	Vereshchagin, 1967
Lesser Caucasus subdistrict	41.40 N	42.30 E	6.2	−6.2	17.3	7	Vereshchagin, 1967
Great Britain							
Dingwall Region	57.30 N	4.00 W	8.3	3.0	14.2	3	Arnold, 1993
Exmoor NP	51.10 N	3.40 W	10.5	5.5	16.1	3	Arnold, 1993
Hertfordshire	51.55 N	0.10 E	9.5	3.1	16.5	3	Arnold, 1993
Kintyre	55.30 N	5.30 W	8.9	3.8	14.3	3	Arnold, 1993
New Forest	50.50 N	1.30 W	10.7	4.6	17.3	3	Arnold, 1993
Norfolk Broads	52.40 N	1.40 E	9.7	3.3	16.6	3	Arnold, 1993
Southern Northumberland NP	55.05 N	2.20 W	7.4	1.3	13.9	3	Arnold, 1993
Southern Snowdonia NP	52.50 N	4.00 W	9.6	4.3	15.2	3	Arnold, 1993
Hungary							
Hortobagy	47.35 N	19.55 E	10.3	−2.7	22.0	5	Palotás and Demeter, 1983
Kiskunsag	47.00 N	18.55 E	10.6	−1.7	21.8	6	Demeter and Topál, 1987
Iran							
Aghbolagh Morched	35.40 N	46.30 E	14.0	2.1	27.0	3	Misonne, 1959
Geh	26.30 N	62.00 E	26.0	19.7	31.0	0	Lay, 1967
Gorgan Province	36.50 N	54.30 E	17.8	8.4	27.8	1	Lay, 1967

Table 1 (*Continued*)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
Seistan	31.00 N	61.00 E	21.7	9.5	33.4	0	Lay, 1967
Shush	32.20 N	48.25 E	20.3	8.2	35.4	2	Lay, 1967
Talysh forest sector	37.30 N	48.30 E	9.6	−2.0	20.1	3	Vereshchagin, 1967
Upland Talysh steppe sector	38.30 N	48.25 E	9.8	0.1	20.0	4	Vereshchagin, 1967
Italy							
Partenio Mts	40.50 N	14.35 E	13.9	5.8	23.2	3	Capolongo and Caputo, 1990
Ticino	45.25 N	8.40 E	13.1	2.3	23.1	1	Galeotti, 1981
Kazakhstan							
Kazakh uplands	49.50 N	73.10 E	2.3	−15.3	20.1	6	Ognev, 1948,Ognev, 1950, Corbet, 1978
Zaisan	67.30 N	84.55 E	4.0	−17.2	23.0	5	Ognev, 1948,Ognev, 1950, Corbet, 1978
Northern Korea							
Wonsan	39.10 N	127.25 E	10.6	−3.8	23.4	3	Corbet, 1978
Kyrgyzstan							
Central Kirgizia	43.00 N	75.00 E	2.1	−18.2	16.5	4	Kouznetov, 1939
Liechtenstein							
Liechtenstein	47.10 N	9.30 E	6.9	−2.4	15.4	7	Lehmann, 1963
Lithuania							
Lithuania	56.00 N	23.00 E	6.0	−5.1	18.1	6	Ivanauskas et al., 1964
Mongolia							
Central Mongolia	48.00 N	107.00 E	−1.7	−23.7	17.1	9	Ognev, 1948,Ognev, 1950, Corbet, 1978
Norway							
Kautokeino	69.00 N	23.00 E	−2.6	−13.8	13.0	6	Niethammer and Krapp, 1982
Pasvik	69.10 N	29.15 E	−1.0	−13.0	13.0	7	Niethammer and Krapp, 1982
Rørøs	62.35 N	11.25 E	−0.2	−10.5	11.4	6	Niethammer and Krapp, 1982
Pakistan							
Lyallpur	31.00 N	73.00 E	24.5	12.1	34.3	0	Taber et al., 1967
Murree	33.55 N	73.25 E	12.9	2.9	21.1	3	Roberts, 1977
Quetta	30.10 N	67.00 E	15.1	3.6	26.6	1	Roberts, 1977
Poland							
Babia Gora I	49.10 N	19.30 E	8.1	−2.9	18.2	5	Cohen, 1988
Babia Gora II	49.10 N	19.30 E	5.7	−5.8	16.0	5	Cohen, 1988
Bialowieza	52.40 N	23.40 E	6.8	−4.7	18.3	7	Pucek and Raczynski, 1983
Nowy Targ Valley	49.20 N	20.00 E	4.5	−5.0	15.2	8	Pucek and Raczynski, 1983
Swietokrzyski	50.50 N	21.00 E	7.5	−3.5	18.0	4	Szafera, 1959
Russia							
Anadyr	64.40 N	177.30 E	−7.4	−21.4	10.8	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Archangelsk	64.35 N	40.30 E	1.4	−11.7	16.3	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Ayan	56.35 N	138.10 E	−3.3	−19.4	12.6	6	Ognev, 1948,Ognev, 1950, Corbet, 1978
Blagoveshchensk	50.15 N	127.30 E	0.2	−24.2	21.7	6	Ognev, 1948,Ognev, 1950, Corbet, 1978
Bratsk	56.05 N	101.50 E	−2.6	−23.7	18.2	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Cherskiy	68.40 N	160.50 E	−12.4	−35.7	11.8	9	Ognev, 1948,Ognev, 1950, Corbet, 1978
Chita	52.05 N	113.30 E	−2.9	−26.7	18.5	8	Ognev, 1948,Ognev, 1950, Corbet, 1978
Chokurdakh	70.40 N	147.55 E	−13.3	−35.7	10.5	10	Ognev, 1948,Ognev, 1950, Corbet, 1978
Ciscaucasian subdistrict	45.40 N	41.50 E	9.0	−4.0	20.0	5	Vereshchagin, 1967
Dagestan subdistrict	42.10 N	46.30 E	2.2	−17.8	21.6	5	Vereshchagin, 1967
Erbogacem	61.15 N	108.00 E	−6.8	−31.1	17.0	8	Ognev, 1948,Ognev, 1950, Corbet, 1978
Ivanovo	57.00 N	41.00 E	3.3	−12.0	18.8	8	Ognev, 1948,Ognev, 1950, Corbet, 1978
Kandalaksha	67.30 N	33.20 E	−1.1	−13.2	13.1	9	Niethammer and Krapp, 1982, Ognev, 1948,Ognev, 1950
Karelia	64.00 N	33.00 E	1.0	−11.3	15.9	8	Isakov, 1939
Kazan	55.45 N	49.10 E	3.1	−13.1	19.4	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Khatanga	72.55 N	102.30 E	−13.8	−34.8	11.8	10	Ognev, 1948,Ognev, 1950, Corbet, 1978

Table 1 (*Continued*)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
Kyusyur	70.45 N	127.20 E	−14.3	−40.8	12.0	10	Ognev, 1948,Ognev, 1950, Corbet, 1978
Narjan Mar	67.40 N	53.00 E	−3.2	−15.6	12.2	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Nizhneyansk	71.30 N	136.00 E	−13.2	−29.4	2.5	10	Ognev, 1948,Ognev, 1950, Corbet, 1978
Northeastern Urals	65.00 N	65.00 E	−3.8	−21.7	17.1	8	Flerov, 1933
Novosibirsk	55.00 N	82.55 E	−0.3	−19.3	18.7	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Petropavlosk	53.00 N	158.45 E	1.9	−8.5	13.7	6	Ognev, 1948,Ognev, 1950, Corbet, 1978
Salekhard	66.35 N	66.40 E	−5.7	−21.9	14.1	8	Ognev, 1948,Ognev, 1950, Corbet, 1978
Shelagontsy	70.10 N	170.20 E	−12.7	−41.6	14.8	10	Ognev, 1948,Ognev, 1950, Corbet, 1978
Sofiysk	52.15 N	134.00 E	−7.4	−34.2	15.2	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Telotskoye Lake	51.30 N	86.15 E	3.0	−12.6	18.4	7	Ognev, 1948,Ognev, 1950, Corbet, 1978
Terek-Kuma sector	44.20 N	46.20 E	11.2	−2.5	24.3	4	Vereshchagin, 1967
Ulan Ude	51.50 N	107.35 E	−2.2	−26.7	19.2	8	Ognev, 1948,Ognev, 1950, Corbet, 1978
Ust Tsilma	61.30 N	52.10 E	−2.6	−18.2	14.4	10	Ognev, 1948,Ognev, 1950, Corbet, 1978
Vladivostok	43.10 N	131.55 E	4.6	−13.7	20.6	5	Ognev, 1948,Ognev, 1950, Corbet, 1978
Yakutsk	62.15 N	129.50 E	−10.2	−43.2	18.8	9	Ognev, 1948,Ognev, 1950, Corbet, 1978
Zlatoust (Southern Urals)	55.10 N	59.40 E	0.4	−15.8	16.0	9	Ognev, 1948,Ognev, 1950, Corbet, 1978
Spain							
Aiguamolls de l'Empordà	42.15 N	3.15 E	16.0	9.0	24.0	3	Sargatal and Fèlix, 1989
Alto Tajo	40.35 N	2.50 W	10.0	2.0	20.0	2	Amores et al., 1992
Cazorla	37.55 N	3.05 W	17.0	8.0	28.0	3	Otero et al., 1978
Do – ana	37.00 N	6.30 W	18.0	10.3	26.3	1	Valverde, 1964,Valverde, 1967
Sierra de Gredos	40.30 N	5.00 W	10.0	2.0	20.0	2	P. Fandos, pers. comm.
Sweden							
Dalsland	58.50 N	12.00 E	5.9	−4.3	16.9	3	Karvik, 1964
Malmberget	67.10 N	20.40 E	0.2	−10.4	13.9	9	Niethammer and Krapp, 1982
Storavan Lake	65.45 N	19.25 E	0.1	−10.4	13.7	6	Niethammer and Krapp, 1982
Turkey							
Urfa	37.10 N	38.45 E	18.1	4.7	31.8	1	Harrison and Bates, 1991
AFRICA							
Algeria							
Ain Sefra	32.50 N	0.35 E	20.2	8.7	32.6	0	Kowalski and Rzebik-Kowalska, 1991
Algiers	36.50 N	3.00 E	18.2	12.0	25.5	0	Kowalski and Rzebik-Kowalska, 1991
Annaba	36.35 N	7.50 E	17.9	11.3	25.3	0	Kowalski and Rzebik-Kowalska, 1991
Beni Abbes	30.10 N	2.10 W	20.2	8.7	32.6	0	Kowalski and Rzebik-Kowalska, 1991
Biskra	34.50 N	5.40 E	21.8	11.0	33.5	0	Kowalski and Rzebik-Kowalska, 1991
Brezina	33.00 N	1.20 E	20.2	8.7	32.6	0	Kowalski and Rzebik-Kowalska, 1991
Djanet	24.30 N	9.30 E	23.5	12.5	31.6	0	Kowalski and Rzebik-Kowalska, 1991
Djelfa	34.40 N	3.10 E	21.8	11.0	33.5	0	Kowalski and Rzebik-Kowalska, 1991
El Golea	30.30 N	2.50 E	21.6	9.0	34.0	0	Kowalski and Rzebik-Kowalska, 1991
Ghardaia	32.25 N	3.40 E	21.3	10.5	33.8	0	Kowalski and Rzebik-Kowalska, 1991
Oran	35.40 N	0.40 E	18.4	12.5	25.5	0	Kowalski and Rzebik-Kowalska, 1991
Tamanrasset	22.40 N	5.30 E	21.0	11.5	28.3	0	Kowalski and Rzebik-Kowalska, 1991
Libya							
Northern Cyrenaica	32.35 N	20.35 E	20.1	13.9	25.8	1	Ranck, 1968
Sabha	27.00 N	14.25 E	22.6	11.6	31.1	0	Ranck, 1968
Tripoli	32.55 N	13.10 E	19.6	12.4	26.3	0	Ranck, 1968
Morocco							
Agadir	30.30 N	9.30 W	18.4	14.0	22.5	0	Aulagnier and Thévenot, 1986
Figuig	32.10 N	1.10 W	20.2	8.7	32.6	0	Aulagnier and Thévenot, 1986
Jbel Ouarkziz	28.30 N	9.00 W	19.6	15.4	23.6	0	Aulagnier and Thévenot, 1986
Moyen Atlas	33.30 N	4.30 W	15.0	7.6	25.4	0	Aulagnier and Thévenot, 1986
Oujda	34.40 N	1.50 W	17.1	10.5	25.5	0	Aulagnier and Thévenot, 1986
Tarfaya	27.50 N	12.30 W	19.1	16.4	21.2	0	Aulagnier and Thévenot, 1986

Table 2
List (Part 2) of extant faunas used in this study, with their geographical position, the mean annual daily temperature (Ann.), the mean daily temperature of the coldest (Min.) and warmest (Max.) months, the number of species of Arvicolinae, and the bibliographical references for the arvicolid data. Temperature data from Wernstedt (1972)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
NORTH AMERICA							
Canada							
Calgary, Alberta	51.00 N	114.05 W	3.6	−9.9	16.7	7	Banfield, 1974
Slave Lake, Alberta	55.20 N	114.50 W	1.0	−16.3	15.9	7	Banfield, 1974
Hudson Hope, British Columbia	56.00 N	121.55 W	1.8	−13.9	15.6	7	Banfield, 1974
Rossland, British Columbia	49.05 N	117.50 W	6.1	−5.4	18.1	6	Banfield, 1974
Churchill, Manitoba	58.50 N	94.10 W	−7.3	−26.8	12.6	9	Banfield, 1974
Hamilton Inlet, New Foundland	53.20 N	60.25 W	0.2	−16.6	16.3	6	Harper, 1961
Hopedale, New Foundland	55.30 N	60.10 W	−1.8	−17.1	11.1	7	Hall and Kelson, 1959, Banfield, 1974
Fort Good Hope, Northwest Territory	66.15 N	128.35 W	−8.2	−30.7	15.2	9	Banfield, 1974
Fort McPherson, Northwest Territory	67.30 N	134.50 W	−9.1	−28.7	13.6	10	Hall and Kelson, 1959, Banfield, 1974
Fort Providence, Northwest Territory	61.00 N	117.40 W	−3.9	−26.7	16.1	7	Banfield, 1974
Fort Reliance, Northwest Territory	62.45 N	109.10 W	−7.2	−29.7	12.9	9	Banfield, 1974
E Great Bear Lake, Northwest Territory	64.55 N	125.30 W	−6.2	−28.1	15.5	9	Banfield, 1974
NW Nueltin Lake, Northwest Territory	61.00 N	98.00 W	−9.4	−31.6	12.4	9	Harper, 1956
Kenora, Ontario	49.50 N	94.30 W	2.3	−17.1	19.6	6	Banfield, 1974
Lansdowne House, Ontario	52.15 N	87.55 W	−1.4	−22.2	17.1	5	Banfield, 1974
Quetico Provincial Park, Ontario	48.25 N	91.30 W	3.3	−12.9	18.6	4	Cahn, 1937
Fort Chimo, Québec	58.05 N	68.20 W	−5.2	−23.9	11.8	7	Harper, 1961
Fort George, Québec	53.50 N	79.00 W	−3.2	−22.4	12.3	6	Harper, 1961
Knob Lake, Québec	54.50 N	66.50 W	−4.3	−23.0	12.8	7	Harper, 1961
Lac Saint−Jean, Québec	48.30 N	72.20 W	2.7	−15.7	18.7	4	Harper, 1961
Lac La Ronge, Saskatchewan	55.05 N	105.15 W	−0.5	−20.3	17.7	6	Banfield, 1974
Bonnet Plume Lake, Yukon	64.20 N	135.00 W	−4.2	−25.4	15.3	10	Youngman, 1975
Dawson, Yukon	64.00 N	139.25 W	−4.7	−27.6	15.4	9	Youngman, 1975
Kluane Lake, Yukon	61.20 N	138.50 W	−1.5	−20.1	14.1	9	Youngman, 1975
Lapierre House/Summit Lake, Yukon	67.40 N	136.30 W	−8.2	−28.8	14.7	10	Youngman, 1975
Mayo/Keno, Yukon	63.40 N	135.30 W	−3.7	−25.2	14.7	8	Youngman, 1975
Old Crow, Yukon	67.35 N	139.40 W	−6.4	−28.8	14.9	9	Youngman, 1975
Teslin Lake, Yukon	60.05 N	133.00 W	−1.3	−19.4	13.4	8	Youngman, 1975
Watson Lake, Yukon	60.10 N	128.25 W	−2.6	−24.2	15.1	8	Youngman, 1975
Whitehorse, Yukon	60.40 N	135.05 W	−2.6	−24.2	15.1	8	Youngman, 1975
U.S.A.							
Eagle, Alaska	64.45 N	141.10 W	−4.2	−25.4	15.3	9	Hall and Kelson, 1959, Rearden, 1981
Fairbanks, Alaska	64.50 N	147.45 W	−3.6	−23.8	15.8	8	Hall and Kelson, 1959, Rearden, 1981
Fort Yukon, Alaska	66.35 N	145.20 W	−6.4	−28.8	16.3	9	Hall and Kelson, 1959, Rearden, 1981
Katmai National Monument, Alaska	58.30 N	155.00 W	0.6	−11.5	12.6	6	Cahalane, 1959
McGrath, Alaska	63.00 N	155.35 W	−3.8	−22.6	14.7	8	Hall and Kelson, 1959, Rearden, 1981

Table 2 (*Continued*)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
Seward Peninsula, Alaska	65.00 N	165.00 W	−3.3	−15.3	9.7	8	Quay, 1951, Hall and Kelson, 1959, Rearden, 1981
San Francisco Mts, Arizona	35.10 N	111.40 W	7.6	−2.6	18.6	3	Hoffmeister, 1986
Santa Cruz County, Arizona	31.35 N	111.05 W	17.9	9.1	27.4	0	Hoffmeister, 1986
Southern Apache County, Arizona	34.10 N	109.15 W	9.3	−0.5	19.4	5	Hoffmeister, 1986
Greene County, Arkansas	36.00 N	90.30 W	15.4	3.7	26.4	4	Sealander and Heidt, 1990
Hot Springs County, Arkansas	34.30 N	93.05 W	17.3	6.4	27.8	2	Sealander and Heidt, 1990
Sebastian County, Arkansas	35.20 N	94.20 W	16.4	4.3	27.9	3	Sealander and Heidt, 1990
Union County, Arkansas	33.15 N	92.50 W	18.1	7.8	28.0	2	Sealander and Heidt, 1990
Colorado desert, California	33.00 N	115.30 W	22.6	12.0	33.4	1	Jameson and Peeters, 1988
Colusa County, California	39.05 N	122.00 W	16.1	7.3	25.4	2	Jameson and Peeters, 1988
Del Norte County, California	41.40 N	123.40 W	11.4	8.0	14.6	5	Jameson and Peeters, 1988
Eastern Kern County, California	35.30 N	117.50 W	17.2	6.9	28.9	1	Jameson and Peeters, 1988
Lake Tahoe, California	39.00 N	120.00 W	5.8	−2.9	15.9	3	Jameson and Peeters, 1988
McKittrick, California	35.10 N	119.40 W	19.0	8.7	30.2	1	Schultz, 1938
Modoc Plateau, California	41.40 N	121.00 W	8.2	−2.2	19.2	3	Jameson and Peeters, 1988
Mohave Desert, California	34.40 N	117.30 W	16.4	6.9	27.5	1	Merriam, 1919
Mono Lake, California	38.00 N	119.00 W	12.1	0.1	25.7	2	Jameson and Peeters, 1988
San Joaquim Valley, California	37.20 N	120.40 W	17.1	8.5	26.3	1	Schultz, 1938
Santa Barbara County, California	34.40 N	120.00 W	15.6	11.7	19.4	1	Jameson and Peeters, 1988
Yosemite NP, California	38.00 N	119.35 W	11.4	1.8	21.7	3	Jameson and Peeters, 1988
Grand Mesa, Colorado	39.00 N	108.00 W	4.7	−6.7	16.5	5	Anderson, 1959
Mesa Verde NP, Colorado	37.10 N	108.30 W	10.1	−1.2	22.4	4	Anderson, 1961
Hartford County, Connecticut	41.45 N	72.40 W	9.9	−2.8	22.8	5	Godin, 1977
Gainesville, Florida	29.40 N	82.20 W	21.2	14.3	27.3	0	Humphrey, 1992
Palm Valley, Florida	30.00 N	81.20 W	21.0	14.2	27.5	0	Ivey, 1959
Peoria, Illinois	40.40 N	89.40 W	10.7	−3.8	24.1	5	Jones and Birney, 1988
Hancock County, Iowa	43.20 N	93.50 W	7.9	−8.7	23.1	3	Bowles, 1975
Johnson County, Iowa	41.50 N	91.30 W	9.9	−5.7	23.7	4	Bowles, 1975
Cheyenne County, Kansas	39.50 N	101.50 W	11.4	−1.7	25.2	2	Bee et al., 1981
Republic County, Kansas	39.50 N	98.00 W	11.9	−3.1	26.2	3	Eshelman, 1975
SW Kansas and NW Oklahoma	37.10 N	101.00 W	14.4	1.7	27.7	3	Hibbard and Taylor, 1960
Big Black Mt, Kentucky	37.00 N	83.00 W	13.9	3.7	24.7	4	Barbour, 1951
Baton Rouge, Louisiana	30.30 N	91.10 W	20.1	12.1	27.8	2	Lowery, 1974
Calcasieu County, Louisiana	30.10 N	93.10 W	20.2	11.4	28.2	2	Lowery, 1974
Northeastern Louisiana	32.30 N	91.30 W	18.8	9.5	27.9	2	Lowery, 1974
Androscoggin County, Maine	44.05 N	70.10 W	7.1	−7.1	20.9	4	Godin, 1977
Aroostook County, Maine	46.50 N	68.00 W	3.7	−11.9	18.2	5	Godin, 1977
Frostburg, Maryland	39.40 N	78.55 W	10.4	−0.9	21.9	5	Webster et al., 1985
Berkshire County, Massachussets	42.25 N	73.20 W	7.1	−6.1	19.8	5	Godin, 1977
Ann Arbor, Michigan	42.20 N	83.40 W	10.0	−3.0	23.4	3	Baker, 1983
Charlevoix, Michigan	45.10 N	85.20 W	7.3	−5.5	20.6	3	Baker, 1983
Marquette County, Michigan	46.35 N	87.25 W	5.3	−8.2	18.7	4	Baker, 1983
Schoolcraft County, Michigan	46.00 N	86.10 W	5.6	−7.1	18.4	4	Baker, 1983
Sherburne County, Minnesota	45.35 N	94.10 W	5.4	−12.5	21.2	6	Hazard, 1982
Cook County, Minnesota	47.50 N	90.20 W	3.6	−9.9	−16.5	5	Hazard, 1982
Carter County, Montana	45.30 N	104.30 W	5.8	−9.7	21.2	4	Lampe et al., 1974
Gallatin County, Montana	45.40 N	111.05 W	5.7	−6.4	18.4	4	Hoffmann et al., 1969
Chadron, Nebraska	42.50 N	103.00 W	9.1	−4.6	23.8	3	Jones et al., 1985
Wildcat Hills, Nebraska	41.05 N	103.40 W	8.7	−3.1	22.1	3	Jones et al., 1985

Table 2 (*Continued*)

Country	Location		Temperature(°C)			Arvicolinae	References
Fauna	Latitude(°)	Longitude(°)	Ann.	Min.	Max.	*N* of sp.	
Clark Canyon, Nevada	36.20 N	115.35 W	19.3	11.8	26.8	0	Deacon et al., 1964
New Hanover County, North Carolina	34.20 N	77.55 W	17.6	8.6	26.8	1	Lee et al., 1982
Rockingham County, North Carolina	36.20 N	79.20 W	15.3	5.0	25.6	1	Lee et al., 1982
Union County, North Carolina	35.00 N	80.30 W	16.1	6.4	26.0	2	Lee et al., 1982
Wake County, North Carolina	35.55 N	78.30 W	15.4	5.3	25.7	3	Lee et al., 1982
Bad Lands, North Dakota	47.00 N	103.50 W	6.0	−9.9	21.6	4	Jones et al., 1985
Pembino Hills, North Dakota	48.50 N	97.30 W	2.6	−17.4	20.1	4	Jones et al., 1985
Licking County, Ohio	40.05 N	85.25 W	10.9	−1.3	23.0	4	Gottschang, 1981
Southeastern Oklahoma	34.05 N	94.50 W	17.5	6.6	27.9	2	Jones et al., 1985
Wichita Mts, Oklahoma	35.00 N	98.50 W	16.2	4.2	27.8	1	Glass and Halloran, 1961
Oregon Caves Area	42.00 N	123.25 W	12.4	4.0	21.4	3	Roest, 1951
Beaufort, South Carolina	32.25 N	80.45 W	19.1	10.5	27.3	1	Webster et al., 1985
Harding County, South Dakota	45.30 N	103.30 W	6.4	−8.4	21.6	3	Andersen and Jones, 1971
Sioux Falls, South Dakota	43.30 N	96.40 W	7.5	−9.9	23.2	3	Jones et al., 1985
Great Smoky Mt, Tennessee	35.40 N	83.30 W	15.2	9.1	21.2	2	Fleming, 1973
Big Bend NP, Texas	29.20 N	103.20 W	20.8	9.9	30.5	0	Schmidly, 1977
Guadalupe Mts NP, Texas	32.00 N	104.50 W	18.4	8.5	27.3	1	Schmidly, 1977
Southern Culberson County, Texas	31.10 N	104.25 W	17.3	7.1	26.9	0	Dalquest and Stangl, 1984
San Juan County, Utah	37.15 N	109.35 W	13.0	−0.9	26.6	2	Durrant, 1952
Uintah, Utah	40.20 N	109.20 W	7.6	−9.4	22.3	4	Durrant, 1952
Utah County, Utah	40.20 N	111.55 W	9.2	−3.8	22.4	4	Durrant, 1952
Washington County, Utah	37.15 N	113.00 W	16.4	4.3	29.1	3	Durrant, 1952
Monterrey, Virginia	38.25 N	79.35 W	9.6	−0.9	20.2	5	Webster et al., 1985
Franklin County, Washington	46.10 N	119.05 W	12.0	−0.2	24.2	3	Ingles, 1965
Olympic NP, Washington	48.00 N	124.25 W	9.5	3.4	15.7	6	Ingles, 1965
Pend Oreille County, Washington	48.55 N	117.25 W	6.1	−5.4	18.1	7	Ingles, 1965
Dane County, Wisconsin	43.05 N	89.25 W	7.9	−7.9	22.6	4	Jackson, 1961
Rock County, Wisconsin	42.30 N	89.00 W	9.1	−6.1	23.1	3	Jackson, 1961
Sawyer County, Wisconsin	45.55 N	91.05 W	3.8	−12.8	18.8	4	Jackson, 1961
Big Horn Basin, Wyoming	44.00 N	108.00 W	8.1	−8.7	23.6	5	Clark and Stromberg, 1987
Black Hills, Wyoming	44.10 N	104.10 W	6.9	−6.3	21.7	5	Clark and Stromberg, 1987
Goshen County, Wyoming	42.00 N	104.50 W	9.8	−1.6	23.2	2	Clark and Stromberg, 1987
Jackson Hole, Wyoming	43.50 N	110.40 W	3.3	−9.9	16.1	8	Negus and Findley, 1959
Lower Green River, Wyoming	41.20 N	109.30 W	6.9	−7.1	20.9	5	Clark and Stromberg, 1987
Uinta Mts, Wyoming	41.10 N	110.30 W	4.2	−8.3	16.9	7	Clark and Stromberg, 1987
Yellowstone Park, Wyoming	44.35 N	110.30 W	4.3	−7.6	17.2	6	Clark and Stromberg, 1987
Guatemala							
Huehuetenango	15.20 N	91.30 W	16.7	14.9	18.5	1	Hall and Kelson, 1959
Mexico							
Cabo, Baja California Sur	23.00 N	110.00 W	23.9	17.9	29.7	0	Woloszyn and Woloszyn, 1982
Casas Grandes, Chihuahua	30.20 N	105.00 W	16.5	7.1	25.7	1	Anderson, 1972
Ciudad Camargo, Chihuahua	27.40 N	105.10 W	20.6	11.6	29.1	0	Anderson, 1972
Colima	19.10 N	103.30 W	24.6	22.7	26.3	1	Ramírez-Pulido et al., 1986
Distrito Federal	19.25 N	99.10 W	15.5	12.3	18.3	1	Ceballos and Galindo, 1984
Michoacan	19.00 N	102.00 W	19.8	16.4	22.9	1	Hall and Villa-Rochas, 1949
Morelos	18.40 N	99.00 W	16.8	14.0	19.2	1	Ramírez-Pulido et al., 1986
Zacatepec, Oaxaca	17.20 N	96.00 W	15.6	13.4	17.8	1	Hall and Kelson, 1959
Jalpa, Zacatecas	21.30 N	103.00 W	17.9	13.0	22.0	0	Matson and Baker, 1986
Pinos, Zacatecas	22.25 N	101.30 W	17.6	12.9	21.5	0	Matson and Baker, 1986
Northern Zacatecas	24.30 N	102.00 W	22.0	18.9	23.8	0	Matson and Baker, 1986

Geographical, climatic, and arvicoline data for extant faunas.

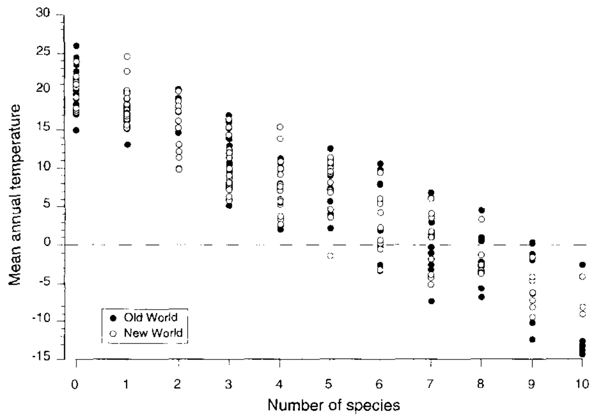

Fig. 2. Scatter diagram of the number of species of Arvicolinae from each fauna and of the mean annual daily temperature of the locality. The dashed line corresponds to the 0°C mean value.

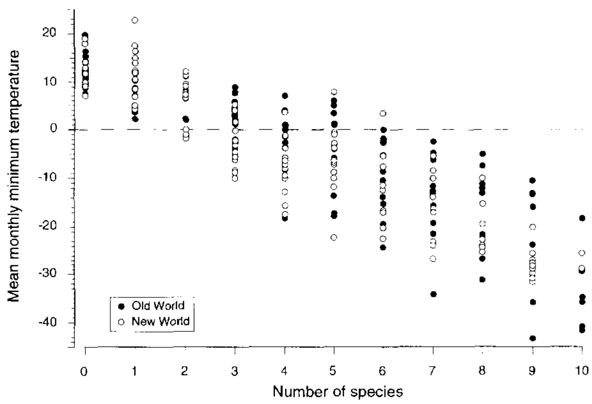

Fig. 3. Scatter diagram of the number of species of Arvicolinae from each fauna and the mean daily temperature of the coldest month in the year (January or February). The dashed line corresponds to the 0°C mean value.

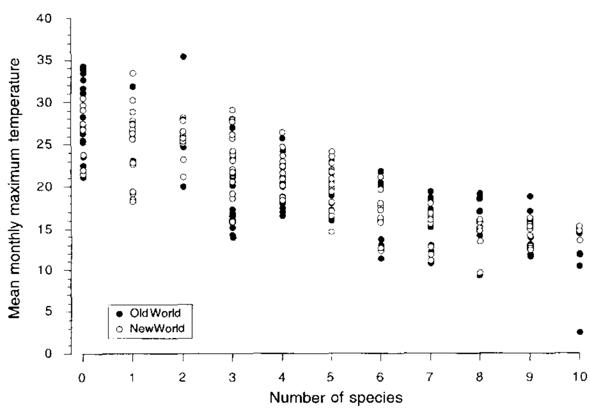

Fig. 4. Scatter diagram of the number of species of Arvicolinae from each fauna and the mean daily temperature of the warmest month in the year (July or August).

Table 3
Parameters of the reduced major axis between number of species, and mean annual temperature, monthly minimum temperature, and monthly maximum temperature

Temperatures	N	r	R^2	Slope	Intercept
Mean annual	253	−0.921	0.849	−3.093	21.360
Mean monthly minimum	253	−0.883	0.780	−4.249	15.446
Mean monthly maximum	253	−0.803	0.645	−2.000	29.186

Parameters of the reduced major axis between the number of arvicoline species and temperatures.

Table 4
Parameters of the least square regression of the number of arvicoline species on mean daily temperatures (annual, minimum monthly, and maximum monthly)

Temperature	N	R^2	Slope	Intercept	Error
Mean annual	253	0.85	−2.82	20.07	3.74
Mean monthly minimum	253	0.78	−4.13	13.12	6.48
Mean monthly maximum	253	0.65	−1.61	27.52	3.52

Parameters of the least square regression between the number of arvicoline species and temperatures.

for the mean annual daily temperature, and the lowest for the mean daily temperature of the warmest month. The correlation coefficient reaches 0.92 for the mean annual temperature, is almost 0.88 for the mean temperature of the coldest month, and is a little greater than 0.80 for the mean temperature of the warmest month. This relationship is inverse, as shown by the Figs. 2–4 and by the negative sign of the correlation coefficient and of the slope (Table 3). The determination coefficient indicates that almost 80% of the variation observed in mean annual temperatures (R^2= 0.85) and mean monthly minimum temperatures (R^2= 0.78) can be explained by the variation in the number of arvicoline species in the faunas, whereas it is only 65% for the mean monthly maximum temperatures (R^2= 0.65).

This very high relationship between the two kinds of parameters is the basis for proposing a linear regression equation to estimate temperatures from the number of arvicoline species found in fossil faunas. This equation has been calculated for the complete data set (i.e. 253 faunas), with the least square regression technique, using temperature parameters as dependent variable. The equation parameters (determination coefficient, slope, intercept, error of the predicted mean) are given in Table 4.

The same techniques were used after separating Old World and New World data, with respectively 121 and 132 faunas. Statistical comparison of linear regression parameters produced an F-value indicating no differences between the two data sets (Table 5).

Table 5
Parameter values of the least square regression between number of species, and mean annual temperature, monthly minimum temperature, and monthly maximum temperature for The Old World and for the New World, and F value obtained for the statistical comparison of Old and New World parameters

Temperature		N	R^2	Slope	Intercept	Error
Mean annual	Old	121	0.84	−2.83	20.46	3.88
	New	132	0.86	−2.88	20.25	3.24
	F-value		*0.41*	*0.09*	*0.82*	
Mean monthly minimum	Old	121	0.75	−3.95	13.21	7.14
	New	132	0.82	−4.36	13.27	5.68
	F-value		*2.33*	*2.19*	*2.29*	
Mean monthly maximum	Old	121	0.63	−1.67	27.67	4.03
	New	132	0.67	−1.53	27.31	2.98
	F-value		*0.40*	*0.97*	*0.35*	

Parameters of the least square regression between the number of arvicoline species from the Old World and from the New World and temperatures.

Calculations after the resampling test by bootstrap for mean annual temperatures confirm these results. The various values of the parameters are very similar and are normally distributed (Figs. 5–7). When the bootstrap technique is applied after separating the Old World faunas and New World faunas from the database, the relationships remain identical as those obtained from the complete data set, and the parameter values are of the same order (Table 6; Figs. 5–7). Randomized data sets show that the correlation coefficient and the slope are very similar for both the Old and the New World (Fig. 8).

Thus, it can be concluded that the relationships between the temperature and the number of arvico-

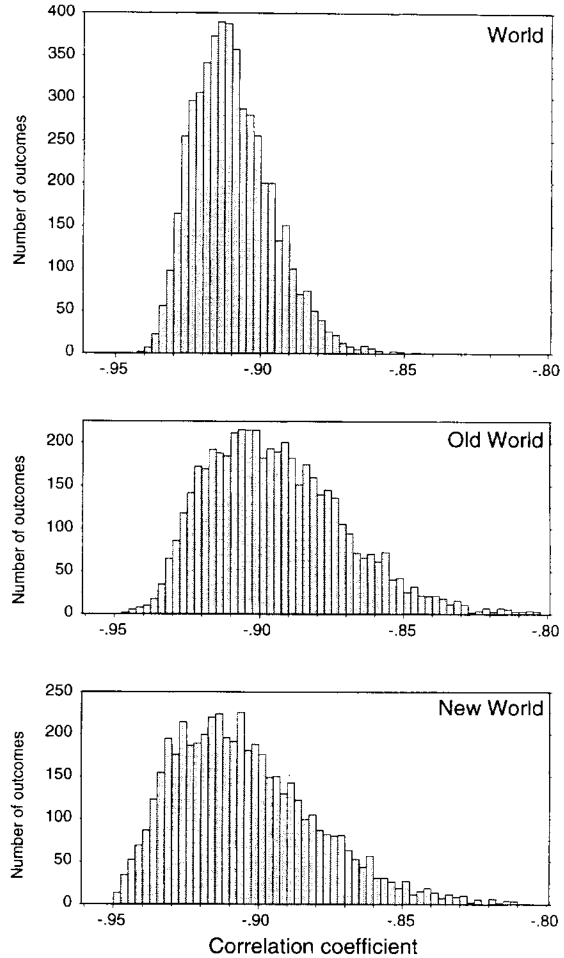

Fig. 5. Comparison of the distribution of the correlation coefficient calculated on 5000 bootstrap resamplings run on the data from the Holarctic ($N=253$), Palaearctic ($N=121$), and Nearctic regions ($N=132$) for the mean annual daily temperature.

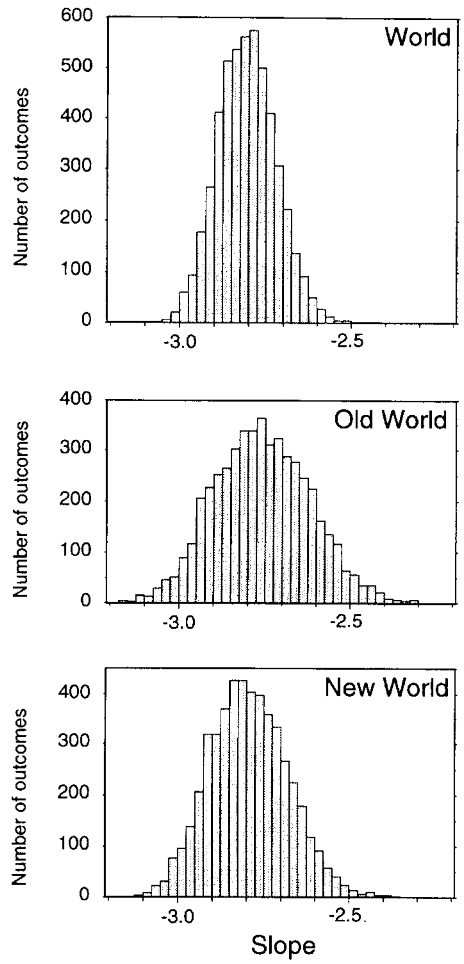

Fig. 6. Comparison of the distribution of the slopes calculated on 5000 bootstrap resamplings run on the data from the Holarctic ($N=253$), Palaearctic ($N=121$), and Nearctic regions ($N=132$) for the mean annual daily temperature using the least square regression method.

line species in mammalian communities do not depend on the palaeobiogeographical history of each continental domain, the Palearctic realm and the Nearctic realm.

6. Example of climatic estimations

In order to exemplify the use of the method, calculations have been run to estimate temperature values for two of fossil fauna sequences: the last 100,000 years in Hungary and the Baume of Gigny in France.

7. Hungary

First the method has been applied to a Plio-Pleistocene sequence in Central Europe (Montuire, 1994, 1996). The results for Hungarian localities from the last 100,000 years are presented here as an example (Fig. 9). They have been compared

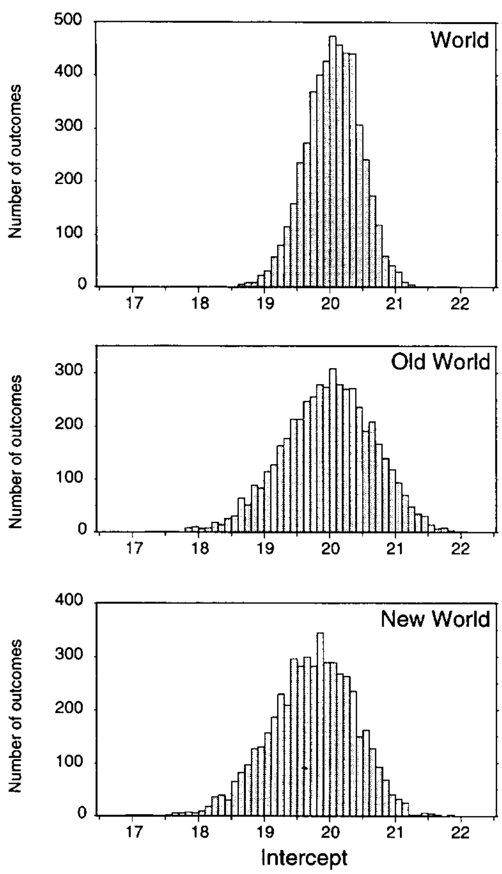

Fig. 7. Comparison of the distribution of the intercept calculated on 5000 bootstrap resamplings run on the data from the Holarctic ($N=$ 253), Palaearctic ($N=$ 121), and Nearctic regions ($N=$ 132) for the mean annual daily temperature using the least square regression method.

with those obtained with other methods, first with the climatic characteristics proposed by Jánossy (1986), and second with the temperatures given by oxygen isotopic curves (Fig. 10).

Jánossy (1986) has discussed the local climatic and environmental changes. In a study of mammals and plants, for example, for the fauna of Tokod Nagyberek dated at around 36,200 yr B.P., a cooling is indicated by the composition of the mammalian fauna (*Megaloceros, Dicrostonyx* and *Microtus gregalis*) and plants. The fauna of Pilisszántó 1 dated at around 25,000 yr B.P. suggests a rather cool environment that corresponds to the present-day Asiatic tundra. The Arctic fox

Table 6
Mean values of the parameters for the least square regression calculated for 5000 bootstrap resamplings ran on the original data given in Tables 1 and 2

Temperature		R^2	Slope	Intercept	Error
Mean annual	All World	0.83	−2.81	20.05	3.75
	Old World	0.80	−2.76	19.97	4.25
	New World	0.82	−2.79	19.73	3.64
Mean monthly minimum	All World	0.77	−4.08	12.88	6.49
	Old World	0.74	−3.88	12.81	7.15
	New World	0.81	−4.28	12.81	5.72
Mean monthly maximum	All World	0.58	−1.56	27.22	3.88
	Old World	0.54	−1.60	27.16	4.63
	New World	0.54	−1.43	26.73	3.72

Parameters of the least square regression between the number of arvicoline species and temperatures. Mean values of 5000 bootstrap resamplings on data from the Holarctic Regions ($N=$ 253), from the Old World ($N=$ 121), and from the New World ($N=$ 132).

(*Vulpes lagopus*), the Arctic lemming (*Dicrostonyx*), some voles (*Microtus gregalis* and *Microtus nivalis*) are characteristic. For the Rejtek fauna dated at around 12,000 yr B.P., Jánossy (1986) notes a change in response to the warming-up that corresponds to the beginning of the deglaciation at the end of the Quaternary. The estimates of the mean annual temperatures of this study coincide with the results of Jánossy (1986) based on his analysis of mammals and plants.

From the oxygen isotope curve (after Martinson et al., 1987), coolings are noted at around 120,000, 80,000–70,000 and 25,000–20,000 yr B.P. There is an important temperature increase at 135,000 yr B.P., and the warming-up at the end of the Quaternary (Duplessy et al., 1981) is dated at around 15,000 yr B.P. The estimates show low temperatures at 100,000 yr B.P. for Hórvölgy and coolings from 50,000 to 36,000 yr B.P., and at around 25,000 yr B.P. A temperature increase occurred for the Rejtek fauna at about 12,000 yr B.P. Thus, the temperature trends as given by the isotope curves agree with the estimates calculated from arvicolines.

8. Baume of Gigny, France

Rodents from the sequence of the Baume de Gigny (Jura, France) have been studied by Brochet

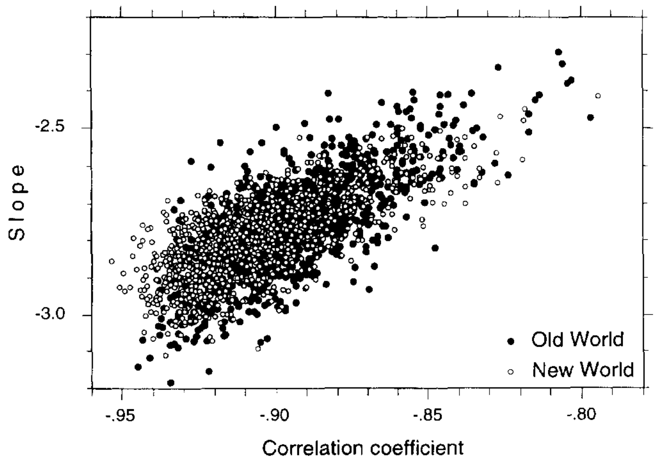

Fig. 8. Scatter diagram of the correlation coefficient and of the slope of the least square regression calculated on 2 × 1000 bootstrap resamplings run on the data for the mean annual daily temperature of the Old World and of the New World.

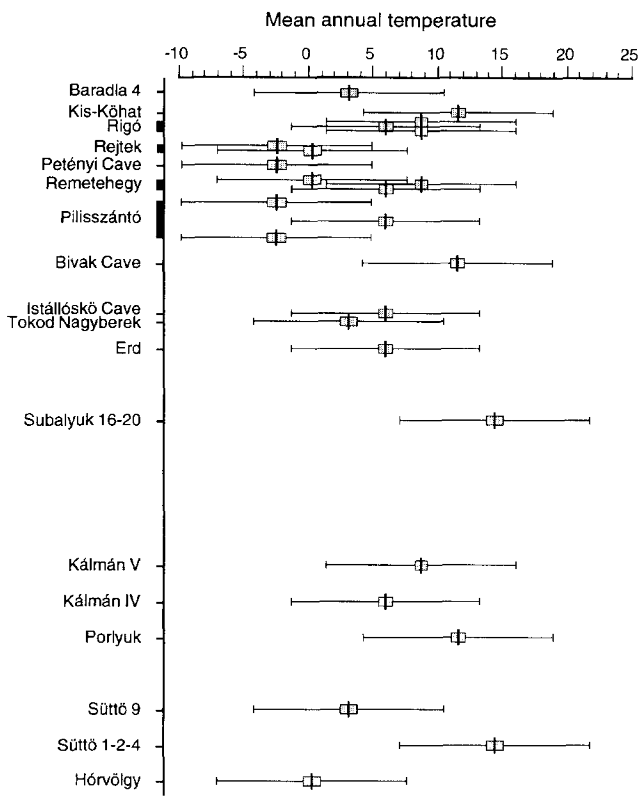

Fig. 9. Temperature estimates for Hungarian localities from the late Pleistocene using the regression parameters from Table 3 (after Montuire, in press). Errors of the estimates (areas) and of the predictions (lines) are given. Difference between the two error types is that the X-value is a value used for the establishment of the model for an estimate, whereas it is not for a prediction (see, for example, Scherrer, 1984).

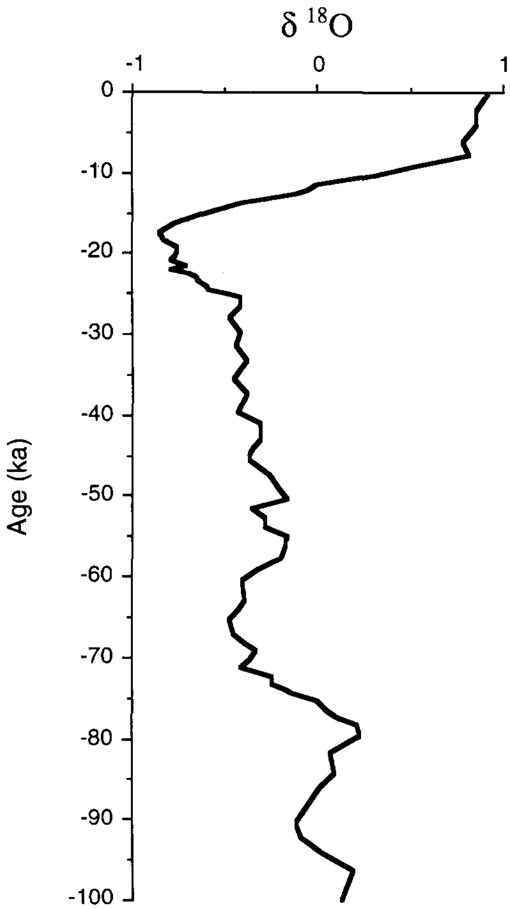

Fig. 10. Synthetic isotopic curve for the last 100,000 years (after Martinson et al., 1987).

(1981), Chaline and Brochet (1989) and Chaline et al. (1995). The results obtained (Fig. 11) can be compared with those deduced from a multivariate analysis of the rodent associations (Chaline et al., 1995) and from a synthetic analysis provided in the same paper using the qualitative composition of the fauna (birds and mammals), pollen analysis, and the sedimentological characteristics of the site (Chaline et al., 1995).

As can be observed in Fig. 11, the results obtained in this study show some differences with those of Chaline et al. (1995).

The estimates obtained with our method (Fig. 11: *a*) present an opposite trend with that proposed by fig. 19 of Chaline et al. (1995) (see Fig. 11: *b*), who interpreted the first axis of a multivariate analysis ran on the rodent associations from the sequence as representing the variation in temperature. Differences also exist with the synthetic climatic evolution proposed by table 1 of Chaline et al. (1995), repeating the results of Campy et al. (1989, 1990), and schematically reproduced in Fig. 11: *c*. The comparison of both results from Chaline et al. (1995) (fig. 19 and table. 1) given here as Fig. 11: *b* and Fig. 11: *c*) shows also differences, which are not discussed in their paper.

Moreover, none of the three curves from Fig. 11 shows any similar trends with the isotopic curve (Fig. 10).

In order to explain the contradiction obtained with our method, a sampling origin could be invoked. A warming trend can be due to a sampling bias, the species list being incomplete. This explanation is valid if the fossil sample for the rodents is poor, but it is likely not accurate when the fossil sample is rich. On the contrary, a low temperature value is obtained with a high number of species, thus a sampling bias would only minimize this number, and the estimated temperature can be even lower. The lack of similarity with the isotopic curve can primarily be due to a dating problem: only four levels from the Baume de Gigny sequence are physically dated.

The contradictory results obtained by the three methods imply further analysis to explain the lack of concordance in the quantitative temperature estimates obtained with these techniques. Comparison of the techniques should improve the methodological conditions needed to apply the various approaches—or determine the technical limits.

9. Conclusion

This method based on the Arvicolinae completes that based on preliminary results of the Murinae (Aguilar et al., in press; Montuire, 1994), that will be extended to a more complete analysis of this last subfamily (Montuire et al., in prep.). Whereas the murines are useful for a more tropical climate, the method based on the arvicolines can be applied for estimating temperate climates. Two other reasons justify their use. Firstly, arvicoline taxa

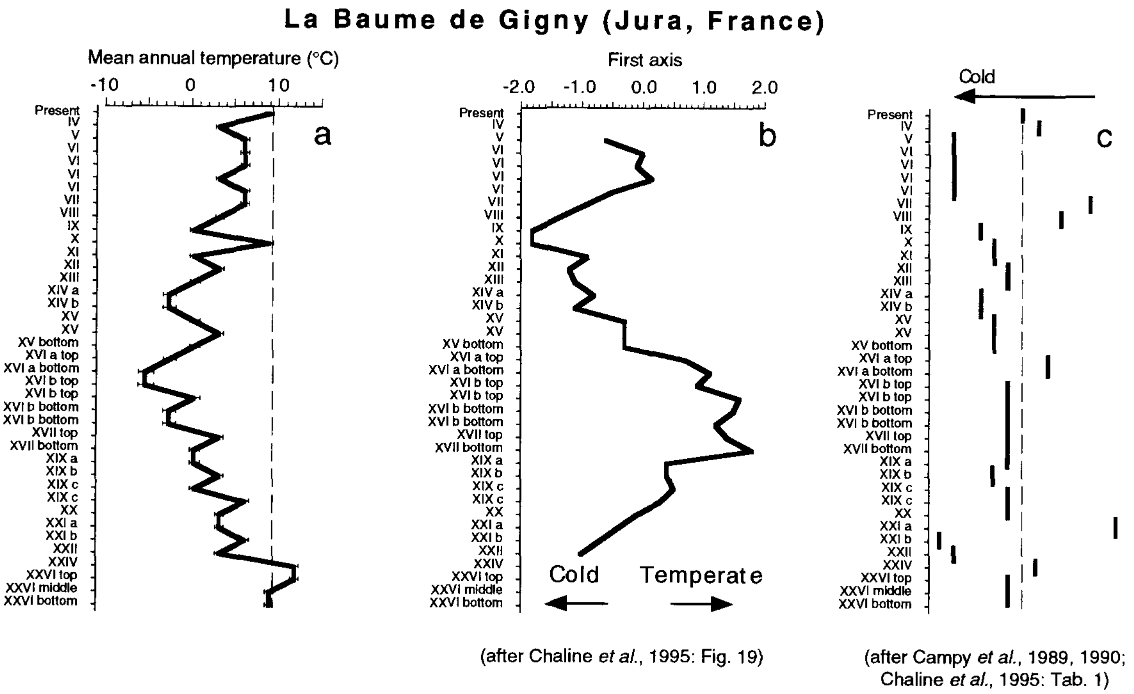

Fig. 11. Comparison of temperature estimates for La Baume de Gigny (Jura, France). *a*: calculations on arvicolid data from Brochet (1981), Chaline and Brochet (1989), and Chaline et al. (1995) using the regression parameters from Table 3. *b*: after fig. 19 from Chaline et al. (1995), based on a component analysis of the rodent associations. *c*: after table 1 from Chaline et al. (1995), based on a synthetic interpretation of faunal, pollen, and sedimentological data. The vertical dotted lines refer to the extant mean annual daily temperature. Some physical ages are available for the sequence (Campy et al., 1989, 1990; Chaline et al., 1995): level IV: 12,370 and 13,620; level V: 22,430; level VIII: 28,500 and 29,500; level IX: >32,000; level XIXc: >32,000; level XXIa: 145,000 (-18,000, +15,000).

are generally abundant in the fossil record from the late Tertiary and the Quaternary of Europe, Asia and North America. Secondly, because of their good biostratigraphical value, arvicolines are generally a well studied group among rodents.

The results obtained with the method for Hungary show a good agreement with the temperature trends indicated by oxygen isotope curves, and with hypotheses proposed on the ecology of plants and mammals. Principally due to correlation problems, the results for the Baume de Gigny sequence are less convincing.

The limit of the method is the same as that using murines: it corresponds to the geographical and stratigraphical limits of the distribution of this subfamily. Thus, the method can be applied to Eurasian and North American mammalian faunas from the Pliocene to the Present.

Acknowledgements

The authors wish to thank the two referees, R. Daams and A. Azzaroli, whose comments improved the manuscript, and the editorial office of Palaeo-3 who communicated a draft of the paper in press of Chaline et alii. B. Marandat helped to improve the English text. Publication I.S.E.M. n° 96–036.

References

Aguilar, J.-P. and Michaux, J., 1990. A paleoenvironmental and paleoclimatic interpretation of a Miocene faunal succession in southern France. Critical evaluation of the use of rodents in paleoecology. Paléobiol. Cont., 16: 311–327.

Aguilar, J.-P., Michaux, J., Bachelet, B., Calvet, M. and Faillat, J.-P., 1991. Les nouvelles faunes de rongeurs de la limite Mio-Pliocène en Roussillon. Implications biostratigraphiques et biogéographiques. Palaeovertebrata, 20: 145–172.

Aguilar, J.-P., Legendre, S., Michaux, J. and Montuire, S., in press. Pliocene mammals and climatic reconstruction in the Western Mediterranean area. Am. Assoc. Stratigr. Palynol. Contrib. Ser.

Amores, F., Oria, J., Roy, E. and Torrent, F., 1992. Estudio faunistico de la zona del Alto Tajo comprendida entre el puente de Valtablado del Rio y el puente de San Pedro. Contribucion al conocimiento de sus recursos naturales como determinantes de su manejo integrado. Monogr. ICONA, 32: 1–73.

Andersen, K.W. and Jones Jr., J.K., 1971. Mammals of northwestern South Dakota. Univ. Kans. Publ. Mus. Nat. Hist., 19(5): 361–393.

Anderson, S., 1959. Mammals of the Grand Mesa, Colorado. Univ. Kans. Publ. Mus. Nat. Hist., 9(16): 405–414.

Anderson, S., 1961. Mammals of Mesa Verde National Park, Colorado. Univ. Kansas Publ. Mus. Nat. Hist., 14(3): 29–67.

Anderson, S., 1972. Mammals of Chihuahua: taxonomy and distribution. Bull. Am. Mus. Nat. Hist., 148: 149–410.

Arnold, H.R., 1993. Atlas of Mammals in Britain. Nat. Environ. Res. Counc., London, 145 pp.

Atkinson, T.C., Briffa, K.R., Coope, G.R., Joachim, M.J. and Perry, D.W., 1986. Climatic calibration of coleopteran data. In: B.E. Berglund (Editor), Handbook of Holocene Palaeoecology and Palaeohydrology. Wiley, New York, pp. 851–858.

Aulagnier, S. and Thévenot, M., 1986. Catalogue des mammifères sauvages du Maroc. Trav. Inst. Sci. Sér. Zool., Rabat, 41: 1–164.

Baker, R.H., 1983. Michigan mammals. Mich. State Univ. Press, East Lansing, 642 pp.

Banfield, A.W.F., 1974. The Mammals of Canada. Univ. Toronto Press, Natl. Mus. Can., 438 pp.

Barbour, R.W., 1951. The mammals of Big Black Mountain, Harlan county, Kentucky. J. Mamm., 32: 100–110.

Bauer, K., 1960. Die Säugetiere des Neusiedlersee-Gebietes (Österreich). Bonn. Zool. Beitr., 11: 141–344.

Bee, J.W., Glass, G., Hoffmann, R.S. and Patterson, R.R., 1981. Mammals in Kansas. Univ. Kansas, Lawrence, 300 pp.

Bowles, J.B., 1975. Distribution and biogeography of mammals of Iowa. Spec. Publ. Mus. Tex. Tech. Univ., Lubbock, 9: 1–184.

Brochet, G., 1981. Etude comparative des faunes d'Arcy-sur-Cure, La Cotte Saint-Brelade et de Gigny à l'aide d'une méthode d'écologie quantitative. D.E.A., Univ. Dijon, Inst. Sci. Terre, 88 pp. (unpublished).

Buchardt, B., 1978. Oxygen isotope palaeotemperatures from the Tertiary period in the North Sea area. Nature, 275: 121–123.

Cahalane, V.H., 1959. A biological survey of Katmai National Monument. Smithson. Misc. Collect., 138, 246 pp.

Cahn, A.R., 1937. The mammals of the Quetico Provincial Park of Ontario. J. Mamm., 18: 19–30.

Campbell, R.C., 1989. Statistics for Biologists. Cambridge Univ. Press, 3rd ed., 446 pp.

Campy, M., Chaline, J., Heim, J., Mourer-Chauviré, C. and Vuillemey, M., 1989. La séquence chronoclimatique de Gigny. In: M. Campy et al. (Editors), La Baume de Gigny (Jura). Gallia Préhist., 17(suppl.): 243–251.

Campy, M., Chaline, J., Heim, J., Mourer-Chauviré, C. and Vuillemey, M., 1990. La séquence pléistocène de Gigny (Jura), référence chronoclimatique de l'Est de la France. C. R. Acad. Sci. Paris, (2), 310: 927–934.

Capolongo, D. and Caputo, V., 1990. Mammals of the Partenio Mountains (Campanian Apennines, southern Italy). Vie Milieu, 40: 156–159.

Ceballos, G. and Galindo, C., 1984. Mamiferos silvestres de la Cuenca de México. MAB, UNESCO, Limusa, 299 pp.

Chaline, J., 1972. Les rongeurs du Pléistocène moyen et supérieur de France. Cah. Paléontol., 410 pp.

Chaline, J. and Brochet, G., 1989. Les rongeurs. Leurs significations paléoécologiques et paléoclimatiques. In: M. Campy et al. (Editors), La Baume de Gigny (Jura), Gallia Préhist., 17 (suppl.): 97–109.

Chaline, J., Brunet-Lecomte, P. and Campy, M., 1995. Rodent quantitative Pleistocene palaeoecology. Application in the karstic sequence of Gigny (Jura, France). Palaeogeogr. Palaeoclimatol. Palaeoecol., 117: 229–252.

Clark, T.W. and Stromberg, M.R., 1987. Mammals of Wyoming. Univ. Kans., Mus. Nat. Hist., Lawrence, 314 pp.

Cohen, F., 1988. Etude de quatre faunes du Pléistocène d'Europe selon deux méthodes paléoécologiques: les cénogrammes et les spectres fauniques. Rapp. D.E.A. Univ. Paris VI, Paris, 86 pp. (unpublished).

Collinson, M.E., Fowler, K. and Boulter, M.C., 1981. Floristic changes indicate a cooling climate in the Eocene of southern England. Nature, 291: 315–317.

Corbet, G.B., 1978. The mammals of the Palaearctic region: a taxonomic review. Br. Mus. (Nat. Hist.), London, 314 pp.

Daams, R. and Van der Meulen, A.J., 1984. Paleoenvironmental and paleoclimatic interpretation of micromammal faunal successions in the upper Oligocene and Miocene of North Central Spain. Paléobiol. Cont., 14 (2): 241–257.

Dalquest, W.W. and Stangl Jr., F.B., 1984. Late Pleistocene and early Recent mammals from Fowkles Cave, southern Culberson County, Texas. In: M.G. Genoways and M.R. Dawson (Editors), Contributions in Quaternary Paleontology: a Volume in Memorial to John E. Guilday. Carnegie Mus. Nat. Hist. Spec. Publ., 8: 432–455.

Deacon, J.E., Bradley, W.C. and Larsen, K.M., 1964. Ecological distribution of the mammals of Clark Canyon, Charleston mountains, Nevada. J. Mamm., 45: 397–408.

Demeter, A. and Topál, G., 1987. Mammals of the Kiskunság. The fauna of the Kiskunság National Park. Akad. Kiado, Budapest, pp. 446–452.

Duplessy, J.-C., Delibrias, G., Turon, J.-L., Pujol, C. and Duprat, J., 1981. Deglacial warming of the Northeastern Atlantic Ocean: correlation with the paleoclimatic evolution of the European continent. Palaeogeogr. Palaeoclimatol. Palaeoecol., 35: 121–144.

Durrant, S.D., 1952. Mammals of Utah. Taxonomy and distribution. Univ. Kans. Publ. Mus. Nat. Hist., 6: 1–549.

Edwards, A.L., 1984. An Introduction to Linear Regression and Correlation. Freeman, New York, 2nd ed., 206 pp.

Ellerman, J.R., 1961a. The fauna of India including Pakistan, Burma and Ceylon. Mammalia, Vol. III: Rodentia (part 1). Zool. Surv. India, Calcutta, 2nd ed., pp. 1–482.

Ellerman, J.R., 1961b. The fauna of India including Pakistan, Burma and Ceylon. Mammalia, Vol. III: Rodentia (part 2). Zool. Surv. India, Calcutta, 2nd ed., pp. 483–884.

Eshelman, R.E., 1975. Geology and paleontology of the early Pleistocene (late Blancan) White Rock fauna from north-central Kansas. Univ. Michigan Pap. Paleontol., 13: 1–60.

Fayard, A. (Editor), 1984. Atlas des mammifères sauvages de France. Soc. Fr. Etud. Protect. Mammif., Paris, 299 pp.

Fejfar, O. and Heinrich, W.-D., 1986. Biostratigraphic subdivision of the European Late Cenozoic based on muroid rodents (Mammalia). Mem. Soc. Geol. Ital., 31: 85–190.

Fejfar, O. and Heinrich, W.-D., 1990. Muroid rodent biochronology of the Neogene and Quaternary in Europe. In: E.H. Lindsay et al. (Editors), European Neogene Mammal Chronology. Plenum Press, New York, pp. 91–117.

Fleming, T.H., 1973. Numbers of mammal species in North and Central American forest communities. Ecology, 54: 555–563.

Flerov, K.K., 1933. Mammals of the Northern Urals and Western Siberia. Bull. Acad. Sci. USSR, 3: 445–470.

Galeotti, P., 1981. I mammiferi del Parco Ticino. Fabbri, 95 pp.

Glass, B.P. and Halloran, A.H., 1961. The small mammals of the Wichita Mountains Wildlife Refuge, Oklahoma. J. Mamm., 42: 234–239.

Godin, A.J., 1977. Wild mammals of New England. Johns Hopkins Univ. Press, Baltimore, 304 pp.

Gottschang, J.L., 1981. A Guide to the Mammals of Ohio. Ohio State Univ. Press, Columbus, 176 pp.

Guiot, J., 1990. Methodology of the last climatic cycle reconstruction from pollen data. In: D.-D. Rousseau (Editor), Methods and Concepts in European Quaternary Stratigraphy. Palaeogeogr. Palaeoclimatol. Palaeoecol., 80:49–69.

Hall, E.R. and Kelson, K.R., 1959. The Mammals of North America. Ronald Press, New York, 2, pp. 547–1083.

Hall, E.R. and Villa-Rochas, B., 1949. An annoted check list of the mammals of Michoacan, Mexico. Univ. Kansas Publ. Mus. Nat. Hist., 1: 431–472.

Harper, F., 1956. The mammals of Keewatin. Univ. Kans. Misc. Publ. Mus. Nat. Hist., 12: 1–94.

Harper, F., 1961. Land and fresh-water mammals of the Ungava peninsula. Univ. Kans. Misc. Publ. Mus. Nat. Hist., 27: 1–178.

Harrison, D.L. and Bates, P.J.J., 1991. The Mammals of Arabia. Harrison Zool. Mus., Sevenoaks, 2nd ed., 354 pp.

Hazard, E.B., 1982. The Mammals of Minnesota. Univ. Minnesota Press, Minneapolis, 280 pp.

Hibbard, C.W. and Taylor, D.W., 1960. Two late Pleistocene faunas from southwestern Kansas. Contrib. Mus. Paleontol. Univ. Michigan, 16: 1–223.

Hoffmann, R.S., Wright, P.L. and Newby, F.E., 1969. The distribution of some mammals in Montana. I. Mammals other than bats. J. Mamm., 50: 579–604.

Hoffmeister, D.F., 1986. Mammals of Arizona. Univ. Arizona Press, Tucson, 602 pp.

Horácek, I., 1990. On the context of Quaternary arvicolid evolution: changes in community development. In: O. Fejfar and W.D. Heinrich (Editors), International Symposium Evolution, Phylogeny and Biostratigraphy of Arvicolids (Rodentia, Mammalia), Rohanov, pp. 201–222.

Hubbard, R.N.L.B. and Boulter, M.C., 1983. Reconstruction of Paleogene climate from palynological evidence. Nature, 301: 147–150.

Humphrey, S.R. (Editor), 1992. Rare and endangered biota of Florida. 1. Mammals. Univ. Press Fla., Gainesville, 392 pp.

Hurka, L., 1978. Die Säugetiere (Mammalia) und ihre Flöhe (Siphonaptera) von Cesky les und vom angrenzenden Hügelland. Fol. Mus. Rer. Nat. Bohem. Occid. Zool. Plzen, 10: 3–49.

Ingles, L.G., 1965. Mammals of the Pacific states. Stanford Univ. Press, Stanford, 508 pp.

Isakov, J.A., 1939. Contributions to the study of the mammalian faunas from Central and Western Carelia. Bull. Soc. Nat. Moscow, Sci. Biol., 48: 2–3 (in Russian).

Ivanauskas, T., Likevicienne, N. and Maldiunate, S., 1964. Analytic tables of mammals from Lithuania. Lietuvos TSR Mokslu, Akad. Zool. Parazitol. Inst., Moscow, 340 pp. (in Russian).

Ivey, R.D., 1959. The mammals of Palm Valley, Florida. J. Mamm., 40: 585–591.

Jackson, H.H.T., 1961. Mammals of Wisconsin. Univ. Wisc. Press, Madison, 504 pp.

Jameson Jr., E.W. and Peeters, H.J., 1988. California Mammals. Univ. Calif. Press, Berkeley, 403 pp.

Janis, C.M., 1984. The use of fossil ungulate communities as indicators of climate and environment. In: P. Brenchley (Editor), Fossils and Climate. Wiley, New York, pp. 85–104.

Jánossy, D., 1986. Pleistocene Vertebrate Faunas of Hungary. (Dev. Paleontol. Stratigr., 8.) Elsevier, Amsterdam, 208 pp.

Jones Jr., J.K. and Birney, E.C., 1988. Handbook of Mammals of the North-central States. Univ. Minn. Press, Minneapolis, 346 pp.

Jones Jr., J.K., Armstrong, D.A. and Choate, J.R., 1985. Guide to mammals of the Plains States. Univ. Nebr. Press, Lincoln, 371 pp.

Karvik, N.-G., 1964. The terrestrial vertebrates of Dalsland in southwestern Sweden. Mamm. Acta Vert., 3: 365–171.

Kouznetov, B.A., 1939. Contributions to the study of the mammalian faunas from Central Kirghizia. Bull. Soc. Nat. Moscow, Sect. Biol., N.S., 48: 51–62 (in Russian).

Kowalski, K. and Rzebik-Kowalska, B., 1991. Mammals of Algeria. Zakl. Narowd. Im. Ossol., Wroclaw, 370 pp.

Lampe, R.P., Jones Jr., J.K., Hoffmann, R.S. and Birney, E.C., 1974. The mammals of Carter County, southeastern Montana. Occas. Pap. Mus. Nat. Hist. Kans., 25: 1–39.

Lay, D.M., 1967. A study of the mammals of Iran resulting from the Street Expedition of 1962–1963. Fieldiana Zool., 54: 1–282.

Lee, D.S., Funderburg Jr., J.B. and Clark, M.K., 1982. A distributional survey of North Carolina mammals. Occas. Pap. N. Carol. Biol. Surv., 1982(10): 1–70.

Legendre, S., 1986. Analysis of mammalian communities from the late Eocene and Oligocene of southern France. Palaeovertebrata, 16: 191–212.

Legendre, S., 1987. Mammalian faunas as paleotemperature indicators: concordance between oceanic and paleontological evidence. Evol. Theory, 8: 77–86.

Legendre, S., 1989. Les communautés de mammifères du Paléogène (Eocène supérieur et Oligocène) d'Europe occidentale: structures, milieux et évolution. Münchn. Geowiss. Abh., A 16: 1–110.

Legendre, S., Badgley, C. and Gingerich, P.D., 1991. Cenograms and environmental parameters for mammalian faunas. J. Vertebr. Paleontol., 11(5): 42A (Abstr.)

Legendre, S., Badgley, C. and Gingerich, P.D., in prep. Mammals, Size, and Climate. Chicago Univ. Press.

Lehmann, E.V., 1963. Die Säugetiere des Fürstentums Liechtenstein. Jahrb. Hist. Ver. Fürstentum Liechtenstein, 62: 159–362.

Lowery Jr., G.H., 1974. The Mammals of Louisiana and its Adjacent Waters. La. State Univ. Press, Baton Rouge, 565 pp.

Manly, B.F.J., 1991. Randomization and Monte Carlo Methods in Biology. Chapman and Hall, London, 281 pp.

Martinson, D.G., Pisias, N.G., Hays, J.D., Imbrie, J., Moore Jr., T.C. and Shackleton, N.J., 1987. Age dating and the orbital theory of the Ice Ages: Development of a high-resolution 0 to 300,000-year chronostratigraphy. Quat. Res., 27: 1–29.

Matson, J.O. and Baker, R.H., 1986. Mammals of Zacatecas. Spec. Publ. Mus. Tex. Tech. Univ., 24:1–88.

Merriam, J.C., 1919. Tertiary mammalian fauna of the Mohave desert. Univ. Calif. Publ. Bull. Dep. Geol., 11: 438–585.

Michaux, J., 1971. Evolution et signification des peuplements de muridés (Rodentia) en Europe sud-occidentale au Néogène supérieur. C. R. Acad. Sci. Paris, D 273: 314–317.

Michaux, J., Aguilar, J.-P., Montuire, S. and Legendre, S., 1996. Mammifères, paléoenvironnements et origine du climat méditerranéen. In: La Méditerranée: variabilités climatiques, environnement et biodiversité. Okeanos, 95, Maison de l'Environnement de Montpellier, pp 98 + 104.

Misonne, X., 1959. Analyse zoogéographique des mammifères de l'Iran. Mém. Inst. R. Sci. Nat. Belg. 2e Sér., 59: 1–157.

Misonne, X., 1969. African and Indo-Australian Muridae. Evolutionary trends. Ann. Mus. R. Afr. Centr. Sci. Zool., 172: 1–217.

Montuire, S., 1994. Communautés de mammifères et environnements: l'apport des faunes aux reconstitutions des milieux en Europe depuis le Pliocène et l'impact des changements climatiques sur la diversité. Thesis. Univ. Montpellier II, 128 pp. [Unpublished].

Montuire, S., 1995. Evolution climatique et diversité chez les mammifères en Europe centrale depuis le Pliocène. Geobios Mém. Spéc., 18: 313–327.

Montuire, S., 1996. Rodents and climate. II. Quantitative climatic estimates for Plio-Pleistocene faunas from Central Europe. Acta. Zool. Cracov, 31: 373–379.

Montuire, S., Legendre, S., Michaux, J. and Aguilar, J.-P., in prep. Rodents and climate. III: a model for estimating past climatic parameters using murines (Mammalia: Rodentia).

Musser, G.G. and Carleton, M.D., 1993. Family Muridae. In: D.E. Wilson and D.M. Reeder (Editors), Mammal Species of the World. Smithson. Inst. Press, Am. Soc. Mammal., Washington, 2nd ed., pp. 501–755.

Negus, N.C. and Findley, J.S., 1959. Mammals of Jackson Hole, Wyoming. J. Mamm., 40: 371–381.

Niethammer, J. and Krapp, F. (Editors), 1982. Band 2/I: Rodentia II (Cricetidae, Arvicolidae, Zapodidae, Spalacidae, Hystricidae, Capromyidae). In: J. Niethammer and F. Krapp (Editors), Handbuch der Säugetiere Europas. Akad. Verlagsges., Wiesbaden, 649 pp.

Ognev, S.I., 1948. Mammals of the U.S.S.R. and adjacent countries. VI: Rodents. Isr. Progr. Sci. Transl., Jerusalem, 508 pp. (transl. 1963).

Ognev, S.I., 1950. Mammals of the U.S.S.R. and adjacent countries. VII: Rodents. Isr. Progr. Sci. Transl., Jerusalem, 626 pp. (transl. 1964).

Ollivier-Pierre, M.-F., Gruas-Cavagnetto, C., Roche, E. and Schuler, M., 1988. Eléments de flore de type tropical et variations climatiques au Paléogène dans quelques bassins d'Europe nord-occidentale. Mém. Trav. E.P.H.E. Inst. Montpellier, 17: 173–205.

Otero, C., Castien, E., Senosiain, R. and Portillo, F., 1978. Vertebrados de la Sierra de Cazorla. In: M.G. de Viedma (Editor), Fauna de Cazorla. Vertebrados. Minist. Agric., Inst. Nac. Conserv. Natur., pp. 9–123.

Palotás, G. and Demeter, A., 1983. Mammals of the Hortobágy. In: S. Mahunka (Editor), The Fauna of the Hortobágy National Park. Akad. Kiado, Budapest, pp. 413–421.

Pantic, N.K., 1986. Global Tertiary climatic changes, paleophytogeography and phytostratigraphy. In: Global Bio-Events, 8. Springer, Berlin, pp. 419–427.

Pucek, Z. and Raczynski, J. (Editors), 1983. Atlas of Polish Mammals. Warsaw, 2 vols.

Quay, W.B., 1951. Observations on mammals of the Seward peninsula, Alaska. J. Mamm., 32: 88–99.

Ramírez-Pulido, J., Britton, M.-C., Perdomo, A. and Castro, A., 1986. Guia de los mamíferos de México. Univ. Autonoma Metropol., Mexico, 720 pp.

Ranck, G.L., 1968. The rodents of Libya: taxonomy, ecology, and zoogeographical relationships. Bull. U.S. Nat. Mus., 275: 1–264.

Rearden, J., 1981. Alaska mammals. Alaska Geogr., 8(2): 1–184.

Repenning, C.A., 1987. Biochronology of the arvicolid rodents of the United States. In: M.O. Woodburne (Editor), Cenozoic Mammals of North America. Univ. Calif. Press, Berkeley, pp. 236–268.

Repenning, C.A., Fejfar, O. and Heinrich, W.-D., 1990. Arvicolid rodent biochronology of the Northern Hemisphere. In: O. Fejfar and W.-D. Heinrich (Editors), Int. Symp.

Evolution, Phylogeny and Biostratigraphy of Arvicolids, Rohanov, May 1987. Geol. Surv., Praha, pp. 385–418.
Retallack, G.J., 1992. Paleosols and changes in climate and vegetation across the Eocene/Oligocene boundary. In: D.R. Prothero and W.A. Berggren (Editors), Eocene/Oligocene Climatic and Biotic Evolution. Princeton Univ. Press, Princeton, pp. 382–398.
Roberts, T.J., 1977. Mammals of Pakistan. Benn, London, 361 pp.
Roest, A.I., 1951. Mammals of the Oregon Caves area, Josephine county. J. Mamm., 32: 345–351.
Rousseau, D.-D., 1987. Paleoclimatology of the Achenheim series (middle and upper Pleistocene, Alsace, France). A malacological analysis. Palaeogeogr. Palaeoclimatol. Palaeoecol., 59: 293–314.
Rousseau, D.-D., 1991. Climatic transfer function from Quaternary molluscs in European loess deposits. Quat. Res., 36: 195–209.
Rousseau, D.-D. and Puisségur, J.-J., 1990. A 350,000-year climatic record from the loess sequence of Achenheim, Alsace, France. Boreas, 19: 203–216.
Rousseau, D.-D., Taoufiq, N.B., Petit, C., Farjanel, G., Méon, H. and Puisségur, J.-J., 1992. Continental late Pliocene paleoclimatic history recorded in the Bresse Basin (France). Palaeogeogr. Palaeoclimatol. Palaeoecol., 95: 253–261.
Sargatal, J. and Fèlix, J. (Editors), 1989. Els Aiguamolls de l'Empordà. Aspectes ecològics, històrics i socials del Parc Natural. Carles Vallès, Figueres, Quad. Indik., 3, 376 pp.
Scherrer, B., 1984. Biostatistique. Gaëtan Morin, Chicoutimi, Qué., 680 pp.
Schmidly, D.J., 1977. The Mammals of Trans-Pecos Texas. Texas A and M Univ. Press, College Station, 225 pp.
Schultz, J.R., 1938. A late Quaternary mammal fauna from the Tar Seeps of McKittrick, California. Contrib. Paleontol. Carnegie Inst. Publ., 487: 11–215.
Sealander, J.A. and Heidt, G.A., 1990. Arkansas mammals. Univ. Arkansas Press, Fayetteville, 308 pp.
Sokal, R.R. and Rohlf, F.J., 1981. Biometry. Freeman, New York, 2nd ed., 859 pp.
Szafera, W., 1959. Swietokrzyski Park Narodowy. Pol. Akad. Nauk, Krakow, 16, 201 pp.
Taber, R.B., Sheri, A.N. and Ahmad, M.S., 1967. Mammals of the Lyallpur region, West Pakistan. J. Mamm., 48: 392–407.
Tomassone, R., Lesquoy, E. and Millier, C., 1983. La régression. Nouveaux regards sur une ancienne méthode statistique. Actualités scientifiques et agronomiques 13. I.N.R.A., Masson, Paris, 184 pp.
Valverde, J.A., 1964. Remarques sur la structure et l'évolution des communautés de vertébrés terrestres. I. Structure d'une communauté. II. Rapport entre prédateurs et proies. Terre Vie, 111: 121–154.
Valverde, J.A., 1967. Estructura de una communidad de vertebrados terrestres. Monogr. Est. Biol. Doñana, 1, 129 pp.
Van der Meulen, A.J. and Daams, R., 1992. Evolution of Early–Middle Miocene rodent faunas in relation to long-term paleoenvironmental changes. Palaeogeogr. Palaeoclimatol. Palaeoecol., 93: 227–253.
Vereshchagin, N.K., 1967. The mammals of the Caucasus. A history of the evolution of the fauna. Isr. Progr. Sci. Transl., Jerusalem, 816 pp. (transl. 1967).
Webster, W.D., Parnell, J.F. and Biggs Jr., W.C., 1985. Mammals of the Carolinas, Virginia, and Maryland. Univ. N. C. Press, Chapel Hill, 255 pp.
Weisberg, S., 1985. Applied Linear Regression. Wiley, New York, 2nd ed., 324 pp.
Wernstedt, F.L., 1972. World Climatic Data. Climatic Data Press, Lemont, PA, 522 pp.
Woloszyn, D. and Woloszyn, B.W., 1982. Los mamiferos de la Sierra de La Laguna, Baja California Sur. Cons. Nacl. Cienc. Technol., Mexico, 168 pp.
Youngman, P.M., 1975. Mammals of the Yukon Territory. Natl. Mus. Nat. Hist. Publ. Zool., Ottawa, 10: 1–192.
Zheng, S. and Li, C.-K., 1990. Comments on fossil arvicolids of China. In: O. Fejfar and W.-D. Heinrich (Editors), Int. Symp. Evol., Phylogeny Biostratigr. Arvicolids, Rohanov, May 1987. Geol. Surv., Praha, pp. 431–442.