Palaeogeography, Palaeoclimatology, Palaeoecology xxx (xxxx) 111976

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Environmental and climatic inferences for Marine Isotope Stage 2 of southern Belgium (Meuse valley, Namur Province) based on rodent assemblages

Juan Manuel López-García[a, b, *], Hugues-Alexandre Blain[a, b], Quentin Goffette[c], Cécila Cousin[c], Annelise Folie[c]

[a] IPHES-CERCA, Institut Català de Paleoecologia Humana i Evolució Social, Zona Educacional 4, Campus Sescelades URV, Edifici W3, 43007 Tarragona, Spain
[b] Universitat Rovira i Virgili, Departament d'Història i Història de l'Art, Avinguda de Catalunya 35, 43002 Tarragona, Spain
[c] Royal Belgian Institute of Natural Sciences, Vautier Street, 29, 1000 Brussels, Belgium

ARTICLE INFO

Editor: Howard Falcon-Lang

Keywords:
Palaeoenvironment
Palaeoclimate
Latest Pleistocene
MIS 2
Radiocarbon dating
Heinrich Event 1

ABSTRACT

The environmental and climatic conditions of the Late Pleistocene of Southern Belgium are here determined for the final part of Marine Isotope Stage 3 (MIS 3) and for MIS 2 on the basis of a study of rodent assemblages. This paper provides a synthesis of several sets of environmental and climatic data from Late Pleistocene sites, all of which are located in southern Belgium. One has previously been published (Caverne Marie-Jeanne), and seven are unpublished (Cavernes de Goyet, Trou des Nutons, Trou du Frontal, Trou de Chaleux, Grotte la Chefalize, Trou du Chêne, and Trou du Sureau). The habitat weighting and quantified ecology methods are applied to rodent material housed in the Royal Belgian Institute of Natural Sciences (RBINS, Brussels), and previous radiocarbon dates are updated, in order to reconstruct past environments. Among all the sites under analysis, the quantified ecology method shows that Trou de Chaleux corresponds to the coldest temperatures and lowest precipitation. Trou de Chaleux, with a chronology between ca. 15,964–14,014 cal yr B.P., could probably be placed in Greenland Stadial 2 (GS2) or Heinrich Event 1 (HE1). It has a rodent assemblage associated with a predominance of open dry and rocky formations, the most abundant species being the collared lemming and the narrow-headed vole. These data are found to coincide with previous studies carried out on the large-mammal, herpetofaunal, and avifaunal associations of the site, as well as on small-mammal associations from other sites in southern Belgium with similar chronology, such as Grotte Walou. Taken together, this indicates that these latest Pleistocene intervals in southern Belgium were characterized by harsh climatic and environmental conditions. In contrast, the other assemblages under study yielded much more heterogeneous results, frequently inconsistent with an attribution to the Pleistocene. This is likely to be a result of their admixture with Holocene material due to recent intrusions.

1. Introduction

The Late Pleistocene is a geochronological age that began with the Eemian interglacial (ca. 126 ka) and ended at ca. 11.7 ka, with the beginning of the Holocene (Walker et al., 2009). The last phases of this age can be taken to be represented by the last part of Marine Isotope Stage 3 (MIS 3), MIS 2, and the beginning of MIS 1 (ca. 11.7 ka) (e.g. Lisiecki and Raymo, 2005; Walker et al., 2018). These stages are described in all geological literature as the most intense phase of the Pleistocene, characterized by major, rapid climate changes (e.g. Railsback et al., 2015; Vermeersch, 2005). They range chronologically from ca. 40 to 11.7 ka. The last part of MIS 3 contains two Heinrich Events (H4 and H3), dated respectively to between ca. 38–35 ka (H4) and between ca. 31–29 ka (H3). MIS 2 contains two Heinrich Events (H2 and H1), dated respectively to between ca. 24–22 ka (H2) and between ca. 16–14 ka (H1, or the Oldest Dryas), as well as the Last Glacial Maximum (LGM), the period of maximum marine regression (Clark et al., 2009). The chronological range of the LGM is controversial: for some authors it

* Corresponding author at: IPHES-CERCA, Institut Català de Paleoecologia Humana i Evolució Social, Zona Educacional 4, Campus Sescelades URV, Edifici W3, 43007 Tarragona, Spain.
E-mail addresses: jmlopez@iphes.cat (J.M. López-García), hablain@iphes.cat (H.-A. Blain), qgoffette@naturalsciences.be (Q. Goffette), ccousin@naturlasciences.be (C. Cousin), afolie@naturalsciences.be (A. Folie).

https://doi.org/10.1016/j.palaeo.2023.111976
Received 16 October 2023; Received in revised form 13 December 2023; Accepted 13 December 2023
0031-0182/© 20XX

Note: Low-resolution images were used to create this PDF. The original images will be used in the final composition.

CORRECTED PROOF

ranges from ca. 23 to 19 ka (Ravazzi et al., 2007), whereas for others it ranges from ca. 26 to 19 ka (Clark et al., 2009). This glacial maximum phase is followed by the most recent phase of MIS 2 and the beginning of MIS 1, known as the Late Glacial, which precedes the Holocene and ranges chronologically from ca. 14.7 to 11.7 ka. This period features a set of climatic fluctuations called the Bølling period interstadial or Greenland Interstadial 1 (GI-1) at about ca. 14.5 ka, with a rapid increase in temperatures similar to today's, as well as the Younger Dryas or Greenland Stadial 1 (GS-1), a climatic cooling with a loss of vegetation cover and a return to steppe conditions, dated to ca. 12.6 ka (e.g. Ravazzi et al., 2007; Vescovi et al., 2007).

This is the climatic context of the Belgian Late Pleistocene assemblages housed in the Royal Belgian Institute of Natural Sciences (RBINS). Rodent studies of these sites can provide new terrestrial data to shed light on the past environment and climate of this region. In general, there are some studies of Late Pleistocene small mammals in Belgium, such as those of Trou des Blaireaux (Cordy and Peuchot, 1983), Trou Jadot (Cordy and Toussaint, 1993), Grotte du Coléoptère (Dewez et al., 1983), Grotte Walou (see review in Stewart and Parfitt, 2011), Trou Al'Wesse (Brace et al., 2012; Miller et al., 2012), Grotte Scladina (Cordy, 1992; López-García et al., 2017a), Trou du Diable (Toussaint, 1988), Trou Magrite (Cordy, 1995), and Caverne Marie-Jeanne (López-García et al., 2017b). However, only a few of these sites contain deposits with studies of rodent remains and a stratigraphic origin that is more or less clearly ascribed chronologically. These are Grotte Walou (Stewart and Parfitt, 2011), Scladina (López-García et al., 2017a), and Caverne Marie-Jeanne (López-García et al., 2017b).

Against this background, the aims of this paper are: 1) to identify the rodent remains of the seven Late Pleistocene sites (Cavernes de Goyet, Trou des Nutons, Trou du Frontal, Trou de Chaleux, Grotte la Chefalize, Trou du Chêne, and Trou du Sureau) housed at the RBINS; 2) to update the radiocarbon dating of the dated sites with the last version of OxCal 4.4.4. (Bronk-Ramsey, 2021) in order to put this dating into context with the atmospheric data from Reimer et al. (2020); 3) to apply different methods (the habitat weighting and quantified ecology methods) to the rodent assemblages in order to reconstruct the past environment and climate of the sites that fall within MIS 2; 4) to try to identify different oscillations of the latest Pleistocene on the basis of the rodent assemblages together with the environmental and climatic data obtained; and 5) to compare our results with other vertebrate studies performed at the analysed sites, such as studies of amphibians and squamate reptiles (Blain et al., 2022) and avifauna (Goffette et al., 2020), as well as with the results from other sites with rodent studies, with a view to establishing the wider context of the latest Pleistocene in southern Belgium.

2. Material and methods

2.1. Rodent sorting and the palaeontological and taphonomical study

The rodent fossil remains used for this study come from the collections of the Royal Belgian Institute of Natural Sciences (RBINS) in Brussels. This material consists of disarticulated bone fragments, mandibles, maxilla, and isolated teeth, probably collected (we lack information on the samples recovered) by water-screening with a 1 or 2 mm mesh screen, judging by the dimensions of the bone remains, of which are basically represent by fragment of mandibles and maxilla with teeth and isolated teeth. The fossil material was processed, sorted, classified, and deposited in the collections of the RBINS. The studied fossil assemblage comprises 2477 identified specimens, corresponding to 1380 individuals from eight different sites in southern Belgium, representing at least 14 rodent taxa (Table 1; Fig. 3). The rodent fossil fragments were identified mainly in accordance with the palaeontological criteria proposed by Chaline (1972) and López-García (2011). The specific attribution of this material is based principally on the best diagnostic elements: mainly mandibles, maxilla, and isolated teeth for the different groups of rodents under analysis. Moreover, the fossils were quantified using the minimum number of individuals (MNI) method, by counting the most represented diagnostic elements and taking laterality into account where appropriate.

The taphonomic study of small mammals is based on a descriptive and systematic method that studies the changes resulting from predation (Andrews, 1990). For this preliminary study, the alterations caused by digestion present in the first lower molars were observed and described in accordance with Andrews (1990) and Fernandez-Jalvo et al. (2016) for the arvicoline rodent species, allowing us to identify and recognize the action of the predators that accumulated the small-mammal remains.

2.2. Radiocarbon dating

The sites of Grotte la Chefalize, Trou du Chêne, and Trou du Sureau, which are without an absolute dating and whose chronological attribution is unclear, are not used for the environmental and climatic reconstruction, and although the data inferred from these sites will be displayed in the tables and figures, they are not used for further interpretation.

The radiocarbon datings from the other sites analysed, Cavernes de Goyet, Trou des Nutons, Caverne Marie-Jeanne, Trou du Frontal, and Trou de Chaleux (Charles, 1998; Brace et al., 2012; Germonpré, 1997, 2004; Germonpré and Sablin, 2001; Germonpré et al., 2009; Van

Table 1
Representation of the percentage (%) of the MNI of the species by layer from the studied sites. MNI = minimum number of individuals; NISP = number of identified specimens.

	Goyet (A)	Goyet (M/A)	Goyet(M)	Nutons	Marie-Jeanne(2)	Frontal	Chaleux	Chefalize	Chêne(2)	Chêne(3)	Sureau
Arvicola amphibius	4.4	9.5	8.9	12.5	14.2	6.7	1.1	36.4	16.3	25.0	31.4
Chionomys nivalis	0.6	9.5	1.8	0.0	0.8	0.0	0.0	0.0	0.7	0.0	0.0
Clethrionomys glareolus	6.6	0.0	0.0	3.1	3.3	6.7	0.3	9.1	1.4	0.0	1.0
Dicrostonyx torquatus	33.1	26.2	26.8	43.8	9.4	0.0	28.8	0.0	2.7	0.0	0.0
Lemmus /Myopus	0.6	2.4	48.2	0.0	1.5	0.0	0.0	9.1	2.7	0.0	1.0
Lagurus lagurus	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Microtus agrestis	4.4	4.8	3.6	6.3	5.1	6.7	0.0	0.0	4.8	0.0	12.4
Microtus arvalis	22.7	23.8	3.6	12.5	36.6	40.0	18.4	18.2	23.1	52.5	9.5
Stenocraneus anglicus	22.7	19.0	7.1	15.6	20.1	13.3	47.5	18.2	27.9	10.0	21.0
Alexandromys oeconomus	2.2	4.8	0.0	0.0	5.1	6.7	3.9	0.0	13.6	12.5	14.3
Microtus (Terricola) subterraneus	1.7	0.0	0.0	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cricetus cricetus	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	6.8	0.0	8.6
Apodemus gr. *sylvaticus-flavicollis*	1.1	0.0	0.0	3.1	2.3	20.0	0.0	9.1	0.0	0.0	1.0
Glis glis	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
MNI	**181**	**42**	**56**	**32**	**393**	**15**	**358**	**11**	**147**	**40**	**105**
NISP	**320**	**60**	**96**	**51**	**711**	**20**	**688**	**15**	**263**	**71**	**182**

CORRECTED PROOF

Strydonck et al., 2001), were calibrated with OxCal 4.4.4. (Bronk-Ramsey, 2021 (Table 2; Fig. 2) in order to update them, and put into context with the atmospheric data from Reimer et al. (2020) (Fig. 2).

2.3. Palaeoenvironmental reconstruction

To reconstruct the past environment at the different sites under analysis, we use the habitat weighting method (see Evans et al., 1981; Andrews, 2006), distributing each rodent taxon where it can be found at present in accordance with López-García et al. (2017a and b). The habitats are divided into five types (in accordance with Cuenca-Bescós et al., 2005; Blain et al., 2008; López-García et al., 2010). These types are defined as follows: "open dry", meadows under seasonal climate change; "open humid", evergreen meadows with dense pastures and suitable topsoil; "woodland", mature forest, including woodland margins and forest patches, with moderate ground cover; "water", areas along streams, lakes, and ponds; and "rocky", areas with a rocky or stony substratum.

2.4. Palaeoclimatic reconstruction

In order to assess the palaeoclimatic data from the different sites under study, we use

the quantified ecology (QE) method, which was developed by Jeannet (2010). This method is based on a combination of the geographic and climatic distributions of small-vertebrate species today. In this case we use the rodent data, calculated from the

sum of the climatic parameters (mean temperature and mean precipitation) by species, divided by the total of the species represented at each of the studied sites. On the basis of these methods, two climatic factors are estimated: the mean annual temperature (MAT) and the mean annual precipitation (MAP). These climatic parameters are compared with the modern climatic data (over a period of 30 years) from the meteorological stations of the municipalities of Namur, Givet, and Dinant (Climate-Data.org) located near the sites in question (Fig. 1).

3. Studied sites and results

3.1. Cavernes de Goyet

The system of caves and galleries known as "Cavernes de Goyet" (50° 26′ 39″ N, 5° 00′ 51″ E) is located 130 m a.s.l. in a carboniferous limestone cliff 10 km southeast of the city of Namur (Ulrix-Closset, 1975; Otte, 1979; Cahen and Haesaerts, 1984) (Fig. 1). Discovered in 1869 by Dupont (Dupont, 1869), the system underwent a complex history of field excavation campaigns, summarized in Otte (1979). The rodent material analysed in this study comes from the excavations carried out by the RBINS in 1937 and 1938, when a Middle Palaeolithic level was discovered (de Bournonville, 1955). These excavations focused on four main parts of the system of caves: the "Salle du Mouton", a set of galleries numbered 1 to 6, the "central corridor", and the "well". Except for the Middle Palaeolithic level, these works seem to have found only reworked ground (Eloy, 1943; Blouard, 1946; Eloy, 1952–1953). From the labels kept in the RBINS drawers, various labelled samples are here considered: 1) the "Salle du Mouton" 2e and 1er niveau Moustérien, which probably refers to Mousterian levels; 2) the "Salle du Mouton" – Terre noire, which is considered mixed Mousterian and Aurignacian; and 3) the "Salle du Mouton" – Terre jaune, which is considered Aurignacian in origin (Otte, 1979). The radiocarbon AMS dating of selected bones reveals a chronological period from ca. 12 to 31 ka (Germonpré, 1997, 2004; Germonpré and Sablin, 2001; Van Strydonck et al., 2001) (Table 2).

The rodent remains from the different levels of Goyet's "Salle du Mouton" amount to a total of 476 identified specimens and 279 individuals, corresponding to 11 taxa (Table 1). The most abundant species in "2e and 1er niveau Moustérien" and "Terre noire" are *Dicrostonyx torquatus* (collared lemming), *Stenocranius anglicus* (= *Lasiopodomys gregalis*, priority discussed by Baca et al., 2019, 2023; Lemanik et al., 2020) (narrow-headed vole), and *Microtus arvalis* (common vole), representing 78.5% of the total number of individuals in "2e and 1er niveau Moustérien" and 69% in "Terre noire". The most abundant species in "Terre jaune" are *Lemmus/Myopus* (Norway/wood lemming, see discussion in Arbez et al., 2023) and *D. torquatus*, representing 75% of the total number of individuals (Table 1). For the taphonomic study, a total 481 arvicolinae first lower molars were observed. Among the types of digestion, according to Andrews (1990) and Fernandez-Jalvo et al. (2016), light (ca. 80%) and moderate (ca. 20%) digestion predominates, indicating that the accumulation is associated with predation. This kind of digestion can probably be associated with Category 2 predators, which in general not display a specific prey consumption pattern. Unfortunately, there is no data for birds from Cavernes de Goyet (Goffette, 2023). The habitat weighting method applied to the rodent assemblage reveals a landscape with a predominance of open dry and rocky formations (between 43.6% and 61.6%), also with a good representation of forest landscape (between 24.1% and 36.3%) (Table 3). The quantified ecology method for reconstructing climatic parameters shows that the mean annual temperatures and mean annual precipitation were lower than at present ($\text{MAT}_{\text{Goyet}}$ = −7.8 to −5.8 °C; $\text{MAP}_{\text{Goyet}}$ = −307 to −300 mm) (Table 4). At present, MAT = 10.3 °C and MAP = 864 mm at the weather station at Namur (Climate-Data.org).

3.2. Trou des Nutons

Trou des Nutons (50° 12′ 50″ N, 4° 57′ 24″ E) is a 25-m-long, 2.5-m-wide cave located about 30 m above the right bank of the Lesse River, about 5 km southeast of the city of Dinant on the territory of the Furfooz village (Fig. 1). Two levels from this site described by Dupont (1868) delivered osteological material. The upper layer (first ossiferous layer) was attributed to the "Âge du Renne" (meaning "reindeer age"), whereas a deeper layer (second ossiferous layer) delivered bones considered older and attributed to the "Âge du Mammouth" (meaning "mammoth age"). Various radiocarbon datings suggest a latest Pleistocene age of around 12.8 ka, in agreement with the Magdalenian material culture uncovered at this site. However, one older date has been obtained (21.8 ka), and more recent material is certainly also present, as shown by several radiocarbon results that fall within the Holocene (Germonpré et al., 2009; Charles, 1998) (Table 2).

The rodent remains studied here from the first ossiferous layer are scarce: 51 specimens and 32 individuals, corresponding to eight taxa, have been identified (Table 1). Among these remains, the best-represented species are *D. torquatus*, *S. anglicus*, *M. arvalis*, and *Arvicola amphibius* (European water vole), representing 84.4% of the total number of individuals (Table 1). For the taphonomic study, a total 50 arvicolinae first lower molars were observed. Among the types of digestion, according to Andrews (1990) and Fernandez-Jalvo et al. (2016), light (ca. 71%) and moderate (ca. 28%) digestion predominates, indicating that the accumulation is associated with predation. This kind of digestion can probably be associated with Category 2 predators, which in general not display a specific prey consumption pattern. Among the possible candidates for this category of predation, we find *Bubo scandiacus* (Snowy owl) present at the site (Goffette, 2023).The habitat weighting method applied to the rodent assemblage reveals a landscape with a predominance of open dry and rocky formations (44.5%), also with a good representation of forest landscape (31.3%) and stable watercourses (16.4%) close to the cave (Table 3). The quantified ecology method for reconstructing climatic parameters shows that the mean annual temperatures and mean annual precipitation were lower than at present ($\text{MAT}_{\text{Nutons}}$ = −5.3 °C; $\text{MAP}_{\text{Nutons}}$ = −335 mm) (Table 4). At

Table 2
Radiocarbon dates for the different sites analysed, calibrated with the OxCal 4.4.4. software (Bronk Ramsey, 2021).

Reference n°	site	level	species	element	14C date BP	14C cal yr B.P. (68,3%)	14C cal yr B.P. (95,4%)	reference
OxA-24,122	Marie-Jeanne	2	*Dicrostonyx*	teeth	12,275 ± 55	14,292–14,090	14,456–14,057	Brace et al., 2012
Oxa-24,123	Marie-Jeanne	2	*Dicrostonyx*	teeth	20,930 ± 140	25,365–25,055	25,670–24,916	Brace et al., 2012
GrA-3238	Goyet - 3rd cave	Horizon 1	*Ovibos moschatus*	phalanx	12,620 ± 90	15,202–14,866	15,310–14,790	Germonpré, 1997
GrA-3237	Goyet - 3rd cave	Horizon 1	*Equus* sp.	vertebra	12,770 ± 90	14,351–14,058	14,629–14,020	Germonpré, 1997
GrA-3239	Goyet - 3rd cave	Horizon 1	*Crocuta crocuta*	calcaneum	27,230 ± 260	31,488–31,205	31,740–31,004	Germonpré, 1997
Utc-8957	Goyet - 3rd cave	Horizon 1	*Equus* sp.	bone	12,560 ± 50	15,083–14,840	15,139–14,801	Stevens et al., 2009
OxA-12,121	Goyet - 3rd cave	Horizon 1	*Ovibos moschatus*	bone	12,775 ± 50	15,309–15,149	15,454–15,074	Stevens et al., 2009
OxA-V-2223-48	Goyet - 3rd cave	Horizon 1	*Equus* sp.	bone	12,775 ± 55	15,316–15,143	15,474–15,064	Stevens et al., 2009
OxA-6592	Goyet - 3rd cave	Horizon 1	*Coelodonta antiquitatis*	bone	16,320 ± 140	19,874–19,538	20,118–19,376	Stevens et al., 2009
OxA-V-2223-44	Goyet - 3rd cave	Horizon 1	*Equus* sp.	bone	31,750 ± 200	36,328–35,894	36,502–35,551	Stevens et al., 2009
Beta-239,920	Goyet	–	Large canid	Skull	31,680 ± 250	36,280–35,737	36,504–35,422	Germonpré et al., 2009
KIA-25296	Goyet - 3rd cave	Level A1	Large canid	bone	13,680 ± 60	16,638–16,408	16,792–16,321	Germonpré et al., 2009
KIA-25297	Goyet	Level B4	Large canid	bone	24,780 ± 140	29,148–28,876	29,220–28,741	Germonpré et al., 2009
KIA-22275	Goyet - 3rd cave	Horizon 2	*Alopex lagopus*	bone	12,380 ± 60	14,539–14,241	14,864–14,160	Dalén et al., 2007
OxA-V-2223-49	Goyet - 3rd cave	Horizon 2	*Equus* sp.	bone	29,420 ± 170	34,225–33,830	34,390–33,568	Stevens et al., 2009
KIA-22280	Goyet - 3rd cave	Horizon 3	*Ursus spelaeus*	bone	23,580 ± 130	27,852–27,652	27,938–27,405	Germonpré and Hämäläinen, 2007
KIA-18986	Goyet - 3rd cave	Horizon 3	*Ursus spelaeus*	bone	27,440 ± 170	31,548–31,222	31,712–31,147	Germonpré and Hämäläinen, 2007
KIA-22281	Goyet - 3rd cave	Horizon 3	*Rangifer tarandus*	bone	27,590 ± 170	31,667–31,310	31,825–31,190	Germonpré and Hämäläinen, 2007
OxA-4194	Trou des Nutons	–	*Cervus elaphus*	scapho-cuboid	2210 ± 80	2328–2126	2352–1999	Hedges et al., 1994
Lv-1137	Trou des Nutons	–	Unidentified	Multiple bone fragments	7720 ± 110	8600–8392	8980–8330	Gilot, 1984
OxA-4195	Trou des Nutons	–	*Equus ferus*	phalanx	12,630 ± 140	15,274–14,824	15,464–14,301	Hedges et al., 1994
OxA-4014	Trou des Nutons	–	*Equus ferus*	pisiform	12,870 ± 110	15,557–15,230	15,712–15,078	Hedges et al., 1994
KIA-25298	Trou des Nutons	–	*Canis lupus*	Skull	21,810 ± 90	26,086–25,913	26,326–25,882	Germonpré et al., 2009
OxA-4193	Trou de Chaleux	–	*Sus scrofa*	Humerus	3060 ± 85	3374–3162	3450–3000	Hedges et al., 1994
OxA-5679	Trou de Chaleux	–	*Homo sapiens*	bone	8730 ± 80	9887–9552	10,120–9540	Bronk Ramsey et al., 2002
OxA-3632	Trou de Chaleux	–	*Equus ferus*	cuneiform	12,790 ± 100	15,430–15,115	15,590–14,988	Hedges et al., 1993
OxA-4192	Trou de Chaleux	–	*Ovibos moschatus*	pisiform	12,860 ± 140	15,580–15,176	15,785–14,970	Hedges, 1994
OxA-3633	Trou de Chaleux	–	*Equus ferus*	cuneiform	12,880 ± 100	15,555–15,254	15,694–15,114	Hedges et al., 1993
Lv-1568	Trou de Chaleux	–	Unidentified	Multiple bone fragments	12,370 ± 170	14,646–14,151	15,141–14,014	Otte and Teheux, 1986
Lv-1136	Trou de Chaleux	–	Unidentified	Multiple bone fragments	12,710 ± 150	15,446–14,906	15,630–14,784	Gilot, 1984
Lv-1569	Trou de Chaleux	–	Unidentified	Multiple bone fragments	12,990 ± 140	15,734–15,324	15,964–15,155	Otte and Teheux, 1986
OxA-V-2216-44	Trou de Chaleux	–	*Equus ferus*	bone	12,375 ± 50	14,515–14,246	14,637–14,168	Stevens et al., 2009
OxA-V-2216-45	Trou de Chaleux	–	*Equus ferus*	bone	12,630 ± 55	15,141–14,969	15,259–14,837	Stevens et al., 2009
OxA-4196	Trou du Frontal	–	*Homo sapiens*	Tibia	4430 ± 80	5273–4877	5290–4860	Hedges et al., 1994
GrN-10,179	Trou du Frontal	–	*Homo sapiens*	Multiple ribs	4430 ± 30	5259–4887	5280–4870	Twiesselmann, 1971

(*continued on next page*)

CORRECTED PROOF

Table 2 (*continued*)

Reference n°	site	level	species	element	14C date BP	14C cal yr B.P. (68,3%)	14C cal yr B.P. (95,4%)	reference
Lv-1135	Trou du Frontal	–	Unidentified	Multiple bone fragments	10,720 ± 120	12,810–12,499	12,970–12,200	Gilot, 1984
OxA-4197	Trou du Frontal	–	*Equus ferus*	metacarpus	12,800 ± 130	15,504–15,106	15,713–14,896	Hedges, 1994
Lv-1749	Trou du Frontal	–	*Equus ferus*	bone	12,950 ± 170	15,732–15,250	16,001–15,010	Dewez, 1992
Lv-1750	Trou du Frontal	–	*Equus ferus* + *Canis lupus*	bone	13,130 ± 170	16,018–15,506	16,250–15,264	Dewez, 1992

Fig. 1. Location of the different sites analysed. 1.Marie-Jeanne; 2. Goyet; 3. Chêne, Sureau; 4. Nutons; Frontal; 5. Chaleux; 6. Chefalize.

Table 3
Percentage representation of rodent taxa associated with open dry meadows (OD); open humid meadows (OH); woodland environments (Wo); rocky environments (R); and landscapes beside running water (Wa).

	OD + R	OH	Wo	Wa
Trou de Chaleux	42.7	13.8	29.5	14.0
Trou du Frontal	23.3	10.0	55.0	11.7
Marie-Jeanne (2)	33.6	10.1	35.8	20.5
Trou des Nutons	44.5	7.8	31.3	16.4
Goyet (A)	43.6	9.4	36.3	10.6
Goyet (A/M)	47.6	9.5	26.8	15.5
Goyet (M)	61.6	3.6	24.1	10.7

Table 4
Relation of temperature and precipitation for the different sites analysed; MAT. mean annual temperatures; MAP. mean annual precipitation; Δ. Average values in relation to present data; SD. standard deviation of values obtained.

	MAT	SD	Current	ΔMAT	MAP	SD	Current	ΔMAP
Trou de Chaleux	1.01	5.6	9.8	−8.79	480	77	899	−419
Trou du Frontal	4.4	5.4	9.8	−5.4	530	110	866	−336
Marie-Jeanne (2)	5	4.6	9.8	−4.8	529	102	866	−337
Trou des Nutons	4.5	6.3	9.8	−5.3	531	111	866	−335
Goyet (A)	4.5	6.3	10.3	−5.8	564	125	864	−300
Goyet (A/M)	2.5	6.3	10.3	−7.8	557	148	864	−307
Goyet (M)	3.5	6.4	10.3	−6.8	561	159	864	−303

present, MAT = 9.8 °C and MAP = 899 mm at the weather station at Dinant (Climate-Data.org).

3.3. Caverne Marie-Jeanne

Caverne Marie-Jeanne (50° 13′ 23″ N, 4° 48′ 51″ E) is located 25 m above the right bank of a small tributary (Féron) of the River Meuse, near the town of Hastière-Lavaux (Ballmann et al., 1980; Brace et al., 2012) (Fig. 1). The cave is formed from Tournaisian (Early Carboniferous) calcareous deposits. The excavations at this site began in 1943, conducted by M. Gilbert of the RBINS. The excavated deposits were made up of ten layers, of which layers 10 to 7 were sterile and layers 6 to 2 contain a large number of faunal remains. The small-mammal remains of the entire sequence were published in extended form by López-García et al. (2017b). Here the focus is on upper layer 2, which is latest Pleistocene in age (ca. 12–20 ka) (Brace et al., 2012) (Table 2). This may help us in drawing comparisons with the other sites under consideration.

The rodent remains from layer 2 of Caverne Marie-Jeanne amount to a total of 711 identified remains and 393 individuals, corresponding to 13 taxa (Table 1). The most abundant species are *M. arvalis*, *S. anglicus*, and *A. amphibius*, representing 70.2% of the total number of individuals. For the taphonomic study, a total 682 arvicolinae first lower molars were observed. Among the types of digestion, according to Andrews (1990) and Fernandez-Jalvo et al. (2016), light (ca. 73%) and moderate (ca. 16%) digestion predominates, indicating that the accumulation is associated with predation. This kind of digestion can probably be associated with Category 2 predators, which in general not display a specific prey consumption pattern. Unfortunately, no predatory birds are found in Marie-Jeanne layer 2 (Ballmann, 1973) Applying the habitat weighting method to the rodent assemblage brings to light a more or less equal representation of forest formations (35.8%) and open and dry and rocky landscapes (33.6%), also with a good representation of stable watercourses (20.5%) (Table 3). According to the quantified ecology method of reconstructing climatic parameters, the mean annual temperatures and mean annual precipitation were lower than at present ($MAT_{Marie\text{-}Jeanne}$ = −4.8 °C; $MAP_{Marie\text{-}Jeanne}$ = −337 mm) (Table 4). At present, MAT = 9.8 °C and MAP = 866 mm at the weather station at Givet (Climate-Data.org).

3.4. Trou du Frontal

Trou du Frontal (50° 12′ 46″ N, 4° 57′ 22″ E) is located on the right bank of the Lesse River 16 m above it, and is part of the Furfooz cave complex (Dupont, 1866) (Fig. 1). The excavations yielded remains of Magdalenian culture, together with large-mammal (herbivore and carnivore), bird, fish, amphibian, and reptile remains (Blain et al., 2022; Dupont, 1873; Germonpré et al., 2009; Van Neer et al., 2007). Various radiocarbon datings have situated the Late Pleistocene material between ca. 12.8–13.1 ka, but several bones have given a Holocene age (Germonpré, 1997; Germonpré et al., 2009) (Table 2).

The rodent assemblage of Trou du Frontal is very scarce. A total of only 20 specimens and 15 individuals have been identified, corresponding to seven species, of which the most abundant is *M. arvalis* (40%), together with *Apodemus* gr. *sylvaticus-flavicollis* (20%) (Table 1). For the taphonomic study, a total 16 arvicolinae first lower molars were observed. Among the types of digestion, according to Andrews (1990) and Fernandez-Jalvo et al. (2016), light (ca. 60%) and moderate (ca. 30%) digestion predominates, indicating that the accumulation is associated with predation. This kind of digestion can probably be associated with Category 2 predators, which in general not display a specific prey consumption pattern. As is the case in Trou des Nutons, among the possible candidates for this category of predation, we find *Bubo scandiacus* represented at the site (Goffette, 2023). Bearing in mind that any possible interpretation of this site should be treated with caution given the scarcity of remains, the habitat weighting method shows a predominance of forest formations (55%), together with a relatively high component of open dry and rocky environments (23.3%) (Table 3). The quantified ecology method for reconstructing climatic parameters indicates mean annual temperatures and mean annual precipitation lower than at present ($MAT_{Frontal}$ = −5.4 °C; $MAP_{Frontal}$ = −336 mm) (Table 4). At present, MAT = 9.8 °C and MAP = 866 mm at the weather station at Givet (Climate-Data.org).

3.5. Trou de Chaleux

Trou de Chaleux (50° 13′ 11“ N, 4° 56’ 41” E) is located 6 km southeast of the city of Dinant in a limestone cliff on the right bank of the Lesse River (Ulrix-Closset, 1975; Cahen and Haesaerts, 1984; Otte, 1994) (Fig. 1). Various archaeological interventions have been undertaken at the site, mainly in the second half of the 19th century (Dupont, 1865, 1867) and at the end of the 20th century (Otte, 1994). Several radiocarbon datings constrain the Late Pleistocene assemblage between ca. 12.4–13.0 ka, but two bones yielded results corresponding to the Holocene (Germonpré, 1997; Germonpré et al., 2009) (Table 2). These excavations yielded very abundant material attributed to upper Magdalenian culture (Sonneville-Bordes, 1961; Otte, 1994; Charles, 1998; Dewez, 1987), including a good representation of large-mammal, bird, fish, amphibian, and reptile remains (Blain et al., 2022; Germonpré, 1997; Dupont, 1873; Van Neer et al., 2007). It should be noted that a recent study of the avifauna (Goffette et al., 2020) shows that the presence of birds such as ptarmigans, pine grosbeak and the snowy owl is consistent with Trou de Chaleux being attributed to the late Magdalenian.

The rodent remains from Trou de Chaleux amount in total to 688 identified specimens and 358 individuals, corresponding to six taxa (Table 1). The two most abundant species are *S. anglicus* and *D. torquatus*, making up 76.3% of the total number of individuals. For the taphonomic study, a total 688 arvicolinae first lower molars were observed. Among the types of digestion, according to Andrews (1990) and Fernandez-Jalvo et al. (2016), light (ca. 81%) and moderate (ca. 18%) digestion predominates, indicating that the accumulation is associated with predation. This kind of digestion can probably be associated with Category 2 predators, which in general not display a specific prey consumption pattern. Also, in this case it could coincide with the presence of *Bubo scandiacus* identified in the site (Goffette et al., 2020; Goffette, 2023). Application of the habitat weighting method to the rodent assemblage indicates a landscape with a predominance of open dry and rocky formations (42.7%), also with a good representation of forest landscape (29.5%) and stable watercourses (14%) close to the cave (Table 3). According to the quantified ecology method, the mean annual temperatures and mean annual precipitation were lower than at present ($MAT_{Chaleux}$ = −8.8 °C; $MAP_{Chaleux}$ = −419 mm) (Table 4). At present, MAT = 9.8 °C and MAP = 899 mm at the weather station at Dinant (Climate-Data.org).

3.6. Other sites

Three other sites whose remains are housed at the RBINS were studied, although they are without an absolute dating and their chronological attribution is unclear. Methods for reconstructing the environment and climate were not applied to these sites, but the number of identified specimens and the minimum number of individuals appear in Table 1.

Trou du Chêne is a small cave that forms part of the Montaigle caves, located to the south of Namur (Fig. 1). This cave was excavated by Dupont in 1867 (Dupont, 1868). The material deposited at the RBINS corresponds to two levels: “3e niveau ossifère”, ascribed by Otte (1979) to the Upper Perigordian (ca. 35–20 ka), and “2e niveau ossifère”, probably associated with the Magdalenian (Otte, 1979). The two levels yielded a total of 334 identified remains and 187 individuals, corresponding to ten species (Table 1). In both levels, the most abundant species are *A. amphibius*, *M. arvalis*, *S. anglicus*, and *Alexandromys oeconomus* (Table 1).

Trou du Sureau is the largest of the Montaigle caves and is located to the south of Namur (Fig. 1), a few metres east of Trou du Chêne. It was also excavated by Dupont in 1867 (Dupont, 1868). Various layers have been described for this site, which is very rich in mammals, birds, anurans, shells, and fishes (Dupont, 1868, 1873; Van Neer et al., 2007). On the basis of the lithic assemblage, Otte (1979) proposed that level 2 was associated with a Perigordian occupation, probably related with the “3e niveau ossifère” of Trou du Chêne, and that level 1 was a mixture between Mesolithic and Neolithic periods. The rodent material identified from the RBINS pertains to level 2 of Trou du Sureau. A total of 182 remains and 105 individuals have been identified, corresponding to eight taxa (Table 1). The most abundant species, as in Trou du Chêne, are *A. amphibius*, *M. arvalis*, *S. anglicus*, and *A. oeconomus* (Table 1).

There is no archaeological or geological information from Grotte la Chefalize, but the general inventory number of the RBINS suggests that

CORRECTED PROOF

the cave is located in the municipality of Jemeppe-sur-Sambre, about 15 km west of Namur. The rodent material that was deposited in the RBINS in 1970 is labelled "Salle I" and "Salle II". The material identified is very scarce, amounting to 15 specimens corresponding to 11 individuals, ascribed to six taxa (Table 1). The most abundant species are *A. amphibius*, *M. arvalis* and *S. anglicus*.

4. Discussion

4.1. Rodent assemblages from southern Belgium

Of the rodent species identified in the eight latest Pleistocene sites under analysis here, the most commonly represented taxa are the water vole (*A. amphibius*), the Arctic lemming (*D. torquatus*), the common vole (*M. arvalis*), and the narrow-headed vole (*S. anglicus*) (Table 1). Although the species *D. torquatus* and *S. anglicus* are not currently present in Belgium, during the Late Pleistocene they were relatively abundant, as evidenced by studies of Scladina cave (López-García et al., 2017a), the lower layers (6 to 4) of Caverne Marie-Jeanne (López-García et al., 2017b), and Grotte Walou (Stewart and Parfitt, 2011). On the one hand, *D. torquatus* is a species linked nowadays to Arctic and sub-Arctic tundra and forest-tundra (Tsytsulina et al., 2016), whereas *S. anglicus* is currently reported to inhabit higher altitudes in grass steppes and alpine and water meadows (Batsaikhan et al., 2008). On the other hand, an abundance of *A. amphibius* and *M. arvalis* is relatively common in the MIS 2 sites of western Europe, as it is evidenced by studies in Belgium (Grotte Walou; Stewart and Parfitt, 2011), France (Royer et al., 2016), the Italian Peninsula (Berto et al., 2019; López-García et al., 2014, 2015), and the Iberian Peninsula (Fernández-García et al., 2016; López-García, 2011). The European water vole, *A. amphibius*, nowadays occupies a range of habitats around rivers, streams, and marshes in lowlands and mountains (Batsaikhan et al., 2021). In Belgium the species inhabits relatively open meadows with abundant vegetation, cultivated fields, and gardens near watercourses (Frechkop, 1981). *M. arvalis* is currently found in a great variety of habitats, including moist meadows, forest steppe, moist forest, and agricultural areas (Yigit et al., 2016). In Belgium the species inhabits non-humid, open, herbaceous meadows, open areas, and forest edges, as well as cultivated fields and gardens (Frechkop, 1981).

4.2. Marine Isotope Stage 2 sites with constrained chronology

The two MIS 2 sites analysed here that are best constrained chronologically are Trou de Chaleux and Trou du Frontal (Table 2; Fig. 2). With a chronology between ca. 15,964–14,014 cal. BP, Trou de Chaleux could be located between Greenland Stadial 2 (Heinrich Event 1) and Greenland Interstadial 1 (the Bølling interstadial) (Germonpré et al., 2009; Stevens et al., 2009; Goffette et al., 2020). The large-mammal assemblage from Trou de Chaleux is dominated by horse, fox, and muskox, suggesting open-dry and cold environmental and climatic conditions (Charles, 1998; Germonpré, 1997). The avifaunal studies performed by Goffette et al. (2020) show the presence of cold-environment

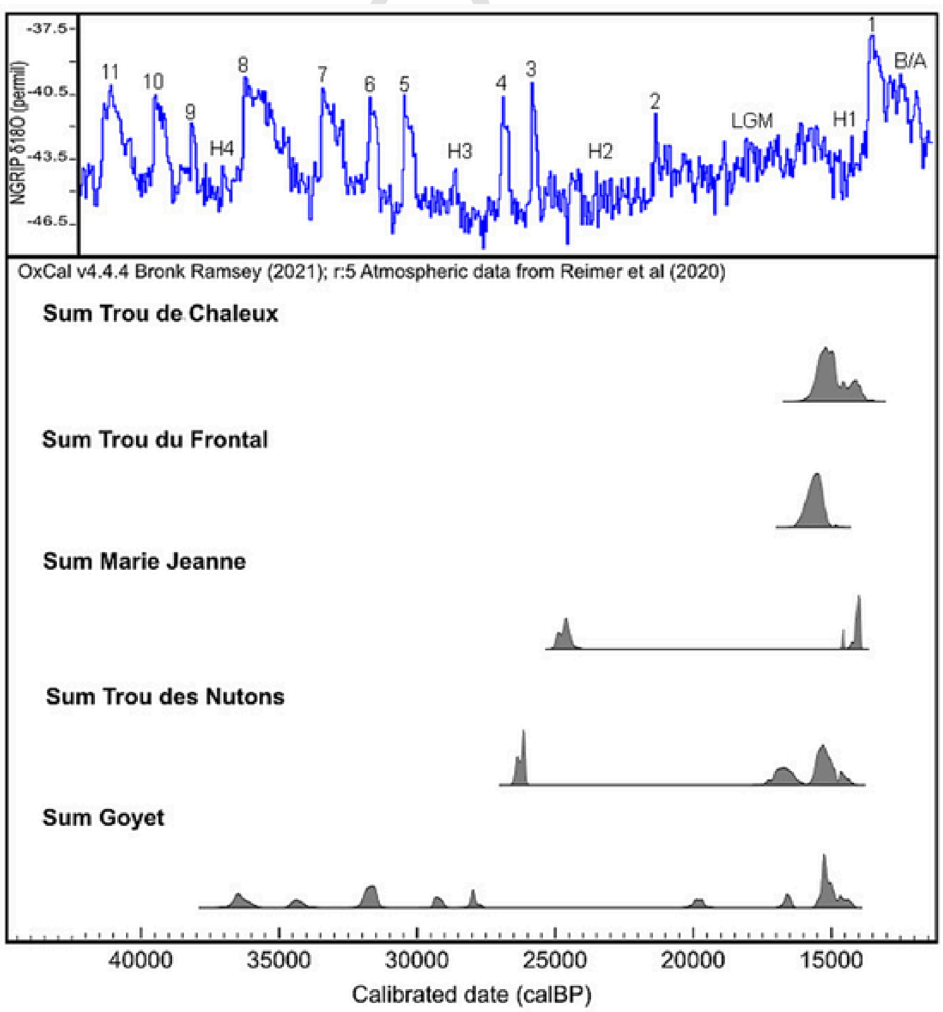

Fig. 2. Plot of the late Pleistocene radiocarbon dates calibrated with the atmospheric data (Reimer et al., 2020) [Prepared using OxCal v. 4.4.4; Bronk Ramsey, 2021].

species, such as the snowy owl, ptarmigans, and the pine grosbeak, together with other species more characteristic of boreal or temperate climates, such as the grey partridge and the tawny owl. Most of the identified bird taxa are associated with open landscapes, but the western capercaillie and the tawny owl indicate the presence of forested areas in the vicinity of the cave. In addition, the presence of ducks, geese, and swans indicates ponds or large water bodies near the cave. Recent intrusions are observed in the bird study, since a few bones belonging to the domestic chicken are present, which was introduced to Belgium at the end of the Iron Age at the earliest (Goffette et al., 2019). However, the bird assemblage seems homogeneous overall and is generally consistent with an attribution to the Pleistocene. The Pleistocene level of Trou de Chaleux was covered by a thick layer of rocky blocks, which acted as a protective barrier against burrowing mammals, preventing recent intrusions to some extent (Dupont, 1872). The studies of the amphibian and squamate assemblages of Trou de Chaleux, carried out by Blain et al. (2022), show a very low diversity, with only two taxa present (*Rana temporaria* and cf. *Vipera* sp.), suggesting a predominantly dry and open environment. Additionally, the application of the quantified ecology method to the herpetofaunal assemblage indicates a very cold MAT in relation to nowadays (−6.9 °C) and a low MAP (−264 mm) by comparison with current conditions. (See Fig. 4.)

The present environmental and climatic reconstruction based on the rodent assemblage of Trou de Chaleux is consistent with previously published proxy studies. As expounded above, the habitat weighting method shows a landscape with a predominance of open dry and rocky formations, together with a good representation of forest landscape. The quantified ecology method also reveals that Trou de Chaleux corresponds to the coldest MAT (−8.7 °C) and lowest MAP (−419 mm) of all the sites analysed (Table 4) with respect to present-day climatic conditions (Dinant; Climate-Data.org). Together with the chronological range of the site, these data suggest that the rodent accumulation could have been produced during a cold interval, probably Greenland Stadial 2 (Heinrich Event 1).

By contrast, the chronology of Trou du Frontal places the site immediately prior to Greenland Interstadial 2 (Heinrich Event 1), although previous studies of the herpetofauna suggest that the deposit could consist of a mixed Late Pleistocene and Early Holocene fauna (Blain et al., 2022). The study of bird remains undoubtedly confirms the mixed nature of the '1er niveau ossifère' of this site, since it identifies both taxa characteristic of cold climates such as the snowy owl, pine grosbeak, and rock ptarmigan, and also a majority of temperate forest bird taxa, with a large proportion of chicken remains (Goffette, 2023). This point was also highlighted by the analysis of the large mammals (Charles, 1998). These results from other animal groups make it difficult to interpret the data obtained from the rodent association, which is furthermore scarce, as pointed out above.

4.3. Other sites analysed

Of the six other sites analysed, Grotte la Chefalize, Trou du Chêne, and Trou du Sureau, though they could correspond to a Late Pleistocene assemblage, lack a clear chronological attribution for interpreting the data. The other three sites, Cavernes de Goyet, Trou des Nutons, and Caverne Marie-Jeanne, have a rather disparate chronological range (Table 2; Fig. 2). Goyet has undergone a series of datings that range between the end of MIS 3 and MIS 2, with a radiocarbon calibrated age from 36,504–14,020 cal. BP (Table 2; Fig. 2). Two groups of datings are observed in the sum calibration of Goyet (Fig. 2). The first group comprises all the datings from ca. 36 to 27 ka, and the second group comprises the datings between ca. 20–14 ka. It is not possible to correlate the analysed layers directly with the chronological datings, but the results obtained from the rodent assemblage detect a temperate signal from the Mousterian and Aurignacian layers (see MAT in Table 3) in comparison with the transitional layer (Mousterian/Aurignacian). Similar results have been obtained with the herpetofaunal assemblage published by Blain et al. (2022), where the presence of *Epidalea calamita* suggests a temperate signal for the Aurignacian and Mousterian levels. Together with Trou de Chaleux, the data obtained from the rodent assemblage for the Mousterian/Aurignacian layer present the lowest values for mean annual temperatures (−7.8 °C in relation to present-day temperatures) (Table 3), which, according to the calibrated dating, could correspond to the data around ca. 30 ka, consistent with Heinrich Event 3 (Fig. 2). Trou des Nutons and Caverne Marie-Jeanne (layer 2) could present a similar chronological range of between ca. 26–14 ka (Table 2; Fig. 2). This chronology is consistent with the interval between the Bølling interstadial and Interstadial 4 (Fig. 2). This extended range makes palaeoenvironmental and palaeoclimatic interpretations of both sites difficult. However, the rodent results suggest that the deposition of this material could have been produced during a relatively temperate period between the above-mentioned intervals. As laid out above, Caverne Marie-Jeanne (layer 2) and Trou des Nutons present, to-

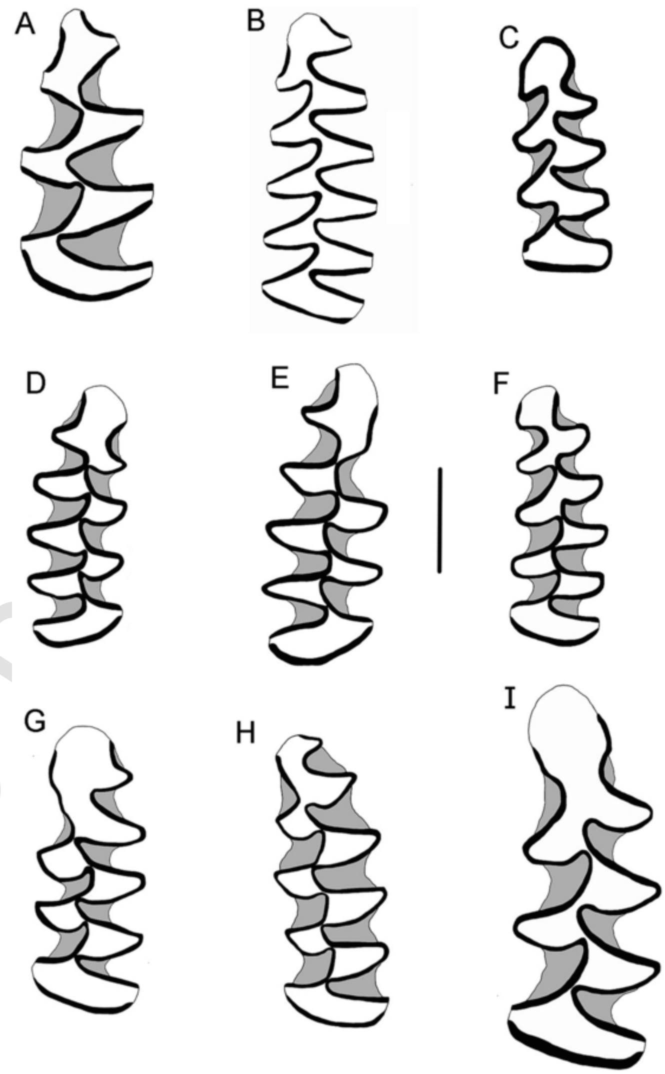

Fig. 3. Some of the identified rodents from the different sites analysed. A. left m1 (first lower molar) *Lemmus/Myopus* from Goyet 2e niv. Inf.; B. left m1 *Dicrostonyx torquatus* from Goyet 2e niv. Inf; C. left m1 *Clethrionomys glareolus* from Goyet Terre Jaune; D. right m1 *Microtus arvalis* from Trou de Chaleux; E. right m1 *Stenocraneus anglicus*from Trou des Nutons; F. left m1 *Microtus* (*Terricola*) *subterraneus* from Trou des Nutons; G. left m1 *Alexandromys oeconomus* from Trou de Chaleux; H. left m1 *Microtus agrestis* from Trou du Frontal; I. left m1 *Arvicola amphibius* from Trou du Sureau. All teeth are in occlusal view. Scale 1 mm.

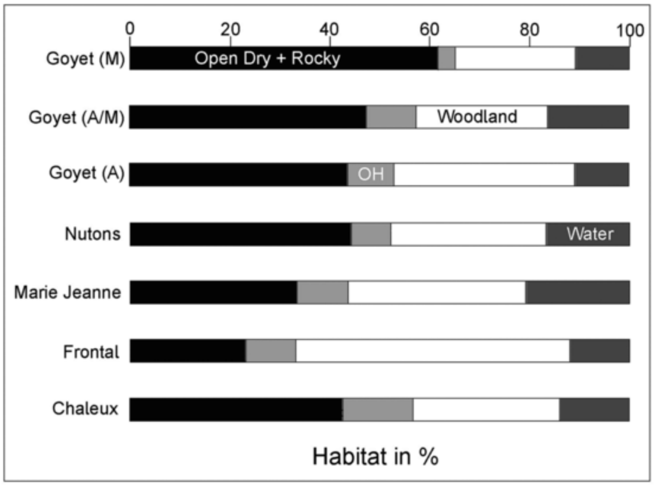

Fig. 4. Environmental comparison of the different sites studied by means of the habitat weighting method applied to the rodent assemblages. OH = Open Humid. A = Aurignacian levels; A/M = Aurignacian/Mousterian levels; M: Mousterian levels.

gether with Goyet (Aurignacian), the highest values for the mean annual temperature (Table 4). In the case of Caverne Marie-Jeanne (layer 2), these data coincide with previously published studies in molluscs, which show an increase in species diversity in relation with the lower layers, and also with the large- and small-mammal assemblages, which show an increase in forest formations in relation to the lower layers (Ballmann et al., 1980; López-García et al., 2017b). In the case of Trou des Nutons, the analysis of the large-mammal and bird remains testifies to a mixture of Pleistocene and Holocene material, which certainly accounts for the more temperate climate reconstructed on the basis of micromammals (Charles, 1998; Goffette, 2023).

4.4. Comparison with other latest Pleistocene sites

Few sites in Belgium contain Late Pleistocene sequences with rodent assemblages that have been studied from an environmental point of view. In addition to the sites analysed here, such studies exist for the lower layers of Caverne Marie-Jeanne (López-García et al., 2017b), Trou Magrite (Cordy, 1995), Grotte Walou (Stewart and Parfitt, 2011), and Scladina (López-García et al., 2017a). In the case of Trou du Diable (Toussaint, 1988), a rodent study was performed by G. Brochet, but the faunal list is not published, and the number of remains is too low for environmental interpretations. The rodent studies from Trou Magrite (Cordy, 1995) are rather old (Middle Pleistocene) and difficult to compare with our data. Taking into account these data and our results, Grotte Walou (Stewart and Parfitt, 2011), Scladina (López-García et al., 2017a), and the lower layers of Caverne Marie-Jeanne (López-García et al., 2017b) can be compared with our only site with a clear chronological range, Trou de Chaleux (Table 2; Fig. 2).

Of the aforementioned sites, only one layer of Grotte Walou is chronologically similar to Trou de Chaleux. The other sites are chronologically older, but the cold and dry requirements detected in the rodent taxa of Trou de Chaleux could be comparable with some layers of these sites. In layer B-2/3/4 of Grotte Walou (dated to between 16,296–15,203 cal. BP; Pirson, 2011), the relative abundance of *D. torquatus* and *S. anglicus* indicates cold and dry environmental conditions (Stewart and Parfitt, 2011). In Scladina layer I too (dated to between ca. 43–40 ka), species associated with strictly dry requirements such as *Lemmus/Myopus*, *D. torquatus*, *M. arvalis*, and *C. nivalis* are predominant (López-García et al., 2017a). In the lower layers of Caverne Marie-Jeanne (6 to 4; MIS 3 in age), the conditions are similar to those of the sites described above, with a predominance of species related to dry and cool requirements: *S. anglicus*, *M. arvalis*, and *D. torquatus* (López-García et al., 2017b). All the above mentioned layers of these different sites coincide with MIS 2 of the Trou de Chaleux site, with a predominance of just a few species associated with strictly dry and cool requirements, as laid out above in Table 1, where *S. anglicus*, *D. torquatus*, and *M. arvalis* are the predominant species in the rodent assemblage. In general and according to Cordy (1991), this is corroborated by the mammal assemblages during these latest Pleistocene climatic periods in southern Belgium, which are characterized by a predominance of the reindeer (*Rangifer tarandus*) and the collared lemming (*D. torquatus*), indicating harsh climatic conditions, together with a predominance of tundra vegetation.

Furthermore, Trou de Chaleux can be compared with other latest Pleistocene site in Central Europe sites. In Poland at Biśnik cave, Socha (2014) identified in Layer 1 (with an age comprise between 16.2 and 15.2 ka) a rodent association dominated by the species *D. torquatus*, *S.anglicus* and *M. arvalis*, indicating cold and dry environmental conditions for this layer (Socha, 2014). Also, the in the synthesis proposed by Royer et al. (2016) for Late Pleistocene southwestern French sites, identified that during the MIS 2 the rodents assemblages are relatively dominated by the abundance of *S. anglicus* and *D. torquatus*. Also showing that its last species (*D. torquatus*) disappear from the studied area before the Younger Dryas (YD) and *S. anglicus* is perturbed by the Bølling interstadial warming, decreasing in great number (Royer et al., 2016). As observed in the previous paragraph, for the rest of the Belgian sites, the rodent association of MIS 2 of Trou de Chaleux coincides with the interpretations made for the aforementioned rodent studies from Central Europe.

5. Conclusions

The following conclusions can be drawn from the foregoing analysis of the rodents from eight Late Pleistocene sites located in southern Belgium: Cavernes de Goyet, Trou des Nutons, Caverne Marie-Jeanne, Trou du Frontal, Trou de Chaleux, Grotte la Chefalize, Trou du Chêne, and Trou du Sureau:

1) A total of 2477 rodent remains have been identified from eight different sites in southern Belgium, housed in the RBINS. These correspond to 1380 individuals and represent at least 14 rodent taxa: *Arvicola amphibius*, *Chionomys nivalis*, *Clethrionomys glareolus*, *Dicrostonyx torquatus*, *Lemmus/Myopus*, *Lagurus lagurus*, *Microtus agrestis*, *Microtus arvalis*, *Stenocranius anglicus*, *Alexandromys oeconomus*, *Microtus* (*Terricola*) *subterraneus*, *Cricetus cricetus*, *Apodemus* gr. *sylvaticus-flavicollis*, and *Glis glis*.

2) Among the rodent species identified in these eight latest Pleistocene study sites, the most commonly represented taxa are the water vole (*A. amphibius*), the collared lemming (*D. torquatus*), the common vole (*M. arvalis*), and the narrow-headed vole (*S. anglicus*).
3) The preliminary taphonomic study performed on 1177 arvicoline first lower molars from Goyet cave, Trou des Nutons, Caverne Marie-Jeanne (layer 2), Trou du Frontal and Trou de Chaleux shows that the agents responsible for the accumulation were probably predators with an intermediate capacity for modification. In the cases of Trous des Nutons, Trou de Frontal and Trou de Chaleux, a possible candidate for the arvicoline accumulation could be *Bubo scandiacus* (Snowy owl), present in the three analysed sites.
4) The sites of Grotte la Chefalize, Trou du Chêne, and Trou du Sureau, which lack an absolute dating and whose chronological attribution is unclear, are not used for the environmental and climatic reconstruction, and although the data inferred from

CORRECTED PROOF

these sites are displayed in the manuscript, they are not used for further interpretation.

5) Of the other sites under analysis, Trou de Chaleux and Trou du Frontal are the best constrained chronologically. With a chronology of between ca. 15,964–14,014 cal yr B.P., Trou de Chaleux could be located between Greenland Stadial 2 (Heinrich Event 1) and Greenland Interstadial 1 (the Bølling interstadial). The chronology of Trou du Frontal places the site immediately prior to Greenland Stadial 2 (Heinrich Event 1). Together with previous studies, however, the scarce rodent remains recovered from Trou du Frontal suggest that it could be a mixed Late Pleistocene and Holocene deposit, making it difficult to interpret the data. The same applies to Trou des Nutons. By contrast, the assemblage from Trou de Chaleux appears much more homogeneous and reliable.

6) The present environmental and climatic reconstruction based on the rodent assemblage of Trou de Chaleux is consistent with previously published proxy studies of large mammals, herpetofauna, and avifauna. The habitat weighting method applied to the rodent assemblage shows a landscape with a predominance of open dry and rocky formations, together with a good representation of forest landscape. The quantified ecology method shows that Trou de Chaleux corresponds to the coldest MAT (−8.7 °C) and lowest MAP (−419 mm) of all the analysed sites in relation to present-day climatic conditions. Together with the chronological range of the site, these data suggest that the rodent accumulation could have been produced during a cold period, probably Heinrich Event 1 (Greenland Interstadial 2).
7) Trou de Chaleux can be compared with Grotte Walou (layer B-2/3/4), which has a similar chronology, and where the relative abundance of *D. torquatus* and *S. anglicus* indicates cold and dry environmental conditions. Comparison with layers of other MIS 3 sites with strictly cold and dry conditions, such as Scladina (layer I) or Caverne Marie-Jeanne (layers 6 to 4), shows that these Late Pleistocene climatic periods in southern Belgium were in general characterized by harsh climatic and relatively dry environmental conditions.

CRediT authorship contribution statement

Juan Manuel López-García: Conceptualization, Formal analysis, Funding acquisition, Investigation, Writing – original draft, Writing – review & editing. **Hugues-Alexandre Blain:** Conceptualization, Writing – original draft, Writing – review & editing. **Quentin Goffette:** Conceptualization, Writing – original draft, Writing – review & editing. **Cécila Cousin:** Data curation, Writing – original draft, Writing – review & editing. **Annelise Folie:** Data curation, Writing – original draft, Writing – review & editing.

Uncited reference

Leotard, 1993

Declaration of Competing Interest

The authors declare no conflict of interest.

Data availability

Data will be made available on request.

Acknowledgments

The study of the RBINS Quaternary collections was possible thanks to two Synthesys Grants BE-TAF-5468 and BE-TAF-823827 to J.M.L.-G. and three Synthesys Grants BE-TAF-4385, BE-TAF-5469, and BE-TAF-1329 to H.-A.B. This paper is also part of projects 2021- SGR-01238 (Gov. of Catalonia, AGAUR) and 2023PFR-URV-01238 (URV), and PID2021-122533NB-I00 (Spanish Ministry of Science and Innovation - MCIN/AEI/10.13039/501100011033/FEDER, UE). The Institut Català de Paleoecologia Humana i Evolució Social (IPHES-CERCA) received financial support from the Spanish Ministry of Science and Innovation through the "María de Maeztu" program for Units of Excellence (CEX2019-000945-M). Special thanks are due to Mrs. Carole Paleco (RBINS), the Synthesys staff in Brussels for administrative management, and Alain Drèze (RBINS) for logistical support. We would like to thank Rupert Glasgow for reviewing the English language of the manuscript. We want also to thank the editor Dr. Howard Falcon-Lang and the two anonymous reviewers for their suggestions and comments that improved the final version of the manuscript. Finally, we thank the guest's editors of this special Issue for inviting us to submit this article for publication.

CORRECTED PROOF

References

Andrews, P., 1990. Owls, caves and fossils. In: Predation, Preservation and Accumulation of Small Mammal Bones in Caves, With an Analysis of the Pleistocene Cave Faunas From Westbury-Sub-Mendip. The University of Chicago Press, Somerset, UK, London.
Andrews, P., 2006. Taphonomic effects of faunal impoverishment and faunal mixing. Palaeogeogr. Palaeoclimatol. Palaeoecol. 241, 572–589.
Arbez, L., Tereza, H., Royer, A., Montiure, S., Horáček, I., 2023. The wood lemming and the development of taiga in late Pleistocene Central Europe. Quat. Sci. Rev. 303, 107974.
Baca, M., Popović, D., Lemanik, A., Baca, K., Horáček, I., Nadachowski, A., 2019. Highly divergent linaje of narrow-heades vole from late Pleistocene Europe. Sci. Rep. 9, 17799.
Baca, M., Popović, D., Agadzhanyan, A.K., Baca, K., Conard, N.J., Fewlass, H., Filek, T., Golubiński, M., Horáček, I., Knul, M. V., Krajcarz, M., Krokhaleva, M., Lebreton,L., Lemanik, A., Maul, L.C., Nagel, D., Noiret, P., Primault, J., Rekovets, L., Rhodes, S.E., Royer, A., Serdyuk, N. V., Siressi, M., Strukova, T., Talamo, S., Wilczyński, J., Nadachowski, A., 2023. Ancient DNA of narrow-headed vole reveals common features of the late Pleistocene population dynamics in cold-adapted small mammals. Proceedings of Royal Society B 290, 20222238.
Ballmann, P., 1973. Die fossilen Vögel aus dem Jungpleistozän der Höhle Marie-Jeanne bei Hastière (Belgien). Le Gerfaut 63 (1–2), 3–16.
Ballmann, P., De Coninck, J., de Heinzelin, J., Gautier, A., Geets, S., Rage, J.-C., 1980. I. Les Dépôts Quaternaires; Inventaire Paléontologique et Archéologique. In: Gautier, A., de Heinzelin, J. (Eds.), La Caverne Marie-Jeanne (Hastière-Lavaux, Belgique). Institut Royal des Sciences Naturelles de Belgique, Mémoire, vol. 177, pp. 3–24.
Batsaikhan, N., Tsytsulina, K., Formozov, N., Sheftel, B., 2008. Microtus gregalis. The IUCN Red List of Threatened Species 2008: e.T13431A3936243. https://doi.org/10.2305/IUCN.UK.2008.RLTS.T13431A3936243.en.
Batsaikhan, N., Henttonen, H., Meinig, H., Shenbrot, G., Bukhnikashvili, A., Hutterer, R., Kryštufek, B., Yigit, N., Mitsainas, G., Palomo, L., 2021. Arvicola amphibius (amended version of 2016 assessment). The IUCN Red List of Threatened Species 2021: e.T2149A197271401. https://doi.org/10.2305/IUCN.UK.20211.RLTS.T2149A197271401.
Berto, C., Lopez-García, J.M., Luzi, E., 2019. Changes in the late Pleistocene small-mammal distribution in the Italian Peninsula. Quat. Sci. Rev. 225, 106019.
Blain, H.-A., Bailon, S., Cuenca-Bescós, G., 2008. The Early-Middle Pleistocene palaeoenvironmental change based on the squamate reptile and amphibian proxy at the Gran Dolina site, Atapuerca, Spain. Palaeogeogr. Palaeoclimatol. Palaeoecol. 261, 177–192.
Blain, H.-A., Martínez Monzón, A., Bisbal Chinesta, J.F., López-García, J.M., Cousin, C., Folie, A., 2022. The last interglacial-glacial cycle in the Meuse Valley (southern Belgium) inferred from the amphibian and reptile assemblages: implications for Neanderthals and anatomically modern humans. Archaeol. Anthropol. Sci. 15, 5.
Blouard, R., 1946. La Basse-Meuse namuroise, Namur.
Brace, S., Palkopoulou, E., Dalén, L., Lister, A.M., Miller, R., Otte, M., Germonpré, M., Blockley, S.P.E., Stewart, J.R., Barnes, I., 2012. Serial population extinctions in a small mammal indicate Late Pleistocene ecosystem instability. PNAS 109, 20532–20536.
Bronk Ramsey, C., Higham, T.F.G., Owen, D.C., Pike, A.W.G., Hedges, R.E.M., 2002. Radiocarbon dates from the oxford ams system: archaeometry datelist 31. Archaeometry 44 (s1), 1–150.
Bronk-Ramsey, C., 2021. OxCal 4.4.4 calibration program. https://c14. arch. ox. ac. uk/oxcal/OxCal. html.
Cahen, D., Haesaerts, P. (Eds.), 1984, Peuples chasseurs de la Belgique préhistorique dans leur cadre naturel. Patrimoine de l'Institut royal des Sciences naturelles de Belgique, Bruxelles.

Chaline, J., 1972. Les rongeurs du Pléistocène moyen et supérieur de France. Cahiers de Paléontologie. C.N.R.S, Paris.
Charles, R., 1998. Late Magdalenian chronology and faunal exploitation in the North Western Ardennes. Archaeopress Oxford BAR International Series 737, 246.
Clark, P.U., Dyke, A.S., Shakun, J.D., Carlson, A.E., Clark, J., Wohlfarth, B., Mitrovica, J.X., Hostetler, S.W., McCabe, A.M., 2009. The last glacial maximum. Science 5941, 710–714.
Cordy, J.M., 1991. Résultats préliminaires de l'analyse des micromammifères de la grotte Walou (Trooz). Notae Praehistoricae 10, 15–19.
Cordy, J.-M., 1992. Bio- et chronostratigraphie des dépôts quaternaires de la grotte Scladina (province de Namur, Belgique) à partir des micromammifères. In: Otte, M. (Ed.), Recherches aux grottes de Sclayn. Volume 1: Le contexte. 27. Études et Recherches Archéologiques de l'Université de Liège. pp. 79–125.
Cordy, J.-M., 1995. Études de restes microfauniques provenant du Trou Magrite. In: Otte, M., Straus, L.G. (Eds.), Le Trou Magrite: fouilles 1991–1992. Résurrection d'un site classique en Wallonie vol. 69. Étude et Recherches Archéologiques de l'Universitéde Liège. pp. 159–166.
Cordy, J.-M., Peuchot, R., 1983. Le Trou des Blaireaux à Vaucelles. Apport de l'étude de la microfaune à la bio- et chronostratigraphie des dépôts. Notae Praehistoricae 3, 115–118.
Cordy, J.-M., Toussaint, M., 1993. Bio- et chronostratigraphie des dépôts du Trou Jadot à partir des Micromammifères. In: Toussaint, M., Becker, A., Burhenne, M., Cordy, J.-M., Gilot, É., Heim, J., Juvigné, É. (Eds.), Le Trou Jadot à Comblain-au-Pont (Province de Liège, Belgique). Paléoécologie et archéologie d'un site du Paléolithique supérieur récent vol. 58. Étude et Recherches Archéologiques de l'Université de Liège, Liège, pp. 39–53.
Cuenca-Bescós, G., Rofes, J., García Pimienta, J.C., 2005. Environmental change across the early-middle Pleistocene transition: small mammalian evidence from the Trinchera Dolina cave, Atapuerca, Spain. In: Head, M.J., Gibbard, P.L. (Eds.), Early-Middle Pleistocene Transitions: The Land-Ocean Evidence. Geological Society Special Issue, London, pp. 277–388.
Dalén, L., Nyström, V., Valdiosera, C., Grmonpré, M., Sablin, M., Turner, E., Angerbjörn, A., Arsuaga, J.L., Götherström, A., 2007. Ancient DNA reveals lack of postglacial habitat tracking in the artic fox. PNAS 104, 6726–6729.
de Bournonville, D., 1955. Étude de quelques documents paléolithiques provenant des Grottes de Goyet-Mozet (Province de Namur). Bulletin De La Société Royale Belge D' anthropologie Et De Préhistoire 66. 9–3.
Dewez, M., 1987. Le Paléolithique supérieur récent dans les grottes de Belgique. Institut supérieur d'archéologie et d'histoire de l'art, Collège Erasme, Louvain-la Neuve, Belgique. Publications d'histoire de l'art et d'archéologie de l'Université catholique de Louvain 57.
Dewez, M., Cordy, J.-M., Gilot, É., Koslowki, S., 1983. La couche mésolithique de la Grotte du Coléoptère (Bomal-sur-Ourthe). Société Wallonne de Palethnologie. Mémoire. 5, 54.
Dupont, E., 1865. Étude sur les cavernes des bords de la Lesse et de la Meuse explorées jusqu'au mois d'octobre 1865. Bull. Acad. royale Belgique 2e série, 20, 824–850.
Dupont, E., 1867. Étude sur cinq cavernes explorées dans la vallée de la Lesse et le ravin de Falmignoul pendant l'été de 1866. Bull. Acad. roy. Sci., Lettres et Beaux-Arts Belgique 2 série, 23, 244–265.
Dupont, E., 1868. L'Homme pendant les âges de la pierre dans les environs de Dinant. Première partie, Annales de la Société archéologique de Namur 10, 1–50.
Dupont, E., 1869. Note sur la découverte de Goyet. Bull. Acad. Roy. Sci., Lettres et Beaux-Arts Belgique 38, 193. . 2e session, 27.
Dupont, E., 1872. Les temps préhistoriques en Belgique. L'homme pendant les âges de la pierre dans les environs de Dinant-sur Meuse. Bruxelles, 2e éd.
Dupont, E., 1873. L'homme pendant les âges de la pierre dans les environs de Dinant-sur-Meuse. C. Muquardt, Bruxelles.
Eloy, L., 1943. Pointe du Type de la Font-Robert provenant des Grottes de Goyet (Province de Namur, Belgique). Bulletin De La Société Préhistorique Française 40, 194–196. Eloy, L., 1952–1953. Grande pointe Moustérienne de Goyet (vallée du Samson. Province de Namur). Bulletin des Chercheurs de la Wallonie 15, 134–138.
Evans, E.M.N., Van Couvering, J.A.H., Andrews, P., 1981. Palaeoecology of Miocene sites in western Kenya. J. Hum. Evol. 10, 99–116.
Fernández-García, M., López-García, J.M., Lorenzo, C., 2016. Palaeoecological implications of rodents as proxies for the late Pleistocene-Holocene environmental and climatic changes in northeastern Iberia. C. R. Palevol 15, 707–719.
Fernandez-Jalvo, Y., Andrews, P., Denys, C., Sesé, C., Stoetzel, E., Martín-Monfort, D., Pesquero, D., 2016. Taphonomy for taxonomists: implications of predation in small mammal studies. Quat. Sci. Rev. 139, 138–157.
Frechkop, S., 1981. Mammifères. Faune de Belgique. Institut Royal des Sciences Naturelles de Belgique, Bruxelles.
Germonpré, M., 1997. The Magdalenian upper horizon of Goyet and the late Upper Palaeolithic recolonisation of the Belgian Ardennes. Bulletin De L'institut Royal Des Sciences Naturelles De Belgique, Série Sciences De La Terre 67, 167–182.
Germonpré, M., 2004. The Pleniglacial cave bears from Goyet, Belgium. Bulletin De L' institut Royal Des Sciences Naturelles De Belgique, Série Sciences De La Terre 74 (supplement), 213–229.
Germonpré, M., Hämäläinen, R., 2007. Fossil bear bones in the Belgian Upper Palaeolithic: the possibility of a proto-bear ceremonialism. Arct. Anthropol. 44, 1–30.
Germonpré, M., Sablin, M.V., 2001. The cave bear (Ursus spelaeus) from Goyet, Belgium. The bear den in Chamber B (bone horizon 4). Bulletin De L'institut Royal Des Sciences Naturelles De Belgique, Série Sciences De La Terre 71, 209–233.
Germonpré, M., Sablin, M.V., Stevens, R.E., Hedges, R.E.M., Hofreiter, M., Stiller, M., Després, V.R., 2009. Fossil dogs and wolves from Palaeolithic sites in Belgium, the Ukraine and Russia: osteometry, ancient DNA and stable isotopes. J. Archaeol. Sci. 36, 473–490.
Gilot, E., 1984. Datations radiométriques. In: Cahen, D., Haesaerts, P. (Eds.), Peuples chasseurs de la Belgique préhistorique dans leurs cadre naturel. Institut Royal des Sciences Naturelle de Belgique, Bruxelles, pp. 117–125.
Goffette, Q., 2023. Nouveau regard sur l'exploitation des oiseaux par les groupes humains du Paléolithique moyen et supérieur en Wallonie (Belgique) au travers du prisme de l' archéozoologie et de l'expérimentation : apports et limites de 150 ans de collections archéologiques. PhD thesis (unpublished). Université de Liège, Faculté de Philosophie et Lettres, Département des Sciences historiques, TraceoLab. 428 p.
Goffette, Q., Ervynck, A., Van Neer, W., 2019. Have birds ever mattered? An evaluation of the contribution of avian species to the archaeozoological record of Belgium (Iron Age to recent times). Archaeol. Anthropol. Sci. 11, 6353–6369.
Goffette, Q., Germonpré, M., Lefèvre, C., Brecko, J., Goemaere, E., Rots, V., 2020. Bird bones from Trou de Chaleux and the human exploitation of birds during the late Magdalenian in Belgium. J. Archaeol. Sci. Rep. 29, 102096.
Hedges, R.E.M., Housley, R.A., Bronk Ramsey, C., Van Klinken, G.J., 1993. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 16. Archaeometry 35, 147–167.
Hedges, R.E.M., Housley, R.A., Bronk Ramsey, C., Van Klinken, G.J., 1994. Radiocarbon dates from the Oxford AMS system: Archaeometry datelist 18. Archaeometry 36, 337–374.
Jeannet, M., 2010. L'ecologie quantifée. Essai de description de l'environnement continental à l'aide des microvertébrès. Préhistorie mediterranéennes 1, 11–34.
Lemanik, A., Baca, M., Wertz, K., Socha, P., Popivić, D., Tomke, T., Lipecki, G., Kraszewska, A., Miękina, B., Żeromska, A., Pereswiet-Soltan, A., Szyndlar, Z., Cieśla, M., Valde-Nowak, P., Mackiewicz, P., Nadachowski, A., 2020. The impact of major warming at 14.7 ka on environmental changes and activity of Final Palaeolithic hunters at a local scale (Orawa-Nowy Targ Basin, Western Carpathians, Poland). Archaeol. Anthropol. Sci. 12, 66.
Leotard, J.-M., 1993. Dinant/Furfooz: « Trou du Frontal ». Chronique de l'Archéologie Wallone 1, 100.
Lisiecki, L.E., Raymo, M.E., 2005. A Pliocene–Pleistocene stack of 57 globally distributed benthic d 18O records. Paleoceanography 20, PA 1003.
López-García, J.M., 2011. Los micromamíferos del Pleistoceno superior de la Península Ibérica. Evolución de la diversidad taxonómica y cambios paleoambientales y paleoclimáticos. Saarbrücken, Editorial Académica Española.
López-García, J.M., Blain, H.-A., Cuenca-Bescós, G., Ruiz-Zapata, M.B., Dorado Valiño, M., Gil-García, M.J., Valdeolmillos, A., Ortega, A.I., Carretero, J.M., Arsuaga, J.L., Bermúdez de Castro, J.M., Carbonell, E., 2010. Palaeoenvironmental and palaeoclimatic reconstruction of the latest Pleistocene of El Portalón Site, Sierra de Atapuerca, northwestern Spain. Palaeogeogr. Palaeoclimatol. Palaeoecol. 292, 453–464.
López-García, J.M., Berto, C., Colamussi, V., Dalla Valle, C., Lo Vetro, D., Luzi, E., Malavasi, G., Martini, F., Sala, B., 2014. Palaeoenvironmental and palaeoclimatic reconstruction of the latest Pleistocene-Holocene sequence from Grotta del Romito (Calabria, southern Italy) using the small-mammal assemblages. Palaeogeogr. Palaeoclimatol. Palaeoecol. 409, 169–179.
López-García, J.M., Dalla Valle, C., Cremaschi, M., Peresani, M., 2015. Reconstruction of the Neanderthal and Modern Human landscape and climate from the Fumane cave sequence (Verona, Italy) using small mammal assemblages. Quat. Sci. Rev. 128, 1–3.
López-García, J.M., Blain, H.-A., Cordy, J.M., Pirson, S., Abrams, G., Di Modica, K., Bonjean, D., 2017a. Palaeoenvironmental and palaeoclimatic reconstruction of the Middle to late Pleistocene sequence of Scladina Cave (Namur, Belgium) using the small-mammal assemblages. Hist. Biol. 29, 1125–1142.
López-García, J.M., Blain, H.-A., Lozano-Fernández, I., Luzi, E., Folie, A., 2017b. Environmental and climatic reconstruction of MIS 3 in northwestern Europe using the small-mammal assemblage from Caverne Marie-Jeanne (Hastière-Lavaux, Belgium). Palaeogeogr. Palaeoclimatol. Palaeoecol. 485, 622–631.
Miller, R., Zwyns, N., Otte, M., Stevens, C., Stewart, J., 2012. La séquence mésolithique et néolithique du Trou Al'Wesse (Belgique): résultats pluridisciplinaires. l' Anthropologie 116, 99–126.
Otte, M., 1979. Le Paléolithique supérieur ancien en Belgique. Musées royaux d'art et d' histoire. Bruxelles Monographies D'archéologie Nationale 5, 1–684.
Otte, M. (Ed.), 1994. Le Magdalénien du Trou de Chaleux (Hulsonniaux, Belgique). Etudes et Recherches Archéologiques de l'Université de Liège, ERAUL 60, 1–258.
Otte, M., Teheux, E., 1986. Fouilles 1986 à Chaleux. Notae Praestoricae 6, 63–77.
Pirson, S., 2011. Contextes paléoenvironnemental et chronostratigraphique du remplissage de la grotte Walou: apport de la géologie et comparaison avec les autres disciplines. In: Draily, C., Pirson, S., Toussaint, M. (Eds.), La Grotte Walou à Trooz (Belgique) fouilles de 1996–2004. Les Sciences de la Terre, vol. 1, pp. 170–201. Études et Documents, Archéologie 21, Wallonie, Belgium.
Railsback, L.B., Gibbard, P.L., Head, M.J., Voarintsoa, N.R.G., Toucanne, S., 2015.An Optimized scheme of lettered marine isotope substages for the last 1.0 million years, and the climatostratigraphic nature of isotope stages and substages. Quat. Sci. Rev. 111, 94–106.
Ravazzi, C., Peresani, M., Pini, R., Vescovi, E., 2007. Il Tardoglaciale nelle Alpi italiane in Pianura padana. Evoluzione stratigrafica, storia della vegetazione e del popolamento antropico. Il Quaternario 2, 163–184.
Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., van der Plicht, J., Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon 62, 725–757.

CORRECTED PROOF

Royer, A., Montuire, S., Legendre, S., Discamps, E., Jeannet, M., Lécuyer, C., 2016. Investigating the influence of climate changes on rodent communities at a Regional Scale (MIS 1-3, Southwestern France). PloS One 11, e0145600.
Socha, P., 2014. Rodent paleofaunas from Biśnik Cave (Kraków-Częstochowa Upland, Poland) : Palaecological, palaeclimatic and biostratigraphic reconstruction. Quat. Int. 326–327, 64–81.
Sonneville-Bordes, D., 1961. Le Paléolithique Supérieur En Belgique. L'anthropologie 65, 421–443.
Stevens, R.E., Germonpré, M., Petrie, C.A., O'Connell, T.C., 2009. Palaeoenvironmental and chronological investigations of the Magdalenian sites of Goyet Cave and Trou de Chaleux (Belgium), via stable isotope and radiocarbon analyses of horse skeletal remains. J. Archaeol. Sci. 36, 653–662.
Stewart, J.R., Parfitt, S.A., 2011. Late Quaternary environmental change at Walou cave: Evidence from a preliminary analysis of the small mammals. In: Draily, C., Pirson, S., Toussaint, M. (Eds.), La Grotte Walou à Trooz (Belgique) fouilles de 1996–2004. Les Sciences de la Vie et les Datations vol 2. Études et Documents, Archéologie 21, Wallonie, Belgium. pp. 38–59.
Toussaint, M., 1988. Fouilles 1978–1981 au Trou du Diable à Hastière-Lavaux, province de Namur, Belgique. Helinium 28, 35–43.
Tsytsulina, K., Formozov, N., Sheftel, B., 2016. Dicrostonyx torquatus (errata version published in 2017). In: The IUCN Red List of Threatened Species 2016. e.T6568A115082665. https://doi.org/10.2305/IUCN.UK.20163.RLTS.T6568A2233207.
Twiesselmann, F., 1971. Belgium. In: Oakley, K.P., Campbell, B.G., Molleson, T.I. (Eds.), Catalogue of Fossil Hominids, Part II: Europe (pp. 5-13). British Museum (Natural History), Londres.
Ulrix-Closset, M., 1975. Le Paléolithique Moyen dans le Bassin Mosan en Belgique. Bibliothèque de la Faculté de Philosophie et Lettres de l'Université de Liège. Publications exceptionnelles, no. 3, 1975. 221 pp. text, 144 pp. drawings and site plans, 17 pl., 17 pp. maps.
Van Neer, W., Wouters, W., Germonpré, M., 2007. Fish remains from three Upper Palaeolithic cave deposits in southern Belgium. Anthropologica et Præhistorica 118, 5–22.
Van Strydonck, M., Landrie, M., Hendrix, V., Maes, A., Van der Borg, K., de Jong, A.F.M., Alderliesten, C., Keppens, E., 2001. Royal Institute for Cultural Heritage. Radiocarbon Dates 8, 1–50.
Vermeersch, P.M., 2005. European population changes during the Marine Isotope stage 2 and 3. Quat. Int. 137, 77–85.
Vescovi, E., Ravazzi, C., Arpenti, E., Finsinger, W., Pini, R., Valsecchi, V., Wick, L., Ammann, B., Tinner, W., 2007. Interactions between climate and vegetation during the Lateglacial period as recorded by lake and mire sediment archives in Northern Italy and Southern Switzerland. Quat. Sci. Rev. 26, 1650–1669.
Walker, M., Johnsen, S., Rasmussen, S.O., Popp, T., Steffensen, J.-P., Gibbard, P., Hoek, W., Lowe, J., John, A., John, B., Björck, S., Cwynar, L., Hughen, K., Konrad, K., Peter, K., Kromer, B., Litt, T., Lowe, D.J., Nakagawa, T., Newnham, R., Schwander, J., 2009. Formal definition and dating of the GSSP (Global Stratotype Section and Point) for the base of the Holocene using the Greenland NGRIP ice core, and selected auxiliary records. J. Quat. Sci. 11, 3–17.
Walker, M., Head, M.J., Berkelhammer, M., Björck, S., Cheng, H., Fisher, D., Gkinis, V., Long, A., Lowe, J., Newnham, R., Rasmussen, S.O., Weiss, H., 2018. Formal ratification of the subdivision of the Holocene Series/Epoch (Quaternary System/Period): two new Global Boundary Stratotype Sections and Points (GSSPs) and three new stages/subseries. Episodes 41, 213–223.
Yigit, N., Hutterer, R., Krytufek, B., Amori, G., 2016. Microtus arvalis. The IUCN Red List of Threatened Species 2016. e.T13488A22351133. https://doi.org/10.2305/IUCN.UK.20162.RLTS.T13488A22351133.en.

CORRECTED PROOF