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The new insights into the subsistence and early farming from neolithic settlements in Central Europe: the archaeozoological evidence from the Czech Republic

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ABSTRACT: The archaeozoological evidence from two Neolithic settlements occupied in the periods of the Linear Pottery Culture (LBK) and the Stroke Pottery Culture (SBK) has provided new insights into the way of life of early farmers in the Czech Republic. Though LBK and SBK sites are abundant, only isolated studies allow one to reconstruct stockbreeding practices on the basis of archaeozoological and isotopic data. Our results confirm that livestock provided most of the animal products consumed and that hunting was a marginal activity. Though cattle were the dominant stock, with small stock and swine playing a secondary role in the animal economy, our results reveal variability at a regional scale. The management of cattle and small stock at Chotěbudice and Černý Vůl changed according to the time period and the so-called secondary products (milk, maybe hair) were exploited since the LBK. Mortality profiles of swine evidenced a peak between 6 and 24 months with few individuals surviving to adulthood. The $\delta^{13}C$ and $\delta^{18}O$ analyses of cattle tooth enamel yielded values suggesting pasture in open areas and grouped births. The combination of data from stable isotope analysis and kill-off patterns suggests that calving took place during the spring.

KEYWORDS: CZECH REPUBLIC, BANDKERAMIK, DOMESTIC UNGULATES, KILL-OFF PATTERNS, STABLE ISOTOPES, TOOTH ENAMEL

RESUMEN: Las evidencias arqueozoológicas de dos asentamientos neolíticos ocupados en los periodos de la cultura de la cerámica de bandas y la cultura de la cerámica incisa proporciona nuevos datos sobre los modos de vida de los primeros granjeros de la República Checa. Aunque existen numerosos asentamientos de estas dos culturas, solo estudios aislados nos permiten inferir las prácticas pecuarias sobre la base de datos arqueozoológicos e isotópicos. Nuestros resultados confirman que la ganadería proporcionó la mayor parte de los productos animales consumidos y que la caza era una actividad marginal. Aunque el vacuno parece haber sido la cabaña dominante, con ovicaprinos y porcino desempeñando un papel secundario en la economía animal, nuestros resultados evidencian variabilidad a escala regional. El manejo del vacuno y los ungulados de pequeño tamaño en Chotěbudice y Černý Vůl cambiaron con el tiempo aunque los llamados productos secundarios (leche, posiblemente cueros) fueron explotados desde época de la cultura de la cerámica de bandas. Los perfiles de mortandad del porcino muestran un pico entre los 6 y 24 meses, con pocos individuos llegando a la edad adulta. Los análisis del $\delta^{13}C$ y $\delta^{18}O$ del esmalte dentario del vacuno proporcionan valores que apuntan al pastoreo en áreas abiertas y nacimientos agrupados. La combinación de datos de los análisis de isótopos estables y los patrones de mortandad sugieren que los terneros nacerían en primavera.

PALABRAS CLAVE: REPÚBLICA CHECA, CULTURA DE LA CERÁMICA DE BANDAS, UNGULADOS DOMÉSTICOS, PATRONES DE MORTANDAD, ISÓTOPOS ESTABLES, ESMALTE DENTARIO

INTRODUCTION

Neolithization was not a process that affected the entire European continent either continuously or simultaneously. The range and intensity of signatures were variable (Bogucki, 2003). Different regions developed in greater isolation than others, promoting a regionalization of styles of certain artifacts (Modderman, 1988; Pavlů, 2005). The agricultural entity called the Linear Pottery Culture (LBK from here onwards; Bogucki, 1988; Whittle, 1996; Gronenborn, 1999; Price *et al*., 2001; Mazurié de Keroualin, 2003) was responsible for the introduction of farming in Central Europe between 5700 and 4800 BC (Gronenborn, 1999, 2009; Dolukhanov, 2004; Dolukhanov *et al*., 2005). The LBK originated on the western border of Hungary and Eastern Austria (Gronenborn, 1999, and 2007), where it emerged, stemming from the cultural complex of Starčevo in Pannonia. In general, LBK culture was geographically uniform in terms of crop species, cultivation, tools, the location of settlements and house groundplans [see Price (2000) for a synthesis). In the area of today's Czech Republic there exists no continuity between the Neolithic and Mesolithic settlements (Končelová, 2005; Vencl, 2006). Adaptation to new environments in the LBK of Central Europe could be reflected by the emergence of the Stroke Pottery Culture or Stichbandkeramik Culture (SBK from here onwards), which originated in the north-western sector of the Czech Republic around 5100/5000 (Zápotocká, 2007, 2009) and lasted until 4200 BC (Pavlů & Zápotocká, 2007). In the Czech Republic, the location of the SBK was more or less consistent with the distribution of the LBK (Rulf & Zápotocká, 1994; Zápotocká, 2009).

Neolithic people in the area of the Czech Republic settled at heights of 250-300 m above sea level (Rulf, 1983; Květina, 2001; Končelová, 2005). These settlements were established in most cases on the edges of valleys, particularly those with low and gently sloping terraces (Pavlů & Zápotocká, 2007). Early settlements were in any case connected to the floodplain (Rulf, 1983). Preferences for luvisoils and loess substrates declined with the advent of the SBK (Květina, 2001). Of particular relevance was the proximity of water sources (Rulf, 1983; Květina, 2001; Končelová, 2005). Vegetation development tended towards an expansion of mixed oak forests, which in many areas incorporated a high proportion of broadleaved trees (e.g. Ložek, 1973, 2007; Beneš, 2004; Sádlo *et al*., 2005).

Archaeozoological studies, including stable isotope analyses, constitute an effective tool for understanding the functional features of Neolithic settlements. Coupled with environmental and food preference analyses, they provide crucial data for inferring the development of prehistoric pastoral economies. As of this writing, there only exist a few archaeozoological studies that help the archaeologist reconstruct the animal husbandry strategies in the Czech Republic during the 6^{th}-5^{th} millenia BC (e.g. Peške, 1991; Peške *et al*., 1998; Kovačiková, 2005, 2007, 2009; Dreslerová, 2006; Kovačiková, 2005, 2007, 2009; Kovačiková & Daněček, 2008). This paper aims at enlarging this literature and to offer a synthesis on the Neolithic husbandry in this area. Specifically, we aim at documenting:

– the husbandry economies and herd management strategies for cattle, sheep, goats and Suinae in two emblematic settlements (Chotěbudice and Černý Vůl) of the Czech Neolithic.

– The role that domestic and wild animals played in the Neolithic economy on the basis of archaeozoological data provided by Chotěbudice and Černý Vůl and other contemporaneous settlements.

– The environment where the animals were bred and the seasonality in cattle births through the analysis of the stable carbon and oxygen isotope compositions of tooth enamel bioapatite at the site of Chotěbudice.

MATERIAL

The LBK settlement of Chotěbudice (Figure 1) was investigated within the context of sand mining works carried out in the 1970s and 1980s (Rada, 1981, 1986; Šumberová, 1991, 1995). The excavated area totalled 7960 m^2. A total of nineteen groundpans of long houses and 800 LBK structures were discovered. Other prehistoric cultures were documented only sparsely. The site, located on a gentle slope facing southeast, close to the Dubá brook, appears at an elevation of 287-290 m above sea level. The subsoil is a relatively thin bed of calcic loess (up to about 1 m) covering the underlying sands. Anthracological analyses highlight the existence of oak wood with an important proportion of pine trees around the site (Kočár *et al*., 2008; unpublished data). Deciduous trees (e.g. maple and elm) were a minor component of these forests. The abundance of pine trees, along with the presence of the heliophilous common hazel, Malaceae, damson plum tree and poplar/willow, suggests the existence of human activity within the forests (e.g. harvesting of logs, dried twigs and shoots). The naturally occurring presence of steppe and impoverished woodland mollusc faunas, on the other hand, suggest the existence of xerotherm biotopes either in the settlement or in its neighbourhood.

Chotěbudice can be envisioned as a long-term occupation. Its absolute chronology ranges from 5400-5100 BC (Šumberová, unpublished). The earliest archaeological structures fall within the LBK I/IIa-LBK IIa stage of the Neolithic and the occupation was prolonged at least until the LBK IIIb stage. Some radiocarbon dates suggest a later occupation of the site (i.e., about 5000 BC). Given the small number of features from the SBK period, this stage could not be accurately defined. The animal remains of Chotěbudice were well preserved thanks to soil conditions. The abundant osteological material was found almost in all settlement pits (e.g. loam pits, building pits and grain storage pits) in the building complex of the LBK houses and they are spatially and functionally related to them.

A rescue excavation at the brickfield in Černý Vůl (district Prague-West) was carried out between 1975 and 1977 under the supervision of M. Zápotocká, I. Vojtěchovská and P. Sankot from the ČSAV Archaeological Institut and The Museum of Central Bohemia in Roztoky (Řídký *et al*., 2009; Řídký, 2011; Figure 2). The locality is part of a micro-region of the Únětice Brook Basin. The Neolithic settlement is situated in the northern part of the village of Černý Vůl, some 10 km northwest of Prague, at a narrow and *circa* 1 km long loess bank sloping eastwards. The soil cover is a brown soil. The nearest watercourses are the Únětice Brook, lying aprox. 200 m southwards and a paleo-channel some 80 m north of the excavated area, which used to empty into the Únětice brook, southeastwards of the settlement. Archaeobotanical remains were not studied. The ceramic analysis and its partial confrontation with the stratigraphy suggested the existence of at least four Neolithic levels. The settlement originated at the end of the LBK IIc stage and continued during the LBK IIIa and LBK IIIb stages. Afterwards a hiatus followed but the settlement was re-occupied during the later stage of SBK (i.e., SBK IVa; Řídký *et al*., 2009; Řídký, 2011). No radiocarbon dates are available. The remains of nine groundplans of post-hole houses assigned to the LBK were uncovered. Groundplan shapes evidenced a dominance of oval and irregular shapes. The distance between storage pits from the SBK period evidenced certain regularity, suggesting the existence of additional dwelling houses that were not detected during the excavation. Other features included building pits and two hearths from each of the two periods (Řídký *et al*., 2009). The osteological material appeared in 25 archaeological structures of the LBK period and in 14 additional ones for the SBK period within a total of 107 Neolithic features.

In addition to Chotěbudice and Černý Vůl, 13 LBK and SBK sites from Bohemia and Moravia (Figure 3; Tables 1 and 2) have provided fairly well-documented osteological assemblages (i.e., higher than 100 identified specimens) that can used for comparison. All of the animal remains were hand retrieved.

METHODS

The osteological data from Chotěbudice, Černý Vůl and the other thirteen settlements total 13,177 identified remains (Figure 3; Tables 1 and 2). The archaeozoological studies conducted by one of the authors (L. Kovačiková) include seven assemblages analysed between 2005 and 2009 at the Department of Archaeology of the Landscape and Archaeobiology, Institute of Archaeology of the Academy of Sciences of the Czech Republic in Prague (Table 1). Osteological data from a further eight collections was gathered from the literature (Table 2). Faunal spectra were established using the Number of Identified Specimens (NISP). Antler fragments from red deer are included in the NISPs of the literature but were set apart in the faunal assemblages studied by L. Kovačiková. Most of these fragments were apparently the refuse or half-finished products of bone and antler processing activity. Also, given that some fragments correspond to shed antlers, they cannot be taken to evidence the hunting of red deer. The minimum number of individuals (MNI), calculated only for dental remains, has also been included. Permineralization precluded both the use of bone weight as an estimator of abundance/importance

FIGURE 1

Plan of the Neolithic settlement at Chotěbudice (Šumberová, unpublished).

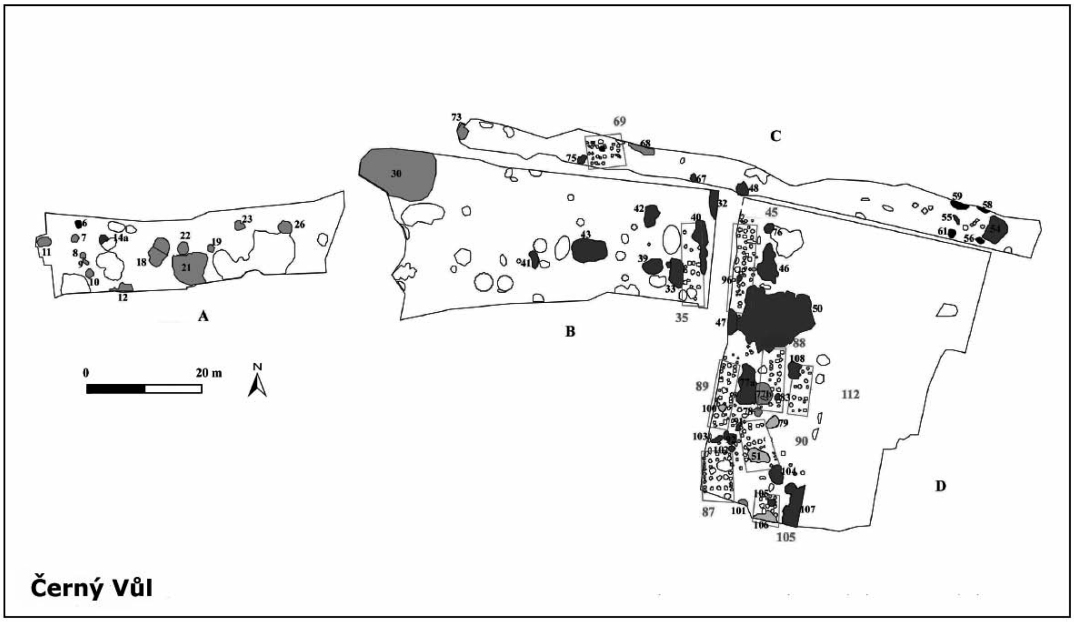

FIGURE 2
Plan of the Neolithic settlement at Černý Vůl (Řídký *et al*., 2009).

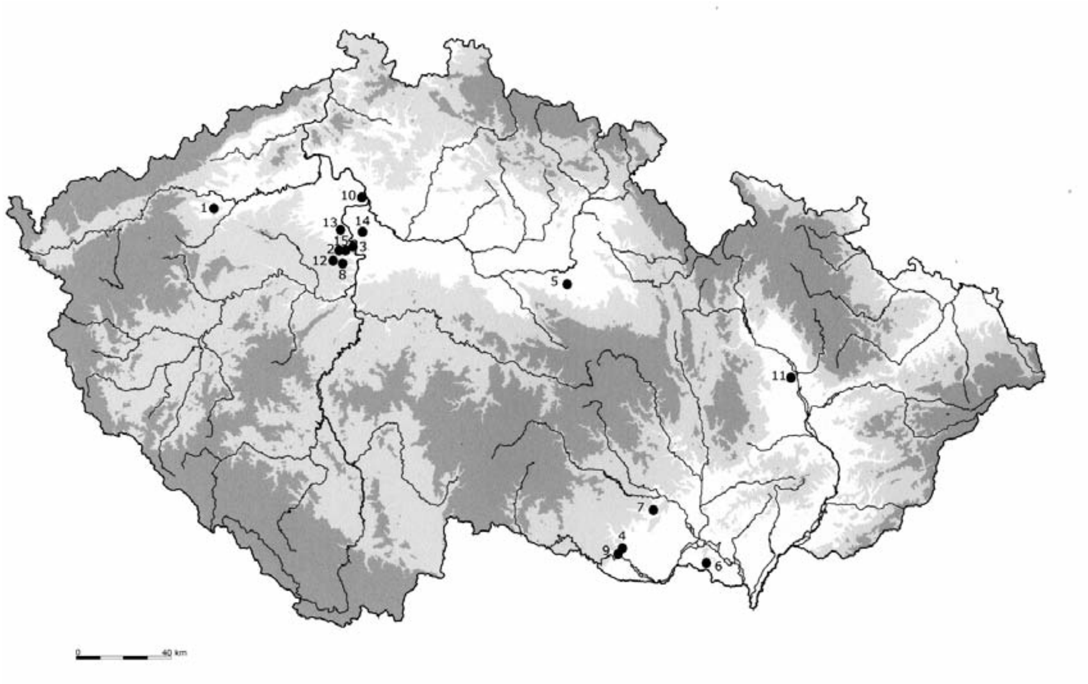

FIGURE 3
Location of the LBK (Linear Pottery Culture) and SBK (Stroke Pottery Culture) sites from the Czech Republic included in the study. 1 – Chotěbudice (LBK, SBK); 2 – Černý vůl (LBK, SBK); 3 – Roztoky (LBK, SBK); 4 - Těšetice-Kyjovice (LBK); 5 – Bylany (LBK); 6 - Jelení louka (LBK); 7 – Vedrovice (LBK); 8 - Hostivice-Sadová (LBK); 9 – Dobšice (LBK); 10 - Dolní Beřkovice-Křivenice (SBK); 11 - Olomouc-Slavonín (SBK); 12 – Kněživka (SBK); 13 – Holubice (SBK); 14 – Klíčany (SBK); 15 – Horoměřice Chotol 1984 (SBK).

and the study of modifications to the bone surfaces.

Two Neolithic cultures have been included in this study: LBK and SBK (9 settlements each, including Chotěbudice and Černý Vůl). The Neolithic assemblages from Chotěbudice and Černý Vůl were divided into smaller samples corresponding to the chronological stages defined on the basis of criteria for the ceramics (i.e., Pavlů & Zápotocká, 1979) in order to compare diachronic faunal changes within the frames of the LBK and the SBK. The significance of the differences between the faunal spectra of Chotěbudice and Černý Vůl were tested using a Chi-square test. Measurements taken on *Bos* and *Sus* remains were used to distinguish wild from domestic. Measurements follow von den Driesch (1976) in all cases.

Livestock management strategies were based on the interpretation of kill-off patterns. The estimated age at death of the animals was based on the stages of tooth eruption, replacement and wear. Kill-off patterns were organized using narrow age classes with a correspondence to absolute ages (e.g. Payne, 1973; Greenfield, 1988, 2005; Helmer, 1992; Vigne *et al*., 2005; Vigne & Helmer, 2007). For cattle, age at death was estimated according to the stages of tooth eruption and replacement provided by Higham (1967), the abrasion indexes proposed for the molars by Ducos (1968) and the abrasion of incisor teeth proposed by Komárek (1993). For sheep and goats, the age estimation method follows Helmer (1995; see Vigne & Helmer, 2007). This last method combines Payne's traditional wear stages (1973) based on the observation of the occlusal surface of the teeth with the abrasion indexes modified after Ducos (1968) for the molars. Both upper and lower teeth have been considered. The age at death for Suinae has been estimated from the abrasion stages of the lower jaw teeth (Grant, 1982). The kill-off patterns being based on the number of teeth (Vigne, 1988). As age classes feature different time-spans, the histograms of relative frequencies established for cattle and for sheep/goats have been corrected according to the size of the time span of each age class (Ducos, 1968). Whenever appropriate, raw data were statistically tested using the Chi-square test. A total of 652 teeth, representing a minimum of 280 individuals from Chotěbudice (LBK) and Černý Vůl (LBK and SBK), were subjected to age determinations.

CHOTěBUDICE AND ČERNÝ VŮL: ANALYSIS OF TWO EMBLEMATIC SETTLEMENTS

Taphonomic analysis

The data from Chotěbudice and Černý Vůl (Tables 3 and 4) derive from archaeological excavations that included both LBK and SBK levels. The percentages of identified and unidentified fragments, complete bones and remains of neonates/very juvenile animals are expressed as a proportion of the total number of remains (Table 3). This same procedure was chosen to express the proportions of taphonomic traces on the bones (Table 4).

At Chotěbudice, 24.3 % of total remains have been identified at the level of genus or species in the LBK phase and 37.7 % in the case of the SBK levels. The percentages at Černý Vůl are of 35 % and 40.8 %. This suggests that the osteological assemblages were on both sites better preserved during the SBK phase than in the LBK (observed differences between percentages are statistically significant: $\varepsilon = 3.85$, $p < 0.05$ and $\varepsilon = 3.27$, $p < 0.05$). It also suggests that for the LBK period, the assemblage from Černý Vůl was better preserved than that from Chotěbudice ($\varepsilon = 8.03$, $p < 0.05$). The differences between the SBK assemblages from the two sites, however, are not statistically significant. The proportion of complete bones lends support to the idea of a better preservation having taken place at Černý Vůl, as these values are always higher than at Chotěbudice (Chotěbudice LBK: 2.8 %, Černý Vůl LBK: 3.9 %; $\varepsilon = 2.14$, $p < 0.05$; Chotěbudice SBK: 0 %; Černý Vůl SBK: 5.6 %; $\varepsilon = 3.02$, $p < 0.05$). As for the proportions of bones from neonatal and very juvenile individuals, we detected a small and statistically insignificant difference between the various stages at both Chotěbudice (LBK: 0.1 %; SBK: 0.6 %) and Černý Vůl (LBK: 0 %; SBK: 0.3 %).

The difference in the frequency of weathering of the bones is not statistically significant between the two phases of Chotěbudice. At Černý Vůl, such proportion is significantly lower in the SBK (i.e., 2.2 % for the LBK *vs*. 0.7 % for the SBK; $\varepsilon = 3.82$, $p < 0.05$). The number of bones permineralized is small on both sites. The differences observed in this case between the LBK and SBK phases are statistically significant at Chotěbudice ($\varepsilon = 27.2$, $p < 0.05$) but not at Černý Vůl. The proportion of root etching and carnivore or leporids/rodents tooth marks on the bone surfaces

Site	Culture (stage)	*Bos taurus*	*Bos primigenius*	*Bos* sp.	*Sus domesticus*	*Sus scrofa*	*Sus* sp.	*Ovis aries*	*Capra hircus*	*Ovis/Capra*	*Canis familiaris*	*Canis lupus/Canis familiaris*	*Equus* sp.	*Cervus elaphus* (bones)	*Capreolus capreolus*	*Alces alces*	*Ursus arctos*	*Lepus europaeus*	*Castor fiber*	*Cricetus cricetus*	*Arvicola terrestris*	*Erinaceus* sp.	*Anser anser*	*Corvus corax*	*Silurus glanis*	*Unio* sp.	Total	References
Chotěbudice	LBK IIa	306	12	32	7	1	4	4	1	30				6	3		2		1								409	Kovačiková, this study
Chotěbudice	LBK IIb	344	7	47	46	3	35	16	8	107	2			14	4			1	1								635	Kovačiková, this study
Chotěbudice	LBK IIc	14		4	1		7	3	1	2				3			1										36	Kovačiková, this study
Chotěbudice	LBK IIc/IIIa	1258	24	185	126	8	110	57	5	192	2		2	35	10		1		2								2017	Kovačiková, this study
Chotěbudice	LBK IIIa	199		28	7		12	9	1	51	1			3	2										1		314	Kovačiková, this study
Chotěbudice	LBK IIIb	168	3	54	24	1	7	15		39	1			9	3												324	Kovačiková, this study
Chotěbudice	LBK	710	7	66	50	2	23	30	6	116	2		4	23	5	5		4									1053	Kovačiková, this study
Chotěbudice	SBK	13								45																	58	Kovačiková, this study
Černý Vůl	LBK	166	1		75		26	12	1	65	5		6	6	6		1	9	1	1	2					6	389	Kovačiková, 2009
Černý Vůl	SBK	236	2	20	96	4	30	132	15	378	3		1	6	9			28	7								967	Kovačiková, 2009
Hostivice-Sadová	LBK	271	26	32	13	25		6	1	19	1	1	1	2	1		4		1	1							405	Kovačiková, this study
Dolní Beřkovice-Křivenice	SBK	272	4	116	34	5	62	36	2	134				7	1			5	2	1			1	3			685	Kovačiková, this study
Kněživka	SBK	86	108*	24	110		19	10	3	23				1				3									387	Kovačiková, 2007
Holubice	SBK	99	2	20	13		59	49	2	87		1						11				8					351	Kovačiková and Daněček, 2008
Horoměřice Chotol 1984	SBK	85	4		10					12	2																113	Kovačiková, 2005

TABLE 1

Faunal spectra of the LBK and SBK sites from the Czech Republic included in the study. List of the studied Neolithic archaeological sites from the Czech Republic pooled by phases: LBK and SBK. The symbol „* “ represents one broken skeletal element.

Site	Culture	*Bos* sp.	*Sus* sp.	Caprines	Others	Total	Reference
Roztoky	LBK	321	58	68	68	515	Peške, 1991
Roztoky	SBK	636	164	167	188	1155	Peške, 1991
Těšetice-Kyjovice	LBK	421	208	263	26	918	Dreslerová, 2006
Bylany	LBK	590	61	39	11	701	Peške *et al*. 1998
Jelení louka	LBK	323	79	135	27	564	Kratochvíl, 1973
Vedrovice	LBK	267	85	103	33	488	Nývltová-Fišárková, 2004
Dobšice	LBK	69	24	24	9	126	Peške, 1992
Olomouc-Slavonín	SBK	217	68	98	23	406	Roblíčková, 1999
Klíčany	SBK	47	55	24	35	161	Peške, 1974

TABLE 2

Faunal spectra of the LBK and SBK sites from the Czech Republic included in the study. List of the published Neolithic archaeological sites from the Czech Republic pooled by phases: LBK and SBK.

does not exceed 0.7 % of the identified remains in either site. We likewise recorded low frequencies of traces connected to human activities (e.g. manufactured or modified bones, evidence of butchering and burning, etc.). The presence of butchering marks and of bone tools at Chotěbudice amounted to 1 % on the LBK samples and 0.6 % of the SBK samples. This difference is not significant (ε 0.5, $p > 0.05$). At Černý Vůl, these percentages were significantly lower for the SBK phase (0.3 %) than for the LBK phase (1.8 %; $\varepsilon = 4.69$, $p < 0.05$). Burnt bone remains and butchering marks during the LBK phase at both Chotěbudice and Černý Vůl occurred only rarely (i.e., on less than 1.8 % of the archaeological structures at each settlement).

All these data suggest that: 1) at both sites, the SBK assemblages were better preserved than the LBK assemblages, and 2) the assemblages at Černý Vůl were in better condition than those at Chotěbudice. This should be kept in mind when considering the faunal spectra and kill-off patterns that will be described below, since differences in preservation constitute an important bias of the faunal samples.

Consumption patterns

The list of taxa from the Neolithic horizons at Chotěbudice and Černý Vůl appears in Table 5. For Bovinae and Suinae, the identification to species level is based upon osteometric data. In the case of the Bovinae, the measurements from the LBK phases at Chotěbudice and Černý Vůl and from another LBK settlement (Hostivice-Sadová) have been compared to Holocene male and female aurochs (*Bos primigenius*) from non-anthropic, pre-Neolithic, contexts (Danemark; Degerbøl & Fredskild, 1970). Figure 4 shows the example of metacarpus distal breadth measured on adults (N = 45). This comparison suggests that most of the LBK Bovinae were domestic cattle (i.e., no less than 64% of the *Bos* remains), and aurochs represented a small component of the assemblages (i.e., 4.4%). About a third of the remains that could be measured were only identified to genus level (category *Bos* sp.). For Suinae, 53.8% of the remains were assigned to pork, 2.8% to wild boar and 43.4% to *Sus* sp. Given such ambiguity, the comparisons on food supply strategies, whether

	Total	% NISP	% unidentified fragments	% complete bones	% neonatus/very juvenile
Chotěbudice LBK	19725	24.3	75.7	2.8	0.1
Chotěbudice SBK	154	37.7	62.3	0	0.6
Černý Vůl LBK	1112	35	65	3.9	0
Černý Vůl SBK	2373	40.8	59.2	5.6	0.3

TABLE 3

Proportions of identified (NISP) and unidentified animal remains, complete bones and bones of neonates/very juveniles at Chotěbudice and Černý Vůl, for LBK and SBK phases.

	% weathering	% permineralization	% root etching	% tooth marks	% burning	% butchering/ bone tools
Chotěbudice LBK	6.5	3.6	0	0.4	1.7	1
Chotěbudice SBK	9.7	0	0	0	0	0.6
Černý Vůl LBK	2.2	5.1	0.1	0.7	1.2	1.8
Černý Vůl SBK	0.7	4.3	0.3	0.2	0.2	0.3

TABLE 4

Results of taphonomic analyses at Chotěbudice and Černý Vůl, for LBK and SBK phases. The percentages are expressed in proportion of total remains.

chronological or among settlements, will be based upon generic categories that will also include species (e.g., *Bos* sp. will also include *Bos taurus* and *Bos primigenius* and *Sus* sp. will also include *Sus domesticus* and *Sus scrofa*). These data are presented in Table 5. The remaining wild species, representing a minor component of the faunas, have been incorporated to the study as a combined category (i.e., «Others»). It should be noted that dogs are included in the later category due to their low frequencies (i.e., 0.2% in the LBK of Chotěbudice, and 1.3% & 0.3% in the LBK and SBK of Černý Vůl).

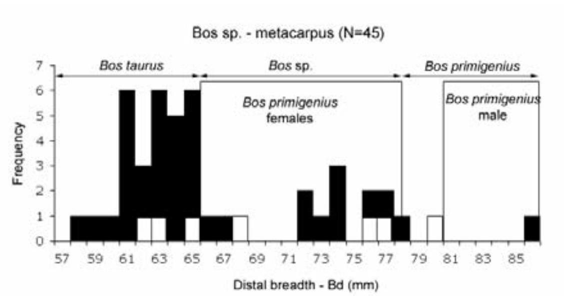

FIGURE 4

Frequency of metacarpus distal breadth from adult Bovinae discovered at LBK settlements: Chotěbudice, Černý Vůl (in black) and Hostivice-Sadová (in white). They are compared to male and female aurochsen from Danemark (Degerbøl & Fredskild, 1970).

During the LBK occupation at Chotěbudice, Bovinae were the dominant taxon at all chronological stages (average = 72 % of NISP; Figure 5). Sheep and goats along with Suinae played a secondary role in the animal economy. In average, the former represented 14.5 % of the fauna and the latter *ca.* 10 %. Six chronological phases (IIa, IIb, IIc, IIc/IIIa, IIIa and IIIb) have been documented during the LBK occupation at Chotěbudice. Non-parametric comparisons of the main faunal groups among the five well-documented phases, reveal that significant changes occurred in the food supply strategies during the LBK stage ($\chi 2 = 97.207$; df = 12; p = 1.96^{e-15}). The earliest phases (IIa, IIb) exhibit the most significant changes (together they contribute 75% to the Chi-square). During the SBK phase at Chotěbudice, the proportion of sheep and goats increased (77.6 % of total NISP), whereas cattle played a less important role (22.4%; Figure 5). The differences between the last phase of the LBK period (IIIb) and the SBK period seem obvious yet the small size of the SBK assemblage (NISP = 58), precludes a reliable conclusion to be drawn from these figures. Wild mammals represented a minimal component of the LBK and SBK faunal spectra at Chotěbudice (LBK: 2.8% & SBK: 0% of the total NISP). However, apart from aurochs and wild boar, at least seven species have been identified in the LBK (Table 1). These include red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), elk (*Alces alces*), wild horse (*Equus* sp.), bear (*Ursus arctos*), hare (*Lepus europaeus*) and beaver (*Castor fiber*). Red and roe deer were by far the most abundant taxa (2.5% of the total NISP). The presence of both these ungulates and bears (i.e., 0.1% of total NISP) is taken to evidence a forested environment. On the other hand, hare and wild horse (0.2% of total NISP) is associated with open biotopes. Elk and beaver (0.2% of the total NISP) place the area close to water bodies (i.e., the river flood-plain).

At Černý Vůl Bovinae were also the main group (i.e., *ca.* 43% of the total NISP) during the LBK. They were followed by Suinae (26%) and Caprinae (*ca.* 20%). The SBK period featured an increase in sheep and goats (54.3% of the total

NISP), whereas Bovinae (26.7%) and Suinae (13.4%) played a less prominent role (Figure 6). A Chi-square test based on raw data (Table 5), between the LBK and SBK phases, confirmed significant changes in the food supply strategies ($\chi 2 = 133.637$; df = 3; $p = 8.9^{e-29}$). Despite slight differences in the state of preservation between the two assemblages (*vide* supra), the increase of the small stock appears reliable. Game taxa (LBK: 7.5 %; SBK: 5.2% of the total NISP) at Černý Vůl (Table 1) are almost a duplicate of the list identified at Chotěbudice.

The LBK occupation at Černý Vůl is equivalent to the three of the later phases at Chotěbudice (IIc, IIIa and IIIb, representing 4 assemblages; Table 5). In this case, a lower proportion of Bovinae was recorded at Černý Vůl whereas both Suinae and wild mammals played a more important role. The assemblages from Černý Vůl were better preserved than those from Chotěbudice but Suinae are not included in the group of taxa exhibiting a high number of alterations. In addition, a Chi-square test based on the raw data from the four largest taxonomic groups (only the four later assemblages are included for Chotěbudice), indicated that food supply strategies at both Chotěbudice and Černý Vůl were significantly different during the LBK stage ($\chi 2 = 171.427$; df = 3; $p = 8.279^{e-36}$). Such result suggests that variability existed within the LBK at the regional scale.

Herd management strategies

Kill-off patterns described below constitute the first published data on the subject for the Neolithic of the Czech Republic. In the case of cattle, Chotěbudice provided large assemblages for the LBK period. These incorporate three chronological phases (LBK IIa, LBK IIb, LBK IIc/IIIa), that roughly cover 200 years. Figure 7 shows that the kill-off patterns from these phases have similar trends. This includes a slaughtering peak of animals between 6 and 12 months, as well as a high proportion of animals slaughtered between 1 and 4 years. Cattle older than 9 years are always present. A Chi-square test, carried out between the three chronological phases, based on the number of teeth for five age classes (the first two age classes and the three last ones have been added in order to avoid null cells), indicates that cattle management strategies did not vary significantly during the LBK ($\chi 2 = 8.999$; df = 8; $p = 0.342$). The cumulative kill-off pattern at Chotěbudice will thus be used in order to discuss the purpose of cattle rearing during the LBK period and also for comparisons (Figure 8A). This is characterized by a low proportion of animals aged less than 6 months (i.e., 3.7% of the slaughtered animals) and by a peak of calves killed between 6 and 12 months (17.8%). The latter were, in fact, mostly slaughtered between 6 and 9 months, according to the

Chotěbudice (NISP)	*Bos* sp.	*Sus* sp.	Caprines	Others	Total
LBK IIa	350	12	35	12	409
LBK IIb	398	84	131	22	635
LBK IIc	18	8	6	4	36
LBK IIc/IIIa	1467	244	254	52	2017
LBK IIIa	227	19	61	7	314
LBK IIIb	225	32	54	13	324
LBK (phase unspecified)	783	75	152	43	1053
SBK	13	0	45	0	58
Total	3481	474	738	153	4846
Černý Vůl (NISP)	*Bos* sp.	*Sus* sp.	Caprines	Others	Total
LBK	167	101	78	43	389
SBK	258	130	525	54	967
Total	425	231	603	97	1356

TABLE 5

Taxonomic categories used to compare food supply strategies between chronological phases and between settlements.

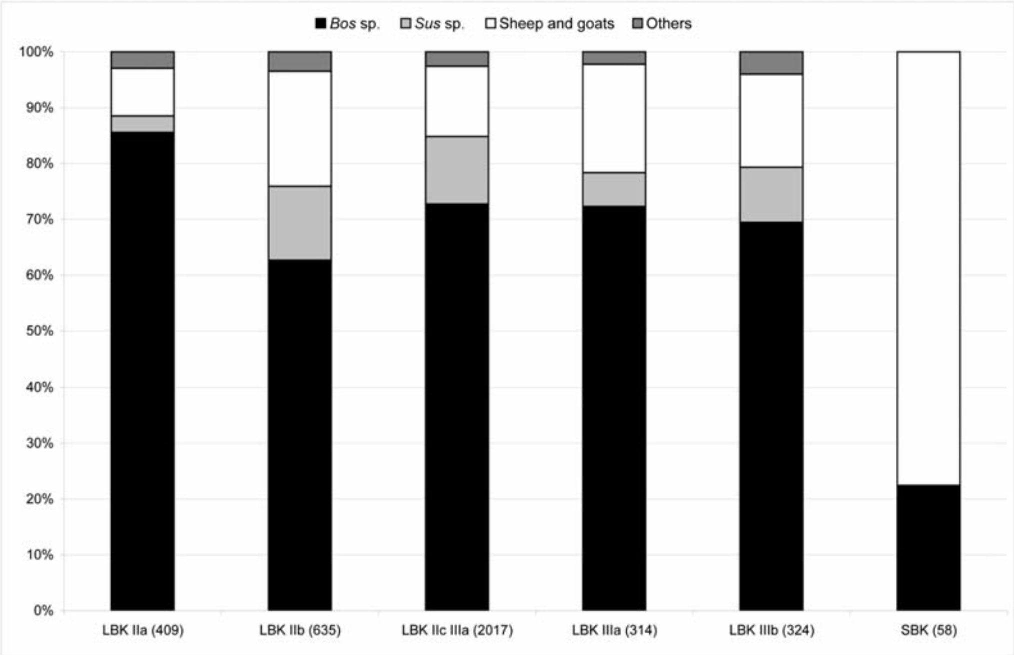

FIGURE 5

Faunal spectra for the LBK and SBK occupations at Chotěbudice. For the LBK, the five well-documented assemblages are distinguished. NISP totals are represented in brackets. Taxonomic categories are detailed in text.

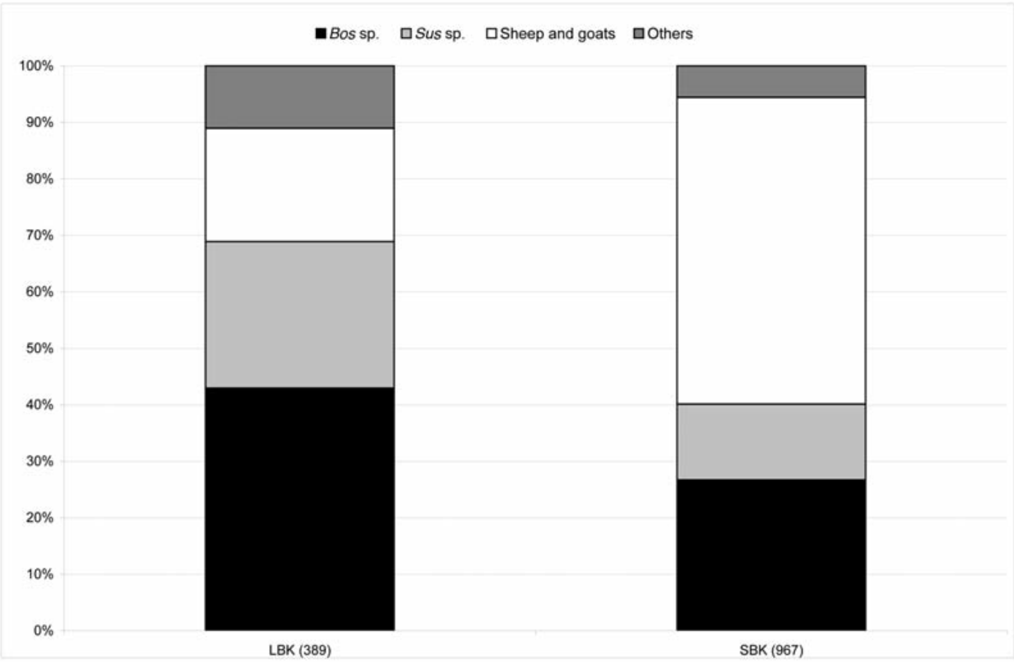

FIGURE 6

Faunal spectra for the LBK and SBK occupations at Černý Vůl. NISP totals are represented in brackets. Taxonomic categories are detailed in text.

data provided by the eruption of the first molar. A high (i.e., 23.7%) proportion of subadults (age class 1-2 years) is also evident. Sexually mature cattle [(maturity is considered to be reached during the third year of life according to unimproved breed's data; Pennetier (1983); see Tresset (1996) for a synthesis]) represent more than half of the slaughtered animals (54.8%). Finally, 14.5% of the cattle teeth from Chotěbudice belong to animals above 9 years. The fact that so many breeding cattle were kept suggests that livestock was exploited following a regime that promotes herd security and even herd increase. The hypothesis of a self-sufficient strategy is thus highly likely.

At Černý Vůl, the assemblage from the LBK occupation is very small (N = 23; Figure 8 B). Nevertheless, the kill-off pattern is quite similar to that observed at Chotěbudice. A slaughter of calves between 6 and 12 months (8.7%), as well as an absence of animals aged less than 6 months. In this case, sexually mature cattle represent 82.6% of the slaughtered animals and include a high proportion (i.e., 21.7%) of old individuals.

The kill-off pattern for the SBK occupation at Černý Vůl is clearly distinct from those from the LBK (Figure 8C). In this case, calves and subadults represent 62.2% of the slaughtered animals. In addition, a very low proportion (10.8%) of teeth from adults aged more than 4 years, as well as an absence of teeth of animals above 9 years, is observed. This kill-off pattern seems to reflect a non-viable breeding population. It is likely to be a truncated profile, which means that it reflects only a portion of the slaughtered herd. Adults must have died elsewhere, in an area of the site not yet excavated or perhaps at another settlement. As a result of this truncated profile, it is not possible to discuss the aims of the cattle rearing strategy for the SBK occupation at Černý Vůl.

The kill-off pattern established for the LBK occupation at Chotěbudice fits the milk exploitation model defined for Neolithic settlements in Western Europe (Tresset, 1996; Balasse *et al.*, 1997; Balasse *et al.*, 2000; Balasse & Tresset, 2002). In primitive breeds, triggering of the milk reflex requires stimulation of the cow by its offspring and the length of the lactation period fluctuates between 6 and 9 months (Quittet & Denis, 1963; Dahl & Hjort, 1976; Peške, 1994; Tresset, 1996; Balasse & Tresset, 2002). A massive slaughter of calves about the weaning age period can then be taken to evidence a management strategy that promotes milk exploitation (post-lactation peak: Peške, 1994). At Chotěbudice, the fact that herders waited until calves had reached at least 6 months before slaughtering them suggests that they were kept alive to allow the community to benefit of milk production. The second element that supports a milk exploitation model in this case is the high proportion of adults over 4 years, evidenced at Chotěbudice. Since keeping animals after they reach their maximum weight (the end of the weight gain period is about $3^{1/2}$-4 years for the slow growth breeds; Soltner, 1990; Tresset, 1996) would lead to lower meat yields, it is likely that a part of the cattle slaughtered after 4 years corresponded to breeding cows, kept alive both for reproduction and for milk production purposes.

On the other hand, as the 2-4 years subjects represent a high proportion of the slaughtered animals at Chotěbudice, exploitation for meat is highly likely. Indeed, the optimal meat gain is obtained when slaughtering cattle before they reach their maximum weight. This may also have coincided with the culling of the barren females. Finally, the hypothesis of cattle kept for draught should be also taken into account given the high proportion of animals kept alive after 11.5 years at Chotěbudice. In this context it should be remarked that no osteological traumas evidencing animal labour have

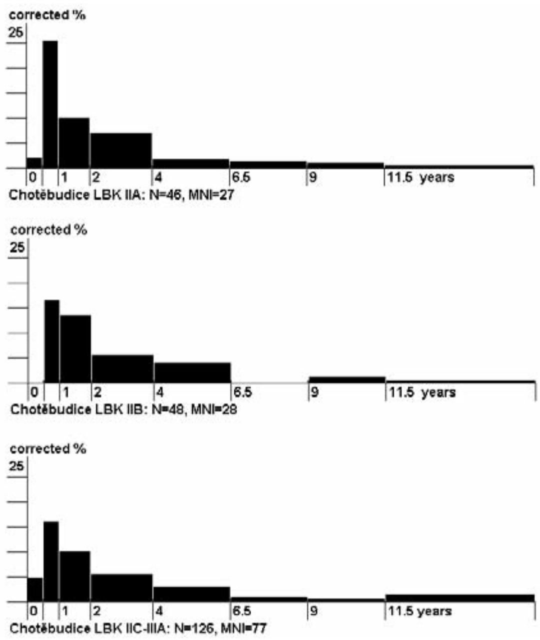

FIGURE 7
Cattle kill-off patterns for the three LBK phases at Chotěbudice.

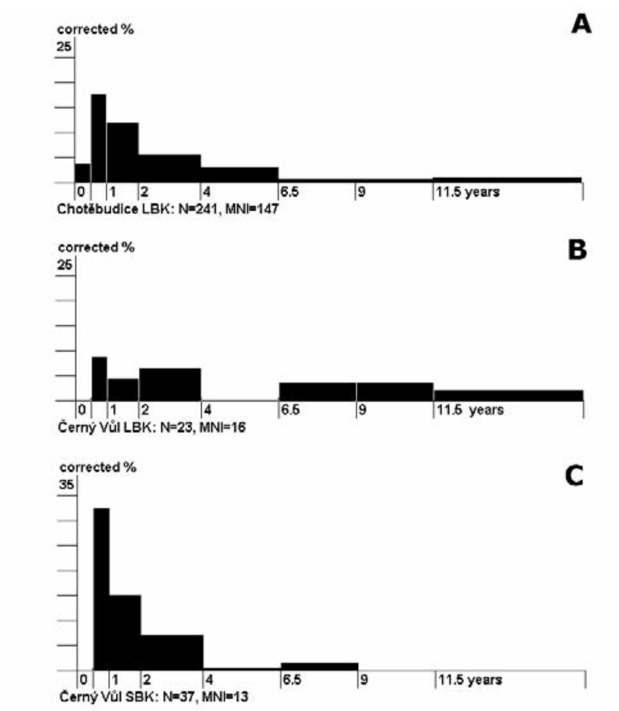

FIGURE 8

Cattle kill-off patterns for LBK at Chotěbudice and for LBK and SBK period at Černý Vůl.

been recorded on the cattle remains. Likewise, no undisputable evidence of cart or plough has thus far been found in Europe prior to the 4th millennium BC (Pétrequin *et al*., 2006). Only an occasional use along these lines appears likely (Bartosiewicz *et al*., 1997; Johannsen, 2006) and then only for tasks such as transportation. The LBK at Chotěbudice was nevertheless characterized by an exploitation strategy for cattle that at least included meat and milk.

Among sheep and goats, the former are clearly dominant (i.e., at least 3 sheep per goat), whatever the chronological phase or the settlement. Kill-off patterns in our study include all of the sheep/goat teeth, as a precaution, following Helmer (2000: 35-36), and Zeder & Pilaar (2010: 241). Two reliable kill-off patterns are recorded for the LBK occupation at Chotěbudice (N = 159; Figure 10A) and for the SBK phase at Černý Vůl (N = 119; Figure 10B). Though the number of teeth assigned to the LBK phase at Černý Vůl is too small (N = 21) to provide reliable information. Two chronological phases (LBK IIb and LBK IIc-IIIa) are illustrated at Chotěbudice (Figure 9A, B). The earliest one (Figure 9A) exhibits a slaughtering peak between 6 and 12 months (age class C), as well as a high proportion of animals killed after 2 years. Similar trends are observed on the second kill-off pattern (Figure 9B) though the frequency of the 1-2 years old cohort (i.e., age class D) is higher. Still, a Chi-square test, carried out between these two phases, and based on the raw data from the five age classes (age classes B and C have been added to avoid null cells), indicates that the management strategies did not vary significantly according to the time period ($\chi 2 = 7.16$, df = 4, p = 0.127). The discussion will thus be based on the cumulative LBK kill-off pattern (Figure 10A). This is first of all characterized by a very low proportion of animals slaughtered before 6 months (1.3% of the teeth). However, since no sieving was carried out at these settlements, such low frequency is likely to be an under-estimation (in particular for age class A, 0-2 months). The main slaughtering peak appeared between 6 and 12 months of age (i.e., age class C; 25.2% of the teeth). A high proportion (43.4%) of sheep and goats above 4 years (i.e., age classes G and H-I) is also observed. As noticed previously for cattle herds from Chotěbudice, this high proportion of adults with breeding capabilities could reflect a management promoting herd security. At Černý Vůl, the kill-off pattern established for the SBK phase (Figure 10B) revealed quite distinct tendencies. Here a lower proportion of animals slaughtered between 6 and 12 months (10.1%) and of adults above 4 years (15.2%) is observed. Conversely, animals slaughtered between 1 and 2 years (age class D) were represented by 40.3% of the teeth. A Chi-square test, carried out between the LBK period at Chotěbudice and the SBK period at Černý Vůl, indicates that management strategies were significantly distinct ($\chi 2 = 39.63$, df = 4, p = 5.17^{e-8}).

It appears that at Chotěbudice sheep and goat herds were exploited for different purposes. The tendencies described above are indicative of an exploitation focused on both tender meat (Payne, 1973; Helmer & Vigne, 2004; Vigne & Helmer, 2007), and «secondary» products. The high proportion of adults above 4 years could indeed reflect a keeping of the females for reproduction and milk exploitation (Helmer, 1992; Halstead, 1998; Helmer & Vigne, 2004). The hypothesis of hair exploitation should also be considered here given that the presence of animals above 6 years is not negligible (Helmer, 1992; Helmer & Vigne, 2004). The SBK at Černý Vůl is characterized by different strategies. The very high proportion of animals slaughtered between 1 and 2 years, in addition to the low frequencies of adults kept alive after 4 years, suggests that meat exploitation did play an important role. According to Helmer & Vigne (2004), the fact that people waited until the animals had reached their maximum weight to slaughter them indicates the focus to optimize meat yield. Thus, whereas the LBK phase at Chotěbudice was characterized by herd management strategies that promoted herd security and a mixed exploitation (meat, milk, and perhaps hair), only meat appears to matter at Černý Vůl during the SBK phase.

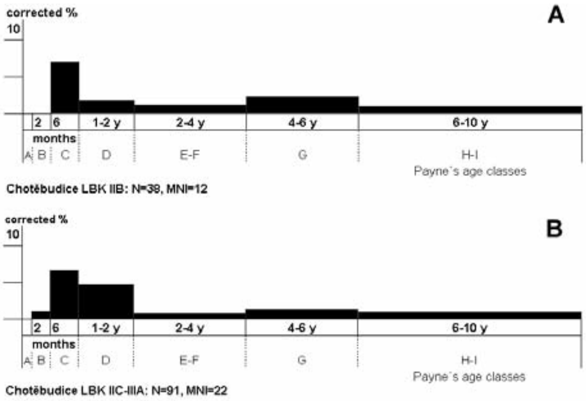

FIGURE 9

Sheep and goats kill-off patterns for two LBK phases at Chotěbudice.

Three kill-off patterns are available for Suinae, one for the LBK occupation at Chotěbudice (MNI = 9; Figure 11A) and two for the LBK and SBK phases at Černý Vůl (LBK: MNI = 5; SBK: MNI = 12; Figure 11B, 11C). The kill-off pattern at Chotěbudice shows that one third of the individuals were infantiles (up to 6 months) and juveniles (between 6 months and 1 year) (Figure 11A). Consequently, it is difficult to distinguish pigs from wild boar in most of the remains, as the discrimination is virtually impossible for young specimens. The remaining two thirds of the individuals were subadults slaughtered between one and two years. Only one individual (pig or wild boar) older than 5 years was found at Chotěbudice. The slaughtering profile at Chotěbudice is to be be expected from a strategy aimed at optimizing meat production, with not too many very young animals being slaughtered and only occasionally allowing animals to get old. At Černý Vůl (Figure 11B, 11C), all Suinae were slaughtered between 6 and 24 months. One individual from the LBK phase and three additional ones from the SBK phase were young (6-12 months) whereas five individuals in the LBK period and nine individuals in the SBK period were subadults (12-24 months). These subadults were killed during or right at the end of the period of rapid weight gain. The profiles are characteristic of an efficient pig exploitation for meat.

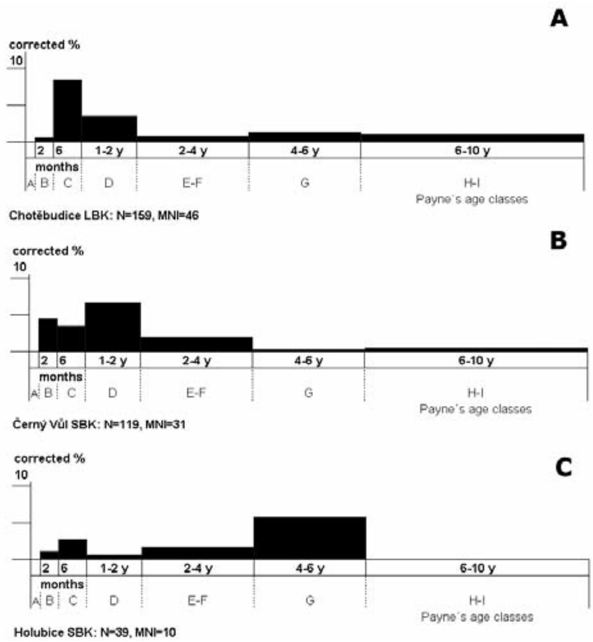

FIGURE 10

Sheep and goats kill-off patterns for the LBK period at Chotěbudice and the SBK period at Černý Vůl and Holubice.

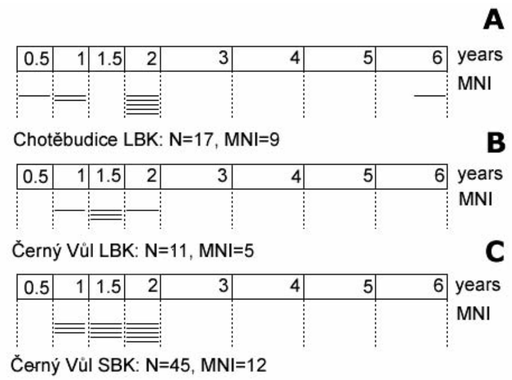

FIGURE 11

Suinae kill-off patterns for the LBK period at Chotěbudice and the LBK and the SBK period at Černý Vůl.

REGIONAL COMPARISONS

At Chotěbudice and Černý Vůl, remains from domesticates are proportionally much more abundant than those from wild animals, suggesting a minor importance of hunting, whatever the period under consideration. Cattle were the main species throughout the LBK in both settlements. Livestock of secondary importance included sheep, goats and Suinae. Compared with Chotěbudice, a lower proportion of Bovinae was observed during the LBK phase at Černý Vůl, while Suinae and wild mammals played a more important role. The statistical difference between these two LBK settlements suggests variability at the regional scale. For the SBK period, it was found that the importance of sheep and goats clearly increased at Černý Vůl (compared to the LBK phase at the same site). These stocks became dominant while cattle declined.

In order to see whether some of these synchronic and diachronic trends were detectable at a higher scale, we compared the proportion of the main taxa in nine LBK (Figure 12) and eight SBK (Figure 13) assemblages from the Czech Republic (Tables 1 and 2) using a rank test (U of Mann-Whitney). The dominant position of cattle during the LBK is evident at the level of the Czech Republic (Figure 12). On the other hand, we did not obtain significant differences in the proportion of cattle ($U = 22$; $p = 0.178$), sheep and goats ($U = 35.5$; $p = 0.962$) and Suinae ($U = 34.5$; $p = 0.885$) between the two Neolithic periods. Still, in the case of sheep and goats, conclusions may have been influenced by the state of preservation of the archaeozoological material, which is often unknown in the data drawn from the literature. Osteological assemblages at Černý Vůl are indeed rather well preserved. At any rate, the increase in small stock between the LBK and SBK phases recorded at Černý Vůl is not detected at a larger scale. Variability in the proportions of cattle, sheep, goats and Suinae among settlements within each period (Figure 12, 13) may reflect different environmental conditions around each settlement.

Wild animals seem to have been scarce everywhere. This agrees with the average proportion of remains from wild animals in Central Europe during the LBK period, where the proportion of game does not usually exceed 10% of the NISP (e.g. Milisauskas & Kruk, 1989; Rulf, 1991; Bakels, 2009). Settlements where hunting exceeded these figures, such as Klíčany (Peške, 1974) or Roztoky (Peške, 1991) (Figure 13), are uncommon. No general increase of hunting in the SBK period, compared to the LBK, has been recorded for the Czech Republic at large ($U = 31$; $p = 0.630$).

We propose a mixed exploitation of cattle and small stock for meat, milk and maybe hair at Chotěbudice, a specialized exploitation appearing unlikely for the LBK period in the case of the

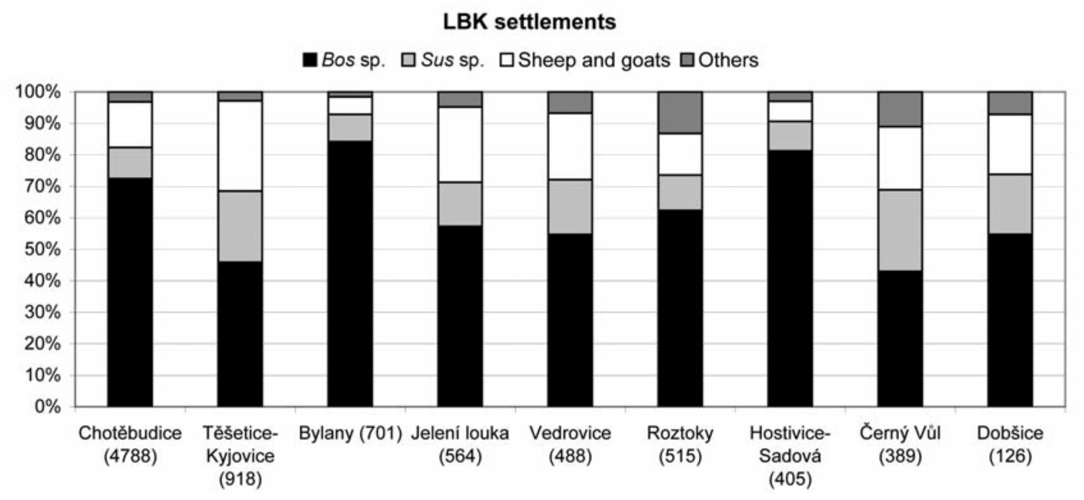

FIGURE 12

Faunal spectra for the LBK settlements from the Czech Republic. In brackets are the NISP totals. For comparisons, only the assemblages with more than 100 identified specimens (NISP) have been included. Raw data and references are in Tables 1 and 2.

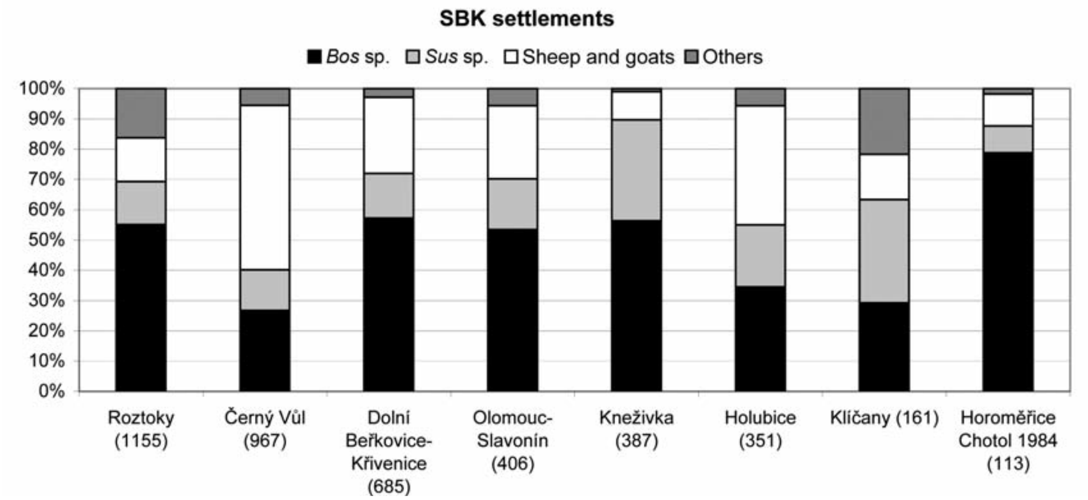

FIGURE 13

Faunal spectra for the SBK settlements from the Czech Republic. In brackets are the NISP totals. For comparisons, only the assemblages with more than 100 identified specimens (NISP) have been included. Raw data and references are in Tables 1 and 2.

ruminants. The exploitation of milk does not conform with the expectations of Sherratt (1981, 1983), who argued for the development of secondary products in Europe from the fourth millennium BC onwards. Recent kill-off pattern analyses (e.g. Vigne & Helmer, 2007; Vigne, 2008; Bréhard *et al*., 2010) and studies of lipid residues found in pottery (Craig *et al*., 2000, 2005; Evershed *et al*., 2008) suggest that the Early Neolithic farmers had the knowledge to make use of certain secondary products, in particular milk. A key process in the prehistory of the Europeans involved the co-evolution of lactase persistence (LP) and dairying (Burger *et al*., 2007; Itan *et al*., 2009). However, DNA typing of genetic markers that correlate with LP indicates that most of the early Neolithic farmers would have been unable to consume significant amounts of fresh milk (Burger *et al*., 2007). Adults can nevertheless digest processed milk (e.g., cheese and other fermented products) without further difficulty (Chandan, 2004; Robinson & Tamime, 2006; Tresset & Vigne, 2011). For such reason, we believe that the milk production suggested by the kill-off patterns at Chotěbudice and Černý Vůl would more likely indicate the consumption of cheese rather than of fresh milk.

Herd management strategies developed during the SBK period can be discussed only for sheep and goats. Distinct trends can be observed between Černý Vůl (Figure 10B) and another SBK settlement from Bohemia: Holubice (Kovačiková & Daněček, 2008; Figure 10C). Whereas at Černý Vůl sheep and goats were mostly raised for meat, the exploitation of secondary products is highly likely at Holubice. If this was indeed the case, several types of exploitation were developed for sheep and goats during the SBK period in this area.

INVESTIGATING CATTLE BIRTH SEASONALITY AND DIET AT CHOTě BUDICE

As the exploitation of cow milk was suggested at Chotěbudice from the kill-off profile, a stable isotope study was conducted on a restricted number of cattle teeth from this site in order to define more precisely the reproduction and feeding management of this species, since both parameters influence the pattern of milk availability for human consumption throughout the year.

THE USE OF STABLE ISOTOPE ANALYSIS

The breeding cycle of domesticates can be under the control of a number of environmental, genetic, cultural and economic variables. Although the cow does not have a true anoestrous season, its fertility varies throughout the year (Hammond *et* *al*., 1971). In particular, it may be influenced by seasonal food availability (Lecomte & Le Neveu, 1986). Although it is most likely that reproduction was seasonally constrained in early European domestic cattle, the actual length of the breeding season might have differed according to environmental parameters thus cannot be presumed *a priori*. Cattle birth seasonality and seasonality of the diet are therefore tightly linked within the wider framework of herd management. Both may be investigated through sequential stable oxygen and carbon isotope analysis in tooth enamel.

During tooth growth, the isotope signal is incorporated and fixed in the enamel, which is not remodelled once fully mineralized (Gage *et al*., 1989). Moreover, tooth enamel bioapatite has been shown fairly resistant to diagenetic alteration (Lee-Thorp & van der Merwe, 1991). In cattle, the growth of the third molar (M_3) crown starts in the sixth month after birth and is completed after the end of the second year (Brown *et al*., 1960). Although a significant subsequent delay is suspected for enamel secondary mineralization, shifting the isotopic record from approximately 6 to 7 months (Balasse, 2002, 2003), the stable isotopic signal measured from sequential sampling along the tooth growth axis remains chronologically stable and has been shown to span for approximately a year in the case of the lower third molar (Balasse & Tresset, 2007).

Reconstitution of the diet from stable carbon isotope ratios

Variability in the carbon isotopic composition of plants is reflected in the bones and teeth of the animals that consume them (Lee-Thorp & Sponheimer, 2006). A cause for this variability is the differential fractionation of carbon isotopes during CO_2 fixation by plants following the C_3 or the C_4 photosynthetic pathway (Smith & Epstein, 1971; Lee-Thorp *et al*., 1989). In Central Europe, C_4 plants currently represent a maximum of 2 % of the total vascular plant species, and most of them are invasive (Pyankov *et al*., 2010). They can thus be considered as not significant in the diet of grazers. The modal stable carbon isotope ratio of preindustrial C_3 plants can be estimated as –25.6‰ after correcting the value of –27‰ for modern plants (O'Leary, 1988; Tieszen & Boutton, 1988) for the fossil fuel effect (1.4‰, Stuiver *et al*., 1984; Friedli *et al*., 1986; Cerling & Harris, 1999; Stuiver *et al.*, 1984; Friedli *et al.*, 1986). The ^{13}C-enrichment factor ε between the values of the diet and the enamel apatite averages 14.1‰ for large mammals (Cerling & Harris, 1999). Consequently, expected modal $\delta^{13}C$ values for enamel bioapatite in animals feeding on C_3 plants oscillates around -11.9 ‰. Environmental influences acting on C_3 plants $\delta^{13}C$ values include the «canopy effect» in dense forests, resulting in lower $\delta^{13}C$ values for plants from the understories and animals feeding on them (Farquhar *et al*., 1982; van der Merwe & Medina, 1991). Kohn (2010) recommends a $\delta^{13}C$ value of -31.5 ‰ as a cut-off indicating the understories of closed-canopy forests. This would be reflected in a $\delta^{13}C$ value of -17.8 ‰ in enamel bioapatite.

Investigating birth seasonality from stable oxygen isotope ratios

Most of the oxygen contributing to skeletal bioapatite comes from ingested water (both drinking water and water in plants) and indirectly from meteoric water (Land *et al*., 1980; Longinelli, 1984; Luz *et al*., 1984; D'Angela & Longinelli, 1990; Delgado Huertas *et al*., 1995). At high and middle latitudes, the oxygen isotopic composition ($\delta^{18}O$) of meteoric water is linked to ambient temperature, causing a seasonal variation in the oxygen isotope ratios of precipitation, with highest value occurring during the warmest months and the lowest values in the coldest months (Gat, 1980). Early studies of the oxygen isotope composition of enamel bioapatite (Bryant *et al*., 1996; Fricke & O'Neil, 1996) have shown variability in the oxygen isotope ratios within a tooth row, due to differences in the season of tooth formation, which, in turn, is linked with the season of birth. Later, the same principle was applied to the interpretation of intra-tooth variations in enamel $\delta^{18}O$ as reflecting the season of birth (Balasse *et al*., 2003; Nelson, 2005; Balasse & Tresset 2007; Britton *et al*., 2009; Henton *et al*., 2010).

Dental material used for the stable isotope analysis and laboratory procedures

Five cattle lower third molars (samples CHBOS1M3-CHBOS5M3), belonging to different individuals from Chotěbudice were chosen for stable isotope analysis. A total of 84 analyses of tooth enamel samples are presented in this study. The teeth were extracted from the mandible and cleaned by brushing. Sequential sampling of enamel powder was performed using a diamond drill bit. Powdered enamel samples were taken from the middle lobe on the buccal surface of the crown. Each sample was located in the tooth crown by the distance of the higher margin from the enamel-root junction. Enamel samples weighing 5 to 10 mg were pre-treated with NaOCl (2-3%) for 24 hours to eliminate the organic component and with 0.1 M acetic acid ($C_2H_4O_2$) for 4 hours, to eliminate diagenetic carbonates. The samples were analysed through isotope ratio mass spectrometry (Thermo Kiel IV device interfaced to a Delta V advantage) at the SSMIM (Muséum national d'Histoire naturelle, Paris). The analytical precision, estimated from 41 laboratory internal standards (Marbre LM) was 0.01‰ for $\delta^{13}C$ and 0.04‰ for $\delta^{18}O$.

RESULTS

Stable oxygen isotope ratios

Stable oxygen isotope ratios in the bovine teeth ranged from –8.4 ‰ to –3.7 ‰ (Table 6 and Figure 14A). The amplitude of variation in $\delta^{18}O$ values varied between 2.8 ‰ and 4.7 ‰, reflecting strong seasonality of ambient temperature (Figure 14A). Figure 14 A compares the patterns of variation of $\delta^{18}O$ along the tooth of the five individuals, highlighting a strong similarity in the timing of the stable isotope record in CHBOS3M3, CHBOS4M3 and CHBOS5M3 in which the highest $\delta^{18}O$ values where measured at approximately 20 mm from the enamel-root junction (erj). In CHBOS1M3 and CHBOS2M3, the highest $\delta^{18}O$ values were measured at approximately 31 mm from erj. Considering a sampling interval of 2 to 3 mm, this difference between both groups is significant.

Stable carbon isotope ratios

Results from the stable carbon isotope analysis are presented in Table 6 and Figure 15. The $\delta^{13}C$ values vary from –11.8 ‰ to –10.1 ‰, with amplitudes of variation along tooth crown (over approximately a year to a year and a half) varying from 0.4 to 1.4‰ (mean = 0.9‰) (Figure 15). This suggests a feeding on C_3 plants year round for these five individuals. Except in CHBOS3M3, where no clear trend could be seen in the variation of $\delta^{13}C$ along tooth crown, in the remaining individuals the highest $\delta^{13}C$ values occurred in autumn and the lowest in the spring.

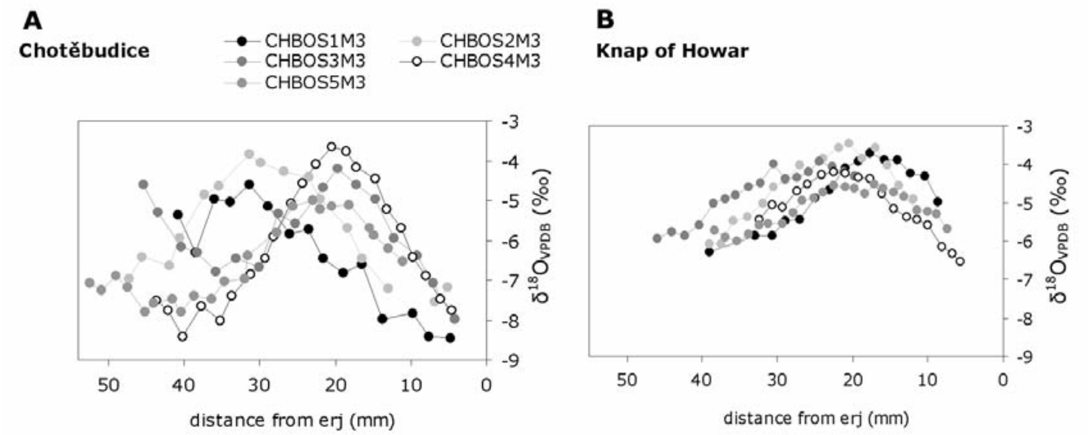

FIGURE 14

Variations in enamel stable oxygen isotope ratios ($\delta^{18}O_{VPDB}$) along the tooth crown of the cattle third molars (M_3) from Chotěbudice and Knap of Howar.

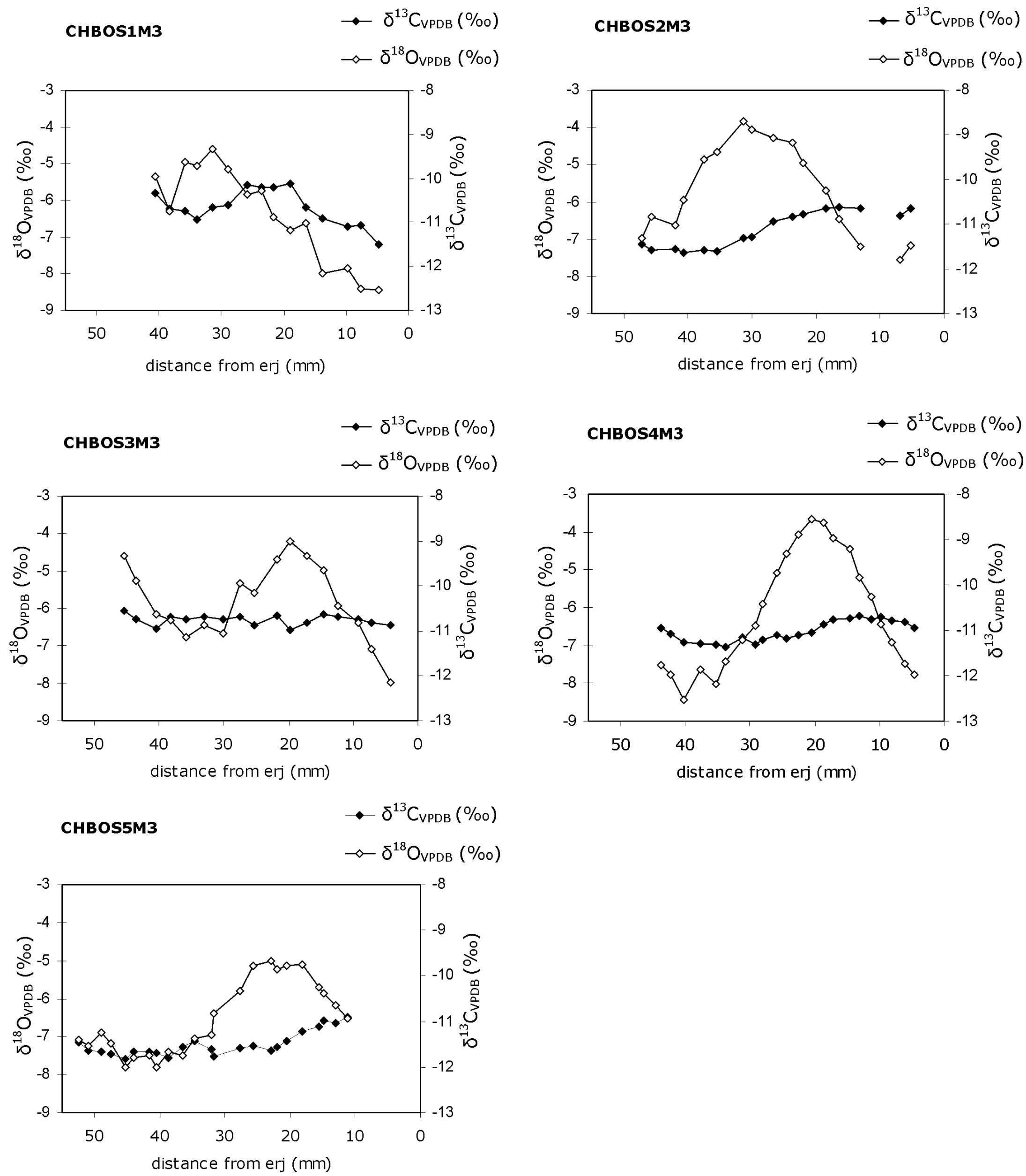

FIGURE 15

Variations in enamel stable oxygen and carbon isotope ratios ($\delta^{18}O_{VPDB}$, $\delta^{13}C_{VPDB}$) along the tooth crown of five cattle third molars (M_3) from Chotěbudice.

CHBOS1M3			CHBOS2M3			CHBOS3M3			CHBOS4M3			CHBOS5M3		
mm	$\delta^{13}C$	$\delta^{18}O$	mm	$\delta^{13}C$	$\delta^{18}O$	mm	$\delta^{13}C$	$\delta^{18}O$	mm	$\delta^{13}C$	$\delta^{18}O$	mm	$\delta^{13}C$	$\delta^{18}O$
40.7	-10.3	-5.3	47.2	-11.4	-7.0	45.4	-10.6	-4.6	43.7	-10.9	-7.5	52.5	-11.4	-7.1
38.4	-10.7	-6.3	45.7	-11.6	-6.4	43.5	-10.7	-5.3	42.2	-11.1	-7.8	50.9	-11.6	-7.2
35.9	-10.7	-5.0	42.0	-11.5	-6.6	40.3	-10.9	-6.1	40.3	-11.3	-8.4	49.0	-11.7	-6.9
33.9	-10.9	-5.1	40.6	-11.6	-6.0	38.3	-10.7	-6.3	37.6	-11.3	-7.6	47.4	-11.7	-7.2
31.5	-10.7	-4.6	37.4	-11.6	-4.9	35.8	-10.7	-6.8	35.2	-11.3	-8.0	45.2	-11.8	-7.8
28.9	-10.6	-5.2	35.5	-11.6	-4.7	33.1	-10.7	-6.5	33.8	-11.4	-7.4	44.0	-11.7	-7.6
26.0	-10.1	-5.9	31.3	-11.3	-3.8	30.2	-10.7	-6.7	31.3	-11.2	-6.8	41.6	-11.7	-7.5
23.5	-10.2	-5.7	30.0	-11.3	-4.1	27.5	-10.7	-5.3	29.2	-11.3	-6.5	40.5	-11.7	-7.8
21.7	-10.2	-6.5	26.8	-10.9	-4.3	25.2	-10.9	-5.6	28.1	-11.2	-5.9	38.6	-11.8	-7.4
18.9	-10.1	-6.8	23.6	-10.8	-4.4	21.7	-10.7	-4.7	25.8	-11.1	-5.1	36.4	-11.6	-7.5
16.4	-10.7	-6.6	22.1	-10.8	-4.9	19.8	-11.0	-4.2	24.3	-11.2	-4.6	34.6	-11.4	-7.0
13.8	-10.9	-8.0	18.4	-10.6	-5.7	17.2	-10.8	-4.6	22.5	-11.1	-4.1	32.1	-11.6	-7.0
9.7	-11.1	-7.9	16.4	-10.6	-6.5	14.7	-10.6	-5.0	20.5	-11.1	-3.7	31.7	-11.8	-6.4
7.7	-11.1	-8.4	13.1	-10.6	-7.2	12.3	-10.7	-5.9	18.6	-10.9	-3.8	27.8	-11.6	-5.8
4.8	-11.5	-8.4	10.6			9.2	-10.7	-6.4	17.2	-10.8	-4.2	25.7	-11.5	-5.1
			6.9	-10.8	-7.5	7.1	-10.8	-7.1	14.7	-10.7	-4.4	22.9	-11.7	-5.0
			5.2	-10.7	-7.2	4.3	-10.9	-8.0	13.2	-10.7	-5.2	22.0	-11.6	-5.2
									11.3	-10.8	-5.7	20.5	-11.4	-5.1
									9.9	-10.7	-6.4	18.2	-11.2	-5.1
									8.1	-10.8	-6.9	15.6	-11.1	-5.7
									6.2	-10.8	-7.5	14.9	-11.0	-5.9
									4.6	-11.0	-7.8	13.1	-11.0	-6.2
												11.2	-10.9	-6.5

TABLE 6

Stable carbon and oxygen isotope ratios ($\delta^{13}C_{VPDB}$ and $\delta^{18}O_{VPDB}$) of enamel bioapatite sampled along the tooth crown of the lower third molar (M_3) of cattle from Chotěbudice. Distance from the enamel-root junction is reported in mm and stable isotope values are reported in ‰.

DISCUSSION

Inferring cattle diet management from $\delta^{13}C$ values

Seasonal changes in the availability of feeding resources for cattle might have constrained the LBK herders to fodder their livestock part of the year. This point might be particularly relevant for the period under consideration, characterized in by the Cerin climatic deterioration (episode 11; 7550–7250 cal. BP), which might have caused bad climatic conditions throughout continental Europe, that included an increase in annual precipitation, cooler summers and a shortening of the growing season (Magny, 1995, 2004). The $\delta^{13}C$ values measured in cattle teeth from Chotěbudice are typical of feeding in open grasslands and do not evidence any significant contribution of tree fodder from a dense forest. The use of tree leaves to feed cattle was confirmed at the site of Weier (Switzerland) in more recent periods for the botanical remains were retrieved in dung layers (Rasmussen, 1989). However, the canopy effect occurs only in dense forests and feeding on leaves from the understorey of an open forest might be difficult to detect from a stable carbon isotope analysis.

Very few equivalent data are available for the Neolithic cattle from Central Europe, in particular for the Czech Republic (Smrčka *et al*., 2005). $\delta^{13}C$ values recorded at Chotěbudice can be compared with those obtained on cattle bone collagen from LBK sites in Central Germany (Oelze *et al*., 2011). Cattle bones from Derenburg (N = 5), Halberstadt (N = 3) and Karsdorf (N = 12) delivered collagen $\delta^{13}C$ values ranging between -22.5 ‰ and -19.6 ‰ (with one exception: -23.2 ‰ at Karsdorf). Considering a 5 ‰ $\delta^{13}C$-spacing between collagen and diet (van der Merwe, 1989; Ambrose, 1993) these $\delta^{13}C$ values measured in bone collagen would correspond to -13.4 to -10.5 ‰ in bioapatite. A $\delta^{13}C$ value of -21.2 ‰ was measured in one cattle bone from the LBK site of Herxheim (Southern Germany, ca 5000 BC; Dürrwächter *et al*., 2006), which would correspond to a value of -12.1 ‰ in bioapatite. The $\delta^{13}C$ bioapatite values measured at Chotěbudice, varying from -11.8 to -10.1 ‰, would therefore compare with the highest obtained in the German LBK sites.

Investigating birth seasonality from the tooth enamel $\delta^{18}O$ values

Although the number of cattle teeth analyzed at Chotěbudice is very low, the shift differentiating both groups is small, corresponding to approximately a quarter of an annual cycle (i.e., 3 months; Figure 14A) which would suggest grouped births. It is not possible from this $\delta^{18}O$ dataset alone to infer the season of birth. However, it is interesting to note that the kill-off pattern shows a slaughtering peak of young cattle aged between 6 and 9 months (Figure 8A). If cattle births were grouped, the culling of individuals from the same age was taking place at the same season of the year. It is likely that these calves, about to be weaned, were slaughtered before the onset of the winter in order to reduce herd size during the bad season, as practiced by traditional husbandry. Such pattern would therefore suggest spring births, in agreement with what is observed nowadays in free ranging, primitive breeds of cattle (Lecomte & Le Neveu, 1986; Reinhard *et al*., 1986).

A comparable $\delta^{18}O$ dataset is available for the site of the Knap of Howar (N = 5; ca 3500 cal. BC; Balasse & Tresset, 2007), located on a very different environment (i.e., Orkney archipelago, Scotland) yet characterized by similar difficult climatic conditions during the bad season. Both datasets differ in the amplitude of $\delta^{18}O$ intra-tooth variation, reaching only 1.5‰ to 2.6‰ at the Knap of Howar (Figure 14B), contra 2.8‰ to 4.7‰ at Chotěbudice (Figure 14A). This suggests a higher annual amplitude of the temperature at Chotěbudice than at Knap of Howar, in agreement with oceanic climatic conditions in the Orkneys compared to a more continental regime at Chotěbudice. At the Knap of Howar, the highest $\delta^{18}O$ values for cattle M_3 were obtained at approximately 20 mm from erj (Figure 14B), which is very similar to what was recorded at Chotěbudice for three of the five individuals (Figure 14A). This comparison suggests that cattle births might have been more grouped at the Knap of Howar than at Chotěbudice.

CONCLUSIONS

This study has revealed that:

1. Faunal spectra indicate the minor importance of hunting in the animal economy.
2. Cattle were the main stock throughout the LBK period.
3. During the SBK culture sheep and goats increased at the expense of cattle in some settlements (e.g. Černý Vůl) but such trend was not significant at a regional level. The variability in the proportions of cattle, sheep/goats and pigs among the various settlements within each period could have resulted from specific environmental conditions around each settlement.
4. A mixed exploitation of cattle and a small stock for meat, milk and perhaps for hair was evidenced at Chotěbudice during the LBK. Different management strategies were apparently developed in the case of sheep and goats during the SBK period. These data confirm that the earliest farmers of Central Europe possessed the knowledge about certain secondary products' use, in particular milk.
5. The stable carbon isotope values ($\delta^{13}C$) measured in the teeth enamel of cattle from Chotěbudice were typical of feeding in the open grasslands and do not evidence any significant contribution of tree fodder from a dense forest.
6. Results from the stable oxygen isotope analysis suggest grouped births for cattle at Chotěbudice although it has not been possible to define the season of birth. The mortality profile for cattle shows a peak of animals aged between six and nine months. This suggests that the culling of individuals from the same age was taking place in the same season of the year. It is likely that these calves, about to be weaned, were slaughtered right before the onset of winter, in order to reduce the size of herd over the bad season. Such pattern would suggest spring births.

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REFERENCES

AMBROSE, S.H. 1993: Isotopic analysis of paleodiets: methodological and interpretive considerations. In: Standford, M.K. (ed.): *Investigations of ancient human tissue, chemical analyses in anthropology*:. 59-130. Gordon and Breach Science Publishers, Langhorne.

BAKELS, C.C. 2009: *The Western European Loess Belt. Agrarian History, 5300 BC-AD 1000*. Springer, Berlin.

BALASSE, M. 2002: Reconstructing Dietary and Environmental History from Enamel Isotopic Analysis: Time Resolution of Intra-tooth Sequential Sampling. *International Journal of Osteoarchaeology* 12: 155-165.

BALASSE, M. 2003: Potential Biases in Sampling Design and Interpretation of Intra-tooth Isotope Analysis. *International Journal of Osteoarchaeology* 13: 3-10.

BALASSE, M.; BOCHERENS, H.; TRESSET, A.; MARIOTTI, A. & VIGNE, J.-D. 1997: Émergence de la production latière au Néolithique? Contribution de l'analyse isotopique d'ossements de bovins archéologiques? *Sciences de la terre et des planètes* 325: 1005-1010.

BALASSE, M.; TRESSET, A.; BOCHERENS, H.; MARIOTTI, A. & VIGNE, J.-D. 2000: Un abattage «post-lactation» sur des bovins domestiques Néolithiques. Étude isotopique des restes osseux du site de Bercy (Paris, France). *Ibex Journal of Mountain Ecology 5, Anthropozoologica* 31: 39-48.

BALASSE, M. & TRESSET, A. 2002: Early weaning of Neolithic domestic cattle (Bercy, France) revealed by intra-tooth variation in nitrogen isotope ratios. *Journal of Archaeological Science* 29: 853-859.

BALASSE, M.; SMITH, A.B.; AMBROSE, S.H. & LEIGH, S.R. 2003: Determining Sheep Birth Seasonality by Analysis of Tooth Enamel Oxygen Isotope Ratios: The Late Stone Age Site of Kasteelberg (South Africa). *Journal of Archaeological Science* 30: 205-215.

BALASSE, M. & TRESSET, A. 2007: Environmental constraints on the reproductive activity of domestic sheep and cattle: what latitude for the herder? *Anthropozoologica* 42 (2): 71-88.

BARTOSIEWICZ, L.; VAN NEER, W. & LENTACKER, A. 1997: Draught cattle: their osteological identification and history. *Annales du Musée Royal de l'Afrique Centrale, Sciences Zoologiques, Tervuren* 281.

BENEŠ, J. 2004: Palaeoecology of the LBK: Earliest agriculturalist and landscape of Bohemia, Czech Republic. In: Lukes, A. & Zvelebil, M. (eds.): *LBK Dialogues. Studies in the formation of the Linear Pottery Culture*: 143-150. B.A.R. (International Series) 1304. Oxford.

BOGUCKI, P. 1988: *Forest farmers and stockherders: Early Agriculture and its Consequences in North-Central Europe*. Cambridge University Press, Cambridge.

BOGUCKI, P. 2003: Neolithic dispersals in riverine interior Central Europe. In: Ammerman, A. & Biagi, P. (eds.): *The Widening Harvest. The Neolithic Transition in Europe: Looking Back, Looking Forward*: 249-272. Archaeological Institute of America (Colloquia and Conference Papers 6). Boston.

BRÉHARD, S.; BEECHING, A. & VIGNE, J.-D. 2010: Shepherds, cowherds and site function on middle Neolithic sites of the Rhône valley: An archaeozoological approach to the organization of territories and societies. *Journal of Anthropological Archaeology* 29 (2): 179-188.

BRITTON, K.; GRIMES, V.; DAU, J. & RICHARDS, M.P. 2009: Reconstructing faunal migrations using intra-tooth sampling and strontium and oxygen isotope analyses: a case study of modern caribou (*Rangifer tarandus granti*). *Journal of Archaeological Science* 36: 1163-1172.

BROWN, W.A.B.; CHRISTOFFERSON, P.V.; MASSLER, M. & WEISS, M.B. 1960: Postnatal tooth development in cattle. *American Journal of Veterinary Research* 21: 7-34.

BRYANT, J.D.; FROELICH, P.N.; SHOWERS, W.J. & GENNA, B.J. 1996: A tale of two quarries: biologic and taphonomic signatures in the oxygen isotope composition of tooth enamel phosphate from modern and Miocene equids. *Palaios* 11: 397-408.

BURGER, J.; KIRCHNER, M.; BRAMANTI, B.; HAAK, W. & THOMAS, M.G. 2007: Absence of the lactase-persistence-associated allele in early Neolithic Europeans. *Proceedings of the National Academy of Sciences of the United States of America* 104 (10): 3736-3741.

CERLING, T.E. & HARRIS, J.M. 1999: Carbon isotope fractionation between diet and bioapatite in ungulate mammals and implications for ecological and paleoecological studies. *Oecologia* 120: 347-363.

CHANDAN, R.C. 2004: Dairy: yogurt. Chapter 16. In: Smith, J.S. & Huy, Y.H. (eds.): *Food processing: principles and applications*: 297-318. Blackwell Publishing, Ames.

CRAIG, O.E.; MULVILLE, J.; PARKER PEARSON, M.; SOKOL, R.; GELSTHORPE, K.; STACEY, R. & COLLINS, M. 2000: Detecting milk proteins in ancient pots. *Nature* 408: 312.

CRAIG, O.E.; CHAPMAN, J.; HERON, C.; WILLIS, L.H.; BARTOSIEWICZ, L.; TAYLOR, G.; WHITTLE, A. & COLLINS, M. 2005: Did the first farmers of central and eastern Europe produce dairy foods? *Antiquity* 79: 882-894.

DAHL, G. & HJORT, A. 1976: *Having Herds, Pastoral Herd Growth and Household Economy*. Stockholm Studies in Social Anthropology. University of Stockholm, Stockholm.

D'ANGELA, D. & LONGINELLI, A. 1990: Oxygen isotopes in living mammal's bone phosphate: further results. *Chemical Geology* 86: 75-82.

DEGERBø L, M. & FREDSKILD, B. 1970: *The Urus (Bos primigenius Bojanus) and neolithic domesticated cattle (Bos taurus domesticus Linné) in Denmark*. Det Kongelige Danske Videnskabernes Selskab. Biologiske Skrifter 17(1). Munksgaard, København.

DELGADO HUERTAS, A.; IACUMIN, P.; STENNI, B.; SÁNCHEZ, CHILLON, B. & LONGINELLI, A. 1995: Oxygen isotope variations of phosphate in mammalian bone and tooth enamel. *Geochimica et Cosmochimica Acta* 59: 4299-4305.

Dolukhanov, P.M. 2004: Prehistoric environment, human migrations and origin of pastoralism in northern Eurasia. In: Scott, E.M.; Alekseev, A.Y. & Zaitseva, G.I. (eds.): *Impact of the Environment on Human Migration in Eurasia*: 225-242. NATO Science Series. IV. Earth and Environmental Sciences - Vol. 42. Kluwer Academic Publishers, Dordrecht.

Dolukhanov, P.; Shukurov, A.; Gronenborn, D.; Sokoloff, D.; Timofeev, V. & Zaitseva, G. 2005: The chronology of Neolithic dispersal in Central and Eastern Europe. *Journal of Archaeological Science* 32: 1441-1458.

Dreslerová, G. 2006: Vyhodnocení zvířecích kostí z neolitického sídliště Těšetice-Kyjovice (okr. Znojmo, Česká republika). *Archeologické rozhledy* LVIII: 3-32.

Driesch, A. von den, A. 1976: *A guide to the measurement of animal bones from archeological sites*. Peabody Museum Bulletin 1, Harvard.

Ducos, P. 1968: *Les origines des animaux domestiques en Palestine*. Publications de l'Université de Bordeaux, Delmas Bordeaux.

Dürrwächter, C.; Craig, O. E.; Collins, M.J.; Burger, J. & Alt, K.W. 2006: Beyond the grave: variability in Neolithic diets in Southern Germany? *Journal of Archaeological Science* 33: 39-48.

Evershed, R.P.; Payne, S.; Sherratt, A.G.; Copley, M.S.; Coolidge, J.; Urem-Kotsu, D.; Kotsakis, K.; Ozdoğan, M.; Ozdoğan, A.E.; Nieuwenhuyse, O.; Akkermans, P.M.; Bailey, D.; Andeescu, R.R.; Campbell, S.; Farid, S.; Hodder, I.; Yalman, N.; Ozbaşaran, M.; Biçakci, E.; Garfinkel, Y.; Levy, T. & Burton, M.M. 2008: Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature* 455 (7212): 528-531.

Farquhar, G.D.; Ball, M.C.; von Caemmerer, S. & Roksandic, Z. 1982: Effect of salinity and humidity on d ^{13}C values of halophytes-evidence for diffusional isotopic fractionation determined by the ratio of intercellular/atmospheric partial pressure of CO_2 under different environmental conditions. *Oecologia* 52: 121-124.

Fricke, H.C. & O'neil, J.R. 1996: Inter- and intra-tooth variation in the oxygen isotope composition of mammalian tooth enamel: some implications for paleoclimatological and paleobiological research. *Palaeogeography*, *Palaeoclimatology*, *Palaeoecology* 126: 91-100.

Friedli, H.; Lötscher, H.; Oeschger, H. & Stauffer, B. 1986: Ice core record of the $^{13}C/^{12}C$ ratio of atmospheric CO_2 in the past two centuries. *Nature* 324: 237-238.

Gage, J.P. ; Francis, M.J.O. & Triffitt, J.T. 1989: *Collagen and Dental Matrices*. Wright, London.

Gat, J.R. 1980: The isotopes of hydrogen and oxygen in precipitation. In: Fritz, P. & Fontes, J.-Ch. (eds): *Handbook of Environmental Isotope Geochemistry, Vol. 1, The Terrestrial Environment*: 21-48. Elsevier, Amsterdam.

Grant, A. 1982: The use of tooth wear as a guide to the age of domestic ungulates. In: Wilson, B.; Grigson, C. & Payne, S. (eds.): *Ageing and sexing animal bones from archaeological sites*: 91-108. B.A.R. (International Series) 109. Oxford.

Greenfield, H.J. 1988: The origins of milk and wool production in the Old World: a zooarchaeological perspective from the Central Balkans. *Current Anthropology* 29: 573-93.

Greenfield, H.J. 2005: A reconsideration of the Secondary Products Revolution in south-eastern Europe: on the origins and use of domestic animals for milk, wool and traction in the central Balkans. In: Mulville, J. & Outram, A.K. (eds.): *The Zooarchaeology of Fats, Oils, Milk and Dairying. Proceedings of the 9th Conference of the International Council of Archaeozoology, Durham, August 2002*: 14-31. Oxbow Books, Oxford.

Gronenborn, D. 1999: A variation on a basic theme: The transition to farming in southern Central Europe. *Journal of World Prehistory* 13 (2): 123-209.

Gronenborn, D. 2007: Beyond the models: 'Neolithisation' in Central Europe. In: Whittle, A.W.R. & Cummings, V. (eds.): *Going over: The Mesolithic-Neolithic transition in north-west Europe*: 73-98. Proceedings of the British Academy 144. Oxford University Press, London.

Gronenborn, D. 2009: Climate fluctuations and trajectories to complexity in the Neolithic: towards and theory. *Documenta Praehistorica* XXXVI: 97-110.

Halstead, P. 1998: Mortality models and milking: problems of uniformitarianism, optimality and equifinality reconsidered. *Anthropozoologica* 27: 3-20.

Hammond, J.; Mason, I.L. & Robinson, T.J. 1971: *Hammond's Farm Animals*. Edward Arnold, London. 4th edition.

Helmer, D. 1992: *La domestication des animaux par les hommes préhistoriques*. Masson, Paris.

Helmer, D. 1995: Biometria i arqueozoologia a partir d'alguns exemples del Proxim Orient. *Cota Zero* 11: 51-60.

Helmer, D. 2000: Discrimination des genres *Ovis* et *Capra* à l'aide des prémolaires inférieures 3 et 4 et interprétation des âges d'abattage: l'exemple de Dikili Tash (Greece). Gestion démographique des animaux à travers le temps. Colloque international de Turin, 16-18 septembre 1998. Ibex. 5. *Anthropozoologica* 31: 29-38.

Helmer, D. & Vigne, J.D. 2004: La gestion des cheptels de caprinés au Néolithique dans le midi de la France.

In: Bodu, P. & Konstantin, C. (eds.): *Approches fonctionnelles en Préhistoire (Actes XXVe Congrès Préhistorique de France Nanterre, 24-26 novembre 2000:* 397-407. Société Préhistorique Française Édition, Paris.

HENTON, E.; MEIER-AUGENSTEIN, W. & KEMP, H.F. 2010: The use of oxygen isotopes in sheep molars to investigate past herding practices at the Neolithic settlement of Catalhöyük, central Anatolia. *Archaeometry* 52: 429-449.

HIGHAM, C.F.W. 1967: Apendix. Stock Rearing as a Cultural Factor in Prehistoric Europe. *Proceedings of the Prehistoric Society* 33: 84-106.

ITAN, Y.; POWELL, A.; BEAUMONT, M.A.; BURGER, J. & THOMAS, M.G. 2009: The Origins of Lactase Persistence in Europe. *PLoS Computational Biology* 5 (8): 1-13.

JOHANNSEN, N.N. 2006: Draught cattle and the South Scandinavian economies of the 4th millennium BC. *Environmental Archaeology* 11(1): 35-48.

KOČÁR, P.; KOČÁROVÁ, R. & ADAMEC, P. 2008: Chotěbudice – pískovna (okr. Louny). *Unpublished report no. 6/08*. ZIP o.p.s., Plzeň.

KOHN, M.J. 2010: Carbon isotope compositions of terrestrial C3 plants as indicators of (paleo)ecology and (paleo)climate. *Proceedings of the National Academy of Sciences of the United States of America* 107 (46): 19691-19695.

KOMÁREK, V. 1993: *Odhad věku domácích přežvýkavců*. Institut výchovy a vzdělávání ministerstva zemědělství ČR v Praze, Praha.

KONČELOVÁ, M. 2005: Struktura osídlení lidu s lineární keramikou ve východních Čechách. *Archeologické rozhledy*, LVII: 651-706.

KOVAČIKOVÁ, L. 2005: Archeozoologie neolitických lokalit na katastru Horoměřic (okr. Praha – západ). *Archeologie ve středních Čechách*, 9: 143-148.

KOVAČIKOVÁ, L. 2007: Zvířecí kosti z neolitických objektů v Kněžívce. *Archeologie ve středních Čechách* 11: 71-77.

KOVAČIKOVÁ, L. 2009: Příspěvek k poznání výživy a hospodářského zázemí neolitického sídliště v Černém Volu, okr. Praha-západ. *Archeologické rozhledy* LXI (2): 254-264.

KOVAČIKOVÁ, L. & DANĚČEK, D. 2008: Užitkový význam hospodářských zvířat na neolitickém sídlišti v Holubicích. In: Beneš, J. & Pokorný, P. (eds.): *Bioarcheologie v České republice*: 177-198. Jihočeská univerzita v Českých Budějovicích, Přírodovědecká fakulta & Archeologický ústav Akademie věd České republiky, Praha, v.v.i..

KRATOCHVÍL, Z. 1973: Der Fund von *Equus* (*hydruntinus*) *hydruntinus* (Regalia, 1907) und anderer Säuger aus dem südmährischen Neolithikum. *Slovenská archeológia* 21 (1): 195-210.

KVĚTINA, P. 2001: Neolitické osídlení Chrudimska. *Archeologické rozhledy* LIII: 682-703.

LAND, L.S.; LUNDELIUS, E.L. & VALASTRO, S. 1980: Isotopic ecology of deer bones. *Palaeogeography, Palaeoclimatology, Palaeoecology* 32: 143-151.

LECOMTE, T. & LE NEVEU, C. 1986: *Le Marais Vernier. Contribution à l'étude et à la gestion d'une zone humide*. Thèse de doctorat. Université de Rouen Haute-Normandie.

LEE-THORP, J.A.; SEALY, J. & VAN DER MERWE, N.J. 1989: Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* 16: 585-599.

LEE-THORP, J.A. & VAN DER MERWE, N.J. 1991: Aspects of the chemistry of modern and fossil biological apatites. *Journal of Archaeological Science* 18: 343-354.

LEE-THORP, J. A. & SPONHEIMER, M. 2006: Contributions of Biogeochemistry to Understanding Hominin Dietary Ecology. *Yearbook of Physical Anthropology* 49: 131-148.

LONGINELLI, A. 1984: Oxygen isotopes in mammal bone phosphate: a new tool for paleohydrological and paleoclimatological research. *Geochimica et Cosmochimica Acta* 48: 385-390.

LOŽEK, V. 1973: *Příroda ve čtvrtohorách*. Academia, Praha.

LOŽEK, V. 2007: *Zrcadlo minulosti. Česká a slovenská krajina v kvartéru*. Dokořán, Praha.

LUZ, B.; KOLODNY, Y. & HOROWITZ, M. 1984: Fractionation of oxygen isotopes between mammalian bonephosphate and environmental drinking water. *Geochimica et Cosmochimica Acta* 48: 1689-1693.

MAGNY, M. 1995: *Une histoire du climat. Des derniers mammouths au siècle de l'automobile*. Collection des Hespérides, Editions Errance, Paris.

MAGNY, M. 2004: Holocene climate variability as reflected by mid-European lake-level fluctuations and its probable impact on prehistoric human settlements. *Quaternary International* 113: 65-79.

MAZURIÉ DE KEROUALIN, K. 2003: *Genèse et diffusion de l'agriculture en Europe. Agriculteurs, chasseurs, pasteurs*. Éditions Errance, Paris.

MILISAUSKAS, S. & KRUK, J. 1989: Neolithic Economy in Central Europe. *Journal of World Prehistory* 3 (4): 403-446.

MODDERMAN, P.J.R. 1988: The Linear Pottery culture: diversity in uniformity. *Berichten van te Rijksdienst voor het Oudheidkundig Bodemonderzoek* 38: 63-139.

NELSON, S.V. 2005: Paleoseasonality inferred from equid teeth and intra-tooth isotopic variability. *Palaeogeography, Palaeoclimatology, Palaeoecology* 222: 122-144.

NÝVLTOVÁ-FIŠÁRKOVÁ, M. 2004: Fauna z vybraných objektů z lokality Vedrovice (lineární keramika-neolit). In: Hašek, V.; Nekuda, R. & Ruttkaj, M. (eds.): *Ve službách archeologie V*: 173-179. Muzejní vlastivědná společnost v Brně-Geodrill Brno-Archeologický ústav Slovenské akademie věd Nitra. Brno.

OELZE, V.M.; SIEBERT, A.; NICKLISCH, N.; MELLER, H.; DRESELY, V. & ALT, K.W. 2011: Early Neolithic diet and animal husbandry: stable isotope evidence from three Linearbandkeramik (LBK) sites in Central Germany. *Journal of Archaeological Science* 38: 270-279.

O'LEARY, M.H. 1988: Carbon isotopes in photosynthesis. *Bioscience* 38: 328-335.

PAVLŮ, I. 2005: Neolitizace Evropy. *Archeologické rozhledy* LVII: 293-302.

PAVLŮ, I. & ZÁPOTOCKÁ, M. 1979: Současný stav a úkoly studia neolitu v Čechách. *Památky archeologické* 70: 281-318.

PAVLŮ, I. (ED.) & ZÁPOTOCKÁ, M. 2007: *Archeologie pravěkých Čech 3, Neolit*. Archeologický ústav AV ČR, Praha, v.v.i, Praha.

PAYNE, S. 1973: Kill-off patterns in sheep and goats: the mandibles from Aşvan Kale. *Journal of the British Institute of Archaeology at Ankara* 23: 281-303.

PENNETIER, G. 1983: *Histoire naturelle agricole du gros et petit bétail*. Librairie Polytechnique, Paris.

PEŠKE, L. 1974: Osteologický rozbor zvířecích kostí z Klíčan, o.Praha-východ. *Archeologické rozhledy* XXVI: 332-338.

PEŠKE, L. 1991: Archeologický výzkum neolitického sídliště v Roztokách. *Muzeum a současnost* 10/2: 271-293.

PEŠKE, L. 1992: Osteologické nálezy z Dobšic okr. Nymburk. In: Břicháček, P. & Rulf, J.: *Objekt kultury s lineární keramikou z Dobšic nad Cidlinou (okr. Nymburk) a mikroregion Dolní Cidliny v neolitu*: 169. *Archeologické rozhledy* XXXXIV: 153-169.

PEŠKE, L. 1994: Příspěvek k poznání počátku dojení skotu v pravěku. *Archeologické rozhledy* XLVI: 97-104.

PEŠKE, L.; RULF, J.& SLAVíKOVÁ, J. 1998: Bylany-ekodata. Specifikace nálezů kostí a rostlinných makrozbytků. *Bylany Varia* 1: 83-118.

PÉTREQUIN, P.; ARBOGAST, R.-M.; PÉTREQUIN, A.-M.; WILLIGEN, S. VAN & BAILLY, M. 2006: *Premiers chariots, premiers araires*. *La diffusion de la traction animale en Europe pendant les IVe et IIIe millénaires avant notre ère*. CNRS Editions, CRA Monographies 29, Paris.

PRICE, D.T. 2000: *Europe's First Farmers*. Cambridge University Press, Cambridge.

PRICE, D.T.; BENTLEY, R.A.; Lü NING, J.; GRONENBORN, D. & WAHL, J. 2001: Prehistoric human migration in the Linearbandkeramik of Central Europe. *Antiquity* 75: 593-603.

PYANKOV, V.I.; ZIEGLER, H.; AKHANI, H.; DEIGELE, C. & Lü TTGE, U. 2010: European plants with C4 photosynthesis: geographical and taxonomic distribution and relations to climate parameters. *Botanical Journal of the Linnean Society* 163: 283-304.

QUITTET, E. & DENIS, B. 1963: *Races bovines françaises*. *Collection Les races d'animaux domestiques*. 3rd edition. La Maison Rustique, Paris.

RADA, I. 1981: The investigation of the Linear Pottery settlement at Chotěbudice in 1974. *Archeologické rozhledy* XXXIII: 3-18.

RADA, I. 1986: Sídliště kultury s lineární keramikou v Chotěbudicích, okr. Louny. *Archeologické studijní materiály* 15: 77-84.

RASMUSSEN, P. 1989: Leaf-foddering of livestock in the Neolithic: archaeobotanical evidence from Weier, Switzerland. *Journal of Danish Archaeology* 8: 51-71.

REINHARDT, C.; REINHARDT, A. & REINHARDT, V. 1986: Social behaviour and reproductive performance in semi-wild Scottish Highland cattle. *Applied Animal Behaviour Science* 15: 125-136.

ROBINSON, R.K. & TAMIME, A.Y. 2006: Types of fermented milks. In: Tamine, A.Y. (ed.): *Fermented milks*: 1-10. A.Y. Blackwell Publishing, Oxford.

ROBLíČKOVÁ, M. 1999: Zvířecí osteologické pozůstatky na sídlišti kultury s vypíchanou keramikou na lokalitě Olomouc-Slavonín. In: Kazdová, E.; Peška, J. & Mateiciucová, I. (eds.): *Olomouc-Slavonín (I). Sídliště kultury s vypíchanou keramikou*: 174-184. Archaeologiae Regionalis Fontes 2.

RULF, J. 1983: Přírodní prostředí a kultury českého neolitu a eneolitu. *Památky archeologické* LXXIV: 35-95.

RULF, J. 1991: Neolithic agriculture of Central Europe - Review of the problems. *Památky archeologické* 82(2): 376-384.

RULF, J. & ZÁPOTOCKÁ, M. 1994: Neolithic Studies in Bohemia: 1969-1994. In: Fridrich, J. (ed.): *25 Years of Archaeological Research in Bohemia*. Památky archeologické, Supplementum 1: 23-36.

ŘíDKÝ, J.; STOLZ, D. & ZÁPOTOCKÁ, M. 2009: Neolithic settlement in Černý Vůl (Prague-west). Forms of features, pottery analysis and chipped stone industry from excavations in 1975-77 and 1914. *Praehistorica* XXVIII: 177-236.

ŘíDKÝ, J. 2011: Rondels and the Structure of settlement Areas in the Late Neolithic Pariod. In: Měřínský, Z. & Klápště, J. (eds.): *Dissertationes Archaeologicae Brunenses/Pragensesque 10*. Praha-Brno.

SÁDLO, J.; POKORNÝ, P.; HÁJEK, P.; DRESLEROVÁ, D. & CíLEK, V. 2005: *Krajina a revoluce. Významné* *přelomy ve vývoji kulturní krajiny Českých zemí*. Malá Skála, Praha.

SHERRATT, A.G. 1981: Plough and pastoralism: aspects of the Secondary Products Revolution. In: Hodder, I.; Isaac, G. & Hammond, N. (eds.): *Pattern of the Past*: 261-306. Cambridge University Press, Cambridge.

SHERRATT, A.G. 1983: The Secondary Products Revolution of animals in the Old World. *World Archaeology* 15: 90-104.

SMITH, B.N. & EPSTEIN, S. 1971. Two categories of $^{13}C/^{12}C$ ratios for higher plants. *Plant Physiology* 47: 380-384.

SMRČKA, V.; BŮZEK, F.; ERBAN, V.; BERKOVEC, T.; DOČKALOVÁ, M.; NEUMANOVÁ, K. & NÝVLTOVÁ FIŠÁRKOVÁ, M. 2005: Carbon, nitrogen and strontium isotopes in the set of skeletons from the Neolithic settlement at Vedrovice (Czech Republic). *Anthropologie* XLIII/2-3: 315-323.

SOLTNER, D. 1990: *L'alimentation des animaux domestiques*. Sciences et techniques agricoles, Paris.

STUIVER, M.; BURK, R.L. & QUAY, P.D. 1984: $^{13}C/^{12}C$ Ratios in Tree Rings and the Transfer of Biospheric Carbon to the Atmosphere. *Journal of Geophysical Research* 89, D7: 11731-11748.

ŠUMBEROVÁ, R. 1991: Neolithic settlement site at Chotěbudice, Distr. of Louny (excavations of 1988 and 1990). *Archaeology in Bohemia*: 194-195.

ŠUMBEROVÁ, R. 1995: Analýza keramiky z objektu 77 ze sídliště kultury s LnK v Chotěbudicích, okr. Louny. In: Popelka, M. (ed.): *Neolitická štípaná industrie z Chotěbudic, okr. Louny*: 9-19. Varia Archaeologica 6, Praha.

TIESZEN, L.L. & BOUTTON, T.W. 1988: Stable carbon isotopes in terrestrial ecosystem research. In: Rundel, P.W.; Ehleringer, J.R. & Nagy, K.A. (eds.): *Stable Isotopes in Ecological Research*: 167-195. Springer-Verlag, New York.

TRESSET, A. 1996: *Le rôle des relations homme/animal dans l'évolution économique et culturelle des sociétés des Ve-IVe millénaires en Bassin Parisien*. Thèse de 3e cycle, Panthéon-Sorbonne, Paris.

TRESSET, A. & VIGNE, J.-D. 2011: Last hunter-gatherers and first farmers of Europe. *Comptes Rendus Biologies* 334(3): 182-189.

VAN DER MERWE, N.J. 1989: Natural variation in ^{13}C concentration and its effect on environmental reconstruction using $^{13}C/^{12}C$ ratios in animal bones. In: Price, T.D. (ed.): *The chemistry of prehistoric human bone*: 105-125. Cambridge University Press, Cambridge.

VAN DER MERWE, N.J. & MEDINA, E. 1991: The Canopy Effect, Carbon Isotope Ratios and Foodwebs in Amazonia. *Journal of Archaeological Science* 18: 249-259.

VENCL, S. (ed.) 2006: *Nejstarší osídlení jižních Čech: paleolit a mesolit*. Archeologický ústav AV ČR, Praha.

VIGNE, J.-D. 1988: *Les mammifères du Post-Glaciaire de Corse, étude archéozoologique*. Gallia Préhistoire. 26ème supplément. CNRS, Paris.

VIGNE, J.-D. 2008: Zooarchaeological Aspects of the Neolithic Diet Transition in the Near East and Europe, and Their Putative Relationships with the Neolithic Demographic Transition. In: Bocquet-Appel, J.-P. & Bar-Yosef, O. (eds.): *The Neolithic Demographic Transition and its Consequences*: 179-205. Springer Netherlands.

VIGNE, J.-D.; HELMER, D. & PETERS, J. 2005: New archaeological approaches to trace the first steps of animal domestication: general presentation, reflections and proposals. In: Vigne, J.-D.; Helmer, D. & Peters, J. (eds.): *First Steps of Animal Domestication. New archaeozoological approaches. Proceedings of the 9th Conference of the International Council of Archaeozoology, Durham, August 2002*: 1-17. Oxbow Books, Oxford.

VIGNE, J.-D. & HELMER, D. 2007: Was milk a «secondary product» in the Old World Neolithisation process? Its role in the domestication of cattle, sheep and goats. *Anthropozoologica* 42(2): 9-40.

WHITTLE, A. 1996: *Europe in the Neolithic. The creation of New Worlds*. Cambridge University Press, Cambridge.

ZÁPOTOCKÁ, M. 2007: Die Entstehung und Ausbreitung der Kultur mit Stichbandkeramik. In: Kozłowski, J.K. & Raczky, P. (eds.): *The Lengyel, Polgár and related Cultures in the Middle/Late Neolithic in Central Europe*: 199-216. The Polish Academy of Arts and Sciences Kraków. Eötvös Loránd University. Institute of Archaeological Sciences. Budapest, Kraków.

ZÁPOTOCKÁ, M. 2009: Der ü bergang von der Linear- zur Stichbandkeramik in Böhmen. In: Zeeb-Lanz, A. (Hrsg.): *Krisen – Kulturwandel – Kontinuitäten. Zum Ende der Bandkeramik in Mitteleuropa. Beiträge der Internationalen Tagung in Herxheim bei Landau (Pfalz) vom 14.–17. 06. 2007*: 303-315. Leidorf, Rahden/Westf.

ZEDER, M.A. & PILAAR, S.E. 2010: Assessing the reliability of criteria used to identify mandibles and mandibular teeth in sheep, *Ovis*, and goats, *Capra*. *Journal of Archaeological Science* 37: 225-242.