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Wealth or Just Job Seekers: Medieval Skeletal Series from Kutná Hora-Sedlec (Czech Republic) with a Notable Surplus of Men

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ABSTRACT

Kutná Hora entered the 14th century as a rich, prosperous, and densely-populated city producing tons of silver. Such an amount of precious metal could not be mined and processed without an influx of people from other cities and rural areas and without the contribution of skilled specialists from abroad. Despite the apparent wealth of the city, its inhabitants (either settled or newly arrived) experienced and died during mortality crises. Evidence of such events was discovered in the Kutná Hora suburbs, where the medieval burial ground, including a significant component of mass burials, has been unearthed. In the data derived from pooled catastrophic and non-catastrophic burials (n=1785 individuals), a notable surplus of males has been identified with a striking imbalanced adult sex ratio of 149. After considering factors potentially influencing this value, we suggest that the figure likely mirrors the original population composition as a consequence of the inflow of men migrating to the town for labour/economic opportunities.

1. Introduction

Silver-bearing ores of the Kutná Hora ore district were probably discovered in the 1260s. Their mining began in the last quarter of the 13th century, peaked during the 14th century and still played an important role in the 15th century. At that time, mining continued at depth, following the ore bodies down, with the deepest part reaching a depth of hundreds of metres (Jaroš, 1955). By the 16th century, mining was then beyond its zenith, its decline already begun, and the deposits were entirely exhausted by the end of the 17th century (Maur, 2001; Vaněk and Velebil, 2007; Frolík, 2012; Duraj *et al.*, 2019).

Traces of old mining activity are ubiquitous in this area. They include shaft adits, collapsed shafts, mining residue dumps, gallery entrances in stream and river valleys, slag heaps, traces of the continual changes and overturning of ground layers, and findings of items of ceramic technology, or lighting instruments, and include the St George mining gallery which is accessible to the public (Valentová, 1999; Bartoš, 2008; Absolon, 2018). Another old mine, its accessibility strictly limited to experts, is situated in a large depression at the top of a nearby hill (Pechočová, 1992; Tomášek, 1999). Old subterraneous workings are subject to ongoing underground prospection, investigation and documentation – both by amateurs and experts of local mining history (Velímský, 2017). Despite the obvious symbiosis of mining and metallurgical activities during the Middle and Early Modern ages, the findings of smelting workshops or places of probable smelting trials are very rare (Valentová, 1993; 1999; Frolík, 2014). It is estimated that the local deposits have yielded over 1700–2500 tons of silver; however, the upper limit of this range has been estimated on the basis of highly indirect entries, such as data on the size of the royal urbura – the monarch's share of the profit – and various royal payments (Kořan, 1950; Vaněk and Velebil, 2007; Holub, 2015).

We have to face even much higher uncertainty when it comes to population estimates of this historical area. Any estimates of the size of medieval cities remain highly speculative, but we cannot avoid them. According to some assessments, at the end of the 14th century, Kutná Hora had about 8,000 inhabitants (Maur, 1998, p.49); however, other studies present (for around 1500 CE) that the population of

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the city and its suburbs was more than 10,000, and perhaps even 18,000 (Molenda, 1976; Macek, 1992, p.27). Urban growth will occur based on natural increases and any net immigration from nearby or relatively more distant regions (Betsinger and DeWitte, 2021), and this certainly also applied to medieval Kutná Hora, whose socio-professional structure was characterised by an absolute predominance of professions and crafts related to mining, metallurgy and minting. The continuing demand for silver affected the mining system, which was forced into an increasing specialisation of workers with the gradual penetration into greater mining depths (Jaroš, 1955).

Thanks to textual as well as pictorial evidence, it is known, which professions worked here. Namely, the Kutná Hora Illumination and the picture in the Kutná Hora Gradual depict the mining and processing of silver in a detailed and almost documentary manner. In addition to the entire technological process (ore milling, ore washing, sales to ore merchants, smelting to produce silver), the illustrations have also captured its protagonists: miners, mine carpenters, workers carrying ore or gangue, organisers of mining works, mine officers, unqualified labourers working on mine ventilation, ore processing, *etc.* (see Stöllner, 2008 for a more detailed description of all possible activities; Štefan, 2013a). The most complex technological steps were performed by early smelters, whose skills and knowledge went deep and were to be admired because they were able to experimentally-empirically develop highly complicated metallurgical processes without relying on a basic theoretical knowledge of chemistry. They were, for example, able to obtain silver from some poorer and resilient ores of various kinds, as was the case in Kutná Hora (Vaněk and Velebil, 2007). All the above-mentioned workers formed very specific and artificial communities working in hostile places, created against all odds and facing regular and serious threats. They were subject to the harsh working conditions associated with mining and smelting: poor ventilation, flooding, mine or rock collapse, and inhalation of noxious gases (toxic) released during metallurgical processes. On the other hand, due to their considerable economic importance, medieval miners were also offered distinct social, economic, and legal advantages over most other physical labourers at that time (Geltner and Weeda, 2021).

During the exploitation of silver deposits, Kutná Hora had always lived "beyond its means" compared to the surrounding territory and the weight of silver could have mitigated against the consequences of disasters and catastrophes (Štefan, 2013b). It is documented that an extensive food supply was necessary to keep early modern Swedish miners and related workers healthy and able to work, and to keep mining operations continuous and at the same intensity (Bäckström *et al.*, 2018). As in Sweden, the Kutná Hora mining community could also have been provided with basic commodities during barren years and the city better buffered from the periodically-occurring famines and disasters. However, the city never resisted completely in every case and occasionally had to surrender. Due to the scarcity of detailed chronicler reports and historical data, little is known about the local famines and epidemic outbreaks, but the town's high population density coupled with its unhygienic conditions made residents prone to infections (Walter and DeWitte, 2017). However, direct evidence of mortality crises has been discovered in a Kutná Hora suburb, where a medieval burial ground that includes a significant component of mass burials has recently been unearthed (Brzobohatá *et al.*, 2019; Brzobohatá *et al.*, 2021; de Lépinau *et al.*, 2021). These mass graves have been assigned to catastrophic events of the second and fifth decade of the 14th century, with famine and mortality that peaked in 1318, and plague mortality that peaked in 1348–1350 (see below).

The need for both skilled and unskilled workforces that could run the mines prompted the necessary immigration of settlers. From the very beginning of the existence of Czech cities, their proportion of Czech inhabitants gradually increased with the arrival of rural populations from surrounding areas (Maur, 1998). In addition to this predominantly Czech group, the influx of new manpower from abroad to the newly-opened mines benefitted both the settlers and the owners of land rich in silver resources. Similar to other East-Central European medieval mining cities, typical foreign settlers were Germans – ready-skilled miners and smelters who migrated here from areas with long-established mining traditions (Maur, 1998, p.49; Szende, 2011, p.196; 2019; Štefan, 2013b). The proportion of Italians, for example the professional tradesmen and financiers involved in organising and financing the mining operations and who carefully selected the commercially-most-significant settlements, was also not negligible (Szende, 2011, p.196; 2019).

Since the medieval towns provided various employment opportunities, women may have constituted a significant proportion of the Kutná Hora incomers. But silver-ore mining and silver metallurgy mainly involved male-dominated jobs and thus it can be assumed, with high probability, that new migrants were predominantly men. However, the extent of this phenomenon is unclear and is not discernible from the written evidence. The high immigration rate of particular segments of the population – such as males capable of silver mining/smelting and those migrating for labour opportunities – should be something reflected in the mortality record (Grauer, 2002, p.277). The aim of this study is to present the first anthropological data from the perspective of the population's sex ratio – an index of the sex composition in demographic and other scholarly analyses that refers to the total number of males for every 100 females in the population (Poston and Micken, 2005, p.42). Much of the contemporary research on sex ratios deals with sex ratios at birth. Worldwide, today, the sex ratio at birth is not equal (but remarkably homogeneous) and usually reaches values about 103–107 boys per 100 girls (Bardsley, 2014; Chao *et al.*, 2019). The child sex ratio, assigned to the period of infancy and childhood, can be affected by a wide range of determinants, such as differential mortality rates, gender-discriminatory practices or less apparent factors such as

various kinds of patriarchal features (Szołtysek *et al.*, 2022). In adult populations, its value depends on several factors: the sex ratio at birth, differential mortality rates between the sexes at different ages, and losses and gains through migration (Hesketh and Zhu, 2006). In most countries throughout the world, the greater mortality rates of males means that the sex ratio decreases across the age range to a value much closer to 100 in full adulthood. In developed countries there is a further decline in the sex ratio and women usually predominate in the older age categories (Coale, 1991; Klufová, 2008, p.41). Currently this indicator can take various forms, such as the operational sex ratio, which captures the number of men and women that are available to potential partners (Filser and Willführ, 2022).

In the current study we have aimed: (1) to investigate the possible differences in male and female counts in the skeletal assemblages derived from the medieval population of Kutná Hora, and (2), if the assumption of a surplus of men is confirmed as a given, to explore whether this surplus is manifested both in years of demographic crises and in non-catastrophic times, in a consistent way.

2. Materials and Methods

2.1 Archaeological Context and Site Information

The recorded evidence of prehistoric and medieval colonisation in the Kutná Hora-Sedlec area is very rich owing to the long-term archaeological research of the site and its key subject, the famous Cistercian monastery (Velímský, 2009; Charvátová, 2013). The Cemetery Church of All Saints with Ossuary, originally Gothic but latterly rebuilt in the Baroque style in the 1700s, is located in the northern part of the monastery complex on a very gentle, north-rising slope that forms part of the southern foot of Kaňk Hill (Figure 1). The cemetery neighbouring the church building is still a functional burial ground for the local population, which is the reason why no archaeological excavation had been carried out there until 2013. The cemetery has been reported as being in this position since the end of the 13th century, when it was to be newly founded as a lay cemetery for the monastery's subjects (tributaries) and the newly-arrived population of upper settlements in the expanding town of Kutná Hora. The first mention of Sedlec cemetery *(Scedlicensi cimiterio)*

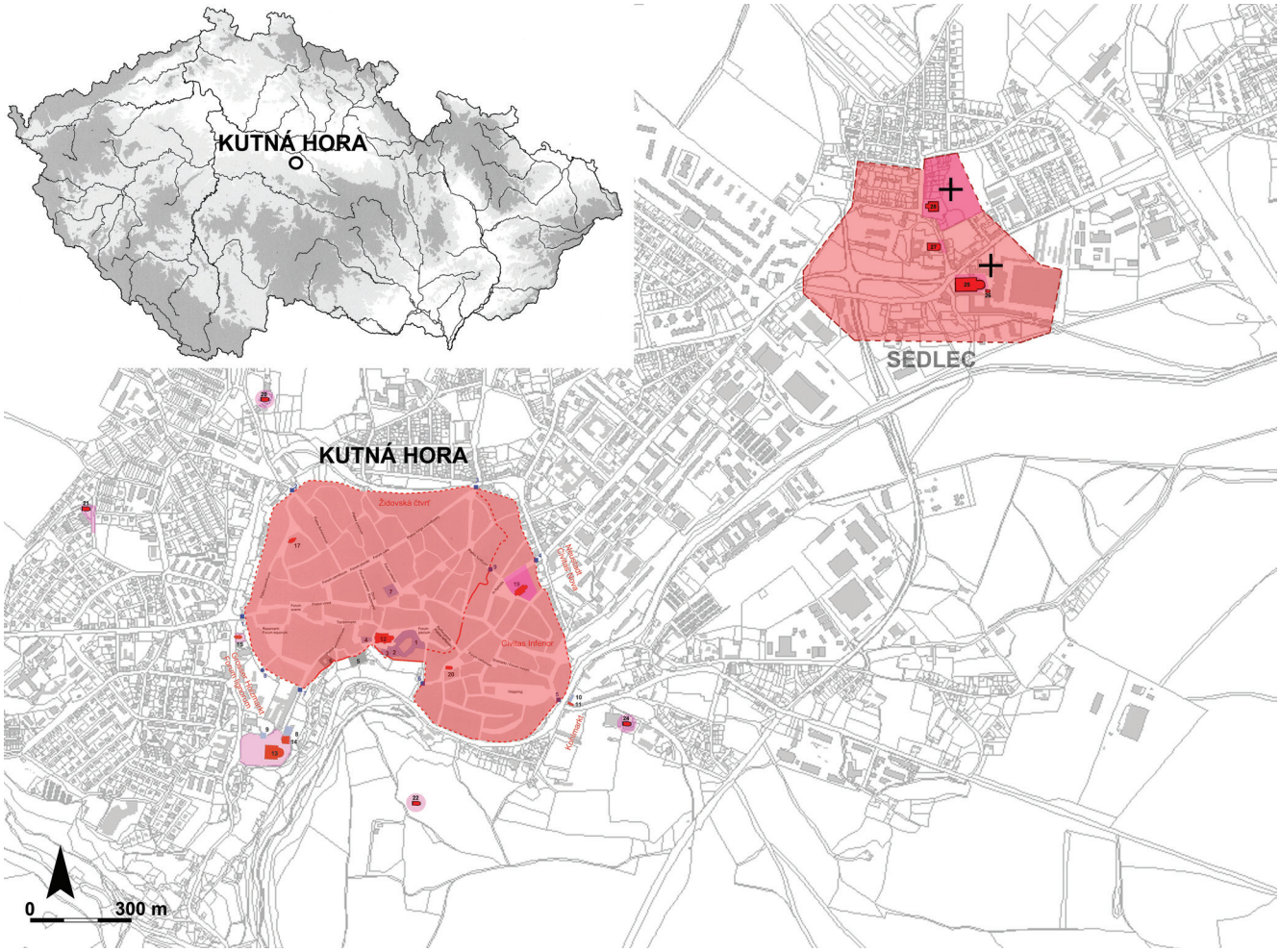

Figure 1. Plan of Kutná Hora and Sedlec suburb with the range of high medieval settlements (indicated in light-red colour and bordered by dashed lines); high medieval church buildings (red ground plans, cemetery areas in pink); the location of the Kutná Hora-Sedlec Cemetery Church of All Saints with Ossuary (upper dagger), and Cathedral of the Assumption of Our Lady (lower dagger).

itself is in the Zbraslav Chronicle of Petr Žitavský, dating from before 1305 (FRB IV., p.51).

The Cemetery Church of All Saints with Ossuary is estimated to contain the bones of 40,000–60,000 people arranged in patterns and pyramids. Recent rescue excavation in the graveyard surrounding the church with ossuary was necessitated by the planned reconstruction and stabilisation of this exceptional building. That led to the discovery of 32 complete and incomplete mass burials in its vicinity, giving a total of around nine hundred skeletons and 878 individual graves, uniquely demonstrating the large-scale mass mortality that had occurred during well-defined periods (dataset CCHURCH TOTAL; the figures refer to primary burials in anatomical contexts; Frolík, 2017a; Frolík, 2017b; Frolík, 2018; Figure 2). The chronology of the mass graves at the ossuary is based on an investigation of the stratigraphic configuration: with two levels of pits corresponding to the two catastrophes. The younger stratigraphic level indicates damage by the ossuary walls. The younger graves are assigned to the fatalities of the 1348–1350 plague epidemic, based on coin excavations from two of the graves, namely, Prague groschen-type coins of the Czech King John of Luxembourg who reigned from 1310 to 1346. These include the last mintage dated 1346. Dates connected with later plague outbreaks are excluded because the ossuary was constructed prior to 1400 (Poche, 1980, p.302; Chadraba, 1984, p.200). The older level is linked to the famine and burial of victims at the front of the gates of Sedlec in Kutná Hora based on the 1318 report of the Zbraslav Chronicle (FRB IV., p.248). During both aforementioned crises, with the initial mortality probably only rising gradually, the first dead could still have been buried in the usual manner, and the mass graves would only have become necessary when the situation had already become unbearable. When the critical moment arrived, corpses were laid out without coffins in a supine position within rectangular pits (ca. 2 m × 2 m, depth ca. 2.5 m) in several cross-stacked layers. Meanwhile, grave diggers would try to save room by placing child cadavers in the pit corners of the 'tomb'. Except for exceptional circumstances, the bodies were not thrown into the pit, but were carefully laid down and separated by layers of soil. The rest of the graves, *i.e.*, single inhumations, are archaeologically dated to the 13–14th centuries, and to the 14–16th centuries, respectively (Brzobohatá *et al.*, 2019). Material artifacts recovered from the site consisted primarily of buckles, rings, pottery sherds and coins (Frolík, 2017b; 2018).

The second skeletal assemblage under study comes from rescue research before the installation of a drainage system surrounding the foundation of the nearby cathedral (conducted by F. Velímský). Behind the presbytery of the Cathedral of the Assumption of Our Lady (a UNESCO-listed site), a section of a multiple-stage medieval cemetery, with 284 individuals in total, was discovered in 2007. The cathedral was a monastery church of the oldest former Cistercian abbey in Bohemia. It was built between 1290 and 1320 in the period of the biggest economic growth of the Cistercian monastic order. The adjacent burial ground (Figure 3) was probably in use throughout the medieval

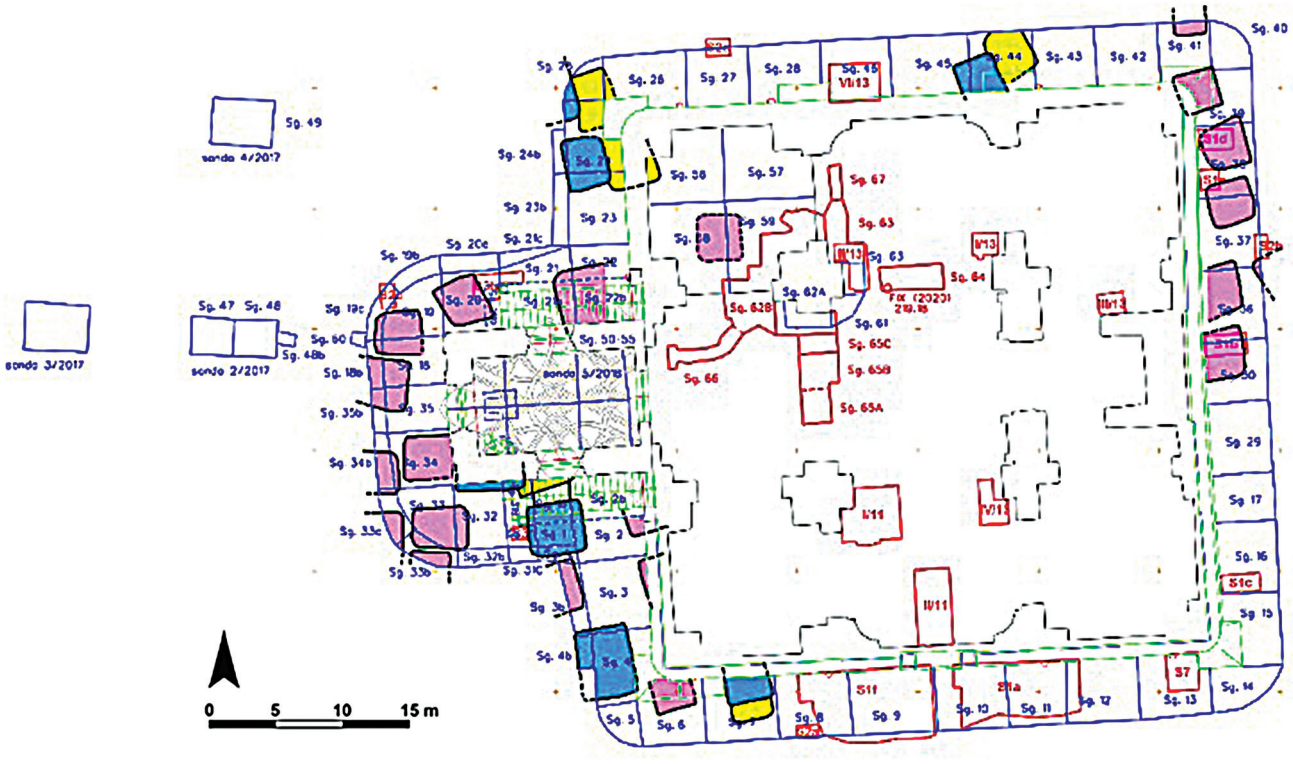

Figure 2. Map showing the site area of the Kutná Hora-Sedlec Cemetery Church of All Saints with Ossuary and the location of mass graves within the excavated area (mass graves are bordered by a black line, the colour of the filling indicates assignment to a catastrophic event: blue, plague-related burials; yellow, famine-related burials; pink, not yet assigned).

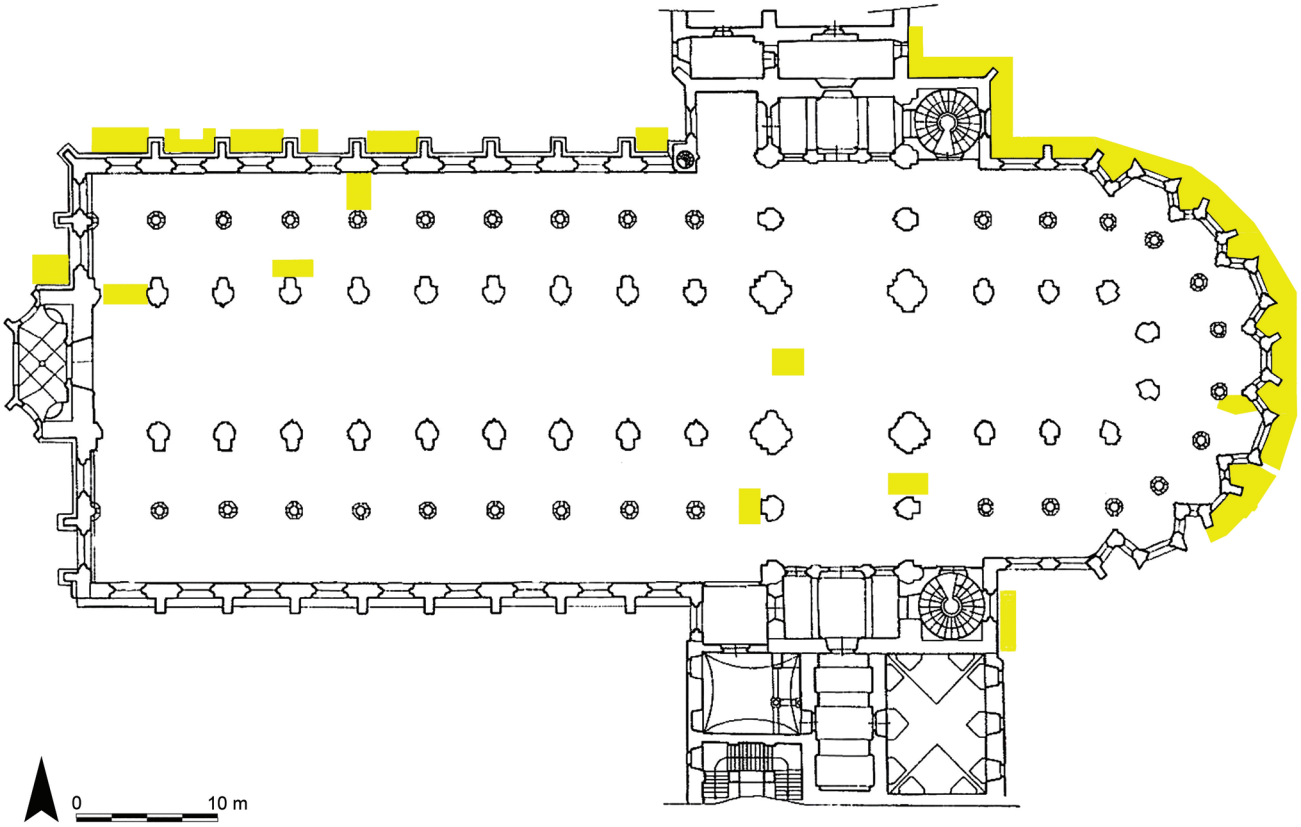

Figure 3. Map of the site area at the Cathedral of the Assumption of Our Lady in Kutná Hora-Sedlec showing the extent of archaeological rescue excavation of a cemetery (in yellow).

period (12th–15th century); nevertheless, without strong confirmation in the archaeological material, burials there ended presumably with the Hussite wars when (in 1421) the Hussite troops attacked and destroyed the Cistercian monastery (including the cathedral), which was burnt down. The temple remained ruined for another 279 years, until its reconstruction in the beginning of the 18th century in the Baroque Gothic style. At this particular necropolis, no mass synchronous deposition of corpses has been found (Velímský *et al.*, 2008). Another comparative medieval – post-medieval skeletal series was selected to meet the criteria of comparable size, geographical and chronological closeness with the aforementioned skeletal assemblages, and the availability of an anthropological report or published demographic data (Živný, 2010).

Skeletal remains from Kutná Hora-Sedlec are deposited in the depository of the National Museum in Prague-Horní Počernice (material from Cemetery Church of All Saints with Ossuary), and in the detached department of the Institute of Archaeology of the Czech Academy of Sciences in Kutná Hora (bones excavated at the Cathedral of the Assumption of Our Lady).

2.2 Methods

The skeletons unearthed at the Cemetery Church of All Saints with Ossuary (CCHURCH TOTAL) were divided into subgroups according to the funeral context. Skeletons from catastrophic graves, both famine-supposed and plague-supposed mass burials, constituted a dataset abbreviated as CCHURCH MASS. Skeletons that came from normative individual burials, pre- and post-dating catastrophic burials, were assigned to the dataset abbreviated as CCHURCH IND. The last sample under study consists of individuals buried around the Cathedral of the Assumption of Our Lady (dataset CATHEDRAL). Details of the samples are given in Table 1.

Once cleaned and restored, the bones were analysed using traditional anthropological methods to determine sex, age at death, and body size. The age at death of adult individuals (>18 years) was estimated based on the degree of dental attrition, and the metamorphosis of sternal rib ends and the articular facets of the ilium (Todd, 1920; Iscan *et al.*, 1984; Lovejoy, 1985; Schmitt, 2005). The sex was determined by the presence of masculine cranial and pelvic features with an emphasis on the latter (Phenice, 1969; Ferembach *et al.*, 1980; Brůžek, 2002; Murail *et al.*, 2005). The final subsamples of sexed individuals consist only of skeletons that had the relevant and adequately-preserved skeletal elements needed for sex determination (Table 1).

Postcranial adult bones from the CCHURCH TOTAL and CATHEDRAL dataset were measured more thoroughly, the set of dimensions thus obtained allowing us to apply the principles of primary and secondary sex diagnosis.

Table 1. Characteristics of the studied samples by age and sex (NAD, non-adults; M, males; F, females; IND, indeterminate adults).

Dataset	Recovered individuals						
	NAD	AD	M	F	IND	Total	Sex ratio
CCHURCH	707	1078	396	266	416	1785	148,9
CCHURCH MASS	322	585	232	168	185	907	138,1
CCHURCH IND	385	493	164	98	231	878	167,3
CATHEDRAL	54	230	106	31	93	284	341,9

This approach has been recommended by Murail and co-authors and consists in using those individuals whose pelvic sex could be determined as a reference sample for the extrapelvic sex estimation of individuals without a preserved pelvis (Murail *et al.*, 1999). To create a reference sample, a total of 16 postcranial measurements of selected right bones (Martin and Saller, 1957) were taken from 413 (CCHURCH TOTAL) and 83 (CATHEDRAL) measurable and sexed individuals (Table 3). The same measurements were taken from the bones of non-sexed measurable adults. All extrapelvic osteometric data were subjected to secondary sex diagnosis performed using the *rdss* package developed and introduced by F. Santos (2021) for the R statistical software (R Core Team, 2020) (*dss* abbreviation is derived from the French *diagnose sexuelle secondaire*). Of the four possible statistical tools for sex estimation implemented in the *rdss* package, linear discriminant analysis (LDA) was chosen with the classification threshold for sex allocation set at 0.95.

Table 2. Characteristics of the studied samples including individuals sexed using the DSS approach (NAD, non-adults; M, males; F, females; IND, indeterminate adults).

Dataset	Recovered individuals						
	NAD	AD	M	F	IND	Total	Sex ratio
CCHURCH DSS	707	1078	477	334	267	1785	142,8
CCHURCH MASS DSS	322	585	275	199	111	907	138,2
CCHURCH IND DSS	385	493	202	135	156	878	149,6
CATHEDRAL DSS	54	230	130	49	51	284	265,3

Table 3. List of extrapelvic variables. The upper and lower limb bone measurements (according to Martin and Saller, 1957) selected for the secondary sex diagnosis of individuals not preserving the pelvis.

Variable	Measurements
H1	Humeral maximul length
H4	Humeral distal epiphyseal breadth
H7a	Humeral midshaft circumference
H10	Humeral head maximum sagittal diameter
R1	Radial maximum length
U1	Ulnar maximum length
F1	Femoral maximum length
F8	Femoral midshaft circumference
F18	Femoral head vertical diameter
F21	Femoral distal epiphyseal breadth
T1a	Tibial maximum length
T3	Tibial proximal epiphyseal breadth
T6	Tibial distal epiphyseal breadth
T10	Tibial midshaft circumference
Ta1	Talar length
Ta2	Talar breadth

The datasets which included those males and females that were newly assigned using secondary sex diagnosis were labelled CCHURCH TOTAL DSS and CATHEDRAL DSS.

For determining the sex composition of a population, we used a standard demographic indicator – the sex ratio, *i.e.*, the number of men for every 100 women, which has been calculated from the number of males divided by the number of females and multiplied by 100: $(N_m/N_f)*100$ (Kalibová, 2005, p.17). In the analyses of the CCHURCH MASS dataset, we intentionally omitted marginally disturbed mass graves with one or two incomplete skeletons (mass grave Nos. 19, 31 and 32).

3. Results

In total, the burial ground at the Kutná Hora-Sedlec Cemetery Church (sample CCHURCH TOTAL, pooling both catastrophic and non-catastrophic medieval burials) contained the remains of a minimum of 1,785 individuals (prime burials, skeletons in their original burial position), with 707 nonadults (<18 years old) and 1,078 adults. The osteological series CATHEDRAL was comprised of the remains of a minimum of 284 individuals, with 54 nonadults

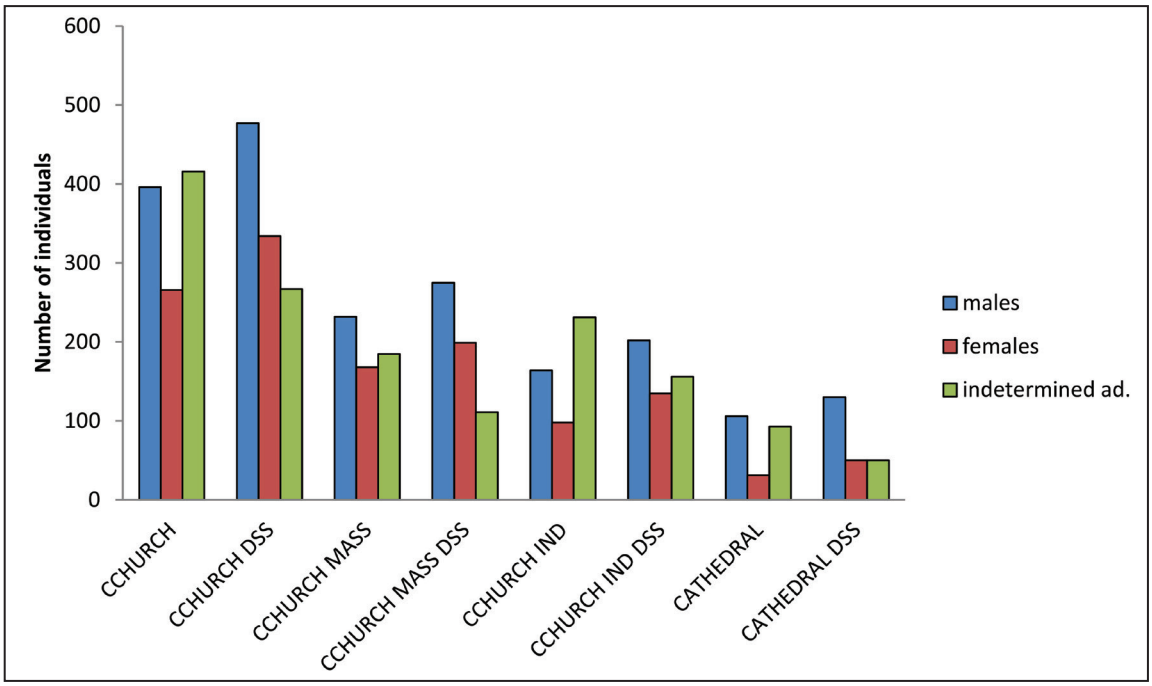

Figure 4. Sex distribution in adult groups within Kutná Hora-Sedlec datasets and effect of secondary sex diagnosis (in DSS samples; ad., adults).

and 230 adults. Substantial numbers of adult skeletons were not assigned a sex because they were either too fragmentary or were lacking important diagnostic elements, a pelvis or skull. The percentage of these sex-undetermined skeletons reached the values of 31.6% for CCHURCH MASS, 46.9% for CCHURCH IND, and 40.4% for CATHEDRAL dataset (Table 1, Figure 4).

The data assembled from all series showed that the sex ratio varied considerably (reaching values from 138.1 in CCHURCH MASS to 341.9 in CATHEDRAL group, Table 1) but it always exhibited a predominance of men. The sex ratio computed from single interments adjacent to the cemetery church (CCHURCH IND) is higher than the sex ratio obtained from the mortality crises assemblage (CCHURCH MASS), but the number of men does not exceed twice the number of women. The value yielded from the CATHEDRAL dataset showed a more than triple surplus of men (Table 1). This ratio was later changed after including adults additionally sexed using the DSS approach (Table 2).

The overall sex ratio of the CCHURCH MASS skeletal group was 138.1 (and 138.2 after DSS) and a closer look at the specific mass graves data revealed that sex distribution more frequently showed a majority of men to women: out of 27 mass burials analysed, a total of 22 exhibited a surplus of males, in four cases a surplus of women was recorded, and in only one case was an equilibrium of both sexes registered. In three mass graves, a comparison could not be performed due to the absence of either sex being determined. In the three mass graves labelled 20, 23 and 26, the category of sex-undetermined adults was very strongly represented and their number exceeded the number of sex-determined adult skeletons (Figure 5).

The question as to how many men and women could have been hidden in this undetermined category obviously occurred and we thus performed the secondary sex diagnosis in the CATHEDRAL skeletal series. What is apparent from Table 3 and Figure 4 is the substantial and beneficial effect of this method and the noticeably larger proportion of sexed adults. When using combined variables obtained from upper and lower limb bones and LDA analyses tailor-made for this particular population, we were able to estimate the sex in a further 24 males and 18 females making up about one fifth (18.3%) of all adult individuals. Another 51 (22.2%) adult individuals remained indeterminate because they had not reached the classification threshold for sex allocation (set at 0.95). After we had included both the original and the newly-identified men and women in the calculation of sex ratio, its value decreased considerably: from the original 341.9 to 265.3. The male bias found across this specific necropolis still remains high, but far lower than when not using extrapelvic osteometric data and secondary sex diagnosis. In the CCHURCH TOTAL dataset, the complementary DSS method increased the number of sexed subjects by 149 (81 males and 68 females) and caused a slight decrease in sex ratio (Table 2).

4. Discussion and Conclusions

Based on evidence from the written records that mentioned a movement of people to the medieval Kutná Hora, we expected a certain surplus of men in the skeletal series from the site, but we were in no way sure of its magnitude. The results of the study confirmed the pronounced predominance

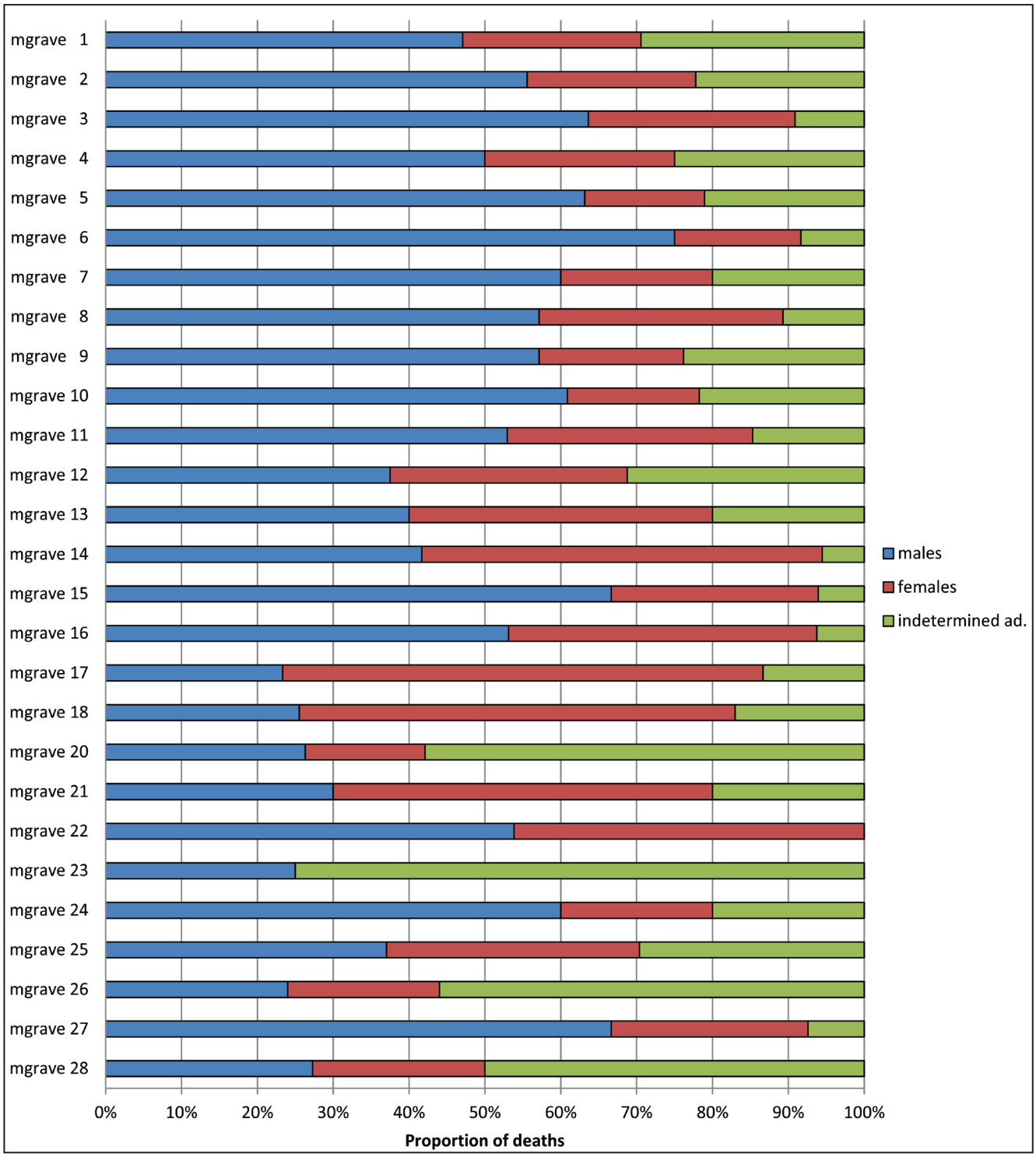

Figure 5. Proportion of males and females in adult groups derived from specific mass graves (n = 27), Kutná Hora-Sedlec, Cemetery Church of All Saints with Ossuary (mgrave = mass grave; ad. = adults). Males and females were sexed using primary and secondary sex diagnosis.

of men, both in the individual datasets under study and on an overall site level.

One of the studied datasets for which we can present a highly probable explanation of the skewed sex ratio is the burial ground enclosing the walls of the Cathedral of the Assumption of Our Lady (Table 1). The dataset CATHEDRAL consists of individuals interred within the area of the Cistercian monastery and thus the noticeable surplus of men could be merely a reflection of the composition of the group that used this particular burial ground. Although archaeological research did not reveal any conspicuous location that could have included only the remains of members of the Cistercian order (Velímský *et al.*, 2008), both friars and laymen could have been buried at the site.

A similar surplus of men has been recorded in the monastic cemeteries of medieval Czech lands (Drozdová, 1998; Kubálek, 2009; Nováček and Dobisíková, 2010) and the rest of Europe (Waldron, 1985; Halpin and Buckley, 1995; Knüsel *et al.*, 1997; Mays, 2006, p.182; Hart and Holbrook, 2011; Torino *et al.*, 2015; Krakowka, 2017; Sundman, 2018).

The archaeological context of the other two datasets (CCHURCH MASS and CCHURCH IND) is quite different and short of readily explicable circumstances. If taken globally, the abundance of males in the archaeological skeletal series is a relatively common phenomenon. Only a few authors have concentrated on this topic systematically, and those who have done only focus on certain chronologically (or otherwise) defined populations (Barbiera, 2012; Cintas-Peña and Herrero Corral, 2020). A systematic bias of 12% towards men was already demonstrated in the classic study of Weiss (1972) and it is generally assumed that this phenomenon is partly related to a methodological bias, *i.e.*, that a series will show an excess of males because of the nature of the sexing criteria themselves.

An obvious lack of women in medieval written sources can be easily explained, these records being selectively created and selectively maintained by men, making women seemingly invisible in most documentary sources (Grauer, 2002, p.267; Bardsley, 2014). However, the scarcity of women found across some medieval skeletal series is much more difficult to explain. For example, Barbiera (2012) noted missing adult females from early medieval Italian cemeteries and explained the surplus of men as follows: adult women may have been absent due to a higher mortality of female children and adolescent girls. Similarly, Kowaleski (2013) paid attention to the scarcity of women found in her review of European cemeteries (11th – 15th centuries, yielding sex ratios of about 112 to 122); she hypothesised a high female infant mortality as a result of differential behaviour towards girls, as, for example, the access to food during hard times. However, both authors finally stated that no discrimination against girls could be demonstrated, either from written sources or from markers of stress that were readable on adult skeletons, and there was no solid proof of such inferior care compared to males.

Given the nature of the unearthed cemetery containing a substantial portion of mass burials, the first factor that should be inspected in a discussion of recorded results is sex-selective mortality. In general, selective mortality indicates individual-level heterogeneity in the risk of death (Milner *et al.*, 2008, p.586). With regard to gender, it could have led to shifts in the frequency of male or female deaths, for example, during an epidemic or famine-epidemic events. Such a shift has also been documented in the recent past, during the COVID-19 pandemic, with male mortality from COVID-19 infection higher than in women (Vahidy *et al.*, 2021). In past populations, male-female differences during large-scale mortality crises were analysed both using death records (Alfani and Bonetti, 2019; Lazzari *et al.*, 2020) and osteological approaches (Bramanti *et al.*, 2018). Studies focusing on medieval or post-medieval plague mortality observed an inhomogeneous distribution of females and males in different European sites and thus suggest that deaths by plague were not significantly affected by gender (DeWitte, 2009; Alfani and Bonetti, 2019; Lazzari *et al.*, 2020).

A different picture could be occurring for victims of famine or famine-epidemic events. Significant amounts of research have suggested that women have a greater capacity to survive famine than do men and that the fundamental cause is their superior ability to deal with periods of severe undernutrition or malnutrition (Grayson, 1996; MacIntyre, 2002; Zarulli *et al.*, 2018; Van Bavel *et al.*, 2020, p.126). It is also known that females generate a more vigorous immune response after an encounter with an infectious agent (most kinds of bacteria, viruses, parasites, and fungi) and thus could better resist the famine-accompanying diseases which killed starving people rather than outright starvation (Scrimshaw, 1987; Lotter and Altfeld, 2019; Van Bavel *et al.*, 2020, p.126). In our study, mass graves Nos. 2, 10, 13 and 24 are now assigned to the period of the presumed famine of 1318, yielding a high sex ratio (328 males to 100 females) that could actually imply a higher resistance of women against the catastrophic event that has not yet been specified (but falls into the second decade of the 14th century corresponding to famine). From the summary of all mass graves, it is clear that men predominate in 18 (of 27) and women only in 5 (in one case, the gender ratio is balanced). When we calculated the sex ratio of the mortality crises assemblage (CCHURCH MASS, 138.1), it emerged that this number was lower than the same ratio obtained from single (non-catastrophic) interments (CCHURCH IND) (167.3).

One explanation that seems more credible is that the skewed sex ratio was not the result of an excess death of males, but rather it was caused by the gain in migration and simply mirrors the original – and gender-unbalanced – population composition. Graves neighbouring the Cemetery Church are dated back to the years of Kutná Hora's prosperity. Silver began to be extracted in massive quantities and the mining operations required a large number of workers who could occupy the newly emerging jobs (Knapp and Pigott, 1997; Craddock, 2014). This could and would have driven the migration: a structured and well-studied aspect of human behaviour, typically performed by a defined subgroup with specific aims, targeted at a known destination – and equally as important as birth and death in determining the structure of the population, *i.e.*, the very last way for individuals to enter or leave a defined system (Anthony, 1990; Morgan, 2013). At the same time, it is a factor influencing the proportional representation of men and women (primarily a migration of labour) (Kalibová, 2005, p.17). Sex-selective labour migration can be identified across all historic periods up to the most recent times (Tumbe, 2015; Leibert, 2016); however, there is scarcely any comparative work on the gendered dimension of migration during the Middle Ages (Kowaleski, 2013).

Likewise, there is only a limited number of studies of European cemeteries directly associated with mining sites (irrespective of the raw material mined). But a gender

imbalance in favour of men (analogous to our results) is discernible from the earliest prehistoric times to the early modern period: almost double the surplus of men in the Early Iron age Hallstatt cemetery in Austria (Pany-Kucera *et al.*, 2019) and double the surplus of men in the 16th century cemetery in the Swedish Sala (Bäckström and Price, 2016). In the absence of censuses and other statistical sources for the entire medieval period, only indirect evidence is available on immigrating individuals or on settlers as a group (Szende, 2019). Nevertheless, according to one of the estimates, there may have been upwards of 100,000 miners across Europe in the early 16th century and these would have been spread quite thinly from English Durham to Tuscany and from the French Alps to Kutná Hora (Nef, 1964, p.43; cf. Geltner and Weeda, 2021). Some individuals may have arrived to Kutná Hora from neighbouring rural districts, but foreign specialists must have come from more remote regions where they had already developed advanced techniques of building shafts and galleries (mostly from Germany). During the European mining boom, after one area had been exploited, miners and experts would most likely have moved to another mining centre and brought their practical knowledge with them (Štefánik, 2010, p.176; Szende, 2011, p.195; Boron and Rozmus, 2014; Krzewińska *et al.*, 2018; Asmussen and Long, 2020). The possible scenario of women leaving medieval Kutná Hora (for example, in fleeing from the plague-stricken area) should also be considered, but it is difficult to estimate if it would have happened to any large extent.

As with the majority of other bioarchaeological research, our current study is subject to limitations. The line between catastrophic and non-catastrophic datasets is not as clear as it might seem. As crises came and then gradually came to an end, some of the catastrophic victims, the first and the last ones, can also be "hidden" among the individual interments. It has been shown recently in the study of Cessford *et al.* (2021), who studied medieval Cambridgeshire burial grounds and identified bodies as positive for the plague bacterium yet interred in a normative way. The uncertainty of the character of some mortality crises may be mentioned as a second limitation. Older and younger stratigraphic levels of catastrophic graves are assigned to particular events (the famine in 1318 and plague in 1348–1350) based on their chronological coincidence with these pan-European disasters. Demographic crises had two basic causes, which were very often combined: epidemics and famine (Steinbachová, 2001). This reason alone makes it very difficult to verify the true cause of mass dying resulting in the construction of chronologically-older (probably famine?) mass burials in Kutná Hora-Sedlec. A pilot anthropological and palaeopathological study of 68 individuals recovered from three mass graves assigned to famine revealed that the general pattern of non-adult mortality, the value of certain demographic indices, and the pattern of skeletal lesions align more closely with the reference data for mortality caused by plague (de Lepinau *et al.*, 2021). However, such data will be significantly enlarged in the future and the final results may differ after the inclusion of all chronologically-older, famine-assigned skeletons. Regarding the second, chronologically-younger, mortality crisis, as yet no genetic analyses have been performed (although planned), and we lack archaeogenetic verification of the specific causative agent (plague bacterium).

Another question that can be asked is whether the studied samples are sufficiently representative of the original undisturbed cemeteries that spread over a much larger area. As many other medieval, urban burial grounds, Kutná Hora-Sedlec cemeteries have been excavated only in part and more skeletons lie buried in an inaccessible area, or have been damaged by early modern and modern graves (some of them have probably been lifted and arranged in the charnel house). The possibility that a strongly higher proportion of women may have been interred in a non-excavated area is not very likely since usually there are no distinct gender-based clusters found in non-clerical, medieval burial areas (Sullivan, 2004).

A similar limitation accompanies all bioarchaeological investigations and we must accept the fact that the funeral assemblage does not depict a faithful picture of the population living at that time (Roberts and Grauer, 2001; Brůžek, 2008; Zazvonilová *et al.*, 2020). One of the possible reasons for the smaller number of female skeletons is their fragility and differential preservation. Different components of the skeleton exhibit various preservation patterns, as they vary in their hardness and structure (Pinhasi and Bourbou, 2008). Male bones – including skulls/pelvises – are larger, denser, and more likely to be better preserved and recovered from the burial context (Gower *et al.*, 2019). Almost every human skeletal assemblage contains a high number of non-sexed adult remains and unknown quantities of men and women could be hidden here. The fact, that unsexed individuals are often the majority of the adults, prevents us from seeing clearly true differences based on sex (Cintas-Peña and Herrero Corral, 2020). Therefore, the size of this ambiguous group needs to be reduced to a minimum – and additional sex estimates can be based on the dimensions acquired from well-preserved limb bones. Whenever such a solution is chosen, consideration of interpopulation variation in skeletal size and the need of a customised (population-specific) procedure is absolutely essential (Wrobel *et al.*, 2002; Brůžek and Velemínský, 2006; Kotěrová *et al.*, 2017). To achieve this goal, we performed secondary sex estimation on the data collected from CATHEDRAL group, and which resulted in a decrease of the sex ratio from the original 341.9 down to 265.3 (secondary sex estimation performed in the CCHURCH TOTAL sample resulted in only a slight decrease in sex ratio). The use of the above-mentioned procedure is still far from bioarchaeological routine, so it is as yet very difficult to trace studies documenting a similar change. As for Bohemia, the study of the medieval-early modern burial ground adjacent to the church of St. Mary Magdalene in Pilsen can be mentioned. Based on the primary (pelvic) sex estimation, a surplus of women had initially been stated here (with a sex ratio of about 66), but the value changed after

including newly-sexed individuals to a slight predominance of men (110.5). In this particular case, using population-specific equations and a secondary sex diagnosis caused the change of the sex ratio in the opposite direction compared to this study (Galeta *et al.*, 2015, p.240). Either way, it points to a key limitation of the study: although we were able to reduce the percentage of unsexed adults, a certain proportion of adult individuals remain undetermined even after secondary sex diagnosis (19–31.6%). As was mentioned above, this subgroup can contain an unknown number of males and females and the failure to recognise their sex may lead to a misleading interpretation of the demography of the Kutná Hora population.

Our datasets date back to the High and Late Middle Ages and thus, a logical step would be to compare them with analogous burial grounds from the wider region. A surplus of men has been observed, for example, in Žatec (sex ratio 131.4) and Prague – Klárov (sex ratio 133.3) (Stránská, 1998; Schmitt *et al.*, 2001). However, the necropolises of Ducové, Kováloy and Prague Týn Church yielded a balanced sex ratio (Hanáková *et al.*, 1984; Měřínský *et al.*, 1984; Stránská, 1997). Although there are hundreds of medieval cemeteries known from the region (see the review in Živný, 2005), the number of comparable skeletal series of a similar size (hundreds or thousands of skeletons) with relevant anthropological documentation is very limited (Živný, 2010, p.63). Furthermore, most of the local medieval skeletal series show a significant overlap with the Early Middle Ages or the Early Modern Ages. For these reasons, the most appropriate comparative assemblage appears to be the skeletal series from the cemetery surrounding the St. James Church in Brno (Moravia), dated from the 13th–16th century and excavated in 2001 and 2003–2004. This cemetery involved only a small proportion of catastrophic burials, and the individuals buried in mass graves accounted for only 4.1 % of all corpses buried (n=1046). Similar to the Kutná Hora datasets, a high proportion of medieval colonists can be presumed here, especially from German-speaking countries (Živný, 2010, p.33). The subgroup of adults unearthed at Brno, St. James Church burial ground, consisted of 299 men and 243 women and yielded a sex ratio of 123. It is obvious that men dominated over women here, but the predominance was not as pronounced as in the datasets derived from the cemeteries of Kutná Hora.

It should be noted that the bioarchaeological data presented here can be considered an initial indicator of the full potential of the Kutná Hora-Sedlec skeletal series. Nevertheless, the findings of this study can be understood as a first archaeological and anthropological corroboration of a large-scale sex-selective labour migration, which, so far, has only been identifiable from historical sources. Future isotope and archaeogenetic investigations are necessary to validate what proportion of the cemetery population did not grow up locally and from what distances did these people come from.

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