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Dietary patterns and social structures in medieval Sigtuna, Sweden, as reflected in stable isotope values in human skeletal remains☆

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ABSTRACT

Stable isotopes ($\delta^{13}C$, $\delta^{15}N$) have been studied in human burials from the medieval town Sigtuna in Sweden. Dietary patterns of 80 adult individuals were analyzed on three cemeteries representing the phases of establishment, prosperity and decline of the town. All analyzed individuals were radiocarbon dated. One of the cemeteries, Church 1, represents a population of higher social status than those at the other two cemeteries.

The $\delta^{13}C$ values are homogenous and showed that the protein intake was mainly of terrestrial origin in the whole population. $\delta^{15}N$ values varies more and they may indicate a higher input of vegetables in the diet at one of the cemeteries, the Nunnan block.

Already in the initial phases of Sigtuna a social hierarchy had been established which is reflected in dietary patterns. Apparently more animal protein was consumed among the high status population of the town. Furthermore, differences in dietary patterns between the sexes were noted. In all phases the females show more clustered values indicating a more homogeneous diet than that of the males.

1. Introduction

The town Sigtuna was established in the late 10th century AD in Eastern Middle Sweden. Sigtuna was a hierarchic society and developed into a true urban center with several religious institutions and a growing social stratification unique in Sweden at the time (Fig. 1) (Hyenstrand, 1996; Zachrisson, 1998; Tesch, 2000). During the 10th and 11th century the town was founded in a rural area in connection to a royal manor. The period 12th–14th century represents the time of prosperity and throughout the 12th century Sigtuna was the only urban settlement in the eastern part of Sweden. Several stone churches were built and in the beginning of the 13th century Sigtuna was still flourishing with a strong religious and social position. The last period of the Middle Ages (c.14th century – the Reformation) is characterized by stagnation and a decline in the development of the town. The stagnation, most likely caused by the foundation of the nearby town Stockholm, seems to have started during the end of the 13th century when the population declined in size and the town lost its former status as an urban center. However, the decline seems to have been a slow process and no signs of mass disasters like fires or major diseases have been identified.

In recent years archaeological investigations have been performed at seven cemeteries, revealing a large collection of human remains (Wikström, 2006). Approximately 775 skeletons have been subject to osteological study (Kjellström, 2005; Kjellström and Wikström, 2008). The burials have been subdivided into three chronological groups roughly corresponding to the formation phase, the time of prosperity and finally the period of decline of Sigtuna (Wikström, 2006). Some of the cemeteries contain burials from all three phases while others were in use for a shorter period of time and are represented by one or two phases only.

In Sigtuna it is possible to follow a human population through the process of urbanization and through the development towards a stratified society. Bioarchaeological investigations have revealed a trend of declining health through time in Sigtuna and a calculated index of health showed that the deterioration of health was more obvious for women than men (Kjellström et al., 2005). The available (faunal) osteoarchaeological and historical sources give few direct

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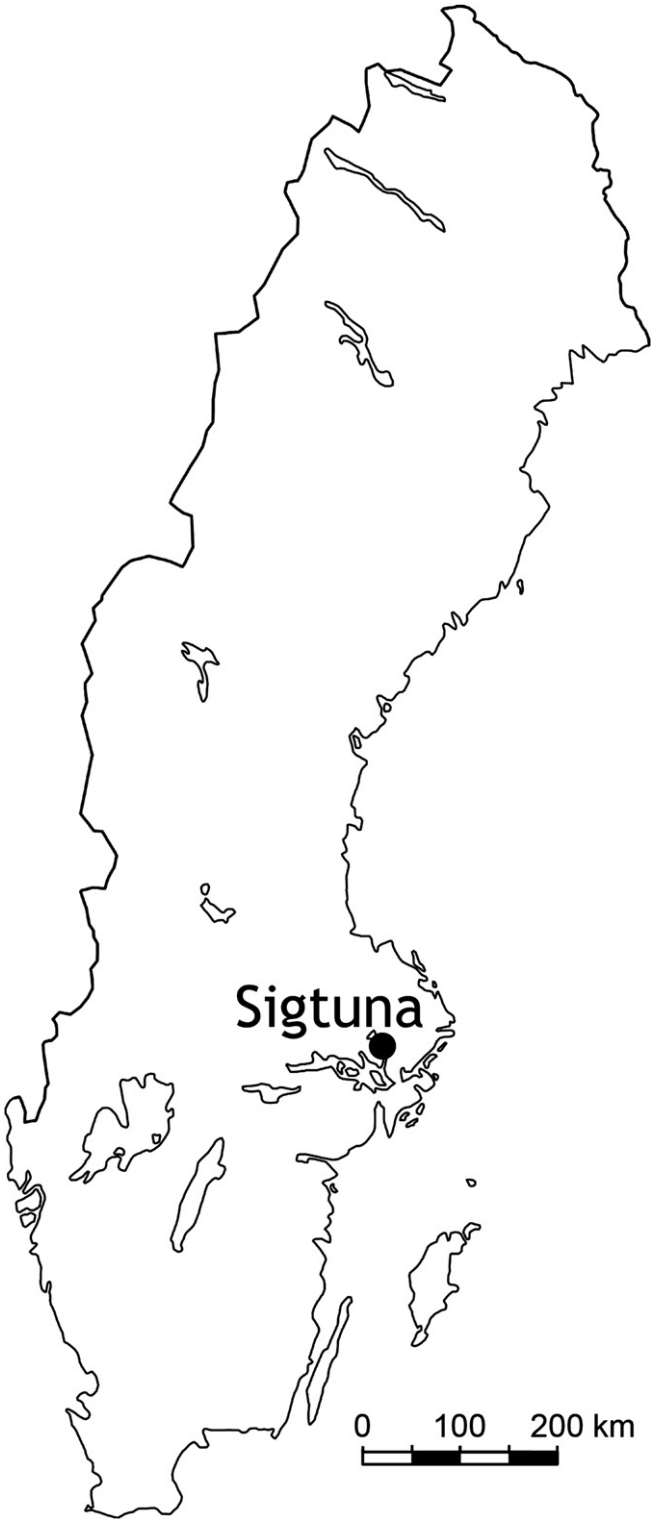

Fig. 1. Map of Sweden with Sigtuna.

clues to dietary patterns in Sigtuna. Beyond a general knowledge of animal utilization, the diet in the town is largely unknown. However, differences between the households can be expected due to social and economic conditions. Several archaeological observations indicate differences in social status between the cemeteries and the churchyard at *Church 1* stands out as exceptional. In the end of the 10th century the plot accommodated a royal manor housing the first Swedish Christian kings (Tesch, 2001a; Tesch and Vincent, 2003). Later, probably in the beginning or middle of the 11th century, a wooden church was founded together with the, in the Mälaren area, first Christian churchyard (Tesch, 2001a, 9ff; Tesch and Vincent, 2003). Some decades later, approximately A.D. 1080, the region's first stone church was constructed. The 28 m long and 12.4 m wide church had an apse and possibly a crypt (Kjellström et al., 2005). In 1993, the remains of a male buried with a crozier-head made of a morse ivory (walrus-tusk) were found close to the southern wall of Church 1 among graves dating to phase 2 (Tesch, 2001b). The crozier-head, the oldest find with a liturgical connection in Sweden, implies that the man was at best an archbishop or at least an abbot (O'Meadhra, 2001). Furthermore, the remains of a baptismal font, probably made by English or North German craftsmen, were recovered in the churchyard. The finds must be regarded as exceptional and prestigious objects denoting a royal family (Karlsson, 1989). In A.D. 995 the first Christian king, Olof Eriksson, founded the first Swedish mint in the same block as the churchyard. This is a strong indication, that the plot accommodated a ruling elite (cf. Hed Jakobsson, 2003). In comparison, the other cemeteries in Sigtuna seem to be more ordinary with a more marginal location and absence of equivalent finds.

2. The dietary background and the stable isotope ecology of Sigtuna

For better understanding of the isotopic data a general overview of the possible food resources is provided. During the excavations in Sigtuna no signs of agrarian character such as stables or barns have been identified indicating that the citizens were dependant on the farms of the surrounding landscape (Kjellström et al., 2005). Generally, barley was the most important cereal during Late Iron and Middle Ages in Sweden (Myrdal, 1999). Province laws and contemporary Scandinavian literature mention peas, beans, turnips, hemp, onions, apples, cabbage and flax and a variety of other plants (cf. Hjelmqvist, 1961, 1965; Lange, 1965). Thus, it may be assumed that, in addition to cereals, various roots, herbs, fruits, mushrooms, nuts and berries were consumed also in Sigtuna (Hjelmqvist, 1966; Lange, 1959, 1966).

In accordance with most medieval zooarchaeological assemblages, the bone debris in the town layers indicates that the most commonly slaughtered animals were cattle, sheep and pig (Hårding, 1990). Contacts with the archipelago are reflected in a rather high frequency of bones from wild birds. In contrast to later more developed towns the amount of wild fowl in Sigtuna exceeds the frequency of domesticated birds (Vretemark, 1997). The importance of marine resources is reflected in the large quantities of local freshwater fish such as pike (*Esox lucius*), pike perch (*Sander lucioperca*) and bream (*Abramis brama*) (Ericson, 1989). It is of interest though that a small amount of bones from herring (*Clupea harengus*) and cod (*Gadus morhua*) have been identified indicating a minor import of fish from the Baltic Sea area (e.g. Hårding, unpublished report).

Sigtuna is located in a narrow bay of the Lake Mälaren, which was connected to the Baltic Sea until the 13th century. This suggests that the area had a more maritime character during the first centuries (phases 1 and 2). However, the isotopic differences between fish from the Lake Mälaren in the two first phases compared to the freshwater fish from the last phase are not believed to be very different (Westman et al., 1999). In addition, as mentioned above, the animal bone debris indicates that consumption of fish from the Baltic must have been limited.

The factors that contribute to the variability in $\delta^{15}N$ values in human bone collagen are many, diverse and poorly understood. Except for being an indicator of the consumption of animal protein,

nitrogen isotope ratios may also be affected by an intake of leguminous or nonleguminous vegetables (Commisso and Nelson, 2006, 2007, 2008), specific dairy products (Minagawa, 1992), suckling animals (Jay & Richards, 2006), migrating birds (Rubenstein & Hobson, 2004), aridity (Schwarcz et al., 1999) and different types of meat or freshwater fish (e.g. Katzenberg, 2000). This suggests that interpretations based on the isotopic nitrogen signature must be made with caution. Furthermore, the food chains in water are longer than on land and are thus affecting the $\delta^{15}N$ value for different fish species (Eriksson et al., 2008). Hence, carnivorous fish such as Pike will get very high $\delta^{15}N$ values and even a low intake may affect the human bone collagen. To some extent it is possible to distinguish between freshwater and marine fish due to the isotope signatures (Eriksson and Zagorska, 2003), however, both groups show a large variation depending on species and habitat.

According to Katzenberg (1992) the isotopic values for a diet with a large intake of terrestrial food and without any aquatic contributions, would result in $\delta^{13}C$ values less than $-19.00‰$. As a reference for the present analysis previous studies from the nearby settlement Birka (A.D. 750–950), also located in the Lake Mälaren area, have shown that cattle range from -22.0 to $-21.8‰$ for $\delta^{13}C$ and 4.0–5.1‰ for $\delta^{15}N$ (Linderholm et al., 2008a). At the same sites the values for omnivores such as pigs range from -21.3 to $-19.9‰$ for $\delta^{13}C$ and 9.7–13.8‰ for $\delta^{15}N$. No terrestrial carnivores or fish bones have been analyzed at Birka. However, sites at Öland (also on the east coast of the Baltic Sea) may be used as a reference (Eriksson et al., 2008). Values from a wild cat (*Felis silvestris*) show a $\delta^{13}C$ value of $-16.4‰$ and of 9.4‰ for $\delta^{15}N$. The fish bones come from pelagic species and show marine isotopic values ranging from -16.6 to -10.8 for $\delta^{13}C$ and 8.8–11.2‰ for $\delta^{15}N$. As a reference for freshwater fish in the Bothnian Bay area, a pike (*Esox lucius*) from Zvejnieki, Latvia, is used, showing a $\delta^{13}C$ value of –23.6‰ and of 11.7‰ for $\delta^{15}N$ (Eriksson and Zagorska, 2003). It is not ideal to use reference samples of different date and context due to variation in particular ecology, however, this helps establishing the approximate isotopic signature for fauna in the region.

In recent years many studies utilizing stable isotope data and trace element analyses of human remains as well as chemical analyses of organic residues on pottery have shed new light on human dietary patterns in Sweden during the period preceding the establishment of Sigtuna. (Arrhenius, 1990; Lidén and Nelson, 1994; Iregren et al., 2000; Isaksson, 2000; Isaksson et al., 2004; Linderholm et al., 2008a; Linderholm et al., 2008b). The results indicate a diet mainly comprising proteins of terrestrial origin (Lidén and Nelson, 1994), however, with an apparently high input of vegetable items (Isaksson, 2000). Interestingly, in the Late Viking Period animal foods seem to have been consumed mainly in ritualized situations and contexts (Isaksson, 2000).

Of interest for the present study was to evaluate the level of animal foods in the diets that can be used as a marker for high status in Sigtuna. The relationship between diet and chemistry of bone has proved to be a valuable clue in the study of ancient dietary patterns revealing information otherwise unavailable. Many studies have examined dietary patterns in relation to social hierarchy (e.g. Aufderheide, 1989; Aufderheide et al., 1988; Baraybar and de la Rua, 1997; During, 1994, 1997; Eriksson, 2003; Honch et al., 2006; Iregren et al., 2000; Jay and Richards, 2006; Katzenberg, 2000; Katzenberg et al., 1995; Lidén, 1995; Lidén and Nelson, 1994; Mays, 1997, 2000, 2003; Müldner and Richards, 2005; Olsson and Isaksson, 2008; Papathanasiou, 2003; Polet and Katzenberg, 2003; Privat et al., 2002; Richards et al., 1998; Richards et al., 2006; Sandford and Weaver, 2000; Schutkowski, 1995; Schutkowski et al., 1999; Ubelaker et al., 1995; Vuorinen et al., 1996; Waldron, 1981; White, 1994; White et al., 1993). Our main objective is to examine dietary patterns in Sigtuna through chemical analyses of human remains using stable isotopes. More specifically, we examine dietary changes related to time, and within each time period, dietary changes related to sex and if possible, social status. In Sigtuna the burials chosen for analysis were initially dated through archaeological criteria (Wikström, 2006) but in order to confirm the chronology all samples were radiocarbon dated. In most previous studies, the analyzed samples have seldom been radiocarbon dated rendering the chronological integrity uncertain.

3. Material

We have sampled adult human remains from three cemeteries representing the three chronological phases (Fig. 2). The sample initially comprised 80 individuals, 31 women and 49 males (Tables 1 and 2). However, as a result of the radiocarbon dating the number and composition of the sample changed somewhat, see below. In addition to the possibility to estimate the sex and age of the individuals, the selection of the human skeletons was based on the preservation of the, in many cases, poorly preserved remains. In the analyzed assemblages no tendencies to spatial groupings of specific individuals (i.e. ecclestical versus layfolk) have been identified, suggesting that the skeletons represent "ordinary" citizens of each cemetery.

The graveyard at the *Nunnan block* is not associated with a church building and belongs to the oldest phase of the town. The graveyard lacks signs of physical delimitation and the burials are all inhumations in single graves that are sparsely distributed.

The churchyard known as *Church 1* was located in the center of Sigtuna on one of the oldest plots of the town. The stone church was most likely founded during the end of the first burial phase and probably replaced an earlier wooden church at the site. The churchyard is thought to hold thousands of burials out of which about 165 skeletons in single graves have been excavated (Kjellström et al., 2005).

The churchyard of *St Laurence's* has a stone church possibly built in the early 12th century (Bonnier, 1987). The excavated graves are from the southeastern and southern part of the churchyard in close vicinity of the church. The sampled burials belong to a period when St Laurence's was a church for the town parish. Thus, the sample

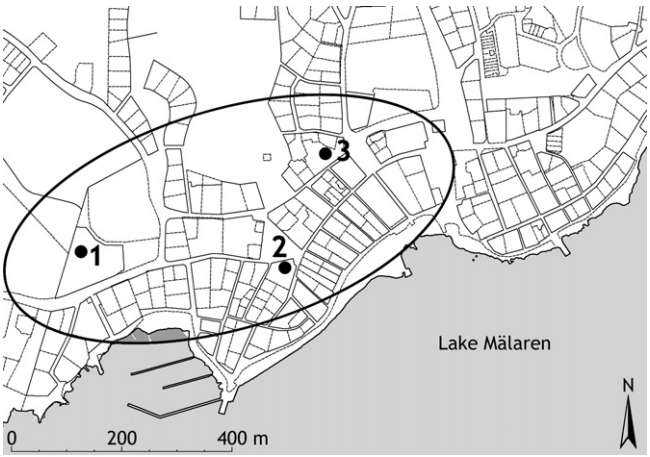

Fig. 2. Map of Sigtuna with the location of the three cemeteries studied; the Nunnan block (1), Church 1 (2) and St Laurence's (3). The map shows the present day plot boundaries. The approximate extent of the medieval settlement denoted.

Table 1
Demographic composition at the cemeteries studied.

Category	The Nunnan block	Church 1, phase 1	Church 1, phase 2	St Laurence's
Subadults	23	6	30	11
Adults	90	23	106	11
Females	35	15	31	4
Males	36	7	61	11

probably represents ordinary citizens in Sigtuna during the final occupational phase.

4. Methods

4.1. Sampling

The sample for stable isotope analysis consists of 80 specimens from the three Sigtuna assemblages, additionally one sample from cattle (*Bos Taurus*), cat (*Felis catus*), pig (*Sus domesticus*) and pike (*Esox lucius*) each was analyzed as comparison (Kjellström & Linderholm, n.d.). The animal bones were explicitly taken from the layers of the churchyards and may not completely represent all potential protein food sources in medieval Sigtuna. The animal sample size is small, since the material is only from the cemeteries and not from the town itself. They will only provide a rough guide to dietary variation in this study. Human samples were mainly taken from long bones (primarily the femur) but in two cases (Idno. 83025 and 97114) from the skull (pars petrosa of the temporal bone). To avoid problems related to differences in turnover rates of bone collagen due to age (Lidén and Angerbjörn, 1999; Mays, 2000), breast feeding and weaning (Wright & Schwarcz, 1998; Dupras et al., 2001) or alteration to diagenetic factors (Lambert et al., 1985) only adults (i.e. for the most part over 20 years of age) were chosen.

For the human collagen extraction approximately 2 g of bone were used. The samples were collected at the Osteoarchaeological Research Laboratory, Stockholm University and prepared at the Ångström laboratory, Uppsala University. The animal sample was prepared at the Archaeological Research Laboratory, Stockholm University.

4.2. Dating

The chemical pre treatment of the bone material followed the routine procedure used at the Uppsala AMS facility for well preserved bones exhibiting normal coloring and plastic properties. A mechanical cleaning of the bone surfaces was followed by an ultra sonic wash in distilled water. The organic fraction normally named "collagen" was extracted according to the HCl method that represents a modified Longin procedure (Brown et al., 1988). 0.8 M HCl (10 °C) was added and stirred for c. 30 min for decalcification. The insoluble fraction was then dissolved under stirring in water (pH = 3) at c.90 °C for 6–8 h. The soluble fraction was centrifuged, dried and collected as "collagen".

Combustion was conducted at 800 °C for c.10 min with CuO as an oxidizer. A small fraction (c.0.1 mg carbon equivalent) of the CO_2 was used to measure the natural mass-fractionation, $\delta^{13}C$, in a conventional dual inlet mass spectrometer (VG OPTIMA), while the major part was mixed with H_2 and Fe-catalytically graphitized at ca. 800 °C.

The radiocarbon measurements were performed with the use of the recently installed 5MV pelletron tandem accelerator used as an ultra sensitive mass spectrometer (AMS). Sequential injection of the stable ^{12}C, ^{13}C and the radioactive ^{14}C at ms intervals was utilized. Absolute transmissions were calibrated with an oxalic acid I NBS standard and background as well as standard material was measured at regular intervals.

The evaluation of the corrected radiocarbon ages was conducted with the OxCal version 3.10 computer code (Bronk-Ramsey, 2005).

4.3. Stable isotopes

Besides the $\delta^{13}C$ measurements used for natural mass fractionation correction of the radiocarbon dating, a separate analysis of $\delta^{13}C$ and $\delta^{15}N$ was performed on ca.1.5 mg of the "collagen" fraction from each bone sample. The analysis was done with a carbon–nitrogen analyzer (Europa Scientific, ANCA-NT system, solid/liquids preparation module) coupled to a conventional isotope ratio mass spectrometer (Europa Scientific, Europa 20-20). Several internal calibrated standards (NBS No 18, USGS24, LSVEC, IAEA-NO-3, IAEA-N-2) were used for consistency check and for absolute VPDB conversion of the results.

The faunal samples were processed at the Archaeological Research Laboratory, Stockholm University (Kjellström & Linderholm, n.d.). The skeletal material was cleaned using deionised water before any sampling occurred. The collagen was extracted in a designated bone laboratory at The Archaeological Research Laboratory, according to the modified Longin method (Brown et al., 1988), which can be summarized as follows. The bone powder was obtained by using a dentist drill approximately 90 mg was used. The sample is demineralised in a 0.25 M HCl solution for approximately 48 h in room temperature, the solution is filtered and washed with deionised water through a glass filter to remove the 0.25 M HCl. A solution of 0.01 M HCl is then added to the sample and this is incubated at 58 °C for approximately 16 h to dissolve the organic material. The dissolved organic residue is filtered and washed with deionised water through an ultra filter (30,000 MWCO Amicon Ultra-15 Centrifugal filter device (Millipore)), removing particles <30 kDa. Particles >30 kDa are considered to be intact collagen, and thus, fragmented chains and humic substances are removed. The residual solvent is then transferred to a 2 ml Eppendorf tube and frozen to approximately −80 °C, after which it is freeze-dried and weighed. The stable isotope analyses on the animal collagen were performed on a Carlo Erba NC2500 elemental analyser connected to a Finnigan MAT Delta+ isotope ratio mass spectrometer (IRMS) at the Department of Geology and Geochemistry, Stockholm University. The precision of the measurements was ±0.15‰ for both $\delta^{13}C$ and $\delta^{15}N$.

4.4. Statistical methods

ANOVA (a one-way analysis of variance) was used to test significant differences between phases and sites in combination with phase, site and sex. The hypothesis postulating a difference between sexes in each site was tested by an independent-sample *t*-test when the values showed a normal distribution as established by a Kolmogorov–Smirnov test. SPSS for windows (version 16.0) was used and the accepted alpha values were set at 5%.

Table 2
Sample included in the present study. Four individuals were later excluded due to poor preservation of the organic bone fraction (Men: one from St Laurence's and one from The Nunnan block, Women: two from The Nunnan block).

Sex	The Nunnan block	Church 1, phase 1	Church 1, phase 2	St Laurence's	Total
Females	10	7	10	4[a]	31
Males	10	13	11	15[b]	49
Total	20	20	21	19	80

[a] Including one individual 17–18 yrs.
[b] Including one 13–18 yrs, one 15–19 yrs and two 17–18 yrs.

5. Results

5.1. Radiocarbon dating

The results of the radiocarbon dating show that the individuals sampled for the study were buried during three different periods dating to approximately A.D. 900–1100, 1100–1300 and 1400–1650 (Fig. 3). The general temporal allocation of the assemblages is for Phase 1 (A.D. 900–1100) = Nunnan and Church 1, phase1; Phase 2 (A.D. 1100–1300) = Church 1, phase 2; Phase 3 (A.D. 1300–1500) = St Lawrence. The burials at the Nunnan block may be slightly older than those at Church 1 (phase 1) but still fall within the expected ranges. The youngest date obtained at Nunnan (Ua-22703, 950BP± 30) is used as the end date for phase one. Two burials from Church 1, phase 2, were dated older than this and two individuals from phase 1 were younger. Despite some contradiction to stratigraphical observations the burials were assigned to chronological groups according to the obtained dates. Noteworthy are the rather young dates from the third phase (St Laurence's) where, in fact, some of the burials are from the Post-Reformation period. Three burials at the St Laurence's cemetery believed to represent the third phase, belonged to either the first phase (one burial) or the second (two burials). The individuals were omitted in the further analyses. Thus, the chronological integrity of the burials sampled in the present study is good.

5.2. Stable isotopes

Degradation of bone post mortem occurs in at least three ways: chemical deterioration of the organic phase, chemical deterioration of the mineral phase and microbiological attack on the overall composition. In addition, several parameters are involved in the loss of collagen from bone, the main ones being time, temperature and pH (Collins et al., 2002; Hedges, 2002). In order to control for diagenetically altered bone, we used the parameters put forward by DeNiro (1985), where the ratio C/N should fall into the range 2.9–3.6.

The comparison of C/N ratio indicates that the preservation of the organic bone fraction was good on all sites (Appendix A–B), only four samples fell outside the given range (struck-out in Appendix A–B). The results from the animal bones used as control showed expected results (Appendix C). The range of the $\delta^{13}C$ values for the terrestrial animals was between –22.47 and –20.35‰ and the range of the $\delta^{15}N$ values was between 5.16 and 13.15‰. The isotopic values for cattle and pig are in the range for the same animals at Birka and with slightly enriched values for carbon compared to Öland. The only fish sampled, a pike, showed a $\delta^{13}C$ value of −20.35‰ and $\delta^{15}N$ value of 13.15‰, which can be considered typical for a freshwater carnivore most likely caught in the Lake Mälaren. The cat bone displayed a $\delta^{13}C$ value of −22.06‰ and a $\delta^{15}N$ value of 10.66‰ indicating, if compared to the cat from Öland in the Batic Sea, only a minor intake of marine resources and possibly a diet of freshwater fish.

The stable isotope values from the human sample indicate a variation in dietary patterns through time and between sites in Sigtuna (Figs. 4–6) (Tables 3 and 4). Even though no significant differences in $\delta^{13}C$ values between the phases in general were observed, the $\delta^{13}C$ values at Church 1, phase 1 are higher than both the values of the Nunnan block and those from Church 1, phase 2 (ANOVA $F_{3,68} = 5.297$ $P < 0.05$).

Nitrogen showed a more varied pattern. There are significantly lower $\delta^{15}N$ values in phase 1 than in phase 2 (ANOVA $F_{2,69}$ $F = 5.436$ $P < 0.05$). The sample from Nunnan shows significantly lower $\delta^{15}N$ values than the other sites (Church 1, phase 1 and 2 and St Laurence

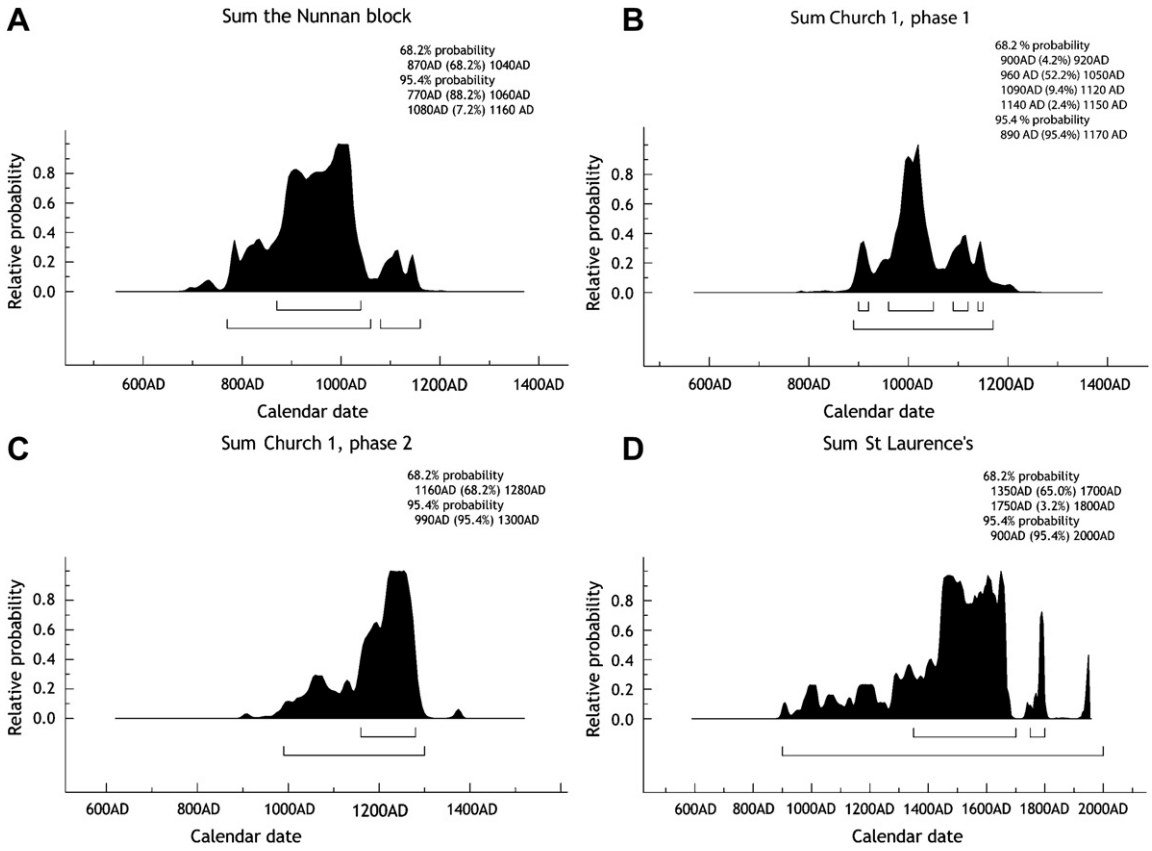

Fig. 3. Results of the summary calibrations of the radiocarbon dates from the Nunnan block (A), Church 1, phase 1 (B), Church 1, phase 2 (C) and St Laurence's (D).

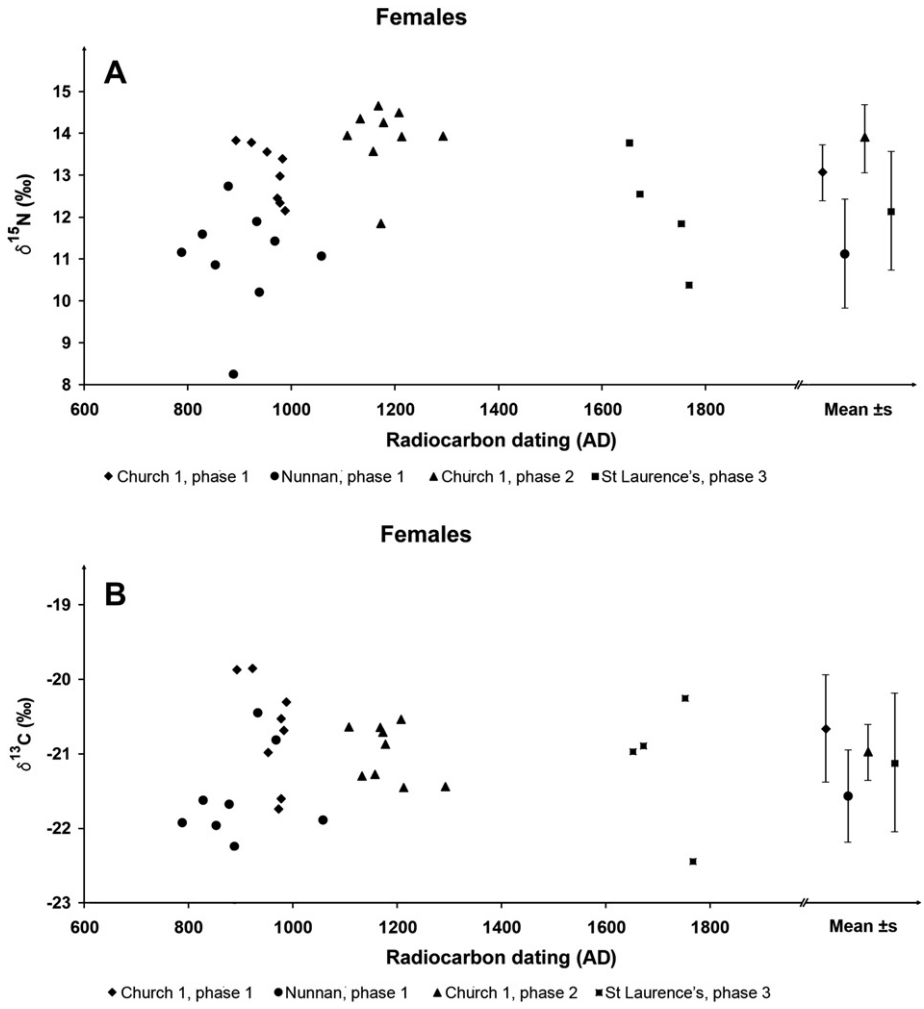

Fig. 4. Scatter plot showing the $\delta^{15}N$ (A) and $\delta^{13}C$ (B) related to radiocarbon dating for females. Mean values with one standard deviation plotted to the right.

ANOVA $F_{2,\ 69} = 9.855$ $P < 0.05$). In addition, the $\delta^{15}N$ values of Church 1, phase 1 are significantly lower than those of Church 1, phase 2 (ANOVA $F_{3,69} = 7.474$ $P < 0.05$), thus indicating a difference in time at the same site.

Looking at sex differences at each site, no significant differences were found in either of the sites in phase 1 or at St Laurence in phase 3. However, at Church 1 in phase 2, both the $\delta^{13}C$ and $\delta^{15}N$ values are significantly higher for the women (*T*-test $P = 0.005$ in both cases).

Investigating differences in site and time for each sex separately, significant differences are only found for females. The $\delta^{15}N$ values of females in the block Nunnan are lower than both their contemporaries from Church1, phase 1 and the women from Church 1, phase 2 (ANOVA $F_{7,64} = 4.938$ $P < 0.05$). In fact, women in general from phase 1 show lower $\delta^{15}N$ values than women from phase 2 (ANOVA $F_{5,66} = 3.402$ $P < 0.05$). That is, for women there is a difference both between sites and over time.

6. Discussion

The $\delta^{13}C$ data indicate a broadly similar dependence on proteins mainly of terrestrial origin in the diet on all cemeteries. In this respect the Sigtuna population can be characterized as homogeneous. Some differences were observed but it should be noted that in no comparison the distance between the mean values exceeds the estimated trophic level distance of 1‰ (Lidén, 1995). However, the results are in good agreement with other studies of medieval material in Sweden, which have indicated diets where the protein is of "predominantly terrestrial origin" (Johanssen et al., 1986; Lidén and Nelson, 1994; Iregren et al., 2000).

The $\delta^{15}N$ values indicate dietary differences between the cemeteries and also between the sexes within one cemetery as well as between the same sex on different cemeteries. The differences were most obvious for females, where Nunnan showed lower values than Church 1, possibly indicating a higher input of vegetables in the diet than on the other cemeteries. The females at Church 1, phase 2 show especially high nitrogen values that might indicate a difference in protein sources from the other groups. As mentioned in the introduction $\delta^{15}N$ ratio differences may be the result of several different factors. Leguminous foods are mentioned in historical records, (though no written data from Sigtuna is available). Suckling animals, migrating birds, meats from different animals as well as several species of fresh water fish are present in bone debris, which suggest that these factors affect the isotopic ratios. Aridity is not believed to be a significant factor since major climatic changes are not recorded during the early middle ages, and, furthermore, would affect the population uniformly. However, the $\delta^{15}N$ difference clearly shows a difference in diet between contemporary groups.

Medieval menus in written records mention different kinds of red meat dishes such as beef, pork, and lamb of the domestic breeds in addition to wild species such as rabbit, roe deer, squirrel, bear

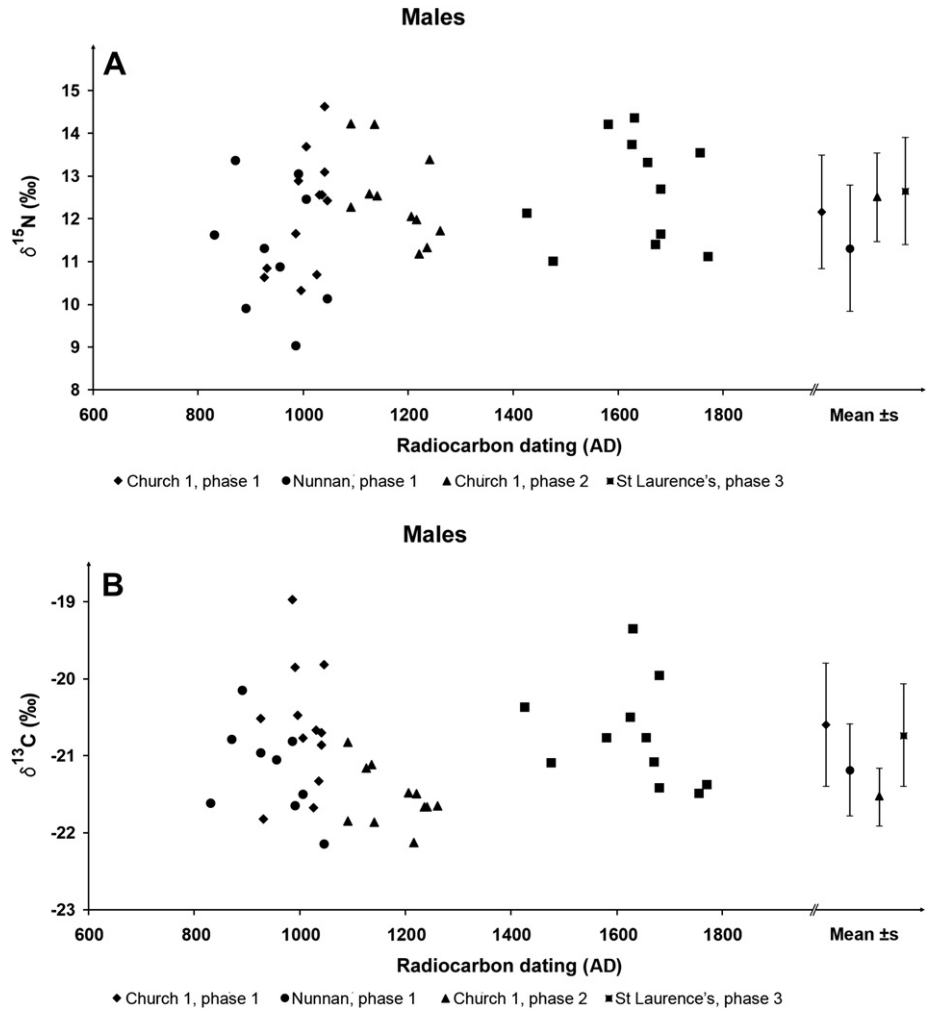

Fig. 5. Scatter plot showing the $\delta^{15}N$ (A) and $\delta^{13}C$ (B) related to radiocarbon dating for males. Mean values with one standard deviation plotted to the right.

and even beaver (Olsson, 1965). However, the Christian rules regarding the fast were strict and regulated the mammalian meat consumption. Although some bone debris show that marine proteins were consumed in Sigtuna this has failed to show up in the $\delta^{13}C$ values of the present study. The high $\delta^{15}N$ values together with the low $\delta^{13}C$ values indicate that most fish consumed in Sigtuna was from the nearby Lake Mälaren, a brackish water inlet of the Baltic Sea during phases 1 and 2 but an isolated freshwater basin during the third phase while the consumption of fish from the Baltic Sea was low.

The animal samples suggest close contact with freshwater resources, this indication is further strengthened by the negative $\delta^{13}C$ value from the pike, which are close to the freshwater sample in the reference material from Latvia.

6.1. Dietary patterns versus social structure

It seems conceivable that in the initial stages of Sigtuna's development the observed social differences were also reflected in dietary habits. A comparison between the Nunnan block and Church 1 during the first phase reveals differences. The population buried at Nunnan included a larger part of vegetables in their diet than that buried in the central parts of the town.

The results from Nunnan cast interesting light on the early urbanization in Sweden. The dietary pattern observed at the site is in agreement with chemical analyses of organic residue on pottery from Eastern Middle Sweden dating to the period AD 500–1000 (Isaksson, 2000). Isaksson (2000) found that a large part of the residue on pottery recovered in settlement contexts was of vegetable origin, thus questioning the often-claimed dependence on meat in the diet during that time-period. A higher frequency of residues indicating animal food sources was found in burial and other ritual contexts suggesting that animals were consumed on special occasions. The general dietary pattern at Nunnan – as reflected through bone chemistry – with an input of vegetables in the diet is in some accordance with these observations. Furthermore, the results are in line with the dietary pattern at the rural cemetery Westerhus where a high input of cereals and vegetables was indicated by chemical analyses (Iregren et al., 2000).

The population buried at Church 1, phase 1 exhibits a different dietary composition. The $\delta^{15}N$ values were higher than those at Nunnan. For females the difference in means for $\delta^{15}N$ between the Nunnan and Church 1, Phase 1 is 1.94‰. The population of Church 1 during the earliest phase of Sigtuna exhibits a different dietary pattern than that at Nunnan and seems to have consumed protein of a higher $\delta^{15}N$ ratio more regularly. If animal protein is the main cause of these differences this is an interesting development compared to earlier periods where meat apparently was consumed more occasionally (Isaksson, 2000). In the early stages of Sigtuna high status can be related to a higher ratio of animal protein in the diet, a rather commonly observed pattern (Montanari, 1994; cf. Isaksson, 2000). Obviously, a social stratification had been established quite early in

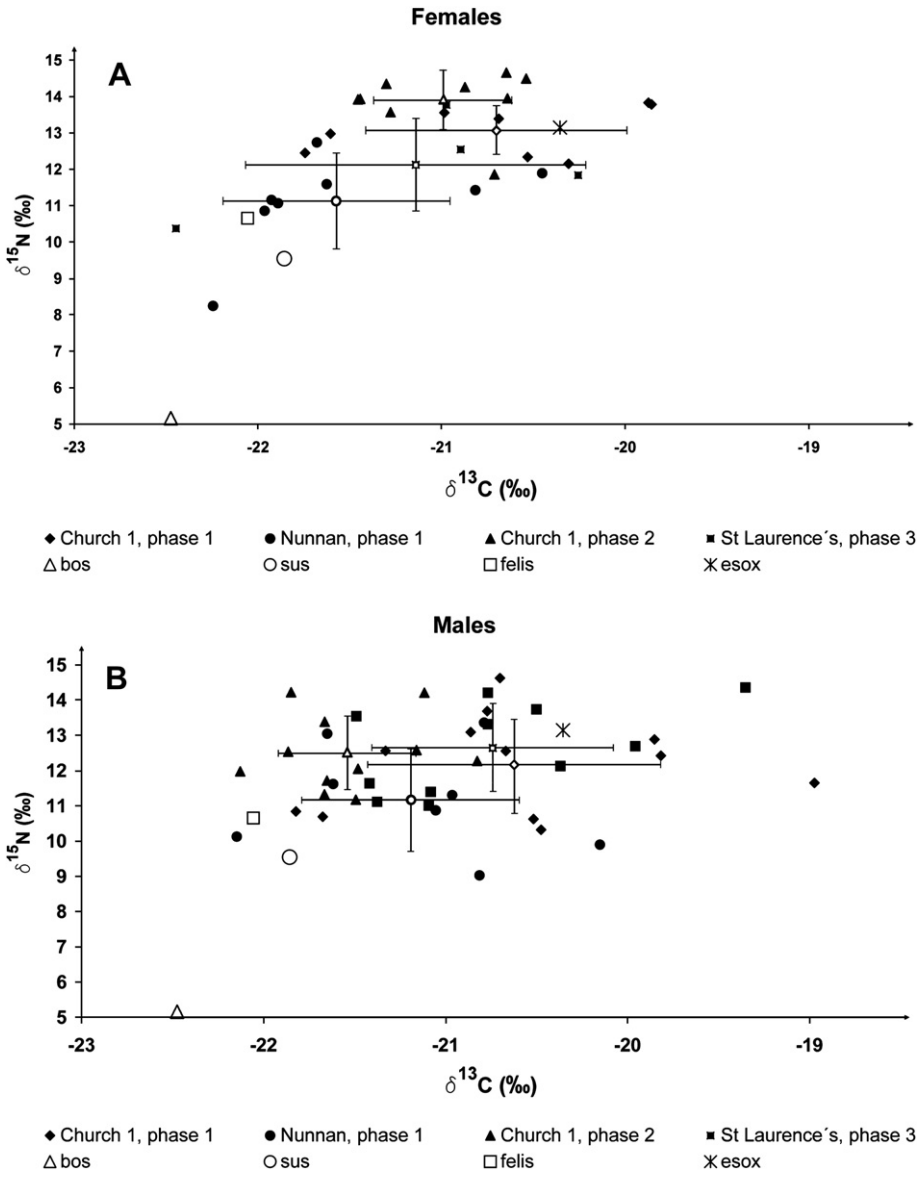

Fig. 6. Scatter plot showing the distribution of the $\delta^{15}N$ and $\delta^{13}C$ values for females (A) and males (B), in addition to the faunal reference sample. Mean values plotted as unfilled symbols, with one standard deviation plotted for both axes.

the history of Sigtuna and those buried in the central parts of Sigtuna exhibited a dietary pattern different from those buried in other cemeteries in the town.

The population buried at Church 1 during the second phase in Sigtuna shows more similarities with that buried during the first phase at Church 1 than that of Nunnan. The difference between Nunnan and Church 1, Phase 2 (2.77‰) signifies a level of difference in dietary composition close to trophic-level ranges (Lidén, 1995). The development over time could possibly be related to stricter adherence to fasting rules, though this does not explain the sex

Table 3
Mean $\delta^{13}C$ values for both sexes at the studied sites.

Sex/Cemetery	*N*	Mean	StDev	Minimum	Maximum
Females					
The Nunnan block, phase 1	8	−21.57	0.61	−22.24	−20.45
Church 1, phase 1	8	−20.70	0.71	−21.74	−19.86
Church 1, phase 2	9	−20.99	0.38	−21.46	−20.54
St Laurence's, phase 3	4	−21.14	0.93	−22.45	−20.26
Males					
The Nunnan block, phase 1	9	−21.19	0.59	−22.15	−20.15
Church 1, phase 1	12	−20.64	0.80	−21.82	−18.97
Church 1, phase 2	11	−21.54	0.38	−22.13	−20.83
St Laurence's, phase 3	11	−20.74	0.66	−21.50	−19.35

Table 4
Mean $\delta^{15}N$ values for both sexes at the studied sites.

Sex/Cemetery	*N*	Mean	StDev	Minimum	Maximum
Females					
The Nunnan block, phase 1	8	10.73	1.51	8.08	12.74
Church 1, phase 1	8	13.06	0.68	12.15	13.83
Church 1, phase 2	9	13.89	0.83	11.86	14.66
St Laurence's, phase 3	4	12.13	1.42	10.38	13.77
Males					
The Nunnan block, phase 1	9	11.30	1.47	9.03	13.36
Church 1, phase 1	12	12.39	1.29	10.32	14.63
Church 1, phase 2	11	12.50	1.05	11.18	14.22
St Laurence's, phase 3	11	12.65	1.25	11.01	14.36

differences. During the second phase Church 1 exhibits a marked difference in dietary patterns between the sexes. Interestingly, the $\delta^{15}N$ values were lower for males than for females. Males exhibit a more scattered distribution indicating a more varied diet than the females, which show a rather clustered distribution. The higher $\delta^{15}N$ values show that females most likely included a higher ratio of animal protein in their diet. The more marked differences between the sexes can be seen as an indication that more strict rules concerning the sexes had developed in the second period. The $\delta^{15}N$ values suggest that the high status population in Sigtuna exhibited gender related dietary patterns, where the clustered female values indicate a more homogeneous dietary pattern than the males. These indications of a static diet may be a reflection of the fact that the women were more stationary in medieval Sigtuna, in agreement with medieval customs (Christensen-Nugues, 2004).

During the third phase the importance of Sigtuna diminished and several of the religious institutions were abandoned, a process perhaps affecting the upper social stratum more than the ordinary citizens of Sigtuna. St Laurence's in phase 3 is in general small in numbers and scattered over time showing no significant developments. St Laurence's can be characterized as a representative cemetery of the period, the $\delta^{15}N$ values fall within a similar range as Church 1 during phase 1. Although the number of analyzed females is low it is of interest that the $\delta^{15}N$ values are lower than those in the main cluster at Church 1, phase 2. If this is representative, the females at St Laurence's consumed less animal protein than the females at Church 1, phase 2.

The observed trends in dietary patterns are interesting and serve as examples of trends in time and space and indicate that food could be linked to social stratification in Sigtuna.

7. Conclusions

Stable isotopes ($\delta^{13}C$, $\delta^{15}N$) have been studied on three cemeteries from the medieval town Sigtuna in Sweden revealing differences between the examined sites as well as between the sexes at the same sites as well as the same sexes from different sites. The analysis of $\delta^{13}C$ showed that in Sigtuna the protein intake was mainly of terrestrial origin while the $\delta^{15}N$ values exhibited a higher input of vegetables in the diet at one of the cemeteries, the Nunnan block.

The dietary patterns seem to reflect a prevailing social hierarchy in Sigtuna and the social stratification is reflected by a different ratio of animal protein sources. In the initial phase of the town, a comparison of $\delta^{15}N$ exhibits that Church 1, located in the center of Sigtuna and representing a population of high status, showed a higher ratio of animal protein in their diet than the contemporary cemetery at the Nunnan block. Apparently already in the initial phases of Sigtuna a social hierarchy had been established which is reflected in different dietary patterns. In the first phase females generally show a higher input of vegetables in the diet than males on both studied sites, though not statistically significant. At Church 1 in the second phase the differences between males and females become significant. Females most likely consumed a higher proportion of animal protein compared to the males, which exhibited a more varied dietary pattern. In the third phase the $\delta^{15}N$ values for males fall within a similar range as at Church 1, however, with a weak trend of increased vegetables in the diet.

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Appendix A. Data for $\delta^{13}C$ and $\delta^{15}N$ values and radiocarbon dating for men at the studied sites.

Id	Church	Phase	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N	^{14}C age BP	Error	Ua
83013	Church 1	1	−20.69	13.39	3.3	1085	35	Ua-22729
93008	Church 1	1	−20.70	14.63	3.5	970	40	Ua-23210
90035	Church 1	1	−21.33	12.56	3.1	975	35	Ua-22733
90070	Church 1	1	−18.97	11.65	3.2	1025	35	Ua-22738
90161	Church 1	1	−19.82	12.42	3.1	965	35	Ua-22741
93022	Church 1	1	−20.86	13.09	3.2	970	40	Ua-22730
93029	Church 1	1	−20.67	12.56	3.2	980	40	Ua-22731
95035	Church 1	1	−21.82	10.84	3.2	1080	40	Ua-22732
95036	Church 1	1	−21.67	10.69	3.2	985	35	Ua-22734
95060	Church 1	1	−20.77	13.69	3.2	1005	40	Ua-22735
95061	Church 1	1	−20.47	10.32	3.1	1015	35	Ua-22736
95063	Church 1	1	−19.85	12.89	3.1	1020	35	Ua-22737
84001	The block Nunnan	1	−21.05	10.87	3.3	1055	30	Ua-22712
84003	The block Nunnan	1	−22.15	10.13	3.3	965	35	Ua-22713
84010	The block Nunnan	1	−21.50	12.46	3.2	1005	35	Ua-22714
~~84012~~	~~The block Nunnan~~	~~1~~	~~−21.50~~	~~9.99~~	~~3.8~~	~~1135~~	~~30~~	~~Ua-22715~~
84015	The block Nunnan	1	−20.79	13.36	3.3	1140	30	Ua-22716
84029	The block Nunnan	1	−20.15	9.90	3.3	1120	30	Ua-22717
84030	The block Nunnan	1	−20.96	11.31	3.2	1085	35	Ua-22718
84037	The block Nunnan	1	−20.81	9.03	3.3	1025	30	Ua-22719
84040	The block Nunnan	1	−21.65	13.05	3.2	1020	35	Ua-22720
84044	The block Nunnan	1	−21.62	11.62	3.3	1180	35	Ua-22721
93003	Church 1	2	−21.66	13.39	3.3	770	40	Ua-23208
93007	Church 1	2	−21.85	14.22	3.6	920	35	Ua-23209
93013	Church 1	2	−21.12	14.21	3.4	875	40	Ua-23211
93015	Church 1	2	−21.67	11.33	3.5	775	35	Ua-23212
93016	Church 1	2	−21.48	12.05	3.3	805	35	Ua-23213
93021	Church 1	2	−21.86	12.54	3.5	870	35	Ua-23214
95037	Church 1	2	−21.49	11.18	3.4	790	40	Ua-23215
95047	Church 1	2	−21.65	11.72	3.6	750	35	Ua-23216
95050	Church 1	2	−22.13	11.98	3.3	795	35	Ua-23217
90158	Church 1	2	−20.83	12.27	3.1	920	35	Ua-22739
90160	Church 1	2	−21.16	12.58	3.3	885	35	Ua-22740
97034	St Laurencés	3	−20.37	12.13	3.4	585	40	Ua-23223
97052	St Laurencés	3	−21.08	11.40	3.4	340	40	Ua-23226

(continued on next page)

Appendix A (*continued*)

Id	Church	Phase	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N	^{14}C age BP	Error	Ua
97053	St Laurencés	3	−19.96	12.69	3.2	330	40	Ua-23227
97063	St Laurencés	3	−21.09	11.01	3.4	535	40	Ua-23228
97072	St Laurencés	3	−21.49	13.54	3.3	255	40	Ua-23230
97083	St Laurencés	3	−19.35	14.36	3.3	380	40	Ua-23231
~~97084~~	~~St Laurencés~~	~~3~~	~~−21.50~~	~~12.46~~	~~3.8~~	680	40	Ua-23232
97088	St Laurencés	3	−20.77	13.32	3.3	355	40	Ua-23233
97089	St Laurencés	3	−21.38	11.12	3.4	240	40	Ua-23234
97099	St Laurencés	3	−20.50	13.74	3.3	385	40	Ua-23235
97113	St Laurencés	3	−20.77	14.21	3.2	430	40	Ua-23236
97120	St Laurencés	3	−21.42	11.64	3.5	330	40	Ua-23237

Appendix B. Data for $\delta^{13}C$ and $\delta^{15}N$ values and radiocarbon dating for females at the studied sites.

Id	Church	Phase	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N	^{14}C age BP	Error	Ua
83011	Church 1	1	−20.69	13.39	3.3	1025	30	Ua-22723
83018	Church 1	1	−20.98	13.56	3.2	1055	40	Ua-22724
83019	Church 1	1	−19.86	13.78	3.2	1085	35	Ua-22726
83021	Church 1	1	−20.31	12.15	3.1	1020	35	Ua-22728
83025	Church 1	1	−20.53	12.34	3.2	1030	30	Ua-22727
83026	Church 1	1	−19.87	13.83	3.2	1115	35	Ua-22722
95041	Church 1	1	−21.60	12.98	3.4	1030	40	Ua-23206
93019	Church 1	1	−21.74	12.45	3.5	1035	35	Ua-22725
84011	The block Nunnan	1	−22.24	8.25	3.3	1120	35	Ua-22704
84016	The block Nunnan	1	−21.63	11.59	3.3	1180	30	Ua-22706
84018	The block Nunnan	1	−21.68	12.74	3.6	1130	30	Ua-22707
~~84021~~	~~The block Nunnan~~	~~1~~	~~−22.32~~	~~8.08~~	~~4.4~~	~~1120~~	~~35~~	~~Ua-22708~~
~~84025~~	~~The block Nunnan~~	~~1~~	~~−22.67~~	~~10.21~~	~~4.0~~	~~1070~~	~~30~~	~~Ua-22709~~
84014	The block Nunnan	1	−20.45	11.89	3.2	1075	35	Ua-22705
84035	The block Nunnan	1	−21.96	10.86	3.2	1155	30	Ua-22710
84036	The block Nunnan	1	−21.93	11.16	3.2	1220	30	Ua-22711
84002	The block Nunnan	1	−20.82	11.43	3.3	1 040	35	Ua-22702
84009	The block Nunnan	1	−21.89	11.07	3.2	950	30	Ua-22703
83001	Church 1	2	−21.28	13.57	3.2	850	40	Ua-23198
83010	Church 1	2	−20.71	11.86	3.2	835	35	Ua-23203
83027	Church 1	2	−20.64	13.95	3.2	900	40	Ua-23202
93010	Church 1	2	−20.54	14.50	3.4	800	35	Ua-23204

Appendix B (*continued*)

Id	Church	Phase	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N	^{14}C age BP	Error	Ua
93004	Church 1	2	−20.87	14.26	3.3	830	35	Ua-23199
93005	Church 1	2	−21.44	13.93	3.5	715	35	Ua-23200
93006	Church 1	2	−21.45	13.92	3.5	795	40	Ua-23201
93014	Church 1	2	−20.65	14.66	3.3	840	35	Ua-23205
95046	Church 1	2	−21.30	14.35	3.4	875	40	Ua-23207
97081	St Laurencés	3	−22.45	10.38	3.5	240	35	Ua-23218
97082	St Laurencés	3	−20.26	11.84	3.4	255	35	Ua-23219
97114	St Laurencés	3	−20.97	13.77	3.4	355	40	Ua-23221
97107	St Laurencés	3	−20.90	12.55	3.5	335	35	Ua-23220

Appendix C. Data for $\delta^{13}C$ and $\delta^{15}N$ values and radiocarbon dating for the animal samples.

Id	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C/N
Bos taurus	−22.47	5.16	3.2
Felis catus	−22.06	10.66	3.3
Esox lucius	−20.35	13.15	3
Sus domestica	−21.86	9.55	2.9

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