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Investigating dietary patterns and organisational structure by using stable isotope analysis: a pilot study of the Danish medieval leprosy hospital at Næstved

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With 3 figures and 5 tables

Summary: During the 12th and 13th centuries, numerous leprosy hospitals were founded in Europe. Given that leprosy was not considered infectious, this may reflect social dimensions of the disease. Aiming at exploring the impact of leprosy on medieval people and the organisation of the Danish leprosy hospital at Næstved, we reconstructed the diet of twenty patients using stable isotopes, and compared our results with relevant historical data. The isotope results revealed a terrestrial C3 diet with a small contribution of aquatic foods. Contrary to historical evidence of daily fish consumption in the leprosy hospital, only six individuals consumed relatively large amounts of freshwater fish. Leprosaria have been considered monastic institutions, and thus a varied diet, poor in aquatic protein, questions the monastic nature of the hospital and points to a social stratification. A multi-isotope analysis of a larger sample set would add to our understanding of the diet of the leprosy patients, as well as their treatment in the leprosarium.

Key words: leprosy, diet, carbon isotopes, nitrogen isotopes, medieval Denmark

Leprosy is a severely debilitating and crippling disease, which changes the physical appearance of its sufferers and stigmatises them physically, psychologically and socially. The disease affects the skin and the peripheral nerves, leading to paralysis of muscle groups in the extremities and subsequent deformity of bones (Job et al. 1966; Lockwood et al. 2012); as well as secondary infection that is facilitated by loss of sensitivity to pain, ulceration of the skin and invasion by environmental pathogens (Roberts and Manchester 2005). Initial skin changes may be quite visible, as is also the involvement of the eyelids, which leads to loss of eye function and blindness (Daniel et al. 1997; Lynnerup and Boldsen 2012). Sufferers may thus exhibit pronounced, visible signs that may lead to stigmatisation with immense social and psychological implications (Heijnders 2004; Rafferty 2005; Lusli et al. 2015). The social stigmatisation of medieval leprosy sufferers has been widely debated by modern scholars (cf. Brody 1974; Touati 2000; Rawcliffe 2006; Boldsen 2009).

Influenced by socioeconomic, cultural and moral determinants, the social dimensions of the disease are closely related to, and thus reflect, the cultural traditions of each society (Bainson and van den Borne 1998). The establishment, therefore, of leprosy hospitals was a reaction to the disease during the High Medieval period when the notion of contagion was not yet established (Rawcliffe 2006). Because leprosy was considered more as a disease of the soul (Roberts and Manchester 2005), this gives an insight into the medieval mentality towards diseases and social relations. The investigation of the link between leprosy and leprosy hospitals (leprosaria) is thus essential for improving our knowledge on how the disease affected institutionalised individuals and society as a whole. This paper aims to explore this link through an isotopic investigation of the dietary patterns and behaviours of medieval leprosy sufferers, complemented further by information from historical sources.

The reconstruction of past human diets is important for understanding how communities were organised, revealing for example distinctions between different sex, age and social groups, as well as
the level of health (e.g. Kjellström 2005; Yoder 2012; Beaumont and Montgomery 2016). Our knowledge of diets in medieval leprosaria derives mainly from regulation documents of the institutions. The amount and types of foods consumed by the patients of the leprosaria depended on the availability of goods and the economic status of each institution. Richards (1977) and Rawcliffe (2006) present several examples for Scandinavian and English leprosaria respectively. However, evidence of corrupt administration at leprosaria raises doubts about the implementation of the regulations mentioned in the historical texts. For example, according to a document dated to 1492, every morning the patients of the Danish leprosarium at Næstved were provided with porridge, fish and beer, but on meat days with either pork, beef or just cabbage, depending on availability (Richards 1977). The same document, however, reveals that the leprosy patients lodged a complaint to the king concerning their warden, who withheld their income, a condition that could have further influenced their diet. A similar event occurred at the leprosarium at Hedon in England, when, in 1334, the administrative body proceeded in the reduction of the daily dietary allowances (Rawcliffe 2006). Examples of corruption are also known from other medieval leprosaria, such as those at Kronoby, Finland and Svendborg, Denmark (Richards 1977).

Unlike historical sources, however, which may provide debatable information about past diets, the method of carbon and nitrogen stable isotope analysis not only provides a means for determining what people were actually eating, but may also provide information to reconstruct the issue of stigma attached to the disease. For example, Taylor et al. (2013) isotopically analysed rib and femur samples from three skeletons excavated from the cemetery of the medieval leprosarium of St. Mary Magdalen in Winchester (England), and revealed that the carbon ($\delta^{13}$C) and nitrogen ($\delta^{15}$N) isotope ratios were enriched in the rib compared to the femur samples in all three individuals. Since bone material undergoes replacement at a faster rate in ribs than it does in femora, Taylor et al. (2013) interpreted this as indicating an increased consumption of marine foods during the last years of life, when these individuals were probably living in the leprosarium. Taylor et al. (2013) further suggested that this implied a monastic diet was imposed on the leprosy patients. The present study will conduct an isotopic dietary reconstruction of twenty leprosy patients from the Danish medieval leprosarium at Næstved, that will be compared with dietary information from historical sources. This study hopes to further explore the organisational structure of this leprosarium.

Materials and methods

The samples analysed in this study are from the medieval leprosarium at Aaderup, a suburb of the town of Næstved in Denmark (Figure 1). The leprosarium was first commemorated in a will that is dated to 1261 (Madsen 1990:8) and functioned for almost 300 years until 1542, when it was allocated to the House of the Holy Ghost (Helligåndshuset) in Næstved (Michelsen 1954).

Twenty skeletons (ten male and ten female) were selected, all aged between 20 and 45 years at death.

The determination of sex was based on the morphological features of the pelvis and the skull (Phenice 1969; Ferembach et al. 1980; Buikstra and Ubelaker 1994; Loth and Henneberg 1996) as well as metrical methods (Bass 2005), while age was estimated, when applicable, by the morphological changes of the auricular surface (Lovejoy et al. 1985), the pubic symphysis (Brooks and Suchey 1990), the sternal rib end (Işcan et al. 1984) and the closure of ectocranial sutures (Meindl and Lovejoy 1985).

Rib fragments were sampled, since collagen in ribs remodels faster than in any other skeletal element, allowing us to gain dietary information for the last 3 to 5 years of life (Jørkov et al. 2009). We do not know how long the sampled individuals had been in the Næstved leprosarium, but sampling ribs maximises the chance of obtaining dietary information for the time of internment. Ribs with pathological lesions were avoided, because the effect of pathological changes on isotope ratios is not sufficiently understood (Katzenberg and Lovell 1999). The samples were taken from the mid-shaft using a low-speed drill, and the first, second, eleventh and twelfth ribs were not included (Jørkov et al. 2009).
All samples weighed up to 200 mg and grinding was avoided, as this would damage proteins and other bone biopolymers (Collins and Galley 1998).

Collagen extraction was based on a modification of the Longin (1971) method by Brown et al. (1988) that includes an additional ultrafiltration step. The isotopic measurements were run in duplicate at the Stable Isotope Biogeochemistry Laboratory (SIBL) at Durham University. Total carbon and nitrogen content, and stable isotope analysis were performed using a Costech Elemental Analyser (ECS 4010) connected to a Thermo Scientific Delta V Advantage isotope ratio mass spectrometer. Isotopic accuracy was monitored through routine analyses of in-house standards and international standards (e.g., USGS40, USGS24, IAEA-600, IAEA-N-1, IAEA-N-2): Analytical uncertainty in carbon and nitrogen isotope analysis was typically <±0.1 ‰ for replicate analyses of the international standards and <0.2 ‰ on replicate sample analysis. Total organic carbon and nitrogen data was obtained as part of the isotopic analysis using an internal standard (Glutamic Acid, 40.82 % C, 9.52 % N).

The non-parametric Kolmogorov-Smirnov two-sample test was performed in order to explore potential dietary differences between the two sexes (Siegel and Castellan 1988). Instead of a parametric, a non-parametric, test was preferred because the size of the samples tested is small (under twenty) (Madrigal 2012).

Results

Table 1 presents in detail the quality indicators and the isotopic values obtained from each sample. Except for a single outlier (371), all samples fall within the suggested range of atomic C/N ratio (2.9–3.6) for well-preserved collagen (DeNiro 1985; Ambrose 1990). Thus, the isotopic values of sample 371 were not considered. The collagen yield and carbon and nitrogen percentages of all samples fall within the range proposed by van Klinken (1999). The $\delta^{13}C$ values range from -20.8‰ to -19.2‰ (mean = -20‰), while the $\delta^{15}N$ values range from 9.9‰ to 12.9‰ (mean = 11.7‰). Males have $\delta^{13}C$ values ranging from -20.3‰ to -19.2‰ (mean = -19.8‰) and $\delta^{15}N$ values ranging from 11.3‰ to 12.6‰ (mean = 11.9‰). Females have $\delta^{13}C$ values ranging from -20.8‰ to -19.6‰ (mean = -20.2‰) and $\delta^{15}N$ values ranging from 9.9‰ to 12.9‰ (mean = 11.6‰).

The narrow range of the $\delta^{13}C$ values suggest that the individuals from Næstved had a diet dominated by terrestrial C$_3$ based foods (Johansen et al. 1986). The majority of the analysed individuals had $\delta^{13}C$ values around -20‰, corresponding to a diet with little or no marine protein (Richards and Hedges 1999; Olsen et al. 2018). The $\delta^{15}N$ values exhibit a range from 9.9‰ to 12.9‰, suggesting that animal protein may have contributed significantly to the diet, since a diet consisting of protein from both plants and animals would give lower $\delta^{15}N$, around 6–9‰ (Jørkov et al. 2010). The consumption of omnivores, for example, pigs feeding on slops (Müldner and Richards 2005) has been connected with the combination of an entirely terrestrial $\delta^{13}C$ signal with high $\delta^{15}N$ values. However, Halley and Rosvold (2014) indicate through $\delta^{13}C$ and $\delta^{15}N$ that domestic pigs from medieval sites of northern Europe had a wide range of diets in different areas. Furthermore, the study of a single pig from the Danish medieval site of Øm Kloster gave a $\delta^{15}N$ of 6% corresponding to an herbivorous diet (Yoder, 2010). The consumption of manured plants, as well as freshwater and suckling animals may also explain the combination of high $\delta^{15}N$ with terrestrial $\delta^{13}C$ (Müldner and Richards 2005; Jay and Richards 2006; Jørkov et al. 2010).

The Kolmogorov-Smirnov tests revealed no significant difference between the diets of men and women ($Z = 1.06, p = 0.21$ for $\delta^{13}C$ and $Z = 0.75, p = 0.63$ for $\delta^{15}N$).
During the medieval period, cereals constituted the main food consumed, with barley and winter rye being the main crops, while wheat was considered as a luxury food source (Stone 2006a). According to Yoder (2012), sheep, pigs and cattle provided the highest proportions of protein intake, while before the later 14th century and the intensification of cattle production in Denmark, dairy products and eggs were an important source of protein. Rawcliffe (2006) further mentions that eggs and fresh milk, among other products, were considered beneficial for leprosy. In antithesis to fresh fruit and vegetables that were considered inappropriate food for the upper class (Dyer 1983), the consumption of birds was a privilege of the aristocracy and the clergy; a concept that rose to prominence during the late 14th century (Stone 2006b).

The δ13C and δ15N values in this study reveal a diet based on C3 plants and various amounts of terrestrial and aquatic protein for both male and female leprosy patients. For a better interpretation of the human isotope data, it is important to have data from a variety of faunal samples from the same period and location. It was not possible, however, to obtain animal bones from the area of the leprosarium. Figure 2 depicts the δ13C and δ15N values of the leprosy patients, as well as the values of terrestrial and aquatic animals mentioned by Yoder (2010, Table 1). This data comes from the Danish medieval monastery at Øm Kloster (Yoder 2010), the English medieval sites of St. Giles and Beverley (a Dominican priory) (Müldner and Richards 2005), as well as from Neolithic sites in Denmark (Fischer 2007) and medieval sites in northern Europe (Barrett et al. 2008).

All the marine fish (ling, haddock, cod and herring) have more positive δ13C and δ15N than the humans, while the herbivores (goat, cow, sheep and pig) have more depleted values. There is a progressive enrichment of δ13C (1‰ to 2‰; Bocherens and Drucker 2003; Brown & Brown 2011:84) and δ15N (3‰ to 5‰; Schoeninger et al. 1983; Bocherens and Drucker 2003) from the lower to higher trophic levels in the food chain. The enrichment of 15N enables the differentiation between animal and plant resources (Schoeninger et al. 1983), while carbon stable isotopes distinguish between plants that follow different photosynthetic pathways (C3 versus C4), as well as between terrestrial and marine resources (Tauber 1981; DeNiro 1985). The lower δ15N of the herbivores indicates that they could have been a staple food source for the leprosy patients. Only one pike sample (pike 2) could possibly contribute to the diet (pike is a freshwater fish). δ13C values that indicate a terrestrial C3 diet and are combined with δ15N values over 12‰, reflect a significant contribution of freshwater fish (Jørkov et al. 2010, based on Bonsall et al. 1997). The daily consumption of fish by the patients of the leprosarium at Naestved is recorded in a 15th century document (Richards 1977). However, from a total of nineteen samples, only six have nitrogen values greater than 12‰. Relative dating, in the form of the arrangement in the grave of the arms in relation to the rest of the body, is available for four of these samples (Figure 3).

The arm-position method is used widely in Denmark for medieval contexts until the Reformation in 1536 (after this period older positions came into use again), as it provides a broad, but rather consistent method for dating. The four arm positions (Position A, AD 1000–1300, arms next to the body; Position B, AD 1300–1350, forearms over the lower parts of the abdomen and hands over the pelvic region; Position C, AD 1350–1400, forearms over the upper part of the abdomen, with elbows flexed at approximately 90°; Position D, 1400–1536, forearms crossed over the chest and hands on the shoulders) have been described by Kieffer-Olsen (1993), and the dates are assigned by Jantzen et al. (1994) based on the dominant arm position for each period. No chronological pattern can be observed in the diet of the sampled individuals.
In medieval England, as fishing rights in local streams and rivers were a privilege of the aristocracy, freshwater fish were regarded to be an expensive foodstuff (Dyer 1988; Hoffman 1996). Rawcliffe (2006), however, mentions the individuals with leprosy from Boughton, England, who owned the right of keeping a boat and fishing in the river Dee. Suða, the longest river in southern Zealand, flows through Næstved and was probably the source of the freshwater fish for the population of the surrounding area.

The high cost of freshwater fish is emphasised by the frequency of ponds found in relation to land owned by aristocrats (Dyer 1994; Serjeantson and Woolgar 2006). Eel, bream, perch, pike, roach and tench were the most common fish consumed by the upper class, and they could be found in both ponds, rivers and streams (Dyer 1988). Hybel and Poulsen (2007) mention that fishponds are frequently encountered in Danish sources that date after the late 14th century. The leprosarium at Næstved owned an area of forest and at least one farm (Richards 1960), although the existence of a pond remains unknown.

Compared to freshwater fish, marine fish were possibly more affordable due to their greater availability, which lowered their market value (Hoffman 1996). In northern Europe there was a wide trade of herring and cod during the Medieval period (Enghoff 1996; Barrett et al. 2008; 2011). The establishment of major marine fisheries, combined with the fasting rules that prohibited the consumption of meat, eggs and dairy products for a large number of days of the year (Dyer 1988; Müldner and Richards 2005) would suggest that marine fish were an important component of the Danish medieval diet. A zooarchaeological study focusing on herring bones that date between the 8th and 13th centuries uncovered large scale activity on Zealand (Enghoff 1996). Moreover, bones from marine fish, such as ling, cod, dab and salmon, as well as from freshwater fish, such as pike, perch, bream and sturgeon, have also been discovered at medieval sites (Arcini 1999).

Yoder (2012) claims that due to the high cost of meat, the lower class probably ate fish more frequently than the upper class. On the contrary, based on historical documents, Dyer (1983) suggests that the upper class was more likely to follow the fasting rules, and therefore consumed larger quantities of fish. Even though the drying and salting of marine fish for preservation was common, Hoffmann (1996) suggests that difficulties of transporting fresh marine fish to the mainland for immediate consumption probably made freshwater fish more desirable even after the expansion of the marine fish trade. Although Næstved’s close proximity to the sea suggests access to marine resources, there is no evidence of significant consumption of marine food in the population from the nearby leprosarium. This has also been noted for other coastal sites, such as the late Anglo-Saxon site in Bishopstone, England, where stable isotope analysis revealed a terrestrial-based diet with only a small input of marine protein (Marsall et al. 2010) – here, too, in contrast to the large amount of recovered marine fish bones (Reynolds 2010). A diet that is completely dependant on marine resources is expected to have δ13C values of approximately -12‰, while a diet that is based on purely Cs plants and terrestrial animals is expected to have values of around -20‰ (Richards and Hedges 1999). Several studies have produced carbon and nitrogen stable isotope values that indicate either a mixed diet or purely terrestrial/marine diets (e.g. Schulting et al. 2008; Keenleyside et al. 2009; Schwarcz et al. 2014; Müldner 2016). Table 2 provides the mean carbon and nitrogen values of various populations from northern Europe. Noteworthy is the progressive enrichment of δ13C values from purely terrestrial to mixed and marine diets, as well as the fact that, in some cases, coastal populations had a minimal dietary contribution of marine protein (e.g. a late Anglo-Saxon population from England; Marsall et al. 2010 and a medieval population from Sweden; Linderholm and Kjellström 2011).

Table 2

The limited contribution of marine resources in the diet of the leprosy patients, in combination with the fact that only six of them have δ15N values indicative of some contribution of freshwater fish to the diet...
(greater than 12‰; Jørkov et al. 2010, based on Bonsall et al. 1997), suggests that the information provided by the 15th century historical source (i.e., daily consumption of fish by the leprosy patients) from Næstved (Richards 1977) is incorrect. Furthermore, this may indicate that less than half of the individuals included in our study followed the fasting rules. Taking into account that the total number of fasting days covered approximately half of a year’s duration (Yoder 2012), it remains uncertain to what extent leprosy patients from Næstved followed the religious food restrictions.

Isotopic analysis for the dietary reconstruction of individuals with bone lesions of leprosy has also been conducted in three other sites: the medieval leprosarium of St. Mary Magdalen in Winchester, England (Roffey et al. 2017); a medieval cemetery in Norwich, England (Bayliss et al. 2004); and a medieval cemetery in Sigtuna, Sweden (Linderholm and Kjellström 2011) (Table 3). δ13C and δ15N values indicate a diet based on C3 plants and various amounts of terrestrial and aquatic protein for all four sites. It is noteworthy however, that all samples from the leprosarium at Winchester and the cemetery in Norwich (probably also related to a leprosarium) have slightly higher δ15N and more positive δ13C than the samples from Næstved, indicating a higher consumption of marine protein. All four samples from Sigtuna have similar δ13C values to Næstved, but higher δ15N, indicating more consumption of freshwater fish; however, these skeletons come from a regular, parish cemetery and are not linked to a leprosarium.

A similar diet to that recorded for the leprosy patients from Næstved is also evident for another four, Danish cemeteries, contemporary to the leprosarium (Table 4). These are located at the town of Holbæk (Jørkov et al. 2009), which is approximately 63 km north of Næstved, at the rural Cistercian monastery at Øm Kloster, at the important administrative, ecclesiastical and mercantile city of Viborg and at Ribe, one of the largest cities in medieval Denmark (Yoder 2010).

Small variations between the mean δ13C and δ15N values of these sites suggest that the diet of the individuals from Holbæk and Øm Kloster consisted of C3 plants and animals, such as pigs, sheep and cows, as well as a relatively small amount of freshwater fish, whereas the diet of the individuals from the larger urban site, Ribe, included large amounts of fish, both marine and freshwater (Yoder 2010). The diet of the individuals from Viborg, seems to be intermediate between the diets from the other sites. The mean values of the individuals from the leprosarium appear to be closer to the mean δ13C and δ15N values of the individuals from Øm Kloster. However, when taking into consideration the different social groups from the monastery, the mean values of the leprosy patients are closer to the values of the peasants (Table 5). Yoder (2006) explores the status-based differences in the diet of the peasants, the monks and the elites from Øm Kloster, with the social class being distinguished by the location of the burial in relation to the church. The diet of the leprosy patients seems to be more closely related to that of the peasant group, which consisted of C3 plant and terrestrial animal proteins with only a small contribution of aquatic foods.

Dietary variation in the leprosarium and possible interpretations
It has been proposed that medieval leprosy hospitals were monastic institutions, and that the leprosy patients had to follow a monastic life of daily prayers and a uniform diet defined by the fasting rules (Rawcliffe 2001; 2006). The δ13C and δ15N values of the leprosy patients from Næstved, however, do show some variation, suggesting a homogeneous diet was not prevalent. Since people from the entire social spectrum were admitted at Danish leprosaria (Dahl 2001), and due to bone turnover rates, this
could partially reflect social status variation of the pre-leprosarium period. Nevertheless, it may also
indicate a social inequality among the patients of the leprosarium, which could further be related to the
organisational structure of the institution.

In contrast to British leprosaria that depended heavily on endowments, gifts and alms provided by
wealthy individuals (Richards 1977; Roberts 1986), leprosaria in Scandinavia mainly acquired their
income through taxes paid by local communities (Richards 1960). The dependence of the Danish
leprosaria on the taxes paid by the local communities, from which they further had the obligation to
receive infected individuals (Ehlers 1898), reveals a direct correlation between leprosaria and the
economic state of the communities that supported them. The economic situation of each community,
therefore, which might have varied over time, must have had a considerable impact on the organisation
of the leprosy institutions, and thus on the diet of the patients. As we do not have precise information
on the dating of our samples, the variation we see could simply reflect the changing ability of the local
community to support the leprosarium.

Unlike the main economic source (a tax-collection system) for the leprosarium in Denmark, that could
have been independent of religious guidelines for equality and sharing, the religious motives of the
benefactors of British leprosaria may have constituted the stimulus for the hospitals to turn to a
monastic lifestyle, aiming at attracting more donations. Rawcliffe (2001:250) mentions that punishment
with the imposition of strict fasting and public repentance was not only frequent, but also a means by
which a leprosy patient would become “a more potent intercessor for benefactors and patrons”.
However, Rawcliffe (2001:233) also refers to high status patients in British leprosaria, “whose rank
merited more solicitous treatment”. Nevertheless, the benefits of a higher social status within the
leprosy community could have been restricted to differences in the type of accommodation and burial
location (cf. Roffey and Tucker 2012), without further encompassing a more varied diet.

Conclusions

The isotopic study of the leprosarium at Næstved has generated a better reconstruction of dietary
patterns and behaviours. The $\delta^{13}C$ and $\delta^{15}N$ values reveal a diet based dominantly on C3 plants, meat
(very likely also eggs and dairy products) and fish for both men and women. However, the contribution
of marine proteins to the diet of most of the leprosy patients was limited, and only six individuals had a
diet that was significantly enriched by freshwater fish (combination of low $\delta^{13}C$ values with $\delta^{15}N$ higher
than 12‰). This contradicts the 15th century historical source that refers to a daily consumption of fish
by the patients of the Næstved leprosy hospital (Richards 1977), something that emphasises the
importance of approaching the study of past diets through a combination of different methods.
Furthermore, a diet poor in aquatic protein raises questions regarding the adherence to the fasting
rules, and consequently to the monastic nature of the hospital. Finally, the diet of the patients was
similar to that consumed by the non-leprous individuals from surrounding areas to the institution,
especially to the diet of the peasant group from Øm Kloster, as well as to the diet of leprous individuals
from other leprous and non-leprous contexts.

This study highlights the importance and value of stable isotope analysis in understanding diet in ancient
hospitals and leprosaria. It is however, a pilot study and the number of analysed skeletons is rather
small. An expansion of the research, with the inclusion of individuals from additional Danish medieval
leprosaria, would provide a more complete picture of medieval diets in the region, including our
knowledge and understanding of the organisational structure of such institutions.

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collection and the Stable Isotope Biochemistry Laboratory, Durham University, for assistance with the
isotopic analysis. The research was funded by the Department of Archaeology, Durham University. The
References


**Figures**

**Figure 1.** Map of Denmark, showing the location of Næstved. The inset illustrates the distance between the medieval town of Næstved and its suburb, Aaderup. The location of the leprosarium’s cemetery is marked by a cross. (Background map adapted from "Denmark physical map" by NordNordWest, based on a work by Urutseg Public Domain Dedication license (CC0 1.0 Universal). Inset based on Madsen (1985:14, table IV)).
Figure 2. δ¹³C and δ¹⁵N values for the individuals from the leprosarium at Næstved (9 females, square; 10 males, circle) as well as for the animals mentioned by Yoder (2010, Table 1).
Figure 3 δ\textsuperscript{13}C and δ\textsuperscript{15}N of the leprosy patients from Næstved, grouped chronologically (information about the position of the arms was only available for fifteen skeletons).
### Table 1 Collagen $\delta^{13}C$ and $\delta^{15}N$ values of the twenty skeletons from the leprosy hospital at Næstved.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Sex</th>
<th>Age</th>
<th>Elem.</th>
<th>C/N</th>
<th>% C</th>
<th>% N</th>
<th>$\delta^{13}C$</th>
<th>$\delta^{15}N$</th>
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<td>35-45</td>
<td>rib</td>
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<td>371</td>
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<td>30-40</td>
<td>rib</td>
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<td>12.3</td>
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<td>rib</td>
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<td>12.1</td>
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<td>rib</td>
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<td>15.3</td>
<td>-20.7</td>
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<td>male</td>
<td>25-35</td>
<td>rib</td>
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<td>42.0</td>
<td>14.9</td>
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<td>12.5</td>
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<td>female</td>
<td>30-40</td>
<td>rib</td>
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<td>-20.4</td>
<td>11.7</td>
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<td>rib</td>
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<td>42.6</td>
<td>15.5</td>
<td>-19.8</td>
<td>11.3</td>
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<td>25-35</td>
<td>rib</td>
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<td>42.9</td>
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<td>-20.4</td>
<td>11.0</td>
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<td>rib</td>
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<td>43.8</td>
<td>15.1</td>
<td>-20.0</td>
<td>11.8</td>
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### Table 2 Stable isotope values and summarised information of various populations from northern Europe.

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Period</th>
<th>N</th>
<th>$\delta^{13}C$ Mean</th>
<th>$\delta^{13}C$ Min.</th>
<th>$\delta^{13}C$ Max.</th>
<th>$\delta^{15}N$ Mean</th>
<th>$\delta^{15}N$ Min.</th>
<th>$\delta^{15}N$ Max.</th>
<th>Interpretation of isotope values</th>
<th>Source</th>
</tr>
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<tbody>
<tr>
<td>Stavanger, Norway</td>
<td>coastal</td>
<td>Viking Age</td>
<td>2</td>
<td>-20.7</td>
<td>-</td>
<td>-</td>
<td>10.8</td>
<td>-</td>
<td>-</td>
<td>terrestrial-based diet</td>
<td>van der Sluis et al (2016) Journal of Archaeological Science: Reports</td>
</tr>
<tr>
<td>Næstved leprosarium, Denmark</td>
<td>coastal</td>
<td>Medieval</td>
<td>19</td>
<td>-20.0</td>
<td>-20.8</td>
<td>-19.2</td>
<td>11.7</td>
<td>9.9</td>
<td>12.9</td>
<td>terrestrial-based diet, some contribution of freshwater resources, limited contribution of marine resources</td>
<td>present paper</td>
</tr>
<tr>
<td>Dalheim, Germany</td>
<td>inland</td>
<td>Medieval</td>
<td>24</td>
<td>-20.0</td>
<td>-</td>
<td>-</td>
<td>9.9</td>
<td>-</td>
<td>-</td>
<td>terrestrial-based diet, &quot;[...] without evidence of marine resource input into the diet&quot; p.1053</td>
<td>Olsen (2018) Archaeological and Anthropological Sciences</td>
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<tr>
<td>Stavanger, Norway</td>
<td>coastal</td>
<td>Post-reformation</td>
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<td>-</td>
<td>12.9</td>
<td>-</td>
<td>-</td>
<td>&quot;[...] decreased amount of marine protein consumption [...]&quot; p. 130</td>
<td>van der Sluis et al (2016) Journal of Archaeological Science: Reports</td>
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Table 3 Descriptive statistics of the isotope values of skeletons with leprosy bone lesions from the leprosy hospitals at Næstved and Winchester (Roffey et al. 2017) and from medieval Norwich (Bayliss et al. 2004) and Sigtuna (Linderholm and Kjellström, 2011).

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>$\delta^{13}C$ Mean</th>
<th>$\delta^{13}C$ Min.</th>
<th>$\delta^{13}C$ Max.</th>
<th>$\delta^{15}N$ Mean</th>
<th>$\delta^{15}N$ Min.</th>
<th>$\delta^{15}N$ Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Næstved leprosarium</td>
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<td>-19.2</td>
<td>11.7</td>
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<td>12.9</td>
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<td>Winchester leprosarium</td>
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<tr>
<td>Norwich</td>
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<td>-17.9</td>
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<td>10.0</td>
<td>13.5</td>
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<tr>
<td>Sigtuna</td>
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<td>-20.2</td>
<td>-21.0</td>
<td>-19.3</td>
<td>13.3</td>
<td>12.7</td>
<td>14.3</td>
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</table>

Table 4 Descriptive statistics of the isotope values of human data from the leprosy hospital at Næstved and the Danish medieval sites: Holbæk (Jørgen et al. 2009), Øm Kloster, Viborg and Ribe (Yoder, 2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>N</th>
<th>$\delta^{13}C$ Mean</th>
<th>$\delta^{13}C$ Std.</th>
<th>$\delta^{13}C$ Min.</th>
<th>$\delta^{13}C$ Max.</th>
<th>$\delta^{15}N$ Mean</th>
<th>$\delta^{15}N$ Std.</th>
<th>$\delta^{15}N$ Min.</th>
<th>$\delta^{15}N$ Max.</th>
</tr>
</thead>
<tbody>
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<td>Næstved leprosarium</td>
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<td>0.4</td>
<td>-20.8</td>
<td>-19.2</td>
<td>11.7</td>
<td>0.7</td>
<td>9.9</td>
<td>12.9</td>
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<tr>
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<td>-20.3</td>
<td>-18.0</td>
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<td>9.9</td>
<td>13.8</td>
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<tr>
<td>Øm Kloster</td>
<td>98</td>
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<td>0.5</td>
<td>-20.6</td>
<td>-18.5</td>
<td>12.0</td>
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<td>9.8</td>
<td>14.6</td>
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<tr>
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<td>0.4</td>
<td>-20.1</td>
<td>-17.9</td>
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<tr>
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<td>0.5</td>
<td>-20.5</td>
<td>-17.9</td>
<td>12.8</td>
<td>0.9</td>
<td>10.9</td>
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</tbody>
</table>

Table 5 Mean values of the leprosy patients from Næstved and of the three social groups from Øm Kloster (Yoder, 2010).

<table>
<thead>
<tr>
<th>Site</th>
<th>Social group</th>
<th>$\delta^{13}C$ Mean</th>
<th>$\delta^{15}N$ Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Øm Kloster Elites</td>
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<td>12.5</td>
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<tr>
<td>Øm Kloster Monks</td>
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<td>12.3</td>
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<tr>
<td>Øm Kloster Peasants</td>
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<td>11.6</td>
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<td>Næstved Leprosy patients</td>
<td>-20.0</td>
<td>11.7</td>
<td></td>
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