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A dietary perspective on Swedish hunter–gatherer and Neolithic populations
An analysis of stable isotopes and trace elements

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This paper discusses the effect of temporal trends and cultural patterns on diet, as opposed to the effect of availability of resources at the geographical location. A number of Swedish Stone Age skeleton populations, coastal and inland ranging from the Mesolithic to the Late Neolithic, have been analysed. The methods employed were stable isotope analysis (^{13}C, ^{15}N) and trace element analysis (Cu, Zn) on bone. No specific temporal trends could be identified, nor a cultural effect. A continued utilization of marine resources was identified in coastal areas, where the proximity to a lagoon seems to have been favoured. The geographical location seems to be one of the major determinants of the diet.

Introduction

Analyses of change in subsistence and dietary transitions traditionally use indirect qualitative evidence, such as changes in technology and available resources. Thus, faunal remains, hunting tools and the identification of different plant species, have so far provided the basis for the general picture of the Mesolithic hunter-gatherer and early farming subsistence in Sweden. From this evidence we know that the main terrestrial prey were large ungulates, where aurochs and elk dominated during the Pre-Boreal period, and red deer, wild boar and roe deer during the Atlantic period (e.g. Price 1985, 1991). Further, it is supposed that vegetable food played a minor role in the diet and that the marine resources (i.e., molluscs, fish and marine mammals) were important in coastal areas (Tauber 1981; Price 1985, 1991). The major differences are seen between inland and coastal sites (Price 1991). The number of species identified from faunal remains increased at the Maglemose and the Ertebølle sites (Price 1991) which indicates a more intense use of resources throughout the Mesolithic.

According to the general temporal picture of the diet and subsistence during the Early Mesolithic, there is a dependence on terrestrial prey or marine resources, seals at coastal sites and elk at inland sites, followed by an increased utilization of other marine resources at coastal sites in the Late Mesolithic. During Neolithic times (Funnel Beaker Culture, TRB) there is a shift towards domesticated mammalian resources, such as pigs, cattle and a vegetable utilization of cereals. The Neolithic Pitted Ware Culture, however, had a varying dependence on marine resources that may be dependent on proximity to the shore line. Lastly, a minor shift of the domesticated animals towards sheep/goat is noticed during the Late Neolithic (Battle Axe Culture). Thus, the cultural pattern follows to a large extent the temporal.

There is a tendency towards increased sedentism during the Mesolithic as seen in the Ertebølle sites (Price 1985). This increased sedentism has implications concerning social structure and complexity (Jennbert 1984; Kent 1989). It has been argued that "sedentary hunter-gatherers tend to share a more similar degree of socio-political, technological complexity and other features with sedentary horticulturalists than they do with mobile but fellow hunters" (Kent 1989:3). Northwest coast Native Americans is an example of hunter-gatherers that are more sedentary than nomadic but still have a high social organization with institutionalized power and hereditary rank (e.g. Kent 1989). Jennbert (1985:197) also discusses sedentism and permanent settlements as prerequisites for a high social complexity and suggests "that there need not be any major differences with regard to social structure between Late Ertebølle [i.e., sedentary Mesolithic] and the Early Neolithic periods". The analysis of the megalithic Funnel Beaker Culture in central Sweden points out the importance of dividing agriculturalists into pastoralists and horticulturalists (Lidén 1995a), and the people of this culture were evidently sedentary pastoralists.

This study will perform dietary analyses of some Swedish populations ranging from hunter-gatherers in the Late Mesolithic to farmers in the Late Neolithic, comprising both coastal and inland materials. Analyses

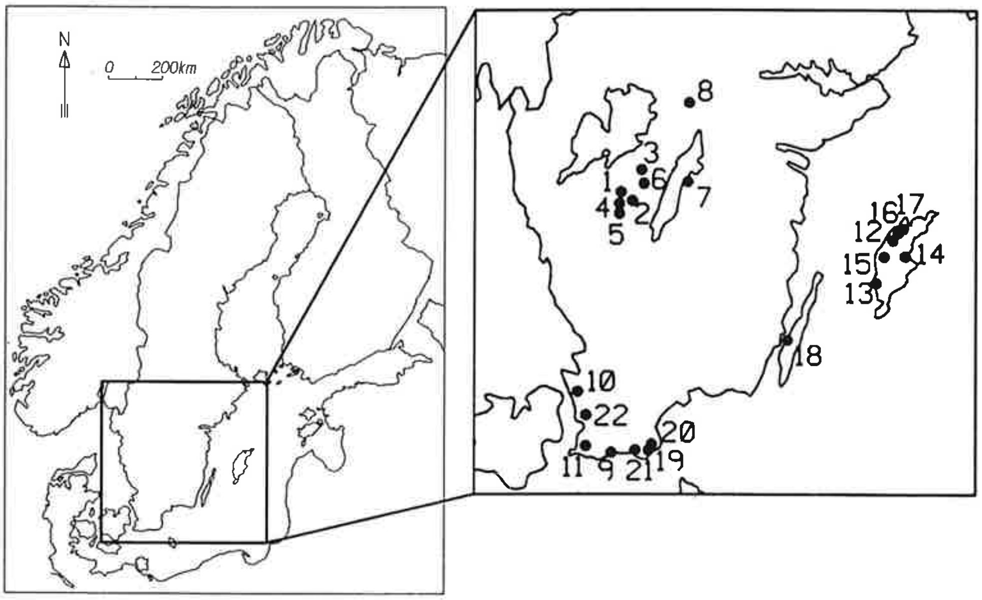

Figure 1. Map of Sweden with sites included in the analyses. 1. Gökhem, 2. Karleby, 3. Varnhem, 4. Luttra, 5. Kinneved, 6. Rössberga, 7. Rogslösa, 8. Hidinge, 9. Skateholm, 10. Kvisttofta, 11. Vellinge, 12. Lummelunda, 13. Ajvide, 14. Västerbjers, 15. Visby, 16. Grausne, 17. Ire, 18. Resmo, 19. Carlshögen, 20. Ramshög, 21. Ingelstorp, 22. Tågarp. Drawing by Kjell Persson.

of trace elements and stable isotopes of human bones will provide information on what individuals actually have been eating, and will therefore explicitly elucidate dietary changes. On the basis of these data I will discuss effects of temporal trends and cultural patterns on diet as opposed to the effects of resource availability at the geographical location. One could characterize this study as a quantitative approach to resource utilization, compared to the more qualitative methods used in previous studies.

Material and Method

The material used in this study is exclusively human bone, preferably skull bones. It has been shown that the choice of bone used for trace element analysis is of great importance. The trace element content in bone differs within a single individual due to the different turnover rate in compact and trabecular bone (Grupe 1988). Compact bone is recommended to use in trace element studies since the content of trace elements correspond with that of the total skeleton, it is also less affected by diagenesis. The samples presented here have been selected from the collections at the Osteological Department at the Museum of National Antiquities, Stockholm. The specific bones have been selected to exclude double samples from the same individual, hence, one sample represents one individual.

Västergötland

Slutarp, Kinneved parish

This megalithic tomb (dolmen) was excavated in 1910 by S. Lindquist (fig. 1, Appendix). The chamber was 2×1 m and contained a maximum of 34 disarticulated inhumated individuals, of which four were children. Among the find material there were three beads of amber (Lindquist 1911; Fürst 1911). The roof slab was covered with cup marks and footprints.

Landbogården, Gökhem parish

This passage grave was excavated in 1987 by L. Bägerfeldt (fig. 1, Appendix). The chamber, 2.8×1.2 m, contained an unknown number of inhumated human bones, five amber beads and two tooth beads. The passage also contained an unknown number of inhumated human bones. This passage grave has been radiocarbon dated to 3055±235 bc (St-11267) to 1465±455 bc (St-11266) (Blomqvist 1989b).

Karleby church, Karleby parish

This passage grave is one of two, the northernmost, situated on the farm Logården (fig. 1, Appendix). It was excavated in 1874 by O. Montelius and G. Retzius and proved to contain both cremated and inhumated bones of animals and humans. Among the find material there were amber beads and flint (Sahlström 1915:36). The length of the passage is 6.4 m and the size of the chamber is 7.3×8 m (Blomqvist 1989b).

Utbogården, Karleby parish

This gallery grave was excavated in 1874 by O. Montelius and is situated on the farm Utbogården (fig. 1, Appendix). The grave was divided into three different compartments separated by upright slab stones. One of the slab stones was perforated by a semi-circular opening. The total length of the passage grave is 7 m. Only two of the compartments contained human bone material. The northernmost compartment contained two different layers of human material of which the lowest also contained 15 flint daggers. Other find materials than flint were slate, amber and two copper beads. The number of deposited skeletons has been estimated at 60 (Sahlström 1915).

Backa, Varnhem parish

This gallery grave was excavated by O. Montelius and G.

Retzius in 1874 (fig. 1, Appendix). The size of the chamber is 2.8×0.8 m. It is divided into two compartments, separated by a stone slab, that is perforated by a circular hole. Unburned human bones representing numerous skeletons were found. Among the find material were a flint dagger, a bone pin and a ceramic bowl (Sahlström 1915).

Knaggården, Luttra parish

This is one of two passage graves situated at Knaggården (fig. 1, Appendix). The easternmost was excavated by B. E. Hildebrand and G. W. von Düben in 1863, and had a chamber of 6×2.5 m. The number of inhumated skeletons was estimated at over one hundred. Among the find material were flint daggers, flint arrows, bone pins, perforated animal teeth and amber pendants (Sahlström 1915).

Östergötland

Bårstad, Rogslösa parish

This site is situated on the farm Bårstad Vågagård (fig. 1, Appendix). The inhumations were found during excavation work to remove a cairn. Beneath the cairn some flint daggers and inhumated bones were found. The archaeological excavation was performed by B. Cnattingius in 1927. The cairn covering the burial was 11 m in diameter and 0.76 m high. The inhumations had been placed directly on the ground and then been covered by pebbles. Approximately 11 skulls were found among the disarticulated skeletons. The other find material consisted of flint arrow heads, a flint dagger and flint scrapers (Cnattingius 1927).

Närke

Lanna Västergård, Hidinge parish

This gallery grave was examined by N. Åberg in 1927, as a rescue excavation (fig. 1, Appendix). All skeletal remains were unburned and disarticulated. The number of individuals was estimated to six. The only other find materials were some ceramic sherds of which three were decorated with comb ornaments (Åberg 1927).

Skåne

Åsahögen, Kvisttofta parish

This passage grave was excavated in 1819 by M. Bruzelius (fig. 1, Appendix). The chamber of 4.2×2.6 m contained inhumated human bones, Middle Neolithic ceramics, amber beads and some flint objects (Bruzelius 1822).

Vellinge 27, Vellinge parish

This grave was excavated as a rescue excavation, in a gravel pit, by O. Rydbeck (1910) (fig. 1, Appendix). The grave contained five inhumations, two adults, one subadult, and two children. Among the finds were a flint arrow head, a bone needle and a bone pin. On top of the Stone Age burials, was a thick cultural layer, containing two Bronze Age cremation burials.

Gotland

Kams, Lummelunda parish

The two skeletons from this site were reportedly found after work in a gravel pit (fig. 1, Appendix). Examination of the graves was performed by M. Stenberger in 1939 (Stenberger 1939), He concluded that the only parts of one of the skeletons that remained *in situ* were the skull, some of the vertebrae, and some of the long bones. He interpreted the position of the skeletons as if they were being deposited in a hocker position. No artefacts were found in connection to the graves. However, Stenberger dates the graves to the Late Neolithic period, based on the position of the skeletons and also on the fact that there were artefacts found in the area belonging to that period. One of the individuals has, however, been radiocarbon dated providing a Mesolithic date, 8050±75 BP (L. Larsson 1982).

Ajvide, Eksta parish

The Stone Age settlement at Ajvide was discovered by O. Wennersten in 1922 and the first excavations were performed by J. Nihlén in 1923 (fig. 1, Appendix). E. Nylén performed a minor excavation of a skeleton grave in 1958, but the large excavation of this site took place between 1980–1987 by I. Österholm (Österholm 1989). She excavated eighteen graves of which three are included in this study. The site is one of the largest Pitted Ware Culture settlements on Gotland and has been dated by ^{14}C at 4270±170 to 3065±75 BP, and by thermoluminescence at 3580±300 to 1340±180 BC. The actual grave area (D upper) has been dated by ^{14}C to 4140±130 BP and by thermoluminescence to 2250±250 BC (grave 13, included in this study) and 1810±200 BC (grave 14)(Österholm 1989). The area is assumed to have been settled from the Mesolithic to the Neolithic; the subsistence during the Neolithic period is being interpreted as based on marine resources with domestic influences of pig and dog (Österholm 1989).

Västerbjers, Gothem parish

This site was excavated by several people during a number of years (fig. 1, Appendix). In 1933 the first excavation was started by E. Floderus and later E. Bellander (1934) continued it. These excavations revealed at least 25 graves, two settlement sites and numerous finds of ceramics (>6000 sherds), bone objects, such as harpoons, tusks of wild boar, and seal teeth (Bellander 1934). The excavations were continued in 1935 by M. Stenberger and six more graves were added to the previous, as well as six more hearths (Stenberger 1935). Grave no. 62 (included in this study) contained 1 flint axe, a number of bone objects, tusks of wild boar, a number of tooth beads and a bone ornament typical for the Battle Axe Culture (Malmer 1975). During extended excavations in 1937 by M. Stenberger yet four additional graves were found (Stenberger 1937). Four more graves were excavated in 1942 by M. Stenberger, in 1950 by G. Arwidsson and in 1963 by G. Trotzig (Janzon 1974). The finds of both Pitted Ware Culture and Battle Axe Culture, and the horizontal stratigraphy, have led Malmer to a relative dating of the cemetery (Malmer 1975). According to this, both the two analysed graves (4, 62) belong to the older northern part. This means that the date of these graves is approximately Battle Axe Culture period 3–4 (Malmer 1975).

Visby

This inhumation is one of three originating from the town of Visby (within the block Priorn 3, 1/60–61, fig. 1, Appendix). It was found during excavations for a building construction. The site was excavated by E. Nylén during three years 1960–62 and contained both Medieval and Stone Age layers. The find material belonging to the three inhumations consisted of a ceramic bowl (Nylén 1965). The individual has been determined to a young male, 14–15 years (Gejvall 1974), and have been radiocarbon dated to 4417 ± 135 bc (St-4298)(Janzon 1974).

Grausne, Stenkyrka parish

This Pitted Ware Culture site was excavated in 1988 by I. Österholm (Österholm 1989), and revealed a grave with two skeletons (fig. 1, Appendix). Skeleton no. 1 (included in this study) was a man who had been buried together with a young woman between his knees. Accompanying them in the grave, were also sixteen jaws of boar, of which some had been filled with red ochre. Some seal bones were also deposited in the grave as well as a number of harpoons and fish hooks, and a bone quadratic ornament, typical for the Danish Battle Axe Culture (Österholm 1989). A battle axe of older type was also found not far from the settlement (Österholm 1989).

Methods

Isotopes

Bone collagen for isotope measurements was extracted according to Brown et al. (1988) which is selective for the high molecular remnants. The collagen was lipid extracted using a modified method by Kates (1986), as proposed by Lidén et al. (1995), to exclude the risk of lipid contamination since lipids have a different isotopic value from bone collagen by as much as 7‰ (Smith & Epstein 1971; DeNiro & Epstein 1978; Vogel 1978; Lidén et al. 1995). The isotopes were measured using a VG Prism mass spectrometer with a precision of <0.1‰. The measurements are given as $\delta^{13}C = (Ru/Rs-1) \times 1000‰$, where Ru and Rs are the respective $^{13}C/^{12}C$ ratios for the unknown and the standard lime stone fossil (PDB), and $\delta^{15}N = (Ru/Rs-1) \times 1000‰$, where Ru and Rs are the respective $^{15}N/^{14}N$ ratios of the unknown and the AIR standard. Carbon isotopic end-values, i.e., the isotopic value for an individual living entirely on marine or, alternatively, terrestrial proteins, are from Lidén & Nelson (1994).

The marine end-value is highly correlated to salinity, thus it differs radically in the Baltic (−14 to −15‰) from that of the big oceans (−11 to −12‰) due to the brackish conditions in the Baltic (Lidén & Nelson 1994). The expected isotopic end-value for bone collagen for a population living entirely of terrestrial protein in Scandinavia would for bone collagen be approximately −21‰.

Although the atmosphere is well mixed it has been shown that terrestrial end-values vary slightly with latitude and longitude (van Klinken et al. 1994). This variation can, however, be disregarded in this study since the analysed samples are from sites situated close to each other.

The application of nitrogen as a dietary tracer is based on a number of studies where it is shown that ^{15}N is enriched ($\delta^{15}N$ increases by approximately 3‰) up a food chain, terrestrial or marine (Wada 1980; Minagawa & Wada 1984; Schoeninger & DeNiro 1984; Peterson & Fry 1987; Sholto-Douglas et al. 1991; Tuross et al. 1994). This means that organisms belonging to the lowest level in a food chain (i.e., photosynthesizing plants) have a $\delta^{15}N$ value of approximately 3‰ as compared to that of air which is 0‰, while those organisms living entirely on plants have a $\delta^{15}N$ of approximately 6‰, i.e., approximately 3‰ higher than the previous level. What must be kept in mind here is that marine and freshwater food chains are much longer than terrestrial, which confers an "end-value" in an aquatic food chain which is much higher than the corresponding terrestrial value. By combining the carbon and nitrogen isotopes it is possible to identify where the major protein intake comes from.

Trace elements

Trace elements in bones as dietary tracers have been successfully used in a number of archaeological applications (Gilbert 1977; Francalacci 1989; Arrhenius 1990; Lidén 1990). There has been discussion on the diagenesis and interpretation of trace elements (e.g., Lambert et al. 1984; Arrhenius 1990; Ezzo 1994; Lidén 1995b) and which ones to use. However, most scholars seem to agree that zinc is an element which is stable to diagenetic alteration and also carries a dietary signal that can be utilized in dietary reconstruction (Gilbert 1977; Lambert et al. 1982, 1985; Rheingold et al. 1983; Nelson & Sauer 1984; Klepinger 1984; Buikstra et al. 1989; Francalacci 1989). For copper the situation is somewhat different especially regarding the sensitivity to diagenetic stability. Lambert et al. (1984) found, in a study on diagenesis of copper and barium, that copper was affected by diagenesis, but that this probably could be overcome by the removal of the outer edge of the bone cortex, which is the moval of the outer edge of the bone cortex, which is the recommended way to collect samples. However, since bone copper is mainly bound to the collagen (Buikstra et al. 1989; Arrhenius 1990), it should hence be relatively unaffected by diagenesis as long as the collagen is stable.

The zinc levels in bone probably originates from a large contribution of animal sources as compared to vegetables in the diet (Underwood 1977; Rheingold et al. 1983; Beck 1985; Hatch & Giedel 1985). It has also been suggested that there is a trophic level effect in zinc bone values, i.e., carnivores have higher zinc values than herbivores (Lambert et al. 1982, 1985; Rheingold et al. 1983). Gilbert (1977) tries to extend this suggestion further by stating that one would expect higher zinc levels for those subsisting on a marine diet than those subsisting on a terrestrial diet.

Copper can be an indicator of a special intake of animal food resources, e. g., crustaceans, shellfish and insects, where body fluids and shells are high in copper (Wing & Brown 1979; Underwood 1977; Gilbert 1977). Viscera, including guts, liver, kidneys and brain, is also reported to have high copper values (Lindh 1993). However, if high copper levels are due to a high intake of these products, they would cause toxic symptoms and poisoning due to other products also being accumulated. Liver of polar bear is, for example, avoided by Inuits, because of the poisoning from the extremely high levels of vitamin A, which causes symptoms similar to those caused by brain tumours (Lindh 1993). Therefore, I find it highly unlikely that viscera would be solely responsible for any elevated bone copper values, consequently, crustaceans and insects are the main sources of high bone copper values.

Buikstra et al. (1989) also point out that zinc and copper are physiological antagonists, i. e., zinc inhibits the uptake of copper. Excessive zinc intake is known to interfere with copper absorption and has been studied carefully in rats (Danks 1980, Mills 1980, Johnson 1989). Copper is mainly bound to collagen and zinc is bound to apatite rather than to collagen (Buikstra et al. 1989). This has implications for the diagenesis where it is easier to test the quality of collagen (DeNiro 1985) than of apatite.

The bones for trace element analysis were dissolved in acid and analysed by polarography (copper), and atomic absorption spectrometry (zinc) with a measurement uncertainty of 0.1 ppm, the results below are reported in ppm.

Results

Västergötland

The stable carbon isotope values for Västergötland were homogenous (Table 1, 2), they ranged from -19.0‰ (SHM 39) to -21.4‰ (SHM 36), with a mean of -20.7‰ (n=30, s.d. =0.4). Both these two outliers came from the same passage grave at Karleby church and sample SHM 39 was also the most deviating sample of all from Västergötland. They all had a terrestrial signature, with the exception of SHM 39 (-19.0‰) that had a slight influence of marine protein.

As for the nitrogen isotopes, there was a larger variation (Table 1, 2), ranging from 9.4‰ (K-109) to 14.1‰ (SHM 18), with a mean of 11.0‰ (n=27, s.d.=1.0). The most deviating value here is SHM 18 (14.1‰) from the passage grave at Karleby church. This individual, who according to the stable carbon isotope value ate only terrestrial protein, must have had a high intake of a top predator from a long food chain, i.e., fresh water fish.

The copper values for the population from Västergötland varied a lot (Table 1, 2), with a mean of 20.9 ppm (n=26, s.d.=21.8), a minimum value of 3.4 (SHM 42, Karleby church) and a maximum of 80.5 ppm (SHM 29, Luttra). The zinc values varied even more (Table 1, 2), with a mean of 388 ppm (n=29, s.d. =306), a minimum of 72 (SHM 1, Gökhem) and a maximum of 1275 ppm (SHM 31, Slutarp). Since normal zinc values vary between 50-826 ppm (Armelagos et al. 1989), I have excluded all values greater than 850.

If we break up this population into different sites, we find that there were no differences in the trace element amounts between sites (Table 2), where the mean value for copper and zinc were: Gökhem Cu=22.8, Zn=285; Karleby Cu=8.6, Zn=284; Varnhem Cu=7.1, Zn=329; and finally Rössberga Cu=27.8, Zn=334.

Östergötland and Närke

The two analysed individuals from Östergötland had approximately the same stable carbon isotope value (Table 1, 2). They both had terrestrial $\delta^{13}C$ signatures, although sample SHM 8 (-19.9‰) might have had a slight influence of marine protein. The stable nitrogen values were also similar and indicated that their main protein intake came from terrestrial meat.

The same was true for the two samples from Närke (Table 1, 2), they both had terrestrial $\delta^{13}C$ signatures, and the $\delta^{15}N$ value indicated that their protein intake mainly came from terrestrial herbivores.

The mean value for copper from Östergötland was 29.8 ppm and the zinc mean was 525 ppm (Table 1, 2). The same holds true for Närke where the copper mean was 13.4 ppm and the zinc mean was 332 ppm (Table 1, 2).

Skåne

The stable carbon isotope values from Skåne had a higher variance than seen before (Table 1, 2), the values ranged from -16.2‰ (Skate 31, Skateholm) to -20.9‰ (SHM 3, Kvisttofta), with a mean of -18.6‰ (n=16, s.d.=1.41). The most deviating values here were Skate 30, 31, from the Mesolithic cemetery at Skateholm, and SHM 3, from the passage grave at Kvisttofta. While the individuals from Skateholm had a fairly large percentage of their protein originating from the sea, the individual from Kvisttofta obtained all his/her protein from terrestrial resources. Only three of the individuals (SHM 3, 4 from Kvisttofta, and SHM 23 from Vellinge) obtained their protein mainly from terrestrial resources. The rest all had a varying contribution of marine protein to their diet.

For the stable nitrogen isotopes there are three values, viz., from individual SHM 3, Kvisttofta (10.1‰); SHM 4, Kvisttofta (10.2‰); and SHM 23, Vellinge (14.9‰). It is thus clear, according to above, that all three individuals obtained their main protein from terrestrial herbivores. However, the individual from Vellinge must have obtained a great deal of protein from freshwater fish.

The mean value of copper from the Skåne population was 22.7 ppm and the mean value for zinc was 115 ppm (Table 1, 2). From Skåne there were two extremely high zinc values, sample SHM 3 and 4 (1500 ppm, 1075 ppm), both from Kvisttofta.

Gotland

The samples from Gotland were different in that there was no single sample which had a completely terrestrial carbon signature. Here the values varied between -14.2‰ (Ire 2) and -19.1‰ (SHM 6, Lummelunda) (Table 1, 2), with a mean of -16.1‰ (n=13, s.d.=1.3). Hence, it is obvious that this population has not had an homogenous diet regarding the marine protein input. All analysed individuals had a marine input into their diet of at least 50% (based on an end-value for the Baltic of -14‰), except for sample SHM 6 from Lummelunda, which has an isotope value of -19.1‰. One of the two samples from Lummelunda (SHM 5) has, however, been

Table 1. Table of samples included in the analyses, originating from different time periods and different geographical locations within Sweden. Sample refers to geographical location, Lab # refers to internal numbers at the Archaeological Research Laboratory, Cu and Zn are given in ppm, $\delta^{13}C$ and $\delta^{15}N$ are given in ‰ with respect to the PDB and AIR standard, %C and %N are calculated from the extracted bone collagen and given as a ratio C/N to provide information on the bone quality, type refers to burial type where D = dolmen, PG = passage grave, GG = gallery grave, MFG = Mesolithic flat grave, NFG= Neolithic flat grave, CG = burial beneath a cairn.

Sample	Lab #	Cu	Zn	δ^{13}C	δ^{15}N	%C	%N	C/N	Type
Västergötland									
Gökhem	SHM 1	58.4	72	-21.1	11.0	39.7	13.7	2.9	PG
Gökhem	SHM 9	12.2	140	-20.9	11.9	42.5	15.1	2.8	PG
Gökhem	SHM 10	10.5	775	-20.7	12.6	44.8	16.1	2.8	PG
Gökhem	SHM 11	10.1	152	-20.1	11.3	40.0	14.3	2.8	PG
Karleby	SHM 18	22.0	152	-20.2	14.1	44.5	16.1	2.8	PG
Karleby	SHM 26	11.0	462	-21.0	—	21.9	7.0	3.1	GG
Karleby	SHM 33	8.2	350	-20.9	11.1	33.8	12.0	2.8	PG
Karleby	SHM 34	—	140	-20.9	11.0	53.2	18.1	2.9	PG
Karleby	SHM 35	11.7	188	-21.1	—	43.5	14.8	2.9	PG
Karleby	SHM 36	—	182	-21.4	10.2	44.0	15.2	2.9	PG
Karleby	SHM 37	1.0	183	-20.9	11.1	45.4	16.3	2.9	PG
Karleby	SHM 38	—	325	-21.0	10.9	46.1	16.0	2.9	PG
Karleby	SHM 39	5.3	750	-19.0	12.5	45.5	16.6	2.7	PG
Karleby	SHM 40	4.0	190	-20.9	12.2	45.6	15.9	2.9	PG
Karleby	SHM 41	3.6	212	-21.0	10.2	47.8	17.3	2.8	PG
Karleby	SHM 42	3.4	175	-20.9	10.9	42.9	15.4	2.8	PG
Varnhem	SHM 24	25.1	212	-20.8	10.7	44.3	15.8	2.8	GG
Varnhem	SHM 25	10.1	202	-20.4	10.8	44.2	15.7	2.8	GG
Varnhem	SHM 27	11.8	995	-20.5	10.7	45.2	16.2	2.8	PG
Varnhem	SHM 28	11.0	575	-20.9	—	31.6	10.1	3.1	PG
Luttra	SHM 29	80.5	375	-20.1	11.3	43.5	15.7	2.8	PG
Kinneved	SHM 30	—	—	-20.5	11.4	43.2	15.7	2.8	D
Kinneved	SHM 31	11.6	1275	-20.6	11.4	41.1	14.3	2.9	D
Rössberga[3]	K-15	60.8	238	-20.9	10.4	52.0	18.4	2.8	PG
Rössberga[3]	K-44	68.4	1000	-21.0	9.7	40.2	14.4	2.8	PG
Rössberga[3]	K-50	26.2	200	-20.8	9.8	44.9	16.3	2.8	PG
Rössberga[3]	K-69	14.4	475	-21.1	10.0	44.3	15.9	2.8	PG
Rössberga[3]	K-94	26.9	450	-20.9	10.9	46.5	17.0	2.7	PG
Rössberga[3]	K-104	8.4	300	-20.8	9.9	45.0	16.1	2.8	PG
Rössberga[3]	K-109	7.3	128	-21.0	9.4	44.6	16.2	2.8	PG
Rössberga[3]	K-110	10.0	550	-20.3	11.5	44.0	15.7	2.8	PG

Sample	Lab #	Cu	Zn	$\delta^{13}C$	$\delta^{15}N$	%C	%N	C/N	Type
Östergötland									
Rogslösa	SHM 7	21.8	525	-20.2	11.1	42.7	15.2	2.8	CG
Rogslösa	SHM 8	37.8	1325	-19.9	11.4	42.8	14.9	2.9	CG
Närke									
Hidinge	SHM 2	11.8	975	-21.8	—	45.3	13.5	2.9	GG
Hidinge	SHM 19	15.0	325	-21.4	10.4	43.6	14.5	3.0	GG
Skåne									
Skateholm[1,2]	Skate 30	42.5	98	-16.3	—	—	—	—	MFG
Skateholm[1,2]	Skate 31	17.4	104	-16.2	—	—	—	—	MFG
Kvisttofta	SHM 3	15.0	1500	-20.9	10.1	45.9	15.8	2.9	PG
Kvisttofta	SHM 4	11.0	1075	-20 6	10.2	44.5	15.7	2.8	PG
Vellinge	SHM 23	27.4	142	-20.5	14.9	41.8	14.9	2.8	NFG
Carlshögen[4]	Lu-253	—	—	-19.5	—	—	—	—	PG
Carlshögen[4]	Lu-255	—	—	-19.1	—	—	—	—	PG
Carlshögen[4]	Lu-277	—	—	-17.6	—	—	—	—	PG
Carlshögen[4]	Lu-282	—	—	-18.8	—	—	—	—	PG
Ramshög[4]	Lu-257	—	—	-17.5	—	—	—	—	PG
Ramshög[4]	Lu-275	—	—	-18.2	—	—	—	—	PG
Ramshög[4]	Lu-276	—	—	-17.2	—	—	—	—	PG
Ramshög[4]	Lu-278	—	—	-18.2	—	—	—	—	PG
Ingelstorp[4]	Lu-350	—	—	-19.4	—	—	—	—	PG
Ö. Tommarp[4]	Lu-473	—	—	-18.5	—	—	—	—	PG
Ö. Tommarp[4]	Lu-436	—	—	-19.1	—	—	—	—	PG
Ö. Tommarp[4]	Lu-472	—	—	-19.7	—	—	—	—	PG
Gotland									
Lummelunda	SHM 5	9.2	900	-17.9	13.4	44.8	15.7	2.8	MFG
Lummelunda	SHM 6	11.8	135	-19.1	13.2	40.7	14.5	2.8	MFG
Ajvide	SHM 12	—	—	-15.6	17.7	43.8	15.5	2.8	NFG
Ajvide	SHM 13	14.1	325	-15.9	16.5	43.7	15.9	2.8	NFG
Ajvide	SHM 14	15.6	178	-17.5	—	46.4	14.5	3.2	NFG
Västerbjers	SHM 15	—	—	-15.5	16.8	45.0	16.1	2.8	NFG
Västerbjers	SHM 21	—	—	-15.2	16.0	43.5	15.6	2.8	NFG
Visby	SHM 16	6.1	1200	-16.2	16.4	45.4	15.8	2.9	NFG
Grausne	SHM 17	38.1	250	-16.5	17.1	38.7	13.3	2.9	NFG
Ire[1,2]	Ire 1	21.9	496	-15.3	—	—	—	3.0	NFG
Ire[1,2]	Ire 2	41.1	329	-14.2	—	—	—	—	NFG
Ire[1,2]	Ire 3	25.0	291	-15.2	—	—	—	—	NFG
Ire[1,2]	Ire 4	37.4	572	-15.0	—	—	—	2.9	NFG
Öland									
Resmo[3]	Resmo 6	112.5	115	-18.5	12.6	—	—	3.1	PG
Resmo[3]	Resmo 8	118.8	153	-18.0	13.6	—	—	3.4	PG
Resmo[3]	Resmo 9	108.2	300	-18.1	12.9	—	—	3.0	PG
Resmo[3]	Resmo 10	144.8	275	-18.9	11.5	—	—	3.1	PG
Resmo[3]	Resmo 11	181.2	250	-19.5	12.2	—	—	3.0	PG
Resmo[3]	Resmo 12	94.8	325	-18.4	13.0	—	—	3.1	PG
Resmo[3]	Resmo 13	110.5	300	-19.3	12.0	—	—	3.1	PG
Resmo[3]	Resmo 14	81.8	142	-19.3	11.8	—	—	3.0	PG
Resmo[3]	Resmo 15	80.2	275	-18.8	11.6	—	—	3.2	PG
Resmo[3]	Resmo 16	51.5	250	-17.9	13.1	—	—	3.0	PG
Resmo[3]	Resmo 17	—	-18.2	13.4	—	—	3.0	PG	
Resmo[3]	Resmo 18	—	-18.6	12.6	—	—	3.0	PG	
Resmo[3]	Resmo 20	57.4	658	-19.7	10.7	—	—	3.0	PG
Bohuslän									
Dafter	Lj-1	10.2	575	-15.0	—	—	—	—	NFG

[1]Lidén & Nelson 1994, [2]Arrhenius 1990, [3]Lidén 1995a, [4]Compiled after Blomqvist 1989a

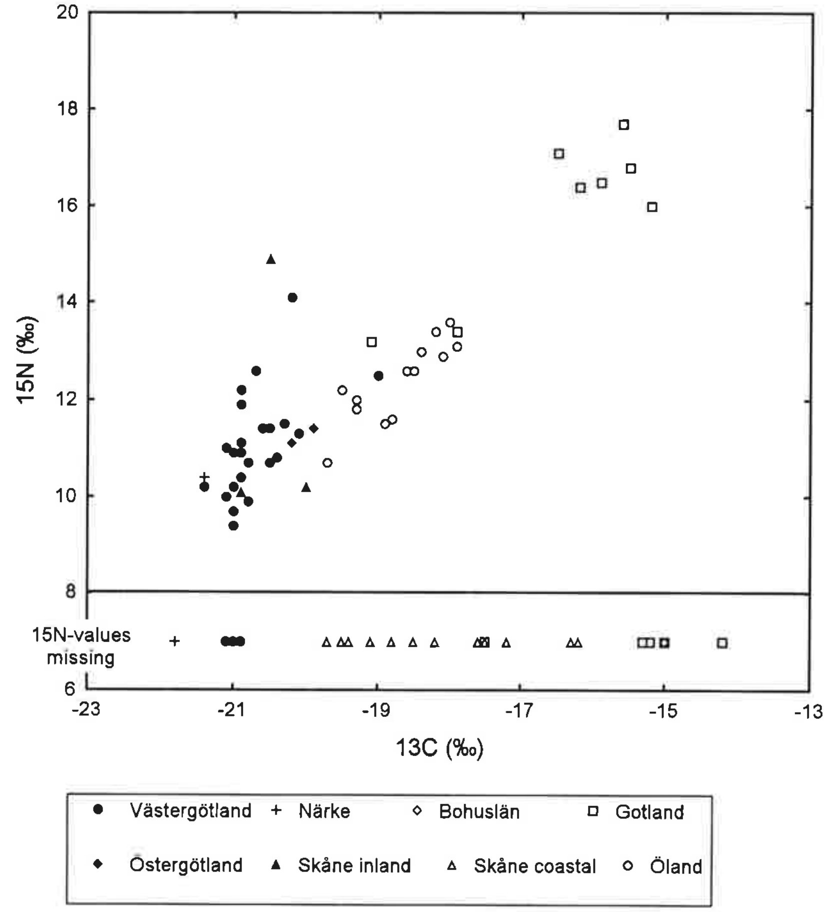

Figure 2 (Left). Stable carbon and nitrogen values from bone collagen ($\delta^{13}C$, $\delta^{15}N$ in ‰) plotted against each other. Originating from different geographical areas in Sweden dating from the Mesolithic to the Neolithic. Open symbols coastal sites, closed symbols inland sites.

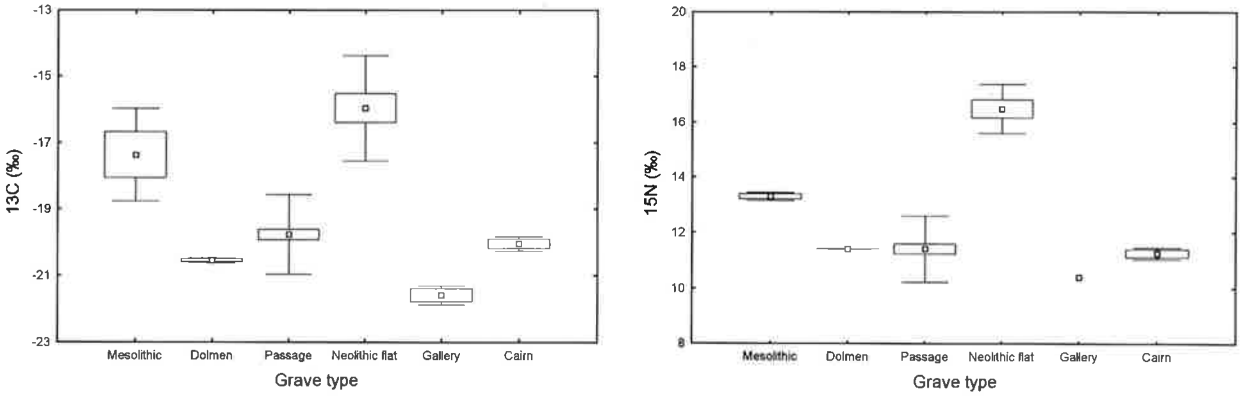

Figure 3 (Below). Stable carbon and nitrogen values from bone collagen ($\delta^{13}C$, $\delta^{15}N$ in ‰) of different burial types (Mesolithic flat ground grave, dolmen, passage grave, Neolithic flat ground grave, gallery grave, Neolithic grave beneath a cairn), plotted as whisker boxes indicating mean, standard deviation and range. Originating from different geographical areas in Sweden dating from the Mesolithic to the Neolithic.

dated to 8050±75 BP (L. Larsson 1982), i. e., when the Baltic was in the final Ancylus Lake stage with a fresh water reservoir.

The stable nitrogen values also differ a lot (Table 1, 2), with a minimum value of 13.2‰ (SHM 5, Lummelunda), a maximum value of 17.1‰ (SHM 17, Grausne), and a mean of 15.9‰ (n=8, s.d. =1.7).

Gotland with its mainly marine diet, according to the carbon isotopes, had a copper mean of 22.0 ppm and a zinc mean of 322 ppm (Table 1, 2). However, if we break down the values from Gotland into different sites we see that there is a difference in both copper and zinc values (Table 2). The individuals from Ire had the overall highest copper and zinc values with a mean of 31.5 and 422 ppm respectively, compared to Lummelunda with a mean of 10.5 and 135 ppm respectively. For both copper and zinc levels the two analysed individuals from Ajvide fall in between.

Öland

All samples from Öland originate from one site, the passage grave at Resmo. All these individuals have had some marine contribution to their diet (Table 1, 2). The carbon isotope values varied between -17.9‰ (Resmo 16) and -19.7‰ (Resmo 20), with a mean of -18.7‰ (n=13, s.d. =0.6). The standard deviation indicates a differentiated access to protein resources, with a maximum contribution of marine protein of 50%, and a minimum contribution of 30%.

Table 2. Mean values of trace-elements and stable-isotope analyses from different counties and sites providing more than one sample within each county. Cu and Zn are given in ppm, $\delta^{13}C$ and $\delta^{15}N$ are given in ‰ with respect to the PDB and AIR standard. Zn values out of range according to previously measured Zn bone values in modern and prehistoric populations (Armelagos et al. 1989) are excluded.

Site	Cu $\bar{x}$ (s.d., n)	Zn $\bar{x}$ (s.d., n)	$\delta^{13}C$ $\bar{x}$ (s.d., n)	$\delta^{15}N$ $\bar{x}$ (s.d., n)
Västergötland	***20.9*** *(21.8, 26)*	***306*** *(192, 26)*	***-20.7*** *(0.4, 30)*	***11.0*** *(1.0, 7)*
Gökhem	**22.8** (24.0, 4)	**285** (329, 4)	**-20.7** (0.4, 4)	**11.7** (0.7, 4)
Karleby	**8.6** (6.3, 8)	**284** (184, 11)	**-20.5** (0.6, 11)	**11.4** (1.3, 9)
Varnhem	**14.5** (7.1, 4)	**329** (212, 3)	**-20.6** (0.2, 4)	**10.7** (0.06, 3)
Rössberga	**7.8** (24.0, 8)	**334** (158, 7)	**-20.8** (0.2, 8)	**10.2** (0.7, 8)
Östergötland	***29.8*** *(11.3, 2)*	***525***	***-20.0*** *(0.2, 2)*	***11.2*** *(0.2, 2)*
Närke	***13.4*** *(2.3, 2)*	***325***	***-21.6*** *(0.3, 2)*	***10.4***
Skåne	***22.7*** *(12.6, 5)*	***115*** *(24,3)*	***-18.6*** *(1.4, 16)*	***11.7*** *(2.7, 5)*
Carlshögen			**-18.8** (0.8, 4)	
Ramshög			**-18.3** (0.8, 4)	
Ö. Tommarp			**-19.1** (0.6, 3)	
Gotland	***22.0*** *(12.9, 10)*	***322*** *(149, 8)*	***-16.1*** *(1.3, 13)*	***15.9*** *(1.7, 8)*
Lummelunda	**10.5** (2.0, 2)	**135**	**-18.5** (0.8, 2)	**13.3** (0.1, 2)
Ajvide	**14.8** (1.0, 2)	**251** (104, 2)	**-16.7** (1.1, 2)	**16.5**
Västerbjers			**-15.4** (0.2, 2)	**16.4** (0.6, 2)
Ire	**31.3** (9.3, 4)	**422** (134, 4)	**-14.9** (0.5, 4)	
Öland				
Resmo	**103.8** (37.5, 11)	**277** (145, 11)	**-18.7** (0.6, 13)	**12.4** (0.8, 13)

The stable nitrogen values from Resmo were nicely correlated to the stable carbon isotope values with a range from 10.7‰ to 13.6‰, and a mean of 12.4‰ (n=13, s.d. =0.8). There were only two values that deviated in that their $\delta^{15}N$ values are too high in comparison to their $\delta^{13}C$ values and those are Resmo 11 and Resmo 12 (Table 1, 2). This could again be explained by a high intake of fresh water fish.

The copper mean from Resmo was the highest overall at 103.8 ppm (n=11, s.d. =37.5) whereas the zinc mean is 277 ppm (n=11, s.d. =145) (Table 1, 2).

Stable isotopes

Carbon

Analysis of the stable carbon isotope data showed essentially that inland sites had terrestrial values and that coastal sites had a marine influence to varying degrees (fig. 2). The only exception to this general pattern was one of the individuals from the passage grave at Karleby church (SHM 39, -19.0‰), with a slight influence of marine protein in his/her diet. This value can be compared to those from the passage graves at Resmo (Öland) and coastal Skåne. This individual (SHM 39) might be regarded as a coastal immigrant to the Västergötland population. The low standard deviation in the population from Västergötland (s.d. =0.4) indicates that all these individuals ate the same amount of terrestrial protein as opposed to marine protein. Excluding this outlier (SHM 39) decreases the standard deviation to 0.3. This is the stipulated standard deviation a population gets if it has been living on the same diet regarding the carbon source (Nelson et al. 1985; Lovell et al.1986).

The striking pattern in the stable carbon isotope results for the entire time span of the Stone Age, is the absence of major transitions during the period predicted according to the former general picture of the Stone Age diet (fig. 3). There are, however, two minor transitions in the stable carbon isotope values, and those are the ones from the Mesolithic coastal sites Lummelunda (Gotland) and Skateholm (Skåne), to the Neolithic sites. At Lummelunda (-17.9‰, -19.1‰) there was a shift towards a heavier dependence on marine resources in the Neolithic Pitted Ware Culture sites ($\bar{x}$=-15.6‰). However, this might be a false transition since we cannot really evaluate the marine influence, by stable carbon isotopes, for this time period of the Baltic because of the marine and fresh water history. Analysis of seal bones from Gotland, dated to the same time as the Lummelunda sample, had almost terrestrial $\delta^{13}C$ values, -18‰ to -21‰ (Lindqvist & Possnert n.d.). Similar terrestrial values on seal were reported from the Estonian Mesolithic site at Lammasmägi, Kunda -23‰ (Lõugas et al. in press) dated to 9500–8000 BP (Åkerlund et al. in press). It is, thus, impossible to conclude whether these people got their protein mainly from the sea or from terrestrial resources.

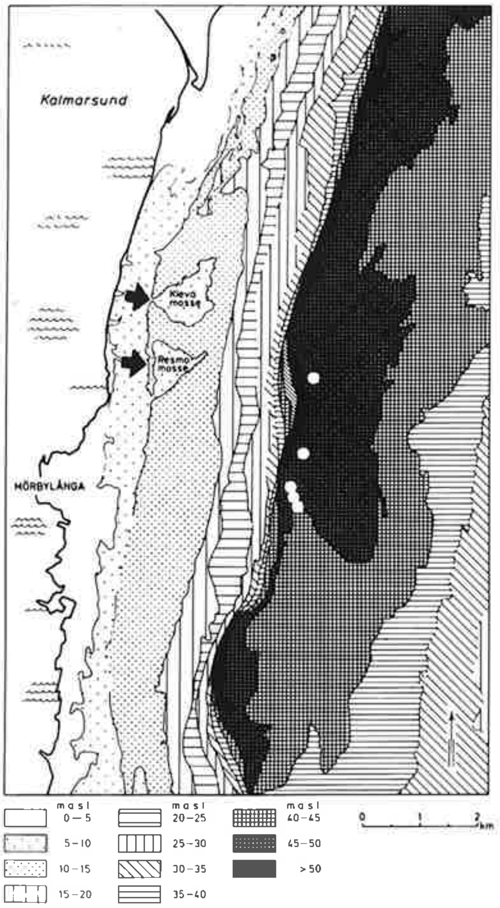

Figure 4. The topographic conditions of the area around the megaliths at Resmo (white dots) on the west coast of Öland. The two lagoons situated nearby the megaliths are Kleva mosse and Resmo mosse (Borg et al. 1979).

It is clear, however, that the two Gotland sites Ire and Västerbjers had the highest marine protein contribution to the diet of the analysed sites on Gotland. There were also single values within the populations at the Pitted Ware sites with similar intermediate values as one of the Lummelunda individuals, e.g., one individual at Ajvide (SHM 12, -17.5‰). This can be interpreted as if these individuals had a terrestrial contribution to their protein diet.

The Mesolithic site Skateholm (-16.2‰) had a higher dependence on marine resources than the Neolithic sites in Skåne (-19.0‰). Further, the coastal sites continued to utilize marine resources to some extent despite the introduction of domesticated resources. This was also seen on Öland, where an individual from the Mesolithic site of Alby provided a $\delta^{13}C$ value of -15.4‰, radiocarbon dated to 5260±70 BP (Königsson et al. 1993), which turns into -18.7‰ in the Neolithic passage grave population at Resmo (Lidén 1995a).

Nitrogen

Analysis of the stable nitrogen isotope data provided the same pattern between inland sites with terrestrial values and coastal sites with marine influences in the diet, albeit to varying degrees (fig. 2). There was also a correlation between the stable carbon and nitrogen values, the more marine protein digested, the higher the $\delta^{15}N$ value. This is, of course, due to the trophic level effect in nitrogen of 3‰ (Wada 1980; Minagawa & Wada 1984), and that the food chains are much longer in marine and lacustrine environments than in terrestrial.

There are, however, some deviating values with respect to nitrogen, i.e., samples with high $\delta^{15}N$ values compared to their $\delta^{13}C$ values. Especially the individual from Vellinge in Skåne (SHM 23, 14.9‰) who had the highest $\delta^{15}N$ value of all individuals feeding on terrestrial resources (Table 1). This could either be explained by the fact that this individual was an infant and still being breast fed, since lactating infants get a $\delta^{15}N$ value 3‰ higher than their mothers due to a fractionation effect in the milk production (Fogel et al. 1989), or that this individual had a high intake of fresh water fish. The bone fragment indicates that this individual was not an infant, although the exact age has not been determined, hence this individual must have been a fish eater.

The high $\delta^{15}N$ value (13.2‰) of sample SHM 6 from Lummelunda (Gotland), compared to the $\delta^{13}C$ value (-19.1‰), should also be noted. This high $\delta^{15}N$ value can be explained by the fact that this individual could also have been eating fresh water fish. On the other hand, considering carbon values (-18‰ to -21‰) of seal bones from Gotland, dated to the same time as the Lummelunda sample (Lindqvist & Possnert n.d.), this could indicate an influence of fish from the Ancylus Lake.

There were also three individuals from Västergötland that had slightly elevated nitrogen values compared to their carbon values suggesting a fish diet, from Gökhem (SHM 10, 12.6‰) and Karleby Church (SHM 18, 14.1‰; SHM 40, 12.2‰). Individual SHM 39 from the passage grave at Karleby church had a $\delta^{15}N$ value of 12.5‰, i. e., about the same as the above values, but this value can be explained by the $\delta^{13}C$ value (-19.0‰) which indicates a slight contribution of marine fish or seal.

Trace elements

Copper

The extremely high levels of copper ($\bar{x}=104$ ppm, n=11) in the population from Resmo, Öland (Table 2), could be explained by a high intake of crustaceans and/or insects, which contain high levels of copper. One could imagine a utilization of the lagoons situated 2 km from the passage tomb (fig. 4)(Borg et al. 1979), where common shrimps living in the seaweed were delicatessen. Although they did not necessarily provide the major source of protein in the diet, a regular intake of unpeeled common shrimps could provide these high copper values.

Shells of shrimps and other shellfish have a copper content of 35 ppm (Bryan 1964) in comparison to shrimp meat, 13 ppm (*Statens Livsmedelsverk 1988*). The utilization of the lagoons, where daily garbage disposal increased the productivity of primary and secondary producers, could be seen as an implement to a delayed-return system (Woodburn 1982). Deliberate or non-deliberate fertilization of aquatic systems has been demonstrated in ingenious irrigation systems of maize fields in the Andes, where fish were harvested in the channels. Fish farming in ponds is also a well known concept in most Asian countries, where still active pond systems date back some 500 years, e.g. the Dyke-pond region in southern China (Chan 1993).

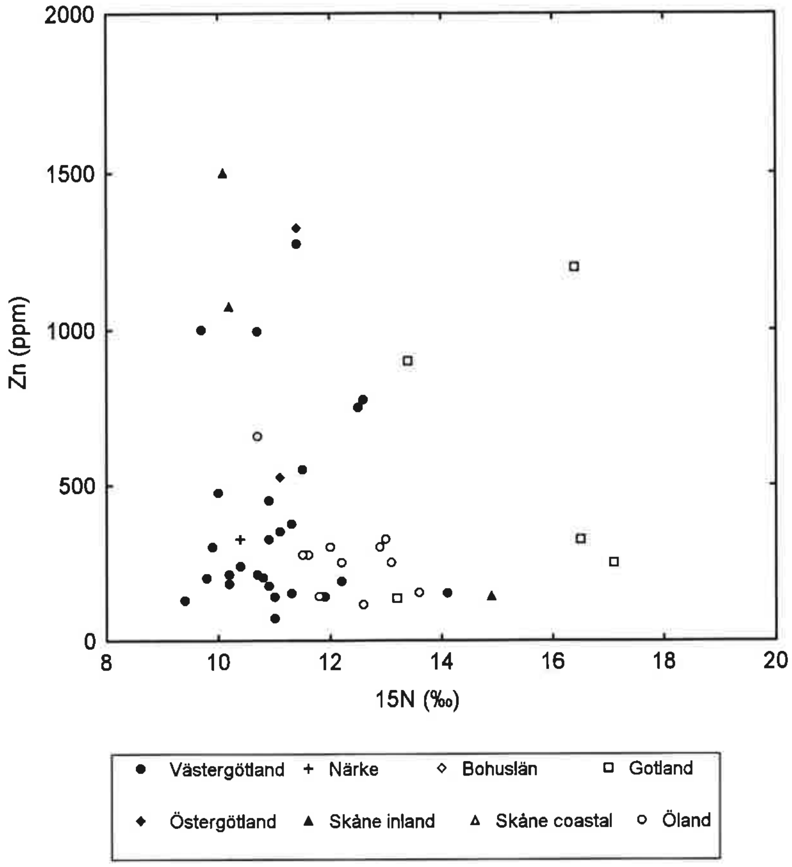

Figure 5. Zinc and stable nitrogen values from bone (Zn in ppm, δ^{15}N in ‰) plotted against each other, originating from different geographical areas in Sweden dating from the Mesolithic to the Neolithic. Open symbols coastal sites, closed symbols inland sites.

The copper values from the other sites were all within the same range, viz., ~20 ppm. The measured range for bone copper values in modern and prehistoric populations is 1-116 ppm (Armelagos et al. 1989). There were some low values in the analysed populations (I prefer to regard them as low with respect to the mean of the analysed populations) and those were Karleby (9 ppm), Lummelunda (10 ppm), those from Närke (13 ppm) and finally those from Ajvide (15 ppm). There were also two values that were slightly higher, viz. Ire (31 ppm) and Östergötland (29 ppm). Low copper values can be explained either by a low utilization of shellfish, crustaceans and insects, or by the antagonistic effect of zinc towards copper, i.e., high zinc values will provide low copper values (Danks 1980). Copper deficiency can also be caused by constant diarrhoea; this deficiency would, however, also show up in the osteological material as, e.g., osteoporosis (Delves 1980). Of these two alternative explanations for the low copper values, I believe that the most parsimonious one is the antagonistic effect of zinc. The slightly elevated values of copper correspond well with the high marine dependence on Ire. In Östergötland, on the other hand, another explanation is required. A high utilization of fresh water molluscs and insects could explain these copper values.

I think it is important to focus on the copper values of the trace elements analysed, because of the affinity to collagen and also, we have a good instrument for testing the collagen quality for diagenesis, i.e., the C/N ratio (see isotope analysis).

Zinc

The measured range for zinc bone values in modern and prehistoric populations is 50-826 ppm (Armelagos et al. 1989). Zinc has a higher affinity to the apatite part of the bone than to the collagen. Since there is no method to test diagenetic alterations in the apatite included in this paper, I have excluded values out of range according to previously measured values, because of risk of diagenetic alterations within the apatite fraction.

The highest zinc values obtained are those from Ire, which fit well with both the trophic level effect and the marine resources. The lowest values obtained are from the Mesolithic Skateholm and Lummelunda. Differences in zinc values are, beside differences in diet, probably also caused by gender differences. Females tend to have lower zinc values, especially when lactating (*National Research Council* 1979). This would also explain why there is not a perfect correlation between zinc and δ^{15}N, as would be if the only variation was due to the trophic level effect in zinc (fig. 5).

The statement that zinc has a trophic level effect does not seem to be true for this material, which is seen if zinc is plotted against ^{15}N (fig. 5). It is quite obvious, however, that there is an antagonistic effect of zinc towards copper as proposed by Danks (1980), Mills (1980), and Johnson (1989). This is clearly seen when zinc and copper are plotted against each other (fig. 6).

Discussion

Earlier research

The Mesolithic. The population at the Late Mesolithic coastal site Skateholm, Skåne, had a diet consisting of mixed marine and terrestrial resources according to earlier results (L. Larsson 1988; Jonsson 1988). This is confirmed by the stable carbon isotope results, although marine resources seem to have dominated (~65%). Additional information was provided by the copper analyses, where the very high values indicate that crustaceans or insects were an important part of the diet (Arrhenius 1990).

This information would not have been possible to obtain unless analysis of trace elements were used, since these resources do not leave any physical remains that can be identified after digestion. It is thus quite obvious that without analysis of isotopes and trace elements there will be no quantitative information of the use of marine vs. terrestrial protein, neither will we get any information on the use of crustaceans and insects.

Previous subsistence analysis in Sweden has shown that in southern Swedish Mesolithic settlements (Skåne) there was a dominance in the faunal material of red deer, in favour of roe deer, e. g., at Segebro, Arlöv and Ageröd (L. Larsson 1983). The Late Mesolithic–Early Neolithic coastal settlement Löddesborg in Skåne provides information on a subsistence being based on red deer, followed by roe deer and wild boar. A minor influence of seal, as well as seabirds, was also present. There was a large amount of fish bones found at this site, dominated by marine and brackish water dwelling species, especially cod. On this site disputable teeth fragments from cattle were also found. Presence of cereal imprints in the Ertebølle ceramics found on this site have been interpreted as evidence of farming (Jennbert 1984). The faunal remains at Löddesborg, are thus almost comparable to the faunal results from the coastal Mesolithic Skateholm (Jonsson 1988). As there are no analyses of human skeletal remains we cannot confirm the plausible hypothesis that the diet at Löddesborg also included crustaceans and insects.

The coastal Mesolithic site at Lummelunda, Gotland, also provides information on a mixed terrestrial and marine diet, according to the stable carbon and nitrogen isotopes. According to the low copper values, however, there is no evidence of any utilization of insects or crustaceans, thus differing from the coastal Mesolithic site Skateholm. The recently found Mesolithic coastal settlement at Huseby Klev, on the Swedish west coast, Bohuslän, dated to approximately 7000–5000 bc, proved to contain mainly fish bones, but also a large number of bones from dolphins (Nordquist 1994). The subsistence at this site seems, thus, to have been based mainly on a high level of marine protein, i.e., quite different from that at Lummelunda on Gotland. However, since there are no analyses of stable nitrogen isotopes or trace elements performed on the human bones found at this site, we cannot compare the diet at Huseby Klev to that of Lummelunda and Skateholm.

The Neolithic. The transition from the Mesolithic to the Neolithic is commonly denoted by the introduction of farming. Thus, after the transition to farming, in the beginning of the Neolithic (i.e., in the TRB Culture), the main subsistence consisted of domesticated mammals, such as pigs and cattle and vegetable (cereals) resources.

An important topic to remember here, however, is that the so-called transition of hunter-gatherers to farmers that supposedly took place at the end of the Mesolithic, i.e., defined by time, did not influence the overall population in Scandinavia. A large part of the population in the northern parts remained hunters, at least as late as the 19th century (Lindqvist 1994 and ref. therein). Hence, the end of the Mesolithic economy in northern Sweden is sometimes defined as equal with the southern Swedish Bronze Age, i.e., defined by time (Knutsson 1995).

The subsistence in a number of Early Neolithic settlements in southern Sweden (Skåne), was based on pig, cattle and cereals (M. Larsson 1984). Two different agricultural traditions were present. One that concentrated on naked barley/wheat and another that concentrated on emmer wheat/einkorn.

The isotope study of the somewhat later megalith populations in southern Sweden (Skåne), does not support any human dietary reliance on cereal products. Also, marine resources were still utilized in coastal areas. The megalith populations in middle Sweden (Västergötland), also provide information on a diet based on meat, in this case terrestrial. The coastal passage grave at Resmo on Öland, also provides evidence that marine resources still were used. What is interesting at Resmo is the high copper values, which are comparable to those from Skateholm. This indicates the use of crustaceans and insects.

It has been proposed that the diet at the Neolithic Alvastra pile dwelling consisted of 75% plants and 25% meat (Browall 1986). This prediction coincided with a similar calculation, based on bone chemistry, stable carbon isotope analysis and analysis of strontium and calcium in human bones (Sælebakke & Welinder 1988).

These assumptions are, however, most unlikely, considering the stable nitrogen analysis performed in this study, as well as the copper analysis of contemporary megalith populations from Västergötland and Öland. These populations had a diet consisting mainly of animal protein. However, carbohydrates and vitamins were naturally supplemented in the form of vegetables. The use of strontium as a dietary tracer is based on the assumption that the reference material used in the analysis and the animals consumed at the site have been feeding at

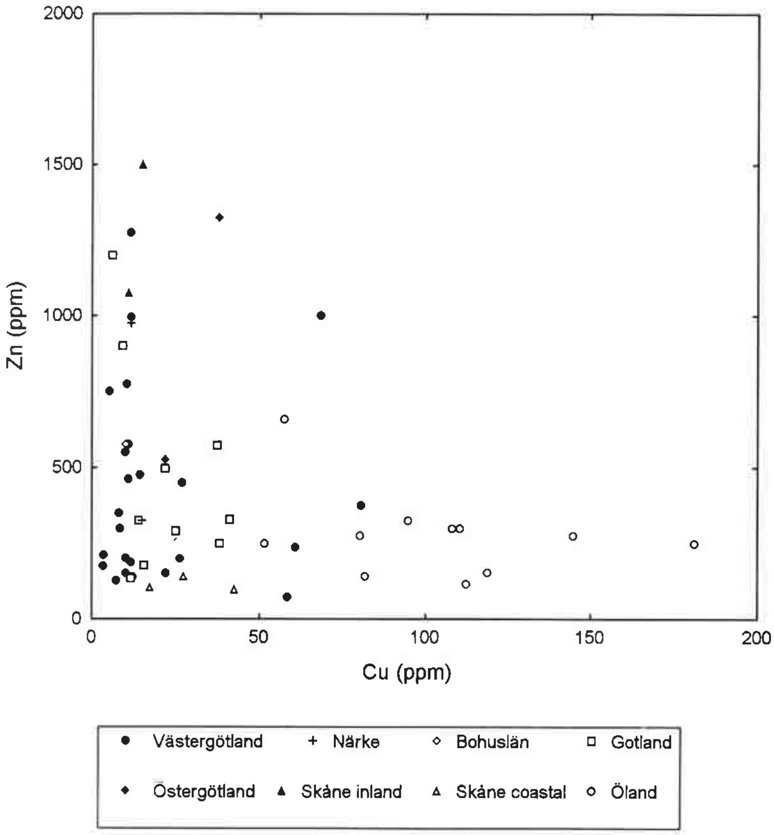

Figure 6. Zinc and copper values from bone, in ppm, plotted against each other. Originating from different geographical areas in Sweden, dating from the Mesolithic to the Neolithic. Open symbols coastal sites, closed symbols inland sites.

the same geographical location. This is due to the strontium content in plants being dependent on the strontium content in the soil in which they grow, and this is extremely variable. This highlights the problem of strontium analysis as a dietary indicator when the reference material does not necessarily originate from the same area.

The interesting results of the excavations at Bälinge mossar, Uppland, provide information on three different types of subsistence from two different cultures, approximately contemporary (Segerberg 1978, 1985a, 1985b). At the Pitted Ware site Vadbro II, the osteological results provide information on a subsistence based mainly on elk (50%) and then, in descending order, sheep, pig and, with a minor contribution, seal. Thus, this is interpreted as a hunting settlement, supplemented with a domestic contribution of sheep and pig. However, at another Pitted Ware location, Sotmyra, located further out in the former archipelago, the bones of ringed seal dominated. This further supports the need for chemical analysis of human bones to gain quantitative dietary information. Also situated at Bälinge mossar is a slightly older settlement, Anneberg, with ceramics belonging to the Early TRB Culture ("Vrå Culture"). This site was a hunting–fishing site, where a large amount of fish bones were found, whereas stock raising was of minor importance, in contrast to former interpretations of the subsistence of the Early TRB Culture (Segerberg 1985a; 1985b). If human bones had been available, it would have been interesting to compare bone chemistry results with those obtained from the megalith site Resmo on Öland. The location and the available resources look similar, and the faunal remains do not contradict the isotope results from the analysed megalith population.

Another Pitted Ware Culture site in central Sweden, Korsnäs (Olsson et al. 1994) provides information on a subsistence based mainly on hunting and fishing of seal, wild boar and herring. The location of this site is supposed to have been in the inner part of the archipelago, and it is interpreted as an all-year-round base camp (Olsson et al. 1994).

The bone chemistry results from the inland Late Neolithic samples included in this analysis do not deviate from those of the inland Middle Neolithic samples. It is, thus, not possible to identify any dietary transitions between these two periods.

According to faunal remains, there was an intensification of hunting and fishing during the Late TRB period in southern Skåne, which has been interpreted as if a lower yield of the farming products was obtained (L. Larsson 1987). The subsistence during the Late Neolithic does not seem to differ dramatically from previous periods (Malmer 1975). The only significant difference was a shift towards sheep raising as compared to the previous importance of cattle and pig, detected in the faunal rermains (Malmer 1975). This shift towards sheep/goat has been interpreted by Kristiansen (1987) as if new techniques were introduced for handling the wool, spinning and weaving, as compared to the old method of twisting. There is no way of detecting such a shift using bone chemistry, unless secondary products such as milk and cheese became more important than previously.

In a dental anthropological study on the Battle Axe Culture by Alexandersen (1987), which compared Late Mesolithic, Early, Middle and Late Neolithic groups in Scandinavia, it was found that the Battle Axe Culture "did not differ significantly from the Neolithic groups in regards to dental attrition, periapical abscesses, dental caries or ante-mortem tooth loss", which is contradictory to any dietary changes. However, "[r]egarding enamel hypoplasia the frequency was significantly lower than in the Late Neolithic". The transition from a hunter–gatherer based subsistence to a subsistence based on farming, is usually seen in the dental records as an increase in caries and enamel hypoplasia, attributed to dietary differences, primarily a higher intake of carbohydrates (Meiklejohn et al. 1984, 1988, 1992; Formicola 1987).

Bone chemistry

The Mesolithic. The dependence on terrestrial and/or marine resources during the Early Mesolithic, and a heavy utilization of marine resources in the Late Mesolithic Ertebølle (supported by isotope studies by Tauber 1981), can neither be proven nor falsified. What can be said is that the resources available in Mesolithic Skateholm, at the lagoon where the site was located, i.e. both terrestrial and marine, were utilized. The mean value of six analysed individuals from Skateholm, in a study by Arrhenius (1990), is 98.9 ppm, i. e. approximately the same as the Neolithic population from Resmo, Öland (103.8 ppm). It is striking that these two populations have about the same carbon isotope values and about the same copper values as well as access to a lagoon (fig. 4, Table 1). Is this evidence for a specific lagoon utilization, where garbage disposal in the water increased the productivity, especially the primary (plankton) and secondary (filtrators, e.g., shrimp and shellfish) productivity? It has been noted among ethnographers that not all food that is edible has equal value. Food is often denoted by different names, as e.g. at Fiji where the staple food is the only one regarded as real food, called *kakana dia,* consisting of starch. Side dishes, that accompany the starch, is called *i coi* and whereas the consumption of the side dishes is a matter of taste the consumption of starch is not (Burghart 1990). I would consequently argue that consumption of common shrimp, at Resmo and Skateholm, was governed by taste rather than necessity and which then resulted in the high copper values.

The individuals from Mesolithic Lummelunda both have low copper values. These two have obviously not been feeding on shellfish and crustaceans. Hence, the two Mesolithic sites included in this study have both been feeding on a mix of terrestrial and marine resources. According to the trace elements, however, there has been a difference in the intake of shellfish and crustaceans.

The Neolithic. Within the inland megalithic sites there is, according to the stable carbon isotopes, no indication of a utilization of marine resources. However, according to the stable nitrogen isotopes, there are no signs of a dependence on vegetable protein either. This is further supported by the zinc values, where a high intake of cereals would show up as low bone zinc values, mainly because of the inhibiting effect of phytates, of which cereals have a high level. Studies of zinc deficiency in Iranian villagers was attributed to high levels of phytate in the bread. Experiments where Iranian men were fed an unleavened bread, *tanok*, which is very high in phytate (Reddy et al. 1982), showed that zinc excretion increased which caused zinc deficiency (*National Research Council* 1979).

The varying copper values between some of the sites in Västergötland could be due to a varying degree of utilization of freshwater molluscs and insects which both would contribute to "high" copper levels (*Statens Livsmedelsverk* 1988).

Within the TRB settlements in Skåne included in this analysis, it is striking that some of the individuals, mainly those from coastal sites, still utilize the marine resources. This is further confirmed in the study from the passage grave in Resmo, Öland. Here it is also clear that there has been a differentiated access to the marine resources.

Also interesting are the high copper values at Resmo, which could be due to a high intake of crustaceans and/or shellfish. I would once again like to argue for the utilization of the nearby lagoon and an implement to a delayed-return system with fertilization of the lagoon by the daily waste disposal. Thus, it should be emphasized that coastal resources continued to be utilized, as seen in the Mesolithic Alby (Königsson et al. 1993) and the Neolithic Resmo.

The dependence on marine resources within the Pitted Ware Culture is clearly demonstrated in the analyses from Gotland where all sites have marine values. Here it can be seen, though, that some sites have had a heavier dependence on marine resources than others, where the population from Ire relied mainly on marine resources. The copper values from Ire are also the highest on the island.

The minor shift in the domesticated animals towards sheep/goat during the Late Neolithic cannot of course be identified in this analysis. The only way to detect such a change would be if there had been a new high utilization of milk products; this would then show up as an elevation of the $\delta^{15}N$ values. An elevation of the nitrogen values can, however, not be demonstrated (Table 3).

Overall there is a higher correlation between geographical location, i.e., coast or inland, than temporal trends, regarding the stable-isotope analysis as well as for the results in previous studies. The trace-element analysis, however, does not have a similar correlation between coast and inland, although the high copper values are mainly found in coastal areas and the high zinc values are mainly found at inland sites (fig. 6). This pattern is most likely due to the antagonistic effects by copper and zinc (Danks 1980; Mills 1980; Johnson 1989), i.e., you don't find high copper and zinc bone-levels in the same individual (fig. 6).

That subsistence is correlated to the geographical location is further emphasized by the utilization of freshwater fish at different sea-coast Ertebølle sites in Denmark. These results should be seen in the light of a differentiated access to resources, rather than differences in cultural concepts. Thus, there is a higher correlation between geographical location than temporal trends. A revision of the original Ertebølle site, based on artefacts, animal bones and shellfish, where the only domesticated animal was the dog, still holds that the site economy was

Table 3. Mean values of trace-element and stable-isotope analyses of bones from different burial types. Cu and Zn are given in ppm, $\delta^{13}C$ and $\delta^{15}N$ are given in ‰ with respect to the PDB and AIR standard. Zn values out of range according to previously measured Zn bone values in modern and prehistoric populations (Armelagos et al. 1989) are excluded. Type refers to burial type where D = dolmen, PG = passage grave, GG = gallery grave, MFG = Mesolithic flat grave, NFG= Neolithic flat grave, CG = burial beneath a cairn.

Type	Cu	Zn	$\delta^{13}C$	$\delta^{15}N$
	x (s.d., n)	x (s.d., n)	x (s.d., n)	x (s.d., n)
MFG	**20.2** (15.2, 4)	**112** (20, 3)	**–17.4** (1.4, 4)	**13.3** (0.1, 2)
D	**11.6**		**–20.6** (0.1, 2)	**11.4** (0, 2)
PG	**44.4** (46.5, 38)	**298** (182, 34)	**–19.8** (1.2, 54)	**11.4** (1.2, 40)
inland	**20.8** (21.8, 25)	**308** (199, 23)	**–20.7** (0.5, 28)	**11.0** (1.0, 25)
coastal	**89.8** (48.3, 13)	**276** (144, 11)	**–18.8** (0.9, 26)	**12.1** (1.1, 15)
NFG	**24.9** (12.9, 8)	**350** (161, 9)	**–15.6** (0.9, 11)	**16.8** (0.6, 6)
CG	**29.8** (11.3, 2)	**525**	**–20.0** (0.2, 2)	**11.2** (0.2, 2)
GG	**13.4** (2.3, 2)	**300** (121, 4)	**–21.6** (0.3, 2)	**10.4**

based on hunting, fishing, and gathering. Remarkable was the large amount of eel (*Anguilla*) bones compared to other Ertebølle sites (Andersen & Johansen 1986). The distribution of fish bones provides information on a heavy utilization of fresh water species (71%), dominated by carp *(Rutilus)* and eel. The contemporary site Maglemosegård, in contrast, had a distribution of 83% marine species, just as the site at Tybrind Vig, that was dominated by marine fish species (Bødker Enghoff 1986).

Stable carbon isotope analysis of a human bone from Tybrind Vig also indicates that the main protein intake was marine resources (Tauber 1981). Other Mesolithic sites, however, have the same dominance of freshwater fish species as the Ertebølle site, e.g., the Bjørnsholm shell midden where the only fish species represented are pike (*Esox*), rudd (*Scardinus*) and eel (Bødker Enghoff 1986). Consequently, the isotope values of human bones from the Bjørnsholm shell midden are almost entirely terrestrial (-19.3‰, -20.8‰, -20.0‰, -19.8‰), whereas the stable nitrogen values in three of the four individuals (*13.8‰*, 10.7‰, *15.0‰*, *12.3‰*) indicate a high dependence of fish, i.e., fresh water species. These results are thus in accordance with the faunal analyses (Bødker Enghoff 1986).

In order to obtain quantitative dietary information it is important to do chemical bone-analyses. This is exemplified by an attempt to a quantitative dietary analysis on Gotland, where the relative importance of different food species from the Pitted Ware sites Visby and Västerbjers on Gotland were calculated, using the faunal remains (Welinder 1975). It was concluded, according to the low percentage of seal (Visby 35.7%, Västerbjers 11.1%), compared to that of domesticated pig (Visby 51.6%, Västerbjers 73.1%), that "the seal hunting of the sites may be interpreted as part of an economy which has been based mainly on pig breeding" (Welinder 1975:33). The relative importance of seal to boar was 1:1.2, at Visby, and 1:6.6 at Västerbjers, according to Ekman (1974). Another Pitted Ware site on Gotland, Ire, differs in the ratio of seal bones to pig bones; here the distribution is the opposite. The ratio of seal bone to pig bone is here 9:1 (Ekman 1974).

Now, if these values are compared with those of the stable isotope analyses (Visby -16.2‰, Västerbjers -15.4‰, Ire -14.9‰), which all show a high dependence on marine resources (Table 1), it is clear that the faunal remains do not provide an accurate picture of the diet at these sites.

An end-value in the Baltic of –14‰, would implicate for Ire a 9:1 relationship between marine vs. terrestrial protein (i.e., seals to pigs). The corresponding ratios for Västerbjers and Visby would be 8:1 and 7:1 respectively.

The difference in the frequency of faunal remains on these sites does not mirror the actual diet. This might, however, be due to differences in deposition and butchering techniques. It would be interesting to see a study on the relative frequency of individual bones of the animals from these sites, as has been done at Star Carr to identify differences in butchering habits (Legge & Rowley-Conwy 1988).

It is also interesting how evidence of cereal pollen in pollen diagrams is interpreted differently. As soon as cereal pollen is identified in pollen diagrams in southern Scandinavia, this is immediately taken as evidence for the existence of cereal cultivation of major importance, i.e., a change in subsistence (Göransson 1977; Welinder 1974). On the other hand, when the same cereals are identified in pollen diagrams in northern Scandinavia, this is, naturally, evidence of the occurrence of cereals, however of minor or subsidiary importance to the subsistence (Barker 1985).

L. Larsson (1987) stresses that pollen indications of cereals should, from an archaeological point of view, first and foremost be interpreted as indicators of a settlement and then secondly as indicators of farming. The problem of pollen interpretation as farming indicators has also been expressed by Kristiansen (1993), "It has been increasingly clear how difficult it is to establish general patterns of development, to delimit cattle husbandry from agriculture, or even define the relationship between cultural and natural processes of vegetational change as reflected in the pollen record". Determining the importance of cereals as a dietary source can hence be solved by the use of stable nitrogen isotopes.

I think it is also worth mentioning problems associated with use of contemporary hunter-gatherers to interpret prehistoric hunter-gatherer groups and their diet. It is a fact that the contemporary hunter-gatherer groups exist only in certain habitats, usually marginal areas and that their ways of life have been altered by contact with agricultural and industrial people (Winterhalder 1981).

Thus, only stable-isotope and trace-element analysis will provide quantitative information of what the individuals actually ate. All the other analysis methods will provide information on the available resources, i.e., qualitative information.

Conclusion

It can be concluded that a general picture of dietary transitions in prehistory does not exist. The geographical location and availability of specific resources are the major determinants of diet. Thus temporal trends and cultural patterns are less obvious than former expected. There are no clear differences in diet between the Mesolithic and the Neolithic, and there are no clear differences between the TRB Culture and the Battle Axe Culture, which is also confirmed in the dental study by Alexandersen (1987). The major differences are between different geographical locations, as seen in, e. g., coastal and inland megalith populations. Further, we can see a continued use of marine resources in coastal areas, such as Öland, with the Mesolithic Alby and the lagoon dwelling megalith population at Resmo. Additionally, the strong correlation between the Pitted Ware Culture and its geographical location explains the result of the relationship between diet and the Pitted Ware Culture, although with some exceptions (e.g., Vadbro II).

The concept of culture is dubious. Thus, this paper argues that the dietary patterns of the Swedish Stone Age are not correlated to any specific culture.

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References

Åberg, N. 1927. Rapport rörande undersökningarna av en hällkista vid Lanna Västergård, Hidinge sn. Närke. 30/ 9 1927. Antikvariskt Topografiskt Arkiv. Dnr 4016. Unpublished report.

Åkerlund, A., Regnell, M. & Possnert, G. In press. Stratigraphy and chronology of the Lammasmägi site at Kunda. *PACT*, Estonia 2. Rixensart.

Alexandersen, V. 1987. Tandforholdene i Enkeltgravstid/ stridsøksetid. In L. Larsson (ed.): *Stridsyxekultur i Sydskandinavien.* University of Lund Institute of Archaeology. Report Series No. 36. pp. 169–180.

Andersen, S. H. & Johansen, E. 1986. Ertebølle revisited. *Journal of Danish Archaeology* 5, pp. 31–61.

Armelagos, G. J., Alcom, M., Martin, D. & Vangreven, D. P. 1989. Factors affecting elemental and isotopic variation in prehistoric human skeletons. In T. D. Price (ed.): *The Chemistry of Prehistoric Human Bone*, pp. 155–210. Cambridge. pp. 230–244.

Arrhenius, B. 1990. Trace element analyses on human skulls. *Laborativ Arkeologi* 4, pp. 15–20.

Barker, G. 1985. *Prehistoric Farming in Europe*. New Studies in Archaeology. Cambridge.

Beck, L. A. 1985. Bivariate analysis of trace elements in bone. *Journal of Human Evolution* 14, pp. 493-502.

Bellander, E. 1934. Rapport rörande undersökningarna av ett stenåldersgravfält vid Västerbjers i Gothem sn. Gotland. 18/ 5–30/6 1934. Antikvariskt Topografiskt Arkiv. Dnr. 3865. Unpublished report.

Blomqvist, L. 1989a. *Neolitikum – typindelningar, tid, rum och social miljö: En studie med inriktning på västra Götaland.* Falköping

Blomqvist, L. 1989b. *Megalitgravarna i Sverige. Typ, tid, rum och social miljö.* Theses and Papers in Archaeology 1. Stockholm.

Bødker Enghoff, I. 1986. Freshwater fishing from sea-coast settlement – The Ertebølle locus classicus revisited. *Journal of Danish Archaeology* 5, pp. 62–76.

Borg, G. C. H., Königsson, L-G. & Pääbo, K. 1979. Resmo mosse and the Littorina transgressions. *Striolae* 1979/5, pp. 3–25.

Browall, H. 1986. *Alvastra pålbyggnad, social och ekonomisk bas*. Theses and Papers in North-European Archaeology 15. Stockholm.

Brown, T. A., Nelson, D. E., Vogel, J. S. & Southon, J. R. 1988. Improved collagen extraction by modified Longin method. *Radiocarbon* 30/2, pp. 171–177.

Bruzelius, M. 1822. Nordiska Fornlemningar från Skåne. *Iduna* 9.

Bryan, G. W. 1964. Zinc regulation in the lobster Homarus vulgaris. 1. Tissue zinc and copper concentration. *Journal of Marine Biological Association U.K.* 44, pp. 549–563.

Buikstra, J. E., Frankenberg, S., Lambert, J. B. & Xue, L. 1989. Multiple elements: multiple expectations. In T. D. Price (ed.): *The Chemistry of Prehistoric Human Bone*, pp. 155–210. Cambridge.

Burghart, R. 1990. The cultural context of diet, disease and the body. In G. A. Harrison & J. C. Waterlow (eds.): *Diet and Disease in Traditional and Developing Societies*. Society for the study of human biology symposium 30, pp. 307–325. Cambridge.

Chan, G. L. 1993. Aquaculture, ecological engineering: Lessons from China. *AMBIO* 7, pp. 491–494.

Cnattingius, B. 1927. Rapport rörande undersökningarna av en stenåldersgrav vid Bårstad i Rogslösa sn. Dals hd. Östergötland 23/8–1/9 1927. Antikvariskt Topografiskt Arkiv. Dnr 3794. Unpublished report.

Danks, D. M. 1980. Copper deficiency in humans. In *Biological Roles of Copper.* Ciba Foundation symposium 79. Excerpta Medica, pp.209–221. Amsterdam.

Delves, H. T. 1980. Dietary sources of copper. In *Biological*

Roles of Copper. Ciba Foundation Symposium 79. Excerpta Medica, pp. 5–22. Amsterdam.

DeNiro, M. J. & Epstein, S. 1978. Carbon isotopic evidence for different feeding patterns in two hyrax species occupying the same habitat. *Science* 210, pp. 906–908.

DeNiro, M. J. 1985. Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature* 317, pp. 806–809.

Ekman, J. 1974. Djurbensmaterialet från stenålderslokalen Ire. Hangvar sn, Gotland. In G. O. Janzon: *Gotlands mellanneolitiska gravar*. Studies in North-European Archaeology 6, pp.212–246. Stockholm.

Ezzo, J. A. 1994. Putting the "chemistry" back into archaeological bone chemistry analysis: Modeling potential palaeodietary indicators. *Journal of Anthropological Archaeology* 13, pp. 1–34.

Fogel, M. L., Tuross, N. & Owsley, D. W. 1989. Nitrogen isotope tracers of human lactation in modern and archaeological populations. *Annual Report of the Director of the Geophysical Laboratory at the Carnegie Institute of Washington*. 1988–1989, pp. 111–117.

Formicola, V. 1987. Neolithic transition and dental changes: the case of an Italian site. *Journal of Human Evolution* 16, pp. 231–239.

Francalacci, P 1989. Dietary reconstruction at Arene Candide cave (Liguria, Italy) by means of trace element analysis. *Journal of Archaeological Science* 16, pp. 109–124.

Fürst, C. M. 1911. Skelettresterna från en dös vid Slutarp, Kinneveds sn, Frökinds hd, Västergötland. *Fornvännen* 6, pp. 140–143.

Gejvall, N-G.1974. Description of the human skeletons from the graves and some associated animal bones. In G. O. Janzon: *Gotlands mellanneolitiska gravar*. Studies in North-European Archaeology 6, pp.141–175. Stockholm.

Gilbert, R. I. 1977. Applications of trace element research to problems in archaeology. In. R. L. Blakely (ed.): *Biocultural Adaptation in Prehistoric America*. Athens.

Göransson, H. 1977. *The Flandrian Vegetational History of Southern Östergötland*. Department of Quaternary Geology. University of Lund. Thesis 3.

Grupe, G. 1988. Impact of the choice of bone samples on trace element data in excavated human skeletons. *Journal of Archaeological Science* 15, pp. 123–129.

Hatch, J. W. & Giedel, A. A. 1985. Status specific dietary variation in two world cultures. *Journal of Human Evolution* 14, pp. 469–476.

Janzon, G. O. 1974. *Gotlands mellanneolitiska gravar*. Studies in North-European Archaeology 6. Stockholm.

Jennbert, K. 1984. *Den produktiva gåvan. Tradition och innovation i Sydskandinavien för omkring 5300 år sedan*. Acta Archaeologica Lundensia. Series in 4°. Nr 16. Lund.

Jennbert, K. 1985. Neolithisation – a Scanian perspective. *Journal of Danish Archaeology* 4, pp. 196–197.

Johnson, M. A. 1989. Influence of ascorbic acid, zinc, iron, sucrose and fructose on copper status. In C. Kies (ed.): *Copper Bioavailability and Metabolism*. Advances in experimental medicine and biology 258, pp.29–44. New York.

Jonsson, L. 1988. The vertebrate faunal remains from the Late Atlantic settlement Skateholm in Scania, South Sweden. In L. Larsson (ed.): *The Skateholm Project I. Man and Environment*, pp. 56–88. Stockholm.

Kates, M. 1986. *Techniques of Lipidology: Isolation, Analysis and Identification of Lipids*. 2nd edition. Elsevier.

Kent, S. 1989. Cross cultural perceptions of farmers as hunters and the value of meat. In S. Kent (ed.): *Farmers as Hunters: The Implications of Sedentism*. New Directions in Archaeology, pp. 1–7. Cambridge.

Klepinger, L. L. 1984. Nutritional assessment from bone. *Annual Reviews in Anthropology* 13, pp. 75–96.

van Klinken, G. J., van der Plicht, H. & Hedges, R. E. M. 1994 Bone $^{13}C/^{12}C$ variation reflect (Palaeo-) climatic variations. *Geophysical Research Letters* 21/6, pp. 445–448.

Knutsson, K. 1995. Mesolithic research in Sweden 1986–1990. *Current Swedish Archaeology* 3, pp. 7–27.

Königsson, L.-K., Königsson, E.-S., Bendixen, K. & Possnert, G. 1993. Topography and chronology of the Alby settlement on Southeastern Öland, Sweden. In G. Arwidsson et al. (eds.): *Sources and resources. Studies in honour of Birgit Arrhenius. PACT* 38, pp. 13–39.

Kristiansen, K. 1987. From stone to bronze, the evolution of social complexity in northern Europe. In E. M. Brumfield & T. Earle (eds.): *Specialization, Exchange and Complex Society*. Cambridge.

Kristiansen, K. 1993. Neolithic farming practice. An archaeological response to the Göransson hypothesis. *Fornvännen* 88, pp. 247–251.

Lambert, J. B., Vlasak, S. M., Thometz, A. C. & Buikstra, J. E. 1982. A comparative study of the chemical analysis of ribs and femurs in Woodland populations. *American Journal of Physical Anthropology* 59, pp. 289–294.

Lambert, J. B., Simpson, S. V., Szpunar, C. B. & Buikstra, J. E 1984. Analysis of soil associated with Woodland burials. In J. B. Lambert (ed.): *Archaeological Chemistry III*. American Chemical Society. Washington D.C.

Lambert, J. B., Simpson, S. V., Szpunar, C. B. & Buikstra, J. E. 1985. Bone diagenesis and dietary analysis. *Journal of Human Evolution* 14, pp. 477–482.

Larsson, L. 1982. De äldsta gutarna. *Gotländskt Arkiv* 1982, pp. 7–13.

Larsson, L. 1983. *Ageröd V. An Atlantic Bog Site in Central Scania*. Acta Archaeologica Lundensia. Series altera in 8° Minore12. Lund.

Larsson, L. 1987. Boplatser, bebyggelse och bygder. Stridsyxekultur i södra Skåne. In L. Larsson (ed.): *Stridsyxekultur i Sydskandinavien*. University of Lund Institute of Archaeology. Report Series No. 36, pp. 53–76.

Larsson, L. 1988. The Skateholm project. Late Mesolithic settlement at a South Swedish lagoon. In L. Larsson (ed.): *The Skateholm Project I. Man and Environment*, pp.9–19.

Larsson, M. 1984. *Tidigneolitikum i Sydvästskåne. Kronologi och bosättningsmönster*. Acta Archaeologica Lundensia Series in 4°. No 17. Lund.

Legge, J. A. & Rowley-Conwy, P. 1988. *Star Carr revisited*. London Centre for Extra-Mural Studies. Birkbeck College. University of London. London.

Lidén, K. 1990. A diet study from the Middle Neolithic site Ire. Analyses of stable carbon isotopes, amino acids and trace elements. *Laborativ Arkeologi* 4, pp. 21–28.

Lidén, K. & Nelson, D. E. 1994. Stable carbon isotopes as dietary indicator, in the Baltic area. *Fornvännen* 89, pp. 13–21.

Lidén, K., Takahashi, C. & Nelson, D. E. 1995. The effects of lipids in stable carbon isotope analysis and the effects of NaOH treatment on the composition of extracted bone collagen. *Journal of Archaeological Science* 22, pp. 321–326.

Lidén, K 1995a. Megaliths, agriculture and social complexity: A diet study of two Swedish megalith populations. *Journal of Anthropological Archaeology* 14, pp. 404–417.

Lidén, K. 1995b. Comments to "Putting the 'chemistry' back into archaeological bone chemistry analysis: Modeling potential palaeodietary indicators". *Laborativ Arkeologi* 8, pp. 78–80.

Lindh, N. O. 1993. *Näringsförsörjningens anatomi och fysiologi*. Institutionen för Biologisk grundutbildning. Umeå Universitet. Umeå.

Lindqvist, C. 1994. *Fångstfolkens bilder. En studie av de nordfennoskandiska kustanknutna jägarhällristningarna.*

Theses and Papers in Archaeology A 5. Stockholm.

Lindqvist, C. & Possnert, G. n.d. The subsistence economy and diet at Jakobs/Ajvide and Stora Förvar, Eksta parish and other prehistoric sites on Gotland in long-term perspective. Unpublished manuscript.

Lindquist, S 1911. Två västgötska grafbyggnader från stenåldern. *Fornvännen* 6, pp. 126–140.

Lõugas, L., Lidén, K. & Nelson, D. E. In press. Resource utilization along the Estonian coast during the Stone Age. *PACT.* Estonia 2. Rixensart. Belgium.

Lovell, N. C., Nelson, D. E. & Schwarcz, H. P. 1986. Carbon isotope ratios in palaeodiet: Lack of sex or age effect. *Archaeometry* 28, pp. 51–65.

Malmer, M. P. 1975. *Stridsyxekulturen i Sverige och Norge.* Lund.

Meiklejohn, C., Schentag, C. T., Venema, A. & Key, P. 1984. Socio-economic change and patterns of pathology and variation in the Mesolithic and Neolithic of Western Europe: Some suggestions. In M. Cohen & G. J. Armelagos (eds.): *Palaeopathology at the Origins of Agriculture*, pp. 75–100. New York.

Meiklejohn, C., Baldwin, J. H. & Schentag, C. T. 1988. Caries as a probable dietary marker in the Western European Mesolithic. In B. V. Kennedy & G. M. LeMoine (eds.): *Diet and Subsistence: Current Archaeological Perspectives*, pp. 273–279. University of Calgary. Calgary.

Meiklejohn, C., Wyman, J. M. & Schentag, C. T. 1992. Caries and attrition: Dependent or independent variables? *International Journal of Anthropology* 7/1, pp. 17–22.

Mills, C. F. 1980. Metabolic interactions of copper with other trace elements. In *Biological Roles of Copper*. Ciba Foundation Symposium 79. Excerpta Medica, pp. 49–65. Amsterdam.

Minagawa, M. & Wada, E. 1984. Stepwise enrichment of ^{15}N along food chains: Further evidence and the relation between δ^{15}N and animal age. *Geochimica et Cosmochimica Acta* 48, pp. 1135–1140.

National Research Council. 1979. Subcommittee on Zinc. *Zinc.* Baltimore.

Nelson, D. & Sauer, N. J. 1984. An evaluation of postdepositional changes in the trace element content of human bone. *American Antiquity 49*, pp. 141–147.

Nelson, D. E., Chisholm, B., Lovell, N. C., Hobson, K. & Schwarcz, H. P. 1985. Palaeodiet determinations by stable carbon isotope analysis. *Proceedings of the International Archaeometry Conference. Washington D. C.*, pp. 49–54.

Nordquist, B. 1994. Bland delfinjägare och äppelplockare i Bohus. *Populär Arkeologi* 12/2, pp. 4–6.

Nylén, E. 1965. Rapport rörande undersökning av lager från medeltid och stenålder samt stenåldersgravar i kvarteret Priorn, Visby stad, Gotland 1960–1962. Antikvariskt Topografiskt Arkiv. Dnr 2766. Unpublished report.

Olsson, E., Granath Zillén, G. & Mohr, A. 1994. Korsnäs - en gropkeramisk grav- och boplats på Södertörn. *Riksantikvarieämbetet Rapport 1994:63.* Stockholm.

Österholm, I. 1989. *Bosättningsmönstret på Gotland under stenåldern. En analys av fysisk miljö, ekonomi och social struktur.* Theses and Papers in Archaeology 3. Stockholm University. Visby.

Peterson, B. J. & Fry, B. 1987. Stable isotopes in ecosystem studies. *Annual Review of Ecology and Systematics* 18, pp. 293–320.

Price, T. D. 1985. Affluent foragers of Mesolithic Southern Scandinavia. In T. D. Price & J. A. Brown (eds.): *Prehistoric Hunter–Gatherers. The Emergence of Cultural Complexity.* San Diego. pp. 341–363.

Price, T. D. 1991. The Mesolithic of Northern Europe. *Annual Review of Anthropology* 20, pp. 211–233.

Reddy, N. R., Sathe, S. K. & Salunkhe, D. K. 1982. Phytates in legumes and cereals. In C. O.Chichester, E. M. Mrak & G. F. Stewart (eds.): *Advances in Food Research* 28, pp. 1–92.

Rheingold, A. L., Hues, S. & Cohen, M. N. 1983. Strontium and zinc content in bones as an indication of diet. *Journal of Chemical Education* 60, pp. 233–234.

Rydbeck, O. 1910. Markgrafvar från stenåldern i Skåne. *Fornvännen* 5, pp. 1–13.

Sælebakke, I. & Welinder, S. 1988. The Alvastra diet from bone chemistry. *Fornvännen* 83, pp. 1–5.

Sahlström, K. E. 1915. Förteckning över Skaraborgs läns stenåldersgravar. *Västergötlands Fornminnesförenings tidskrift.* Bd III. Mariestad.

Schoeninger, M. J. & DeNiro, M. J. 1984. Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochimica et Cosmochimica Acta* 48, pp. 625–639.

Segerberg, A. 1978. Stenåldersboplatser i Uppland. Nya utgrävningar vid Bälinge mossar. Tibble i Björklinge och Torslunda i Tierp. *Årsbok för medlemmarna i Upplands Fornminnesförening* 1978, pp. 7–32.

Segerberg, A. 1985a. Bälinge mossar. Hunters and farmers during the Early and Middle Neolithic in central Sweden. *ISKOS* 5, pp. 157–163.

Segerberg, A. 1985b. Bergmans garage. 1985 års undersökning på stenåldersboplatsen vid Anneberg i Oxsätra. *Fjölnir* 4/3, pp. 3–14.

Sholto-Douglas, A. D., Field, J. G., James, A. G. & van der Merwe, N. J. 1991. 13C/12C and 15N/14N isotope ratios in the southern Benguela ecosystem: Indicators of food web relationships among different size-classes of plankton and pelagic fish: Differences between fish muscle and bone collagen tissues. *Marine Ecology Progress Series* 78, pp. 23–31.

Smith, B. N. & Epstein, S. 1971. Two categories of ^{13}C/^{12}C ratios for higher plants. *Plant Physiology* 47, pp. 298–301.

Statens Livsmedelsverk. 1988. *Livsmedelstabeller.* SLV. Uppsala.

Stenberger, M. 1935. Rapport rörande undersökningar sommaren 1935 på stenåldersboplatsen vid Västerbjers, Gothems sn. Gotland. Antikvariskt Topografiskt Arkiv. Dnr. 4785. Unpublished report.

Stenberger, M. 1937. Rapport rörande undersökningar sommaren 1937 på stenåldersboplatsen vid Västerbjers, Gothems sn. Gotland. Antikvariskt Topografiskt Arkiv. Dnr 3625. Unpublished report.

Stenberger, M. 1939. Rapport rörande efterundersökning av skelettdelar av två individer från Kanalen, Lummelunda sn. Gotland. Antikvariskt Topografiskt Arkiv. Dnr. 2494. Unpublished report.

Tauber, H. 1981. 13C evidence for dietary habits of prehistoric man in Denmark. *Nature* 298, pp. 332–333.

Tuross, N., Fogel, M. L., Newsom, L. & Doran, G. H. 1994. Subsistence in the Florida archaic: The stable isotope and archaeobotanical evidence from the Windover site. *American Antiquity* 59, pp. 288–303.

Underwood, E. J. 1977. *Trace Elements in Human and Animal Nutrition.* New York.

Vogel, J. C. 1978. Isotopic assessment of the dietary habits of ungulates. *South African Journal of Science* 74, pp. 298–301.

Wada, E. 1980. Nitrogen isotope fractionation and its significance in biogeochemical processes occurring in marine environments. In E. D. Goldberg, Y. Horibe & K. Saruhashi (eds.): *Isotope Marine Chemistry.* Uchida Rokakuho. Tokyo. pp. 375–398.

Welinder, S. 1974. *Kulturlandskapet i Mälardalen.* Department of Quaternary geology, University of Lund. Report 5–6.

Welinder, S. 1975. Agriculture, inland hunting, and sea hunting in the western and northern region of the Baltic, 6000–

2000 B. C. In W. Fitzhugh (ed.): *Prehistoric Maritime Adaptations of the Circumpolar Zone*. World Anthropology, pp. 21-39. The Hague.

Wing, E. & Brown, A. B. 1979. *Paleonutrition*. New York.

Winterhalder, B. 1981. Optimal foraging strategies and hunter-gatherer research in anthropology: Theory and models. In B. Winterhalder & E. A. Smith (eds.): *Hunter-Gatherer Foraging Strategies*. Prehistoric Archaeology and Ecology Series, pp. 13-35. Chicago.

Woodburn, J. 1982. Egalitarian Societies. *Man* 17, pp. 431-451.

Appendix

Table of analysed samples from different time periods and different geographical locations within Sweden. Lab # refers to internal lab number, Inv # refers to the Inventory number at the Museum of National Antiquities, Stockholm, Site refers to the geographical location and additional data obtained from the records at the Museum.

Lab #	Inv #	Site
SHM 1	3424/87	Landbogården 11:1 Fornl. 17, Gökhem sn. Västergötland. "Babsans skalle".
SHM 2	18641:12	Lanna västergård #1 ruta L f:12, Hidinge sn. Närke.
SHM 3	2549	Åsahögen, Kvisttofta sn. Skåne.
SHM 4	2549	Åsahögen, Kvisttofta sn. Skåne.
SHM 5	22339	Kams, Lummelunda sn. Gotland. Ind. A. Radiocarbon dated.
SHM 6	22339	Kams, Lummelunda sn. Gotland. Ind. B.
SHM 7	18577	Bårstad A A3 F–, Rogslösa sn. Östergötland.
SHM 8	18577	Bårstad A A3 F–, Rogslösa sn. Östergötland.
SHM 9	3424/87	Landbogården 11:1 Fornl. 17, Gökhem sn. Västergötland. A. F2. "Emils skalle".
SHM 10	3424/87	Landbogården 11:1. Fornl.17, Gökhem sn. Västergötland. A. F1. "Idas skalle".
SHM 11	3424/87	Landbogården 11:1 Fornl. 17, Gökhems sn. Västergötland. A. F1. "Ursulas skalle".
SHM 12	1737/83	Ajvide 2:1, Eksta sn. Gotland. Grav 5.
SHM 13	1737/83	Ajvide 2:1, Eksta sn. Gotland. Grav 13.
SHM 14	1737/83	Ajvide 2:1, Eksta sn. Gotland. Grav 13.
SHM 15	20480	Västerbjers, Gothem sn. Gotland. Grav 4.
SHM 16	28403	Kvarteret Priorn 3, Visby, Gotland. Grav 1/60–61. Skelett A.
SHM 17	5419/19	Grausne 1:17, Stenkyrka sn. Gotland. Grav 1. Skelett 1.
SHM 18	5486:b	Karleby kyrka, Karleby sn. Västergötland.
SHM 19	18641	Lanna Västergård #1, ruta A F:7. Hidinge sn. Närke.
SHM 21	21234	Västerbjers, Gothem sn. Gotland. Grav 62.
SHM 23	13937	Vellinge, Vellinge sn. Skåne. Grav 129. Male.
SHM 24	5386:f	Skarke, Varnhem sn. Västergötland. Backa 33. Retzius Tafl. XVIII.
SHM 25	5386:f	Backa 35, Varnhem sn. Västergötland.
SHM 26	5386:a	Utbogårdens ägor, Karleby sn. Västergötland. Retzius tafl. LIIIAB #46.
SHM 27	5386:f	Backa 34, Varnhem sn. Västergötland. Retzius Tafl. XXXIII AB #26.
SHM 28	5386:f	Skarke, Varnhem sn. Västergötland. Backa 65.
SHM 29	3165	Luttra Knaggården, Luttra sn. Västergötland. Grav 9.
SHM 30	14217	Slutarp A- F–, Kinneved sn. Västergötland. Kranium 467g.
SHM 31	14217:14	Slutarp serie #145, Kinneveds sn. Västergötland. Kranium 502g.
SHM 33	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 26. Kranium 428g.
SHM 34	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 19. Retzius Tafl. XXV AB. Kranium 531g.
SHM 35	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 19. Retzius Tafl. XXIII AB, XXIV AB. Kranium 421g.
SHM 36	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 22. Retzius Tafl. XXVII AB, XXVIII. Kranium 477g.
SHM 37	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 28. Kranium 354g.
SHM 38	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 30. Kranium 232g.
SHM 39	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 29. Kranium 466g.
SHM 40	5386:b	Karleby kyrka, Karleby sn. Västergötland. Grav 32. Kranium 269g.
SHM 41	5386:b	Karleby kyrka, Karleby sn. Västergötland. Kranium 165g.
SHM 42	5386:b	Karleby kyrka, Karleby sn. Västergötland. Gav 63. Kranium 167g.