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ScienceDirect
Journal of Anthropological Archaeology 26 (2007) 394–411
Journal of Anthropological Archaeology
www.elsevier.com/locate/jaa

Stable isotopes as indicators of change in the food procurement and food preference of Viking Age and Early Christian populations on Gotland (Sweden)

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Received 8 April 2006; revision received 1 February 2007
Available online 20 April 2007

Abstract

Archaeological samples of human and faunal remains dating from the Viking (9–11th century AD) and Early Christian (11–12th century AD) periods of Gotland, Sweden were assayed through stable carbon and nitrogen isotope analysis in order to investigate whether changes in subsistence occurred between these periods, particularly regarding the importance of seafood. The study was concerned with how the dietary regime of the Baltic trading port and farming settlement at Ridanäs, Gotland was affected by the widespread environmental and sociocultural transformations that characterized the end of the Viking Age. More generally, the research considers how changes in both food procurement and preference may account for observed differences in the dietary regimes of individuals from the Viking Age and the Early Christian period.

Keywords: Subsistence; Food procurement and preference; Stable isotope analysis; Least-effort models; Viking Age; Christianization; Baltic region; Ridanäs; Gotland; Sweden

Toward the end of the Viking Age (10–11th century AD), three interconnected environmental, socioeconomic, and ideological changes severely altered the everyday activities of people living within the Baltic region (Ambrosiani et al., 1997; see Barrett et al., 2000 for a review). Interpretations vary regarding the timing and relative effect of these changes in northern Europe (e.g. Abrams, 1995; Andrén, 1989; Hedeager, 1994; Myhre, 1993). However, it is generally accepted that the latter part of the Viking Age was a unique and pivotal era in European history that witnessed the development of the centralized monarchal state (Andrén, 1989; Barrett et al., 2000; Gurevich, 1978), a shift from pagan to Christian religious ideology (Sawyer and Sawyer, 1993; Sawyer et al., 1987; Solli, 1996), the emergence of a trading network that influenced the development of an interregional market

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doi:10.1016/j.jaa.2007.02.001

economy (Hedeager, 1994; Saunders, 1995), and the onset of massive rural to urban migration (Callmer, 1994).

At the archaeological site of Ridanäs, a coastal 6–12th century AD settlement located on the island of Gotland (Sweden), excavation data indicate that the latter part of the Viking Age coincided with the gradual acceptance of Christian ideological tenets and religious practices. Intensive archaeological excavations at Ridanäs have demonstrated that, during the Viking Age, this settlement participated in an extensive socioeconomic exchange network, bringing finished products and raw materials from the Baltics, the Black Sea area, the Arabian peninsula, and southern Europe. The Christian conversion of the settlement is marked by the building of a new church at the nearby location of Fröjel, as well as a shift of settlement from the Viking Age port at Ridanäs to a new, more inland site located next to the church. In addition, a gradual geophysical process of post-glacial land uplift affected the settlement by significantly lowering the sea level of the harbor to the extent that its docks could no longer effectively be used. Consequently, Ridanäs lost its function as a center of interregional exchange, becoming a more isolated and self-sufficient Christian community as it was detached from a previously robust Viking Age network of socioeconomic exchange and cultural interconnection.

The overall goal of this research was to document potential changes in the subsistence economy of Ridanäs in light of these dramatic local and regional socioeconomic transformations that occurred in the 10th and 11th centuries AD. Stable carbon and nitrogen isotope analysis of ancient human and faunal remains was employed in order to gauge whether and how the food procurement strategies and food preferences of the population at Ridanäs were altered in response or relation to these changes. Since the end of the Viking Age at Ridanäs coincided with the closing of the harbor and an inland shift of settlement, we expected to find that the subsistence economy of this settlement shifted away from the procurement of marine resources and toward the more intensified production of agricultural and animal foods. Our research focuses upon the combined impact of these regional macro-processes and local events on everyday life at Ridanäs, instead of seeking to isolate or identify any one feature as a principal determinant or cause of dietary change. Comparable studies have recently demonstrated that people within local settings often adapt to, accept, or reject broad social and political transformations by altering everyday practices of food procurement, food preference, food production and consumption (e.g. Dietler, 1996, 1998, 2001; Gumerman, 1997; Hastorf, 2003). We add to the archaeological literature on food procurement and preference by combining excavation data (site-level) with stable isotope analysis results (individual-level), thus considering how changes within the community of Ridanäs related to changes in individual diet. In our study, archaeological excavation data were used in concert with carbon and nitrogen stable isotope results to test multiple hypotheses regarding potential changes in diet. In this way, the research examines the broader anthropological issue of how regional transformations in environment, economic exchange, and ideology may influence changes in local and everyday cultural practices such as food preference, food procurement, and diet.

The site and its function

Previously, the dominant paradigm in Viking studies held that only a limited number of Baltic region ports participated in the extensive socioeconomic exchange network that characterized the Viking Age (Carlsson, 1991). Due to the almost exclusive reliance on written sources, only the location and significance of the larger trading settlements were known. Consequently, an incomplete view of the Viking Age exchange system emerged, suggesting that trade during this period was restricted to or controlled by only the well-documented ports, including Birka, Hedeby, Grobina, Wolin, and Paviken.

However, recent extensive phosphate surveys and archaeological excavations conducted by Dan Carlsson between 1987 and 1995 have identified and analyzed numerous smaller Viking Age trading ports on Gotland, a large island located between modern Sweden and the Baltic nations (Fig. 1; see Carlsson, 1991, 1998,1999,2000). The discovery of these smaller harbor settlements was crucial, allowing for the development of research that concentrates on the daily lives of people living in small Baltic region settlements throughout both the Viking Age and the process of Christianization. Also, the phosphate and archaeological surveys identified the location of Ridanäs, a larger regional trading center on Gotland with long-distance connections. In turn, data from regional centers like Ridanäs

Fig. 1. Map showing Viking Age harbors and trading ports.

can now be compared with knowledge about well-studied sites like Birka in order to expand our general understanding of political and economic processes that occurred throughout the period of sweeping regional change that witnessed the end of the Viking Age trading network and the spread of Christian ideology. To contextualize our stable isotope results, this section provides archaeological information derived from the recent excavations at Ridanäs.

The location of Gotland contributed to the socio-economic development of the island population. Indeed, during the Viking Age, Gotland provided a necessary midpoint for trading between mainland Scandinavia and the Baltic coast (Carlsson, 1991, 1999). Although trade between Viking Age Gotland and other parts of Europe was probably less intensive than that which occurred at larger centers like Birka and Hedeby, the island was certainly an integral part of a vast and complex system of inter-regional exchange. Specifically, the many Gotlandic ports traded regularly with Novgorod in order to obtain the fine Russian furs that were highly valued by European royalty in the 10th and 11th centuries (Sawyer and Sawyer, 1993). Since there are no deep harbors on Gotland, traders would use light and shallow-hulled boats that would allow them to dock or beach their boat at a Gotlandic port, as well as reach Novgorod by way of the River Volkhov (Sawyer and Sawyer, 1993: 155). Population growth, wealth, and emergent complexity on Gotland were facilitated during the Viking Age due to the island population's inclusion in this geographically widespread exchange system. In fact, Gotlanders participated in the exchange network to such a large degree that some of them hoarded large amounts of silver coins[2] (Sawyer, 1982; Sawyer and Sawyer, 1993), perhaps in an effort to influence the regional value of silver by withholding it from exchanges.

Fifteen years of Archaeological excavations (completed in 2005) at Ridanäs indicate that this harbor town was continually occupied from the 6th century until 1180 AD (Carlsson, 1991, 1999, 2000). Throughout the Viking and Early Christian periods of the Baltic region, Ridanäs was one of the largest and more significant regional centers of maritime economic exchange on Gotland (Fig. 2). During the Early Christian period, trading activities at Ridanäs diminished as the Gotlandic urban center of Visby monopolized economic and political activities on the island.

At Ridanäs archaeological indicators of the Viking Age exchange system include raw materials and prestige items like iron ore, fine-grained stone for whetstones, glass cullet, and silver. Continuing excavations at Ridanäs have noted the presence of numerous materials that are not indigenous to Gotland, including amber from the Baltics, rock crystal from the Black Sea area, walrus ivory from

[2] Sawyer (1982: 130) claims that the 11th century Gotlanders obtained these silver coins through piracy rather than socioeconomic exchange. Interestingly, this view is absent from Sawyer and Sawyer (1993: 152) where the authors claim that independent merchants instigated the economic development of Gotland. Archaeological data from Ridanäs, including coins that were cut into small fragments in order to facilitate trade, support the view that this harbor town was involved in economic exchange relations.

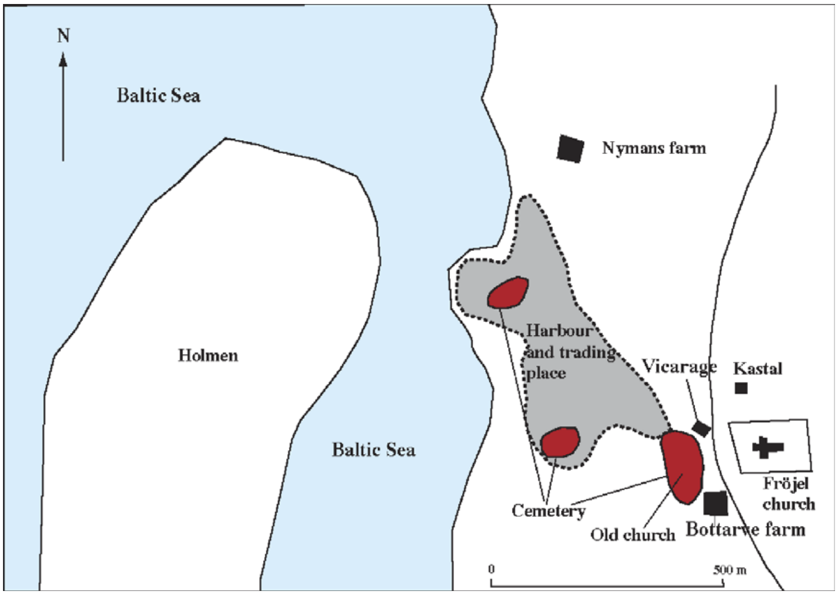

Fig. 2. Map showing the harbor and trading place of Ridanäs.

the North Atlantic, glass from Italy, carnelian, rock crystal, amethyst from the Arabian peninsula, cowry shells from the Indian Ocean, and silver coins of Arabic, English, and German origin (Carlsson, 1999, 2000).

Viking Age scholars have argued that these prestige items may have been the key components of a regional "gift economy" (*sensu* Polanyi, 1963), and that the transactions of this gift economy facilitated the constitution of local chiefly authority in Viking Age Scandinavia (Martens, 1987; Resi, 1987; Saunders, 1995). The data from Viking Age Ridanäs corroborate this view, demonstrating that Gotlandic harbors became centers of intensive gift or trade economies through participation in the long-distance circulation of goods. As expected, the prevalence of foreign prestige goods decreases in the Early Christian period when Ridanäs' participation in this intensive exchange network decreased. The decrease in regional connections is interpreted as marking a shift in the socioeconomic organization of Ridanäs that probably occurred at the same time as environmental land uplift, settlement movement, and ideological changes related to Christianization.

Due to land uplift, the Ridanäs harbor was rendered dysfunctional during the 12th century. As a result, boating activities were relocated at a distance of 500 m to the west and 600 m south of the Ridanäs settlement area. Archaeological excavation data indicate that, at the new harbor, a diminished amount of maritime activity continued until the end of the 17th century. Thus, the original harbor was closed and the extensive trading activities of the Viking Age settlement at Ridanäs most probably ceased due to the combined effect of four factors: (1) the end of Viking Age interregional gift exchange; (2) the decreased depth in the harbor caused by a gradual geologic uprising of land which effectively closed the strait between the offshore island of Holmen and the mainland;[3] (3) the emergence of new technologies in shipbuilding that obviated the necessity for a trading midpoint between Scandinavia and mainland Europe in the Baltic Sea; (4) the emergence of Visby as a socioeconomic and political center; and (5) the acceptance of a new Christian religious ideology and form of political organization that led settlements to become closed communities with regional connections being established only through authorities acting on behalf of new centralized institutions like the Church, regional administrative government, and markets (Barrett et al., 2000; Richards, 1991; Saunders, 1995).

[3] At the nearby harbor of Birka, located 30 km west of modern Stockholm, Miller and Hedin (1988) report that the Viking Age shoreline was approximately 5 m higher than it is today. Such data indicate that, in the Baltic area, a drastic amount of land uplift has been occurring throughout the Holocene (see also Punning, 1984; Salomaa and Matiskainen, 1984).

Overall, in Scandinavia, the Early Christian period witnessed the intensification of local agricultural practices as larger farms were subdivided, new farms were established in previously uncultivated areas, and many small inland hamlets were constructed (Sawyer and Sawyer, 1993). Early Christian settlement in Sweden largely consisted of a patchwork of small farms that were connected to larger political-religious centers and economic markets by inland roads. On Gotland, the rich limestone soils offered a fertile environment for agricultural production, thus providing a means for the development of a rich terrestrial food base including wheat and barley. As already mentioned, at Ridanäs, the Viking Age harbor was closed, and the settlement was relocated at the slightly more inland location of Fröjel. Considering these local and regional factors, we expected to find that the population at Ridanäs shifted from a maritime to a more terrestrial food base during the Early Christian period.[4]

Yet, despite this overall trend of intensified farming, at the archaeological site of Orkney, Scotland, stable isotope analyses have shown that fishing practices at this settlement actually increased during the 10th and 11th centuries (Barrett et al., 1999,2000; Barrett and Richards, 2004). Barrett and Richards (2004) argue that the maintenance of maritime food procurement on Orkney exemplifies how cultural preferences for seafood and fishing were integral aspects of local identity at the settlement (see also Barrett et al., 2000). In a similar way, our study addresses: (1) whether seafood procurement and consumption at Ridanäs continued despite the drastic local and regional transformations that occurred at the end of the Viking Age, or (2) whether the inhabitants of the coastal settlement of Ridanäs shifted to a more intensified cultivation and consumption of terrestrial foods when they shifted the location of their town.

Trade has long been considered a very important factor in the development of Scandinavian political complexity during the Viking Age (Andrén, 1995; Barrett et al., 2000; Blindheim, 1982). In part, our study examines whether and how the end of the long-distance regional trade that characterized the Viking Age incited micro-changes in the daily food procurement practices of the Gotlandic population at Ridanäs. Also, since the end of the Viking Age coincided with the emergence of centralized political authority, the Church, and markets, we take into account whether and how local food preference was affected by the broad ideological and socioeconomic transformations that occurred throughout this extraordinary period of social and ecological change.

In sum, excavation data from Ridanäs demonstrates that Ridanäs was affected by changes that occurred at the end of the Viking Age. Our research asks *how* these changes influenced or were related to alterations in everyday subsistence practices. In other words, we examine whether and how the dramatic transformations occurring at the end of this period of widespread socioeconomic and cultural associations affected the daily dietary regime and food procurement strategies of the inhabitants of Ridanäs.

The skeletal sample

Our study analyzed human skeletal remains that were derived from distinct, spatially segregated Viking and Early Christian period cemeteries at Ridanäs. Since the end of the Viking Age and the conversion of Scandinavia were gradual processes and not exact dates or events, samples were determined to belong to either the Viking Age or the Early Christian period through established site-level controls of artifact associations, grave location, grave goods, coffin-interment, burial alignment, and burial position. Anomalous burials from either cemetery were not included in the sample. Although relatively small, the skeletal sample analyzed here includes sufficient remains from both Viking and Early Christian periods to document subsistence for individuals from each population, and any significant changes that may have occurred. Measurement of stable isotope ratios can add to the archaeological understanding of local sociocultural transformations by providing quantitative information pertaining to specific alterations in ancient diet (Tykot, 2004).

Contiguous to, and partly overlaid by the northern portion of the settlement is a cemetery

[4] We did not expect the coastal location of Ridanäs to bias the results: it is possible that the Early Christian population ate less seafood relative to the amount of terrestrial foods consumed. Stable isotope analysis is well suited for tracking such a relative change. Indeed, Tauber (1981) demonstrates that humans from a suite of coastal sites in Denmark drastically altered their subsistence regimes by consuming much less seafood in the Neolithic relative to the amount consumed during the Mesolithic. In a similar way, our study investigates whether there was a shift in dietary habits and/or food procurement strategies that coincided with the end of the Viking Age on Gotland.

Fig. 3. Crouched Viking Age burial. Male, approx. 2 m tall.

containing over 200 cremation and inhumation burials from the Viking Age—7th to 10th centuries AD. The majority of excavated Viking Age individuals are female, however, the samples tested in this pilot study include an equal number of males and females. DNA analysis of male Viking Age skeletal remains demonstrated that 44% of individuals sampled ($n = 9$) originated from the Baltic and Russian regions [Dan Carlsson, personal communication 2006 (unpublished data)]. These data indicate that, prior to the Early Christian period, Ridanäs was a significant and cosmopolitan trading port with socioeconomic and cultural connections to the important socioeconomic trading area of Novgorod and Northwest Russia, as well as the Baltics.

Viking Age individuals at Ridanäs were interred in a crouched position, without coffins, and covered with stone packing (Fig. 3). Grave goods include local and Norse style jewelry, coins, glass beads, and, in one instance, a 1.6 m picture stone. Unique to Gotland, picture stones[5] are made of limestone and typically depict Norse sagas. The ubiquity of these stones during the Gotlandic Viking Age is exemplary of the island population's development of a distinct cultural variant of the larger and more widespread ideological framework that characterized this period. In other words, Viking Age culture had become so entrenched on Gotland that a unique local variant had developed. In this light, certain cultural preferences and identity markers from the Viking Age may have been maintained on Early Christian period Gotland, or influenced how Christian tenets and practices were to be accepted on the island. Such cultural preferences may include foodways. Indeed, the consumption of seafood has been linked to Viking identity on Orkney, Scotland (Barrett et al., 2000; Barrett and Richards, 2004), and more generally food preference has been demonstrated to reflect and contribute to change or continuity in both local identities and power relations (Hastorf and Johannessen, 1993; Mintz, 1985). Our study explicitly addresses how local cultural food preferences and lifeways converged with macro-processes of change during the end of the Viking Age.

The Early Christian cemetery is located in a churchyard that is directly east of the Viking Age harbor, approximately 150 m north–northwest of the medieval church at Fröjel. Differences in burial practices and grave goods distinguish the Early Christian burials from those attributed to the Viking Age. In the Early Christian cemetery, over 50 individuals were interred in narrow wooden coffins. The burials were situated in an east-west orientation, with the head on the west end. This orientation is usually indicative of Early Christian burials [(Fig. 4) Abrams, 1998; Andersson, 2000; cf. Rosedahl, 1987]. The cemetery dates from the 11th century, and was utilized for approximately 100 years.

Studies of medieval burials in England have demonstrated that monastic and commoner grave lots are often spatially separated (Mays, 1997; Stroud and Kemp, 1993). Monastic cemeteries are easily identified because they only contain male burials. Thus, since both males and females from Ridanäs were interred in the Early Christian church cemetery, we are comfortable with the assumption that the Fröjel church cemetery contained commoners, or possibly lay benefactors to the church rather than specialized religious practitioners like monks. In turn, since they were commoners, the diet of individuals from this cemetery should be representative of the everyday diet of Early Christian period Ridanäs community members.

[5] Sawyer (1982: 130) argues that these picture stones depict Gotlandic warriors on raiding or pirating missions. Yet, Carlsson counters that the imagery of the stones represents mythological rather than actual historical events.

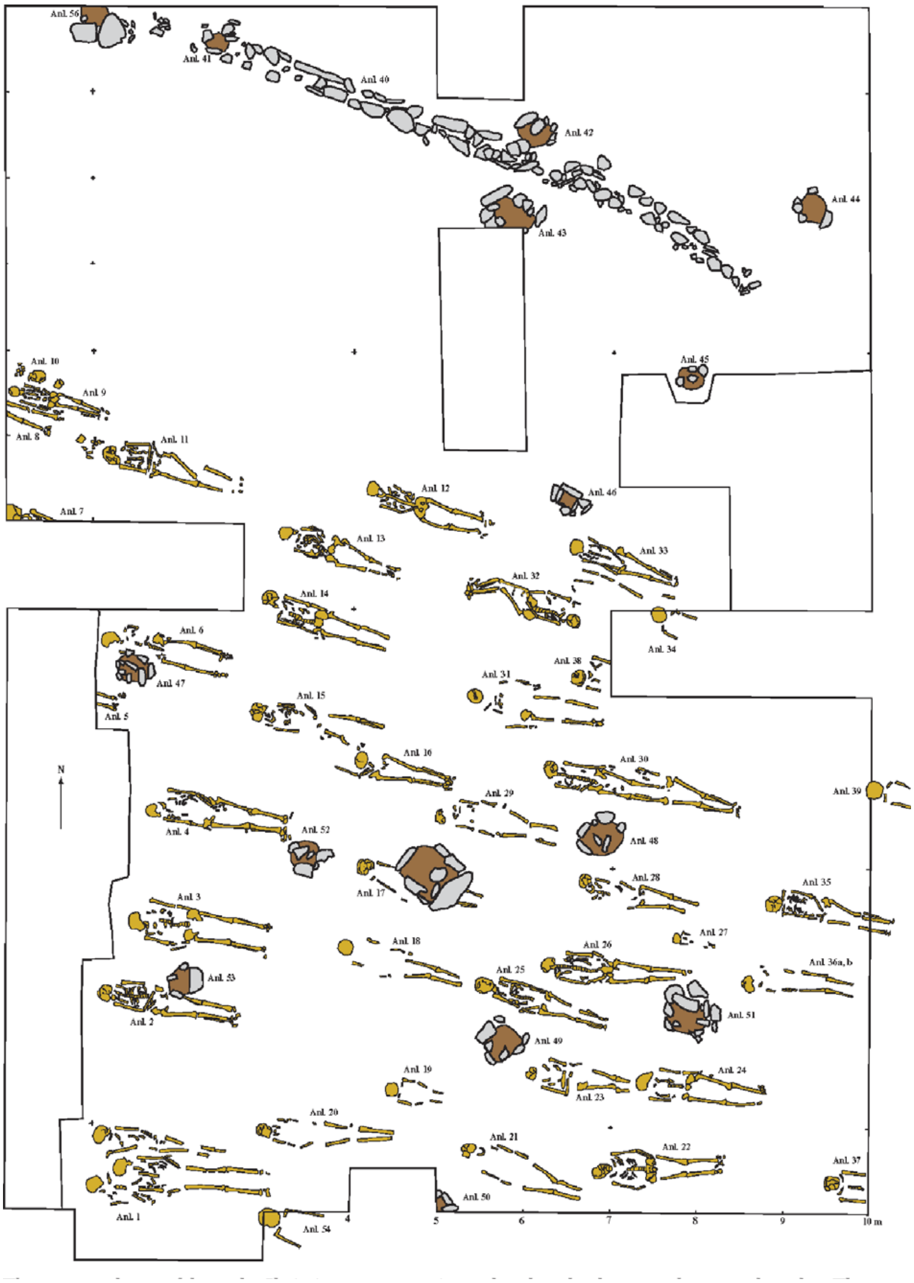

Fig. 4. Early Christian cemetery.

During the Viking Age, Ridanäs was a coastal harbor as well as an agricultural settlement. Numerous remains from domesticated animals such as pigs, cattle, and sheep suggest a subsistence economy that was at least partially reliant on terrestrial foods. Domesticated fauna are well represented in zooarchaeological analyses. However, marine resources including fish, porpoise, and seals are also present within the total faunal sample (Carlsson, 1999). If the terrestrial animals were meant for consumption rather than economic exchange purposes, then relatively depleted carbon isotope values within the human remains should indicate this dietary practice. Conversely, relatively[6] enriched

[6] Carbon and nitrogen values are gauged relative to an ecological baseline that is established through use of ratios obtained from faunal samples.

nitrogen isotope ratios would indicate the consumption of marine foods.

Methods

Stable isotope analysis of human bone has been widely utilized in archaeological reconstructions of prehistoric diets (see Ambrose and Katzenburg, 2000; Schoeninger and Moore, 1992; Schwarcz, 1991; Tykot, 2004,2006 for general reviews of the applications of stable isotope analysis). This study analyzes the two stable isotopes of both carbon (^{12}C and ^{13}C) and nitrogen (^{14}N and ^{15}N). Carbon and nitrogen isotope ratios are applicable to ancient human remains due to the differential fractionation of atmospheric carbon dioxide during photosynthesis and of nitrogen during fixation or absorption. Isotope measurements are reported using delta notation ($\delta^{13}C$, $\delta^{15}N$) and are expressed in parts per thousand (per mil, ‰) relative to the internationally recognized standard reference materials Peedee *Belemnitella* for carbon and AIR for nitrogen.

Stable isotopes can efficiently differentiate between certain types of terrestrial, agrarian plants that contributed to an overall subsistence regime. Grasses that are originally native to hot, arid environments follow the C4 (Hatch–Slack) photosynthetic pathway and will have relatively enriched $\delta^{13}C$ values averaging about −12.5 parts per mil. Maize, millet, and sugar cane are primary examples of C4 plants. These C4 plants are not native to Europe (see the discussion below regarding millet). Plants that follow the Crassulacean acid metabolism (CAM) photosynthetic pathway (e.g. cacti) also have relatively enriched $\delta^{13}C$ values. However, it is highly unlikely that any C4 or CAM plants were grown in northern Europe, or consumed regularly in this area during the Viking Age or Early Christian period. Trees, plants, and shrubs from relatively more temperate regions, including plants that are central to northern European agrarian subsistence economies such as wheat and barley, follow the C3 (Calvin–Benson) photosynthetic pathway and yield relatively depleted $\delta^{13}C$ values averaging about −2 to 6.5‰.

In archaeological studies of ancient diet, stable isotope analysis frequently considers three different skeletal tissues: bone collagen, bone apatite, and tooth enamel/dentin. Stable carbon and nitrogen isotope values derived from bone collagen reflect the average intake of dietary protein throughout the final years of an individual's lifespan (Ambrose and Norr, 1993), at least when protein was a significant percentage of the total diet. Carbon in bone collagen is typically enriched +5‰ relative to the plants consumed, while nitrogen is typically enriched 2–3‰ relative to dietary protein, for each trophic level (Schoeninger and DeNiro, 1984; van der Merwe, 1989; Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Carbon isotope values in bone apatite and tooth enamel reflect the whole diet (protein, fats, and carbohydrates), with enrichment of +9.5‰ (Ambrose and Norr, 1993; Tieszen and Fagre, 1993). Yet bone apatite turns over slowly, thus providing the dietary carbon isotope average of at least the last several years of an individual's life, while tooth enamel (and dentin) does not turn over, and thus represents diet at the age of formation (0–12 years of age depending on the specific tooth), with isotopic changes between certain teeth associated with age at weaning (see Wright and Schwarcz, 1998).

Analysis of all three tissues thus provides information on the whole diet taking into account protein sources in particular, as well as changes over an individual's lifetime (e.g. due to migration or change dietary). Variation between individuals is noted by examining differences in isotope ratios relative to site location, time period, sex, age, status, and burial context. Overall, stable isotope analysis of multiple skeletal tissues can provide a quantifiable dietary life history of the individual, whereas subsistence data from faunal and archaeobotanical remains typically are derived from a multitude of individuals over multiple generations. Stable isotope analysis is thus a useful analytical means of precisely isolating and identifying local instances of dietary change that may reflect broader sociocultural transformations.

The terrestrial crops of the study region considered in this analysis were C3 plants. While there is a possibility that millet, a C4 plant, had spread to Viking Age Sweden, there is no archaeological evidence to substantiate this proposition. However, millet was introduced to southern and central Europe during the Iron Age, apparently as a staple crop at Magdalenska Gora in Yugoslavia (Murray and Schoeninger, 1988) and Tzamala in Greece (Tykot et al., unpublished data), and as a less significant but isotopically noticeable part of the diet at several sites tested in Austria and the Czech Republic (Le Huray and Schutkowski, 2005).

For studies of ancient diet in northern Europe, stable isotope studies focus on determining the proportions of marine, fresh water (riverine/lacustrine), and terrestrial foods that were consumed in past human diets, as well as variations in trophic levels for these groups. The aquatic food chain is longer than the terrestrial food chain. Thus, stable nitrogen isotope values are more positive for many fish and marine mammals (as much as $\delta^{15}N = 20‰$) than their terrestrial animal counterparts ($\delta^{15}N < 10‰$, except for cats/dogs which oftentimes consume aquatic foods) (Schoeninger et al., 1983; Schoeninger and DeNiro, 1984). Consequently, human social groups employing a subsistence strategy that includes a large amount of marine foods yield $\delta^{13}C$ and $\delta^{15}N$ values that are more enriched (more positive) than groups that primarily consume terrestrial foods. For example, human consumers of terrestrial food products typically have $\delta^{15}N$ values in bone collagen that range

Table 1
Ridanäs faunal stable isotope data, plus average/sd for Vasterbjers and Ire

Site	Species	Common name	No.	$\delta^{13}C$ ave.	$\delta^{13}C$ std.	$\delta^{15}N$ ave.	$\delta^{15}N$ std.	Reference
Ridanas	*Bos taurus*	Cattle	1	−16.1		7.3		USF-514
Ridanas	*Sus domesticus*	Pig	1	−17.0		8.2		USF-515
Ridanas	*Ovis aries*	Sheep	1	−16.6		6.3		USF-516
Ridanas	Aves	Bird	1	−19.8		8.6		USF-517
Ridanas	*Phocoena*	Porpoise	1	−15.8		10.5		USF-518
Ridanas	*Pisces*	Fish	1	−16.0		10.1		USF-519
Ridanas	*Felis*	Cat	1	−17.7		10.7		USF-520
Ridanas	Phoca	Seal	1	−18.5		10.1		USF-521
Ridanas	*Lepus*	Hare	1	−21.0		3.5		USF-522
Vasterbjers	*Bos taurus*	Cow	3	−21.1	0.2	4.6	0.4	Eriksson (2004)
Vasterbjers	*Sus scrofa*	Pig	10	−21.1	0.4	5.4	0.6	Eriksson (2004)
Vasterbjers	Ovis aries/Capra hircus	Sheep/goat	4	−20.5	0.3	5.9	1.5	Eriksson (2004)
Vasterbjers	*Canis familiaris*	Dog	19	−14.5	0.8	14.1	1.0	Eriksson (2004)
Vasterbjers	*Lepus timidus*	Hare	1	−22.5		2.6		Eriksson (2004)
Vasterbjers	*Vulpes vulpes*	Red fox	4	−19.1	0.7	7.2	0.8	Eriksson (2004)
Vasterbjers	Aquila chrysaetos	Golden eagle	1	−19.1		7.3		Eriksson (2004)
Vasterbjers	*Esox lucius*	Pike	5	−11.9	0.7	11.0	0.3	Eriksson (2004)
Vasterbjers	*Alca torda*	Razorbill	1	−15.2		14.0		Eriksson (2004)
Vasterbjers	*Mergus merganser*	Common merganser	1	−13.0		12.1		Eriksson (2004)
Vasterbjers	Perca fluviatilis	Perch	1	−14.1		9.6		Eriksson (2004)
Vasterbjers	*Pisces indet.*		1	−10.4		8.2		Eriksson (2004)
Vasterbjers	*Halichoerus grypus, Pagophilus groenlandicus, Pusa hispida*	Grey, harped, ring seals	11	−16.1	0.5	13.4	1.2	Eriksson (2004)
Vasterbjers	*Phocoena phocoena*	Harbor porpoise	1	−15.0		11.4		Eriksson (2004)
Ire	Sus scrofa	Pigs	5	−21.0	0.5	4.6	1.2	Eriksson (2004)
Ire	*Clupea hargengus, Gadus morhua*	Herring, cod fish	4	−13.8	0.6	11.0	1.0	Eriksson (2004)
Ire	*Pagophilus groenlandicus, Pusa hispida*	Harped, ring seal	4	−15.8	0.7	12.9	1.1	Eriksson (2004)

between 6‰ and 10‰, while people who primarily derive dietary protein from marine fish and mammals will have $\delta^{15}N$ values in bone collagen that range between 15‰ and 20‰ (Schoeninger and DeNiro, 1984). Likewise, humans that primarily consume C3 terrestrial foods will be expected to have collagen $\delta^{13}C$ values between −19‰ and −21‰, whereas those that consume large amounts of seafood (and/or C4 foods) will have much more enriched values, as high as –10‰ or more in the most extreme cases (e.g. Tauber, 1986).

The study region considered in this research provides an exception to these more standard end values. For carbon, the brackish waters of the Baltic Sea influences marine values by making them more negative than values of marine foods derived from the larger oceans (Lidén and Nelson, 1994; Lidén, 1995; Eriksson, 2004). However, these brackish local conditions will not affect this study because we do not aim to measure the absolute percentage of consumption for one time period, but the difference in food consumption between two cultural periods. Nevertheless, in order to establish a regional baseline for the faunal remains, nine marine and terrestrial faunal samples from Ridanäs were tested, and compared directly with a significant database available from two Neolithic sites (ca. 2900–2500 BC) on Gotland (Eriksson, 2004) (Table 1).

When stable isotope analysis is applied to human remains derived from environments like Sweden in which no C4 plants were grown, more positive $\delta^{13}C$ and $\delta^{15}N$ values will indicate a larger reliance on marine foods. The simultaneous, bivariate use of carbon and nitrogen isotope ratios in studying coastal marine environments allows for the clarification of what can be conflicting signatures when either element is examined individually (Lidén, 1995). Stable carbon and nitrogen isotopes have been studied numerous times in order to effectively and precisely document the differential contribution of marine and terrestrial resources to the dietary regimes of past European individuals (e.g. Barrett et al., 2001; Eriksson, 2004; Johansen et al., 1986; Herrscher et al., 2001; Lidén, 1995; Lidén et al., 2004; Lubell et al., 1994; Mays, 1997; Polet and Katzenberg, 2003; Richards and Hedges, 1999; Richards et al., 2003; Schoeninger et al., 1983; Tauber, 1981,1986). However, there is certainly much more work that can be done, in terms of analyses of diverse geographic regions and time periods, as well as further research that addresses the understanding and quantitative interpretation of stable isotope data (see Milner et al., 2004 and Hedges, 2004 regarding such interpretation especially when dietary protein is low).

In this study, a total of 10 individuals representing the late Viking and Early Christian chronological phases of the site were prepared and analyzed, with data obtained for nearly all individuals for bone collagen, bone apatite, and tooth enamel. Bone collagen and apatite samples were derived from the proximal end of the third or fourth rib, depending on availability. Tooth enamel samples were extracted by drilling a vertical trench into the tooth surface with a 0.75 mm diamond bit. We extracted bone collagen through use of well established, standardized laboratory methods (Tykot, 2004,2006). Similarly, bone apatite and tooth enamel samples were prepared using procedures designed to remove non-biogenic carbon without altering the biogenic carbon isotopic values. The preservation of these samples was excellent, with very high collagen yields for all samples. All sample preparation was conducted at the University of South Florida, with samples analyzed (along with standard reference materials) by Matt Emmons at Mountain Mass Spectrometry. For collagen, the reliability of the results obtained is supported by the high sample processing yields (all 8.5% or higher), and the mass spec signal strength of the C and N signals produced.[7] For apatite/enamel results, reliability is also supported by yields at each stage of sample processing, and the consistent averages and small standard deviations obtained for the carbon isotope values.

[7] At the time we conducted this research (2000), Kosiba prepared the samples at the University of South Florida (USF), but they were sent to Mountain Mass Spec for the isotope analysis. The instrument used at Mountain Mass Spec did not produce C:N ratio data. However, collagen integrity was assessed by the percent yield on the samples (all 8.5% or higher, when 1% is considered acceptable), the duplicate analyses done for each individual, and the overall consistency of all the results. Kosiba used a chemical preparation procedure that is slow acting, and done on solid samples, so that we also had a visual assessment of intact collagen which appeared as intact organic floaters. Such visual assessment is not possible when using ground/powdered bone samples or high temperature/concentrated HCl processing. In short, the quality of the samples considered in this study is sufficient, considering the consistent results and that these are historic period samples from a northerly location with excellent preservation.

Results

In this study, we observe an overall mean $\delta^{13}C$ of $-17.3 \pm 1.2‰$ for human bone collagen (Table 2). Both Late Viking and Early Christian period individuals exhibit over a 3‰ range of variation, yet there is no significant difference between the means or standard deviations of the $\delta^{13}C$ collagen samples from the two periods. However, there is a slight yet notable difference in the average $\delta^{15}N$ for each period (Fig. 5). The mean for the Viking Age sample is $10.3 \pm 0.6‰$ while the mean of the Early Christian sample is $11.6 \pm 0.8‰$. In summary, the results from bone collagen indicate that the diet of both Viking Age and Early Christian period populations consisted of fairly equal parts of terrestrial and marine foods, with the average values of the foods contributing to bone collagen estimated at $-22.3‰$ for carbon and about 7–9‰ for nitrogen. These data fit well within the range of a menu consisting of both terrestrial and marine resources as dietary staples. Although we recorded a slight increase in $\delta^{15}N$ values for the Early Christian period, the resulting difference in Viking Age and Early Christian $\delta^{15}N$ value means is not statistically significant, although it approaches significance at the 0.05 level (Mann–Whitney $U = 3$; n Viking = 4, n Early Christian = 6). Thus, similar to other studies (e.g. Barrett et al., 2000; Barrett and Richards, 2004), our results suggest more continuity than change in food procurement and/or preference. In a later section, we discuss the potential implications of this continuity in subsistence economy in light of the drastic socio-economic transformations that occurred on both Gotland and in the Baltic region, more generally.

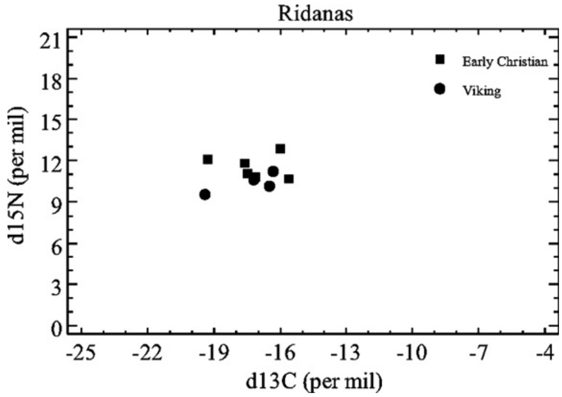

Fig. 5. Viking and Early Christian age collagen isotope data for individuals from Ridanäs.

The bone apatite data from this study, with an overall mean $\delta^{13}C$ of $-13.6 \pm 0.8‰$ (Table 2), indicate that the average carbon isotopic ratio of the food that contributed to the adult whole diet at Ridanäs was about $-23‰$, only slightly more negative than the estimated value for dietary protein for both periods. These values are similar to those obtained for collagen, further indicating that people at Ridanäs consumed both terrestrial and marine foods throughout the Viking Age and Early Christian period.

The tooth enamel data show that the mean $\delta^{13}C$ isotopic value for children was substantially less

Table 2
Ridanäs human stable isotope data

Site	Date	Individual	USF #	$\delta^{13}C_{co}$	$\delta^{15}N_{co}$	USF #	$\delta^{13}C_{ap}$	USF #	$\delta^{13}C_{en}$	Tooth
Ridanas	Viking	3/88	504	−17.2	10.6	560	−13.4	554	−15.6	M3 mandible
Ridanas	Viking	9/88	505	−16.5	10.1	561	−13.6	555	−14.7	Canine mandible
Ridanas	Viking	22/88	506	−19.4	9.5	562	−14.6			
Ridanas	Viking	32/88	507	−16.3	11.2	563	−12.2	552	−15.2	Canine mandible
Ridanas	Early Christian	2/98	508	−15.6	10.7	564		558	−14.1	M2 mandible
Ridanas	Early Christian	3/98	509	−17.5	11.1	565		557	−15.7	M3 mandible
Ridanas	Early Christian	4/98	510	−16.0	12.9	566	−13.8	556	−14.6	M3 maxilla
Ridanas	Early Christian	6/98	511	−17.6	11.8	567	−12.8	553	−14.8	M1 maxilla
Ridanas	Early Christian	12/98	512	−17.1	10.8	568	−14.7	551	−14.7	Premolar maxilla
Ridanas	Early Christian	13/98	513	−19.3	12.1	569		559	−15.1	M3 mandible
	Viking ave.			−17.3	10.3		−13.5		−15.1	
	Viking std.			1.2	0.6		0.8		0.4	
	Christian ave.			−17.2	11.6		−13.8		−14.8	
	Christian std.			1.2	0.8		0.8		0.5	
	Ridanas ave.			−17.2	11.1		−13.6		−14.9	
	Ridanas std.			1.2	0.9		0.8		0.5	

than that of adults by at least 1‰, and perhaps 2–3‰ considering the trophic effect of breastfeeding on several of the teeth tested. The mean $\delta^{13}C$ tooth enamel value of the Ridanäs Early Christian period and Late Viking Age is -14.9 ± 0.5‰, while the mean apatite value for adults is -13.6 ± 0.8‰. This difference is statistically significant at both 0.05 and 0.01 levels (Mann–Whitney $U = 1.5$; n adults[collagen] = 10, n children[tooth enamel] = 9). We interpret this to indicate that most adults ate more seafood than children, and that nursing mothers also consumed less seafood than usual. To assess the human stable isotope results obtained for Ridanäs more specifically, we now focus on the other available data.

In order to confirm the isotopic baseline for terrestrial and marine foods, archaeological samples were tested representing nine species (Table 1). The faunal samples included a hare, a terrestrial herbivore that was most likely not domesticated. The hare bone has typical values for a wild terrestrial herbivore, suggesting that the indigenous C3 plants averaged about −26‰ for carbon. The hare bone value does not vary from the carbon isotope mean (−21.5‰) that has been documented for European terrestrial faunal remains derived from archaeological contexts (Burleigh et al., 1984; Mays, 1997), and is similar to the value recorded for a hare from the Neolithic site of Vasterbjers on Gotland (Eriksson, 2004). Similarly, the porpoise, the fish, and the seal tested in this study all have values expected for the Baltic marine ecosystem, and are similar to the $\delta^{13}C$ and $\delta^{15}N$ values documented for marine species by the earlier study conducted on Gotland (Eriksson, 2004).

In contrast, the three domesticated species (cow, pig, and sheep) vary considerably from both the European carbon isotope mean (Burleigh et al., 1984; Mays, 1997), and from the Neolithic samples from Vasterbjers and Ire (Eriksson, 2004). These three domesticated species have substantially enriched $\delta^{13}C$ values for collagen, suggesting the consumption of either fodder containing a C4 pathway plant (e.g. millet) or marine foods (fish meal). Probably everything that grew naturally on Gotland, however, would have been C3. While millet has been identified from archaeological contexts as far north as Roman London (Wilcox, 1977), it is not evident from collagen isotopic analysis of Medieval people in England (Mays, 1997), Belgium (Polet and Katzenberg, 2003), Norway (Johansen et al., 1986), or Germany (Schutkowski et al., 1999), and is only suggested to a very minor extent at Iron Age sites in Austria and the Czech Republic (Le Huray and Schutkowski, 2005). Millet has not been found at all in Scandinavia, but further archaeological analysis of macrobotanical remains would substantiate whether millet was or was not traded or introduced into the Baltic area, at least for use in domestic animal fodder. In this light, we are comfortable with the conclusion that it is highly unlikely that millet contributed to the human or animal diet at Ridanäs.

To complement these carbon isotope results, our study provides additional evidence for the use of marine foods in animal fodder at Ridanäs. Indeed, the $\delta^{15}N$ values of the three terrestrial domesticated faunal species from Ridanäs are more enriched than those recorded by isotopic studies of the same species in medieval Belgium (Polet and Katzenberg, 2003), as well as on Gotland itself during the Neolithic (Eriksson, 2004). Conversely, the one wild hare tested by our study (with a pure C3 isotope value) has a very similar, low $\delta^{15}N$ value when compared with the Neolithic hare from Vasterbjers. In other words, the hare value establishes an isotopic baseline for Gotlandic fauna, while the domesticated animal values show significant deviation from this baseline. The faunal isotope data thus increase the likelihood that by the Viking Age on Gotland, domesticated animals had regular access to marine foods and/or byproducts, e.g. fishmeal, at least at coastal sites like Ridanäs. The cat bone that was sampled is a trophic level higher in $\delta^{15}N$ than the other domestic animals, indicating that this terrestrial carnivore consumed more marine foods than the other domesticated animals. Overall these data provide preliminary information regarding local cultural practices of animal husbandry during both Viking Age and Early Christian period Ridanäs. Further research will be necessary to test whether a change in the composition of animal fodder coincided with the transition from the Viking Age to the Early Christian period.

In sum, the $\delta^{13}C$ and $\delta^{15}N$ bone collagen isotope ratios obtained for the Ridanäs human populations may well be explained through the consumption of a combination of marine foods and terrestrial animals (including cattle, pig, and sheep and their milk and cheese). More specifically, the collagen results indicate that dietary protein was derived from both marine and terrestrial sources throughout both the late Viking Age and Early Christian period. In addition, the bone apatite results suggest that the average whole diet also contained significant quantities of C3 plant foods, probably including wheat, barley, and/or other domesticated grains.

On the other hand, the tooth enamel data appear at first to be a bit problematic. These data suggest that the consumption of any foods with more positive $\delta^{13}C$ isotope values (e.g. marine foods or domesticates with more enriched $\delta^{13}C$ values) by children was negligible. In short, other than breast milk, C3 plant foods and terrestrial proteins must have comprised the majority of the children's diet. Therefore, throughout early adolescence, the consumption of terrestrial foods comprised a greater percentage of children's subsistence than that of their parents at Ridanäs. These data are consistent with a study of Neolithic diet on Gotland in which analyses of first molar dentin indicated that young children had the lowest $\delta^{15}N$ values (consumed less or smaller seafood) of all age groups in the population (Eriksson, 2004: 148–149). Additional examination of archaeological remains and stable isotope analyses will substantiate whether this remarkable dietary change throughout individual life histories at Ridanäs was actually due to a cultural preference for feeding young children non-marine foods. Also, the DNA evidence suggests that a portion (44%) of the Ridanäs male population migrated from other areas. Thus, it is possible that the tooth enamel data are demonstrating differences in diet as they relate to changes in residence. Yet, it is noteworthy that the tooth enamel data indicate that dietary changes occurred within *each* individual's lifetime (from childhood to adult), i.e. there is no evidence for difference between individual childhood diets. The results are therefore consistent throughout the sample, suggesting a local dietary practice that distinguished childhood and adult diet at Ridanäs. Although additional analysis is necessary, such interpretations could yield interesting anthropological insights into prehistoric child rearing and changes in diet throughout one's life, topics that are not well understood or studied by archaeologists in general.

The small $\delta^{15}N$ difference observed between the Viking Age and Early Christian period human populations is potentially related to the use of marine fodder for domesticated animals or an increase in the consumption of higher trophic level marine foods, which have more positive nitrogen isotope ratios relative to domestic animals. Thus, it is not necessarily that more seafood was consumed within the Early Christian period, but higher trophic level seafood, on average, e.g. less small-size mollusks and shellfish, more large fish and marine animals. Other studies have documented how stable isotope values will fluctuate to a small degree due to the consumption of different kinds or sizes of marine foods (Barrett et al., 2001; Richards and Hedges, 1999). Although we present this rather speculative interpretation, we emphasize that our results show that overall subsistence change between the two periods was minimal, and that further research (faunal and stable isotope analysis) will have to be undertaken in order to flesh out hypotheses that can be derived from our preliminary evidence.

The majority of previous isotope studies in Scandinavia have focused on the Mesolithic and Neolithic time periods. Such studies have demonstrated that the introduction of farming resulted in a concomitant drop in collagen carbon and nitrogen isotope ratios at coastal sites as seafood became less important to the total diet (Lidén, 1995; Lidén et al., 2004; Richards et al., 2003; Tauber, 1981,1983). In a study published on the Neolithic site of Vasterbjers, Gotland, (Eriksson, 2004) both carbon and nitrogen isotope ratios of bone collagen samples are more similar to those reported for Mesolithic coastal sites in Sweden than the values recorded by our research (Table 3; Fig. 6). Indeed, at Ridanäs we documented an average nitrogen isotope ratio that was much lower than that recorded at Vasterbjers/Ire. Our results therefore suggest a major decrease over time in the availability and/or preference of higher trophic level seafood, as well as a lower general contribution of seafood to everyday diet. Since part of the positive isotopic signatures for the Ridanäs population probably came from domestic animals (see discussion above for differences between Ridanäs and Vasterbjers/Ire), as well as secondary products including milk and cheese, there is likely to have been even less direct consumption of seafood at Ridanäs in comparison with Vasterbjers/Ire. In sum, we note that the Viking Age and Early Christian populations at Ridanäs consumed less seafood than the Neolithic population at Vasterbjers/Ire. Generally, this difference may be due to increased productivity and dependence on agriculture and animal husbandry; increases in population size; decreased cultural preference for high trophic level seafood; reduced accessibility of large quantities of seafood on a regular basis, despite advances in maritime technology; as well as cultural, economic, or political factors. We also note that there is likely

Table 3
Average human stable isotope data for selected European sites

Modern country	Site	Inland/ coastal	Date	No.	$\delta^{13}C$ ave.	$\delta^{13}C$ std.	$\delta^{15}N$ ave.	$\delta^{15}N$ std.	Reference
Sweden	Ridanas (Gotland)	Coastal	Viking Age	4	−17.3	1.2	10.3	0.6	This study
Sweden	Ridanas (Gotland)	Coastal	Early Christian	6	−17.2	1.2	11.6	0.8	This study
Sweden	Several sites	Inland	Mesolithic	3	−19.8	0.1	11.5	1.7	Lidén et al., 2004
Sweden	Several sites	Coastal	Mesolithic	6	−15.7	0.4	15.1	0.7	Lidén et al., 2004
Sweden	Rössberga	Inland	Funnel Beaker	4	−20.8	0.3	10.4	0.8	Lidén (1995)
Sweden	Resmo	Coastal	Funnel Beaker	9	−18.8	0.6	12.3	0.8	Lidén (1995)
Sweden	Several sites	Coastal	Neolithic	4	−18.7	2.7	12.0	2.7	Lidén et al., 2004
Sweden	Vasterbjers (Gotland)	Island	Neolithic	26	−15.2	0.7	15.6	0.6	Eriksson (2004)
Denmark		Coastal	Ertebolle	6	−14.9	1.6	11.5	1.7	Richards et al. (2003)
Denmark			Funnel Beaker	12	−20.0	0.5	8.5	1.0	Richards et al. (2003)
Norway	Flakstad	Coastal	Stone Age	2	−13.4	0.8			Johansen et al. (1986)
Norway	Flakstad	Coastal	Late Iron Age	5	−17.0	1.0			Johansen et al. (1986)
Norway	Traena	Coastal	Early Medieval	11	−16.9	1.2			Johansen et al. (1986)
Norway	Heidal	Inland	Medieval	10	−20.6	0.3			Johansen et al. (1986)
Norway	Oslo	Semi-inland	17th century	2	−18.6	0.1			Johansen et al. (1986)
Greece	Tzamala	Inland	Iron Age	1	−15.7		8.5		Tykot et al., unpublished data
Yugoslavia	Magdalenska Gora	Inland	Iron Age	19	−14.7	1.6	9.4	1.1	Murray & Schoeninger (1988)
Czech Republic	Kutna Hora-Karlov	Inland	Iron Age	37	−18.9	0.6	10.0	0.5	Le Huray & Schutkowski (2005)
Czech Republic	Radovesice I	Inland	Iron Age	27	−18.9	0.5	9.9	0.6	Le Huray & Schutkowski (2005)
Czech Republic	Radovesice II	Inland	Iron Age	23	−18.8	0.2	9.3	0.6	Le Huray & Schutkowski (2005)
Austria	Northern sites	Inland	Iron Age	16	−18.6	1.3	8.9	0.7	Le Huray & Schutkowski (2005)
England	Hartlpool Greyfriars	Coastal	Medieval	10	−19.9	0.3			Mays (1997)
England	Newcastle Blackfriars	Coastal	Medieval	9	−18.2	0.2			Mays (1997)
England	Scarborough, Castle Hill	Coastal	Medieval	9	−20.2	1.3			Mays (1997)
England	York	Inland	Medieval	9	−18.3	0.6			Mays (1997)
England	York	Inland	Medieval	10	−19.5	0.8			Mays (1997)
England	Wharram Percy	Inland	Medieval	28	−19.7	0.3	9.2	1.0	Richards et al. (2002)
Scotland	Orkney		1200–1800 AD	11	−20.2	0.7			Barrett et al. (2001)
Scotland	Orkney		Viking Age	8	−20.0	1.1			Barrett et al. (2001)
Scotland	Orkney		Viking Age	19	−19.0	1.4			Barrett et al. (2001)
Belgium	Koksijde	Coastal	12–15th cent AD	19	−19.1	0.5	11.1	0.9	Polet & Katzenberg (2003)
Belgium	Torgny	Inland	6–7th cent AD	20	−19.8	0.3	9.1	0.7	Polet & Katzenberg (2003)
Belgium	Ciply	Inland	6–7th cent AD	9	−20.2	0.5	9.1	0.5	Polet & Katzenberg (2003)
Germany	SW sites	Inland	Early Medieval	37	−19.8	0.7	8.7	0.6	Schutkowski et al. (1999)

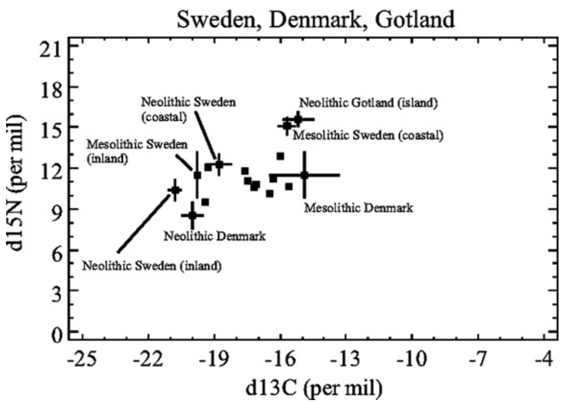

Fig. 6. Collagen isotope data for Ridanäs, plus average/sd of data for Mesolithic–Neolithic sites in Sweden and Denmark.

to be significant variation between sites in different parts of the Baltic and North Seas, as there was in the Mesolithic and Neolithic time periods (e.g. Tauber, 1981).

As noted above, millet was introduced in Iron Age eastern/southern/central Europe, yet studies that have analyzed skeletal remains from northern Europe/Scandinavia have not documented millet consumption. Comparisons can be made, however, between Ridanäs and many other Medieval or Viking age sites in Europe that have been isotopically tested (Table 3; Fig. 7). Compared to contemporaneous coastal sites in Belgium (Polet and Katzenberg, 2003), England (Mays, 1997), Denmark (Sellevoid et al., 1984), and on Orkney in Scotland (Barrett et al., 2001), seafood contributed to everyday diet to a much larger degree at Ridanäs on Gotland. However, the carbon isotope values from Ridanäs are similar to those recorded for a Late Iron Age (600–1000 AD) settlement at Flakstad, Norway (Johansen et al., 1986). Again, such similarities and differences in the contribution of seafood to local diet were expected due to particular differences between these regions in cultural preference, as well as local ecology, availability of marine resources, agricultural productivity, etc.

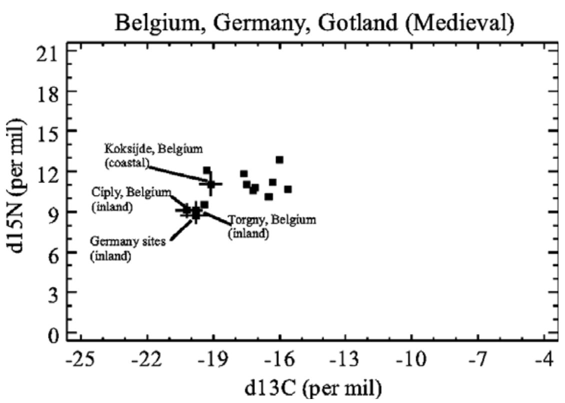

Fig. 7. Collagen isotope data for Ridanäs, plus average/sd of data for Medieval sites in Germany and Belgium.

Lastly, we note that dogs at Vasterbjers, and the cat at Ridanäs, have very similar isotope values to the humans at these sites, supporting the interpretation that such animals had access to household scraps, middens, and general wild and domestic plant and animal resources.

Potential implications

Our study demonstrates that the subsistence economy of Ridanäs remained relatively stable throughout both intra-site changes in settlement organization, as well as the broad macro-regional environmental, ideological and socioeconomic changes that are known to have occurred at the end of the Viking Age. Intensive excavation and stable isotope analysis data suggest that, following the closing of the harbor, the inhabitants of Ridanäs fulfilled a dietary preference for seafood by constructing the additional harbor, boat fishing, and then transporting the marine resources back to the original settlement.[8] Archaeological evidence of a new dock and harbor being constructed after the process of land uplift substantiate the point that these marine food resources continued to be captured through the use of boats.

The persistence of boat fishing as a method of food procurement may have occurred in accordance with the cultural preferences of the people of Ridanäs, or in order to fulfill the political economic demands from a central market, or both. The end of the Viking Age was marked by a series of broad socioeconomic and political changes throughout Northern Europe. Specifically, economic markets, political authority, and urban settlements gradually became more centralized throughout the 10th and 11th centuries (Andrén, 1989; Barrett et al., 2000; Gurevich,

[8] Currently, we lack archaeological data pertaining to the division of labor at Ridanäs, and the possible bifurcation of the settlement into different specialized groups of fisher and farmer. Also, due to our small sample size, we currently lack sufficient data regarding how the consumption of seafood may have differed according to status, gender, or age (e.g. Barrett and Richards, 2004). Such data may shed additional light on how food procurement strategies changed as the Ridanäs began to practice a more insular and closed form of social organization during the Early Christian period.

1978; Saunders, 1995; Sawyer and Sawyer, 1993). This period of political economic centralization may have been accompanied by the intensification of local production in order to provide for the market exchange of staple food products. Indeed, comparable archaeological and isotopic data from Viking Age Orkney indicate that fishing activities increased throughout the Early Christian period (Barrett et al., 2000: 24–25; Barrett and Richards, 2004). Also, studies have noted that the Viking Age and Early Christian periods in Northern Europe involved a drastic intensification of fishing activities (Enghoff, 1999, 2000). Fishing has been interpreted as a political and economic activity, the product of which bolstered local chiefly authority and contributed to the development of centralized markets (Perdikaris, 1999). In this light, it is possible that the people of Ridanäs continued fishing activities in order to both contribute to their settlement's subsistence economy and provide a central market at Visby, Gotland with fresh seafood.

Also, the loss of the function of Ridanäs as a long-distance trading harbor may have influenced the continued use of boats for local food procurement. In other words, labor and boats that were previously invested in trading activities would then have been redirected toward the procurement of marine resources like fish and seals. In addition, boat fishing for marine resources may have been essential to the cultural identity of people within this region. Indeed, recent studies have emphasized the connection between identity and marine food preference in the Viking world (Barrett et al., 2001; Barrett and Richards, 2004), and, more generally, the connection between identity and diet throughout various regions (e.g. Crabtree, 1990; Dietler, 1996, 1998, 2001; Gumerman, 1997; Hastorf, 2003). In short, the end of the Viking Age may have involved a suite of environmental, economic, and sociocultural changes, yet despite these changes practices of food preference and food procurement were maintained within the coastal site of Ridanäs.

Our research contributes to archaeological theories of subsistence by focusing less on simplistic models of economizing activity or mechanistic cost minimization, and more on how the dynamic interrelationship between cultural, socioeconomic, and environmental variables may contribute to change or stability in a dietary regime. In this case, we argue that cultural and socioeconomic directives of food preference guided how a strategy of food procurement was maintained.

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