

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Rick Schulting

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Edited by Chris Fowler, Jan Harding, and Daniela Hofmann

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Abstract and Keywords

Scholars have speculated about the role of the subsistence economy in defining the ‘Neolithic’. In western and eastern Europe, the Neolithic is defined in different terms. In the former, the Neolithic is typically viewed as the shift to an economy dominated by domesticated plants and animals. In the latter, it involves the appearance of pottery. Stable carbon and nitrogen isotope analysis has been used to characterize Neolithic diets and, more recently, to challenge notions of a single Neolithic way of life throughout the continent. This essay explores patterns and variations in stable isotopes and Neolithic subsistence across Europe, focusing on selected areas to highlight similarities and differences. It first looks at the dietary insights offered by carbon and nitrogen isotopes before turning to subsistence practices in regions from the Mediterranean to northern Scandinavia. It then considers the contribution of wild plants and animals, along with variations in food options in communities living near inland lakes and rivers. The article concludes by analysing the significant shift from marine to terrestrial isotopic signatures that seems to coincide with the Mesolithic–Neolithic transition.

Keywords: Subsistence economy, Neolithic, Europe, plants, animals, diets, stable isotopes, Mediterranean, inland lakes, rivers

Introduction

THE role of the subsistence economy in defining the ‘Neolithic’ ranges from central to epiphenomenal in the thinking of various scholars and national traditions. In western Europe, the Neolithic is often defined as the shift to an economy dominated by domesticated plants and animals. In eastern Europe, on the other hand, it involves above all the appearance of pottery. For some scholars, it is a state of mind. Since the definition of the term itself varies, it is not surprising that subsistence evidence also varies widely across Europe. Despite this, the study of ‘Neolithic’ subsistence remains of great interest, since making a living affects so much of people’s day-to-day activities. Biomolecular approaches to the investigation of past human diet are becoming increasingly important, not least in the char-

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acterization of European Neolithic diets, where stable carbon and nitrogen isotope analysis has played a pivotal role in challenging notions of a gradual uptake of domesticated resources. More recently, stable isotope analysis has also been used to challenge the idea of dietary homogeneity across Europe, of a single Neolithic way of life. This chapter presents an overview of the state of play, and raises some cautions regarding the interpretation of finer-scale regional variation in isotopic data.



Fig. 19.1. Map showing locations of key sites.

One cannot hope to cover all of Europe adequately in an overview of this kind. Instead, I focus on a number of regions to highlight themes, and on selected areas that can be used to address both similarities and differences (Fig. 19.1). The question of scale will be crucial. To expect similar subsistence practices from the Mediterranean to northern Scandinavia would clearly be untenable—even before considering different (p. 362) culture histories—given the varying climates, soils, and native fauna and flora, and the diverse possibilities and challenges these present to growing cereals and keeping livestock. On the other hand, one of the characteristics of the relatively restricted number of domesticated plants and animals that have expanded with humans to cover huge parts of the globe is their adaptability (Bellwood 2005). Consider where wheat and barley are grown today, and where cattle, sheep, goats, and pigs are kept, and it is apparent that they are subject to few strictly environmental limitations. But it is the detail that matters here, the particular ways in which cereals are grown and animals are kept, the varying proportions of domestic species, the contribution of wild plants and animals, and how these decisions impact on the routines of individuals and communities.

Stable isotopes

The two stable isotopes of central importance for studying diet are carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$). Most studies have focused on bone and tooth (dentine) collagen, which provide information primarily on the protein component of the diet (Ambrose and Norr 1993; Tieszen and Fagre 1993; Jim et al. 2006). This is a point worth emphasizing, since this means the two other principal components of food—carbohydrates and lipids—will be under-represented, the more so in high-protein diets. Bioapatite, the mineral component of bone, does reflect the whole diet, but is more subject to diagenesis, and so is less used (though see Papathanasiou 2003). This is an area that could certainly benefit from further exploration in the European Neolithic. The other crucial point is that measurements on adult human bone collagen represent protein consumed during approximately the last decade of a person's life. However, the question of carbon and nitrogen turnover in bone is far more complex than this: different bones, for example, can exhibit different turnover rates, and an individual's age and nutritional status are additional factors. But the main point for present purposes is that we are not measuring short-term variation, such as seasonal changes in diet or the last year of a person's life, which may have a greater chance of being atypical. Teeth present an exception, as there is negligible turnover in dentine once it is formed in childhood. They therefore 'lock in' a dietary signal from the time that tooth was developing; this itself varies from tooth to tooth, and so allows us to trace dietary changes through childhood and early adolescence (Eriksson 2004; Sealy et al. 1995).

In Europe, stable isotope analysis, especially $\delta^{13}\text{C}$, has undoubtedly been most effective in coastal areas, because it differentiates clearly between marine and terrestrial protein sources. For $\delta^{13}\text{C}$, typical values for marine organisms' bone collagen are $-12 \pm 1\text{‰}$, whilst those of most terrestrial organisms' bone collagen in C_3 systems are $-21 \pm 1\text{‰}$ (C_4 plants, such as millet, complicate the picture, but do not feature significantly in Neolithic Europe and so are not considered here). These endpoints are crucial to interpreting human bone collagen measurements, and any local variation in their values can greatly affect conclusions. This is especially relevant in the Baltic Sea, for example, where $\delta^{13}\text{C}$ values of marine organisms vary considerably through space and time, depending on the degree of water flow between the Baltic and North Seas. Freshwater systems can also vary quite widely, with some having elevated values and others exhibiting values more depleted than in most terrestrial systems (Dufour et al. 1999).

Stable nitrogen isotopes for the most part reflect trophic level, though there are a number of other factors (Hedges and Reynard 2007). Because aquatic (both marine and freshwater) food chains are usually far longer than terrestrial ones, $\delta^{15}\text{N}$ values of top predators (e.g. seals) will typically be considerably higher than is possible for terrestrial mammalian carnivores. There can be considerable variation in $\delta^{15}\text{N}$ values, but on average the bone collagen of adult terrestrial herbivores in Europe ranges between 4‰ and 6‰, leading to values 3–5‰ higher in predators. Young animals still nursing, or recently weaned, have higher values than their mothers, by as much (p. 364) as 3‰. Their consumption would have an impact on human diets, though their low body mass would limit

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the importance of this resource. Herbivore values themselves depend primarily on the values of the plants consumed, which can also vary widely, though this variation tends to be averaged out by the long-term diet reflected in bone collagen.

One of the interesting points to emerge recently is the extent to which manuring crops with animal dung can increase their $\delta^{15}\text{N}$ values (Bogaard et al. 2007). Experiments show that this enrichment can easily be on the order of a full trophic level. Thus, the high nitrogen isotope values that often characterize Neolithic humans, interpreted as indicating diets high in animal protein (meat and/or dairy products) (e.g. Richards 2000), could equally come about by consuming intensively manured crops, or a combination of cereals and animal protein. This has clear implications for the nature of early farming practices and landscape use. A manuring signal can be retained in charred Neolithic cereal grains through elevated $\delta^{15}\text{N}$ values, so it should be possible to investigate the practice and identify any spatial and temporal variability, though in practice this has turned out to be less than straightforward (Fraser et al. 2011). Another possibility involves naturally elevated $\delta^{15}\text{N}$ values in wetland habitats, as proposed by Britton et al. (2008). Equally, however, aridity has been found to have the same effect (Amundson et al. 2003). Whilst the latter would not be a factor in temperate Europe, it could affect the interpretation of values in the Mediterranean, particularly dry regions such as central Spain. More subtle environmental factors have also been found to be relevant (Hedges et al. 2013).

A further complicating factor arises from the consumption of nitrogen-fixing plants, such as lentils and peas. These leguminous species can exhibit very low $\delta^{15}\text{N}$ values, since they can fix nitrogen directly from the air, rather than from nitrates in the soil (leading to values of around 0‰, that is equivalent to the AIR (Ambient Inhalable Reservoir) standard used in calculating $\delta^{15}\text{N}$ ratios) (Fraser et al. 2011). Considering all the possible sources of variation in $\delta^{15}\text{N}$ values, there is clearly the potential for the problem of equifinality, and interpretation must take into account other sources of information, including above all archaeobotanical and zooarchaeological findings from the site/culture in question. Legumes, for example, will primarily affect human values around the Mediterranean, as they were far less important further north (Colledge and Connolly 2007). The consumption of freshwater fish can lead to elevated values in human consumers, and this possibility also needs to be considered. The dietary use of marine shellfish, fish, and mammals is usually visible in elevated $\delta^{13}\text{C}$ values, and so presents less of an interpretive problem.

Atlantic Europe: a strong pattern and some exceptions

The first application of stable isotope analysis (specifically $\delta^{13}\text{C}$) in Europe was Tauber's (1981, 1986) observation of a seemingly rapid shift from the use of marine to terrestrial resources in Denmark, coinciding with the appearance of the Neolithic at c. 3900 cal. BC.

(p. 365) This pattern remains striking, though it has become clear that the situation may be more complex, and that shellfish and fish, including freshwater species, still con-

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tributed to the diet, though a clear shift away from marine protein remains supported (Fischer et al. 2007; Price et al. 2007).

Subsequent studies in several areas along the Atlantic façade have shown that the Danish pattern is not unique. In Portugal (Lubell et al. 1994), Spain (Arias 2005), Brittany (Schulting and Richards 2001; Schulting 2005), Wales (Schulting and Richards 2002a; Schulting et al. 2013), Ireland (Schulting et al. 2012; Woodman 2004), and Scotland (Richards and Sheridan 2000; Schulting and Richards 2002b, 2009; Schulting et al. 2010) a similar marked shift from marine to terrestrial isotopic signatures appears to coincide with the Mesolithic–Neolithic transition. In all these cases, coastal Mesolithic populations exhibit moderate to high use of marine resources (approaching 100% of the protein consumed in the case of Oronsay in western Scotland, with human values similar to those of seals and sea otters), whilst Neolithic populations in the same regions show little or none. This is not to say that marine foods were never consumed by Neolithic communities, as the resolution of the technique is insufficient to identify the consumption of small amounts (5–10%) of marine protein *on an individual basis*. However, given adequate sample sizes, a comparison of coastal and inland groups should detect differences of this order. Unfortunately, such samples are not always available: survival of bone is rare to non-existent in inland Brittany and Scotland, for example. But at present, in England and Wales at least, no significant differences can be detected in the isotopic signatures of individuals from coastal (within 5km) and inland sites, strongly suggesting that marine protein really did not feature significantly in the diets of coastal populations here (Richards et al. 2003; Richards and Schulting 2006; Schulting 2011, 2013).

As pointed out by Thomas (2003, 2004; see also Milner et al. 2004), that Neolithic individuals in Britain show a terrestrial isotopic signature does not in and of itself indicate that this resulted from the consumption of domesticated resources, since wild terrestrial plants and animals would give similar, if not indistinguishable, values. However, when other lines of evidence are brought to bear, it is clear that domestic animals overwhelmingly dominate *all* Neolithic faunal assemblages throughout Britain, from both ceremonial contexts and settlements (Schulting 2008, 2013). Perhaps most tellingly, this includes the earliest Neolithic site in Orkney with surviving faunal remains, the settlement at Knap of Howar (Ritchie 1983; Tresset 2003), dating to *c.* 3600 BC, only a few centuries later than the initial appearance of the Neolithic in southern England.

Located near Knap of Howar (and possibly representing the burial place for at least some members of that community), the chambered tomb of Holm of Papa Westray North presents an interesting variation on the farming theme. Humans here show slightly but significantly elevated $\delta^{13}\text{C}$ values compared with Neolithic humans from other Scottish coastal sites (Schulting and Richards 2009; Schulting et al. 2010). As noted above, the mammalian fauna at the nearby and contemporary settlement is completely dominated by domestic fauna. A few seals are present, as are shellfish and fish remains. Whilst a small amount of fish could well account for the observed human values, an intriguing alternative presents itself. During AMS ^{14}C dating of animal remains from the tomb, two neonatal (p. 366) lambs presented extremely elevated $\delta^{13}\text{C}$ values, indicating that their mothers

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must have consumed seaweed (and little else) in the months prior to lambing (Balasse et al. 2006; Schulting et al. 2004). Only slightly elevated values were found in adult sheep, so that, unlike on modern North Ronaldsay, where sheep eat seaweed year-round (Ambers 1990), the animals must have usually grazed on pasture. Young lambs would quickly develop typical terrestrial $\delta^{13}\text{C}$ values once they began to consume grass, but because of the relatively slow turnover rates in bone (even for young animals), they would have retained an elevated signal for some months. Thus the consumption of such animals, most probably males culled before winter, would present another way in which humans could *indirectly* acquire a slight 'marine' isotopic signal (though flesh turnover would be quicker, so that the full effect would only be seen with the consumption of very young animals).

Whilst the broad pattern of the shift away from marine resources in the Neolithic is striking and widespread, it is not unvarying across Europe. Even for the areas discussed above, sample sizes are often so small that the results can be viewed as provisional, though their consistency permits a fair degree of confidence. One of the more striking departures from this pattern comes from eastern Sweden, where a strong reliance on marine resources is documented at the Middle Neolithic B (c. 2800 BC) sites of Västernbjers and Ajvide on Gotland (Eriksson 2004; Lidén et al. 2004; Lindqvist and Possnert 1997), and at Korsnäs, at the time a small island on the east central coast (Fornander et al. 2008) (Fig. 19.1). Whilst domestic animals are present, human $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are both very elevated, suggesting a reliance on seals. The sites belong to the Pitted Ware culture (PWC), which shows a strong coastal orientation, with faunal assemblages also supporting the importance of sealing. Thus, there is little indication that these groups were committed to a farming way of life. This is also the case further north and east into the Baltic, where the uptake of farming was much more gradual and incomplete (see Bartosiewicz and Lillie, this volume). This begs the question of how we define the 'Neolithic': if based on a farming economy, then the PWC would not qualify, but of course this quickly becomes a pointless tautological exercise. What we label these societies is less important than understanding them, and in turn the variation that existed across Europe during the sixth to third millennia BC.

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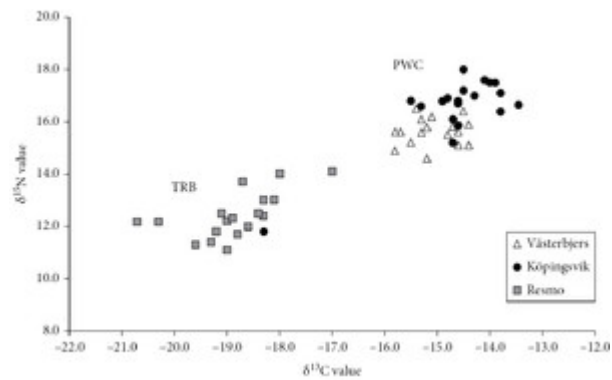


Fig. 19.2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values on human bone collagen from Neolithic sites in eastern Sweden. Västerbjers and Köpingsvik are Pitted Ware culture cemeteries, and Resmo is a Funnel Beaker (TRB) passage tomb. The single outlying datapoint from Köpingsvik is on a tooth (no bone measurement is available), clearly indicating that this individual originated in a group with a very different diet.

(data from Eriksson 2004 and Eriksson et al. 2008).

What makes the PWC in eastern Sweden particularly interesting is its coexistence with the distinct Neolithic Funnel Beaker (TRB) farming culture. Individuals from the TRB passage grave of Resmo on the island of Öland exhibit very different isotopic results, indicating far less use of marine resources (Lidén 1995), though still more than usually seen along the Atlantic façade. Further north on Öland, another Pitted Ware site, Köpingsvik, again shows elevated isotope values suggesting a focus on seals: human isotope values from the two sites are, with a single exception, completely non-overlapping (Eriksson et al. 2008) (Fig. 19.2). Thus, it is clear that the focus on sealing by Pitted Ware groups was not a matter of necessity, but of choice, though likely subject to rather different conditions than found further west in the Baltic, or along the Atlantic façade. Farming, whilst still possible, may have been less attractive given the shorter growing season at higher latitudes, the increased distance (in the Baltic) from (p. 367) the warming influence of the North Atlantic Drift (the Gulf Stream), and, crucially, the availability of viable alternatives. Sjögren's (2003, 170–171) comment that Funnel Beaker farmers on the Swedish west coast (with terrestrial isotopic signatures from the passage grave of Hunnebostrand) chose this way of life *despite* the rather unfavourable environmental circumstances, as a marker of cultural identity, makes the point well. In addition to having different diets and lifeways, recent aDNA findings suggest that PWC and TRB groups in Sweden were also genetically distinct populations (Malmström et al. 2009).

The Netherlands provide a rather different picture to that found elsewhere along the Atlantic façade, with a seemingly more gradual and piecemeal adoption of the Neolithic way of life. Human stable isotope data are currently only available from three sites, but these span the transition: Hardinxveld (Mesolithic, c. 5450–4500 BC), Swifterbant (transitional, c. 4200–4000 BC), and Schipluiden (middle Neolithic, c. 3600–3400 BC) (Smits et al. 2010). Whilst the earlier groups show no clear evidence in their $\delta^{13}\text{C}$ values for any con-

sumption of marine protein (Louwe-Kooijmans 2007; Smits and van der Plicht 2009), they do show significantly elevated $\delta^{15}\text{N}$ values indicating the consumption of freshwater aquatic resources (fish and waterfowl). This is not particularly surprising, since the coastline around the low-lying Rhine–Meuse delta would not have been conducive to the exploitation of open-water marine (p. 368) species in either period. Moreover, Hardinxveld and Swifterbant are some 40–50km back from their contemporary coastlines. The extensive brackish and freshwater marshes behind the coastal barriers offered a rich habitat, but one with predominantly ‘terrestrial’ $\delta^{13}\text{C}$ values. Domestic animal remains first appear in small numbers from *c.* 4500 BC, with evidence of cereals perhaps slightly later. The suitability of this low-lying region for growing cereals and keeping animals is debated (Bakels 2000; Bakels and Zeiler 2005; Cappers and Raemaekers 2008; Louwe-Kooijmans 2007); the highest land would be provided by clay levees and well-drained—but not particularly fertile—sand dunes that formed the focus of lowland occupation. Nevertheless, Cappers and Raemaekers (2008) argue that cereals were being grown here by the transitional Swifterbant culture. Another point of contention is the relationship between lowland and ‘upland’ sites, particularly once domesticates are attested in the latter: are these specialized seasonal camps of farmers based in the uplands, or are they the seasonal camps (none appear to be occupied year-round) of those following a hunting and gathering lifestyle, albeit with some use of domestic crops and animals?

Perhaps the most interesting stable isotope results are those from Schipluiden, a permanent settlement immediately behind the coast dune barriers, only some 3km from the contemporary coastline. The $\delta^{15}\text{N}$ values are as high as those from late Mesolithic Hardinxveld, with highly variable but on average slightly elevated $\delta^{13}\text{C}$ values ($-18.8 \pm 1.7\text{‰}$), suggesting some component of marine protein, but, more importantly, the significant consumption of freshwater fish and waterfowl. One individual in particular demonstrates high marine consumption (Smits et al. 2010). It seems that the community at Schipluiden was practising a broad spectrum economy very different from that of more committed farmers further inland (Louwe-Kooijmans 2007), yet the large mammalian fauna is still dominated by domestic species (*c.* 60%), particularly cattle (Louwe-Kooijmans 2009, fig. 10). Located only *c.* 1km from Schipluiden, the contemporary site of Rijswijk presents a mixed farming economy with over 95% domestic fauna (Louwe-Kooijmans 2009, fig. 12). Unfortunately, no stable isotope data are available, but the close proximity of the two sites must raise questions concerning the relationship between them, as well as between these near-coastal communities, and the farming communities found further inland.

The Mediterranean

Relatively few stable isotope studies have been undertaken in the Mediterranean region, though this is changing rapidly. Mesolithic populations here appear to have made considerably less use of marine resources than in Atlantic Europe (Salazar-García et al. 2014), whilst Neolithic populations do not differ substantially from those further north (it should be noted that the $\delta^{13}\text{C}$ terrestrial endpoint tends to be (p. 369) 1–2‰ higher in southern

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Europe, so that direct comparisons between the two areas are misleading; van Klinken et al. 2000). The earliest site to be considered here is Khirokitia, Cyprus, dating to the seventh/sixth millennium BC and located 6km from the coast. Preservation of human bone collagen was poor, but no samples showed any evidence of marine protein (Lange-Badré and Le Mort 1998). Further west, the sixth/fifth millennium BC Neolithic sites of Pendi-moun (Alpes-Maritimes, France) and Arene Candide (Liguria, Italy) near the coast again show no appreciable use of marine protein (Le Bras-Goude et al. 2006). A series of late Neolithic samples from Brochtorff Circle on Malta, spanning *c.* 4200–2700 BC, could be interpreted as showing some small contribution of marine foods, certainly more than the above sites, though not as much as could be expected given the small size of this island and its rocky soils (Richards et al. 2001). The inland Chasséen (*c.* 4300–4000 BC) site of Le Crès, Hérault, is located 24km from the present French Mediterranean coastline. Some marine molluscs are present, but isotopic analyses indicate a terrestrial diet; that this is based on domesticated resources is confirmed by the exclusively domestic faunal assemblage and by the presence of wheat and barley (Le Bras-Goude et al. 2009). From southern Italy, three individuals from the Neolithic coastal site of Samari are slightly elevated in $\delta^{13}\text{C}$ compared with five early/middle Neolithic individuals from four inland sites (-19.2‰ vs. -19.9‰), but interpretation of this as indicating some use of marine foods is complicated by the fact that $\delta^{15}\text{N}$ values do not show a similar increase (data from Giorgi et al. 2005). Nevertheless, it is possible that low trophic level marine foods such as shellfish made a small contribution to the diet at Samari.

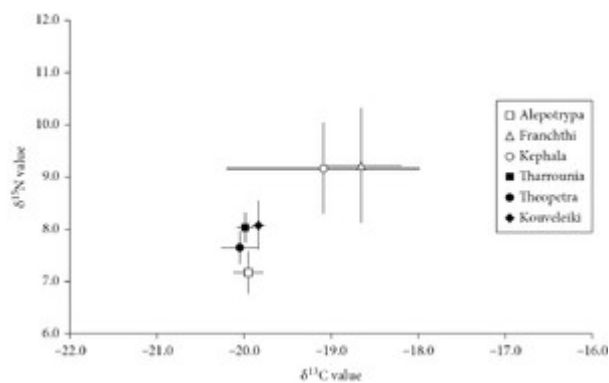


Fig. 19.3. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values on human bone collagen from Neolithic sites in Greece. Open symbols are coastal sites, solid are inland. Note the grouping of coastal Alepotrypa with the inland sites. Error bars show two standard errors.

(data from Papathanasiou 2003).

One of the most interesting Mediterranean studies comes from Greece, where Papathanasiou (2003) compares three coastal and three inland sites (Fig. 19.1). In contrast to Britain, the combined coastal sites exhibit slightly but significantly elevated values compared with the inland sites, suggesting a small contribution of marine protein at the former. However, the picture is more complicated, since one of the coastal sites, Alepotrypa, actually groups with the inland sites and indeed has the lowest $\delta^{15}\text{N}$ values of all sites

(Fig. 19.3), pointing to significant regional variation. This may be the result of the greater consumption of legumes.

Stable nitrogen isotope values from most of the Mediterranean sites discussed here tend to be low compared with those observed in north-west Europe, suggesting that the Mediterranean diet may have relied less on animal protein. For example, there is a shift ($\Delta^{15}\text{N}$) of only 1.6‰ in average $\delta^{15}\text{N}$ values between herbivores and humans at Le Crès (Le Bras-Goude 2009), which can be contrasted with an average difference of *c.* 5‰ at the inland site of Hazleton North (Hedges et al. 2008), a shift by no means atypical for Britain. The relatively high incidence of lactose intolerance in populations around much of the Mediterranean today is intriguing in this regard (McCracken 1971), and could suggest that milking was not as extensively practised in the Neolithic here as further north (Copley et al. 2005). Alternatively, as already mentioned, the consumption of legumes in the Mediterranean could lower human $\delta^{15}\text{N}$ values even if equivalent amounts of animal protein were being consumed (Schulting and Hamilton 2012). This (p. 370) again demonstrates the limitations of the stable isotope technique, and the need for a multidisciplinary approach.

Inland lakes and rivers

Away from the coasts, stable carbon and nitrogen isotopes have offered fewer dietary insights: most terrestrial food options, wild and domestic, exhibit variation that is at present too subtle to distinguish, though some intriguing possibilities are being explored (Lynch et al. 2008). As seen at Schipluiden, a notable exception is provided by communities living alongside and exploiting productive freshwater/estuarine ecosystems. These can be isotopically variable and complex, but elevated $\delta^{15}\text{N}$ values can provide an indication of the consumption of fish and/or waterfowl (sometimes, but not always combined with 'unusual'—whether elevated or depressed— $\delta^{13}\text{C}$ values). The best documented examples are the Iron Gates region of the Danube, and the Dnieper Rapids of the Ukraine (see Bartosiewicz and Lillie, this volume, and references therein). In both cases there are only relatively small differences between Mesolithic and Neolithic isotopic results, though it must be borne in mind that 'Neolithic' contexts in the Ukraine are largely defined by the presence of pottery rather than by subsistence economy. Another notable example is Ostorf in northern Germany, a middle Neolithic cemetery (p. 371) in an area with abundant inland waterways that were clearly being exploited, given the high $\delta^{15}\text{N}$ average of $13.7 \pm 1.0\text{‰}$ (Lübke et al. 2007).

In most other parts of Europe, the importance of freshwater resources is more difficult to demonstrate. Whilst $\delta^{15}\text{N}$ values from Neolithic Britain, Ireland, and north-west France are relatively high (*c.* 9–11‰), they are not sufficiently elevated to suggest the significant consumption of freshwater fish, particularly given the other ways in which such values can be attained (e.g. manuring and/or use of wetland pastures) (Bogaard et al. 2007; Britton et al. 2008).

Variations on a theme

The above examples operate at a very broad scale, potentially glossing over local and regional variation in Neolithic diets. Given the problem of equifinality raised earlier, even isotopically identical diets can result from quite different combinations of domestic and wild plants and animals. This can be dealt with in part by measuring contemporary fauna from the same sites more systematically, and by considering other kinds of information—archaeological, archaeobotanical, zooarchaeological, palynological, osteological, etc.—that can shed further light on how people made their livings.

Less obviously, similar foodways can result in significantly different isotopic signatures, as would occur if animals grazed on plants with different isotopic values (some soils, for example, have higher $\delta^{15}\text{N}$ values, and hence so do plants and the herbivores reliant on them). Thus human consumers in one region might have elevated $\delta^{15}\text{N}$ values suggesting the consumption of a higher proportion of animal protein, whereas in reality the diet may be identical to that in a region with lower $\delta^{15}\text{N}$ values. These are nuances that are only beginning to be appreciated; they come increasingly into play at the smaller scales of analysis that will begin to feature more strongly as the broad patterns are resolved.

A case study in southern England provides a useful illustration. Richards (2000, 2008) found that results from several approximately contemporary earlier Neolithic long barrows and chambered tombs exhibited slightly different isotopic values. This suggests that groups using different mortuary monuments, whilst all primarily farmers, consumed slightly different combinations of plants and animals. More variable results were noted for the large causewayed enclosure of Hambledon Hill, suggesting the presence of people drawn from surrounding communities, each with their variations on the farming theme. This is consistent with how these monuments are viewed, as built and used by a number of local communities. By contrast, individuals from the Hambledon Hill long barrow were suggested to show a narrower range of variation, suggesting they shared a more similar diet. This provides a very coherent and plausible account, and fits in with what we might expect of early farming communities. Similar local small-scale variation in cereal consumption is also suggested by differences in dental caries rates at Pipton and Pen-y-wyr-lod in south Wales (Wysocki and Whittle 2000).

(p. 372) But what has become appreciated recently is that faunal values from Neolithic sites in southern England also demonstrate a degree of inter-site variation, commensurate with that seen in humans, as demonstrated by the accumulating database of measurements on animals and humans from the same sites (Hamilton and Hedges 2011; Hedges et al. 2007, 2008) (Fig. 19.4). In other words, the isotopic differences between humans at different sites may relate to the consumption of the same proportions and types of domestic animals and plants, but with these themselves exhibiting slightly different isotope values (thus the humans from the Hambledon Hill enclosure may represent a coming together of groups from communities living in different environments but sharing similar subsistence patterns, though it should also be remarked here that the variability in the human isotopic data from Hambledon is actually no greater than that seen at a number of

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other sites). This is a difficult tangle to unravel, and demonstrates some of the difficulties of working at the small scale, though it should be possible to resolve some of these issues with adequate sample sizes and a well-designed research strategy.

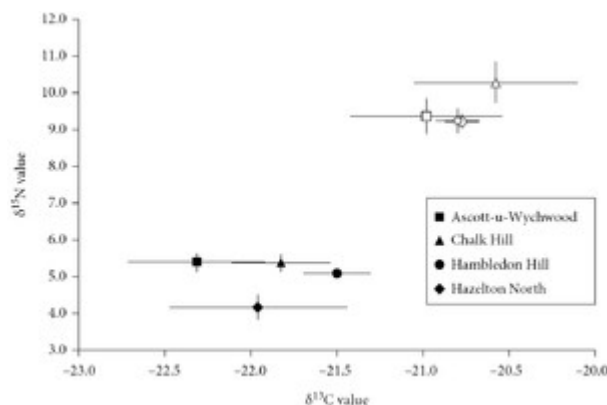


Fig. 19.4. Cattle (solid symbols) and human (open symbols) $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ results for selected earlier Neolithic sites in southern Britain (averages ± 2 SE)

(data from Hamilton and Hedges 2011; Hedges et al. 2007; 2008; Richards 2008).

A recent example of this approach comes from a study of three LBK sites in central Germany. Stable nitrogen isotope values for the adult humans differ only slightly between the sites: $8.4 \pm 0.5\text{‰}$ at Halberstadt; $8.8 \pm 0.5\text{‰}$ at Derenburg; and $9.0 \pm 0.4\text{‰}$ at Karsdorf. Taken at face value, this suggests a similar reliance on animal protein. However, a comparison with domestic herbivore values from the same sites shows that the mean spacing between humans and herbivores ($\Delta^{15}\text{N}$) is only 1.6‰ at (p. 373) Derenburg, whereas it is 2.3‰ at nearby Halberstadt, less than 10km distant (Oelze et al. 2011, tab. 3), indicating surprisingly fine-scaled geographic variability. At a wider scale, as Oelze et al. note (2011, 277), $\Delta^{15}\text{N}$ values at all three sites are considerably lower than those seen in Neolithic Britain (e.g. c. 5‰ at Hazleton North), suggesting quite different farming practices with a greater emphasis on domestic animals in Britain. This does assume, probably legitimately, that the difference is not due to the significant consumption of legumes in Germany, where they are known to have been present (Bogaard 2004), versus their apparent absence in Britain (Jones and Rowley-Conwy 2007).

Sex- and age-based differences in diet

The practice of communal burial in monuments across much of north-west Europe, leading to fragmentary and commingled remains, presents difficulties for the investigation of age- and gender-related isotopic variability. Hence, much more data are available for central Europe, especially for the LBK, where the normative mortuary practice of individual interment greatly facilitates analysis. Many sites show no significant sex-based differences in either $\delta^{13}\text{C}$ or $\delta^{15}\text{N}$ values (Bickle et al. 2010; Dürrwächter et al. 2006; Hedges et al. 2013; Oelze et al. 2011). This is paralleled by results from elsewhere in Neolithic

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Europe, though these are generally based on small sample sizes (Le Bras-Goude et al. 2009; Lillie and Richards 2000; Richards 2008). However, a number of sites do show significant differences in $\delta^{15}\text{N}$, with males in all cases exhibiting the higher values (Table 19.1). This tendency is also seen in sites where the difference is not statistically significant. Some studies have suggested the existence of physiological differences in $\delta^{15}\text{N}$ between the sexes, relating to pregnancy (Fuller et al. 2004), whilst others have found no evidence for this effect in the long-term average represented by measurements on bone collagen (Nitsch et al. 2010). It seems more likely that the difference is indeed dietary, with males in general consuming slightly more animal-based protein. This receives some support in the tendency for LBK females to have slightly higher caries prevalence, possibly reflecting greater carbohydrate consumption (Hedges et al. 2013, 371). By contrast, only the LBK site of Ensisheim in Alsace, France, shows a significant difference in $\delta^{13}\text{C}$, with males having very slightly elevated values compared to females (Hedges et al. 2013). The source of this difference is not clear (the site being too far from the sea to reflect the consumption of marine protein).

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Table 19.1 Average $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values on adult male and female human bone collagen from selected European Neolithic sites. NS = not significant.

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Site	Region	Period	Female					Male					Mann-Whitney significance tests	Source
			$\delta^{13}\text{C}$	\pm	$\delta^{15}\text{N}$	\pm	n	$\delta^{13}\text{C}$	\pm	$\delta^{15}\text{N}$	\pm	n		
Balatonszárszó	Hungary	LBK	-19.9	0.2	9.5	0.5	16	-19.9	0.3	9.6	0.4	14	NS	Hedges et al. 2013
Füzesabony	Hungary	LBK	-19.8	0.1	10.2	0.3	3	-20.0	0.3	10.7	0.3	3	NS	Hedges et al. 2013

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Pol-gár-Ferenci-hát	Hungary	LBK	- 20.0	0.3	10.3	0.6	16	- 19.9	0.3	10.3	0.7	17	NS	Hedges et al. 2013
Nitra	Moravia / Slovakia	LBK	- 20.2	0.3	10.2	0.4	26	- 20.1	0.2	10.5	0.4	14	δ^{15} N, p = 0.025	Hedges et al. 2013
Vedrovice	Moravia / Slovakia	LBK	- 19.7	0.3	9.5	0.4	34	- 19.6	0.3	9.9	0.5	19	δ^{15} N, p = 0.001	Hedges et al. 2013
Middle Elbe-Saale	Saxony-Anhalt	LBK	- 19.9	0.3	8.6	0.7	32	- 19.8	0.3	8.9	0.7	28	NS	Oelze et al. 2011

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Schwetzingen	Baden-Württemberg	LBK	-20.2	0.2	8.9	0.6	52	-20.1	0.3	9.0	0.4	43	NS	Hedges et al. 2013
Herxheim	Rhineland-Palatinate	LBK	-20.0	0.3	9.8	1.0	8	-20.1	0.3	9.9	1.2	11	NS	Dürwächter et al. 2006
Trebur	Hessen	MN	-19.8	0.3	9.4	0.5	20	-19.8	0.4	10.0	0.5	20	$\delta^{15}\text{N}$, $p < 0.00$	Dürwächter et al. 2006

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Aiterhofen	Bavaria	LBK	-20.4	0.2	9.8	0.3	20	-20.4	0.3	9.9	0.4	27	NS	Bickle et al. 2010
Asparn	Austria	LBK	-19.6	0.2	9.1	0.3	6	-19.6	0.1	9.6	0.4	17	$\delta^{15}N$, p = 0.021	Hedges et al. 2013
Kleinhadershof	Austria	LBK	-19.8	0.4	9.5	0.4	10	-19.8	0.2	9.6	0.6	16	NS	Hedges et al. 2013
Rutting	Austria	LBK	-20.5	0.2	9.3	0.9	3	-20.5	0.3	9.7	0.2	6	NS	Hedges et al. 2013

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En- sish- eim	Al- sace , NE Fra nce	LBK	-20. 3	0.5	9.2	0.4	15	-20. 1	0.2	9.5	0.6	17	δ^{13} C, p = 0.03 6	Hed ges et al. 201 3
Ven- den- hei m	Al- sace , NE Fra nce	LBK	-20. 2	0.2	10.0	1.5	2	-20. 1	0.2	10.9	0.3	7	NS	Hed ges et al. 201 3
Le Cré s	Fra nce	EN	-19. 3	0.7	8.3	1.1	8	-19. 4	0.3	8.4	0.7	4	NS	Le Bra s- Gou de et al. 200 9

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Garonnés	France	MN	-20.4	0.3	10.0	1.3	6	-20.8	0.2	9.8	0.7	6	NS	Herscher and Le Bras-Goude 2010
Coldrum	Kent, England	EN	-20.9	0.3	10.5	0.8	6	-20.7	0.2	10.5	0.7	8	NS	Wysoczek et al. 2013
Hambleton Hill	Dorset, England	EN	-20.9	0.3	9.5	0.9	8	-20.6	0.3	9.0	0.8	15	NS	Richards 2008

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Hazleton North	Glos., England	EN	-20.6	0.6	9.6	0.1	2	-20.7	0.1	9.3	0.8	5	NS	Hedges et al. 2008
Haywood Cave	Somerset, England	EN	-20.0	0.3	10.0	0.5	3	-20.4	0.2	10.1	0.1	3	NS	Schulting et al. 2013
Västerbjers	Gotland, Sweden	MN	-15.2	0.5	15.3	0.2	9	-15.1	0.5	15.8	0.3	9	$\delta^{15}N$, p = 0.07	Eriksson 2004

The Pitted Ware site of Västernbjers, introduced above, provides a rare opportunity to explore the life history of sex-based dietary differences. No differences were observed in $\delta^{13}\text{C}$ values for nine females and nine males, though slightly higher $\delta^{15}\text{N}$ values for males approach the 0.05 level of statistical significance (Eriksson 2004, 147). Interestingly, no comparable difference is seen in $\delta^{15}\text{N}$ dentine measurements on molar teeth from the (p. 374) (p. 375) (p. 376) same individuals, indicating that any distinction, tentative as it is, only appeared with adulthood.

Age-based differences are more commonly seen, with infants exhibiting elevated $\delta^{15}\text{N}$ values due to the nursing effect (Schurr 1998). Regional and chronological variation in weaning practices has important implications for fertility, and hence for population growth (Bocquet-Appel 2002; Bocquet-Appel 2012), but too few studies on European Neolithic material have been undertaken at sufficient resolution to discuss this meaningfully.

Conclusions

Foodways refer to more than simply 'diet'. How people obtained their food, managed crops, and kept animals and what wild foods they gathered or hunted, whilst not determining, have strong implications for daily and seasonal routines, how people moved around and perceived their landscape, the sizes and longevity of communities (and hence the intensity of social interaction), and myriad other aspects of their lives. Was transhumance practised, and if so by which subset/s of the community, and how did this affect social relations (cf. Bentley et al. 2003; Whittle 1997)? How often were domestic animals consumed, and how common was milking? Was cereal cultivation extensive or intensive? Were plots long- or short-lived, and how did this affect people's sense of place (cf. Boogaard 2004)? Much of this potential is only beginning to be realized.

The main impact of dietary stable isotope studies in European prehistory has undoubtedly been in demonstrating a remarkable and widespread—though not universal—shift away from marine resources from the beginning of the Neolithic. The exceptions are also interesting, with eastern Sweden for instance providing insights into the very different economic adaptations of two contemporary groups, and strongly supporting their identification as distinct cultures with differing lifeways. The emphasis on coastal situations is largely biased by the method's efficacy in distinguishing marine and terrestrial sources of protein. Dealing with inland situations is far more difficult, though a few areas offer the opportunity to compare Mesolithic and Neolithic diets, particularly the Iron Gates and the Dnieper Rapids, but these areas are unusual in terms of their ecological settings. New studies from the Netherlands have also been useful in demonstrating the degree of variability between Neolithic communities, highlighting the possibility of specialized wetland adaptations.

Less attention has been paid to isotopic shifts within the Neolithic, though in most situations detecting these will be more challenging (cf. Schulting et al. 2010), unless they involve, as in parts of Scandinavia, coastal groups with differing commitments to farming. Of equal interest to community-level variability is within-group variation, whether based

on gender, age, activity, or status distinctions. Few studies have yet addressed these issues, but their potential is clear, provided that samples of (p. 377) sufficient size are available. At the same time, whilst powerful, isotopic studies are clearly limited in many ways. It is thus important to compare stable isotope results with palaeopathological analysis (such as dental caries rates), and with palaeobotanical, zooarchaeological, and artefactual studies to obtain a fuller picture of Neolithic subsistence and social routines.

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References

- Ambers, J.C. 1990. Identification of the use of marine plant material as animal fodder by stable isotope ratios. *PACT* 29, 251–258.
- Ambrose, S.H. and Norr, L. 1993. Experimental evidence for the relationship of the carbon isotope ratios of whole diet and dietary protein to those of bone collagen and carbonate. In J.B. Lambert and G. Grupe (eds), *Prehistoric human bone: archaeology at the molecular level*, 1–37. New York: Springer-Verlag.
- Amundson, R., Austin, A.T., Schuur, E.A.G., Yoo, K., Matzek, V., Kendall, C., Uebersax, A., Brenner, D., and Baisden, W.T. 2003. Global patterns of isotopic composition of soil and plant nitrogen. *Global Biogeochemical Cycles* 17, 1031–1042.
- Arias, P. 2005. Determinaciones de isótopos estables en restos humanos de la región Cantábrica. Aportación al estudio de la dieta de las poblaciones del Mesolítico y el Neolítico. *Munibe* 57, 359–374.
- Bakels, C.C. 2000. The Neolithisation of the Netherlands: two ways, one result. In A.S. Fairbairn (ed.), *Plants in Neolithic Britain and beyond*, 101–106. Oxford: Oxbow.
- Bakels, C.C. and Zeiler, J.T. 2005. The fruits of the land. Neolithic subsistence. In L.P. Louwe Kooijmans, A.L. van Gijn, H. Fokkens, and P. van den Broeke (eds), *The Prehistory of the Netherlands*, Vol. 1, 311–335. Amsterdam: University of Amsterdam Press.
- Balasse, M., Tresset, A., and Ambrose, S.H. 2006. Stable isotope evidence ($\delta^{13}C$, $\delta^{18}O$) for winter feeding on seaweed by Neolithic sheep of Scotland. *Journal of Zoology* 270, 170–176.
- Bellwood, P. 2005. *First farmers. The origins of agricultural societies*. Oxford: Blackwell.
- Bentley, R.A., Krause, R., Price, T.D., and Kaufmann, B. 2003. Human mobility at the early Neolithic settlement of Vaihingen, Germany: evidence from strontium isotope analysis. *Archaeometry* 45, 471–486.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Bickle, P., Hofmann, D., Bentley, R.A., Hedges, R., Hamilton, J., Laiginhas, F., Nowell, G., Pearson, D.G., Grupe, G., and Whittle, A. 2010. Roots of diversity in a Linearbandkeramik community: isotope evidence at Aiterhofen (Bavaria, Germany). *Antiquity* 85, 1243–1258.

Bocquet-Appel, J.-P. 2002. Paleoanthropological traces of a Neolithic demographic transition. *Current Anthropology* 43, 637–650.

(p. 378) Bocquet-Appel, J.-P., Naji, S., Vander Linden, M., and Kozłowski, J.K. 2012. Understanding the rates of expansion of the farming system in Europe. *Journal of Archaeological Science* 39, 531–546.

Bogaard, A. 2004. *Neolithic farming in Central Europe: an archaeobotanical study of crop husbandry practices*. London: Routledge.

Bogaard, A., Heaton, T.H.E., Poulton, P., and Merbach, I. 2007. The impact of manuring on nitrogen isotope ratios in cereals: archaeological implications for reconstruction of diet and crop management practices. *Journal of Archaeological Science* 34, 335–343.

Britton, K., Müldner, G., and Bell, M. 2008. Stable isotope evidence for salt-marsh grazing in the Bronze Age Severn Estuary, UK: implications for palaeodietary analysis at coastal sites. *Journal of Archaeological Science* 35, 2111–2118.

Cappers, R.T.J. and Raemaekers, D.C.M. 2008. Cereal cultivation at Swifterbant? Neolithic wetland farming on the North European Plain. *Current Anthropology* 49, 385–402.

Colledge, S. and Conolly, J. (eds) 2007. *The origins and spread of domestic plants in south-west Asia and Europe*. Walnut Creek, CA: Left Coast Press.

Copley, M.S., Berstan, R., Mukherjee, A.J., Dudd, S.N., Straker, V., Payne, S., and Evershed, R.P. 2005. Dairying in antiquity III. Evidence from absorbed lipid residues dating to the British Neolithic. *Journal of Archaeological Science* 32, 523–546.

Dufour, E., Bocherens, H., and Mariotti, A. 1999. Palaeodietary implications of isotopic variability in Eurasian lacustrine fish. *Journal of Archaeological Science* 26, 617–627.

Dürrwächter, C., Craig, O.E., Collins, M.J., Burger, J., and Alt, K.W. 2006. Beyond the grave: variability in Neolithic diets in southern Germany? *Journal of Archaeological Science* 33, 39–48.

Eriksson, G. 2004. Part-time farmers or hard-core sealers? Västerbjers studied by means of stable isotope analysis. *Journal of Anthropological Archaeology* 23, 135–162.

Eriksson, G., Linderholm, A., Fornander, E., Kanstrup, M., Schoultz, P., Olofsson, H., and Lidén, K. 2008. Same island, different diet: cultural evolution of food practice on Öland, Sweden, from the Mesolithic to the Roman Period. *Journal of Anthropological Archaeology* 27, 520–543.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Fischer, A. 2007. Coastal fishing in Stone Age Denmark—evidence from below and above the present sea level and from human bones. In N. Milner and G. Bailey (eds), *Shell middens and coastal resources along the Atlantic façade*, 54–69. Oxford: Oxbow.

Fornander, E., Eriksson, G., and Lidén, K. 2008. Wild at heart: approaching Pitted Ware identity, economy and cosmology through stable isotopes in skeletal material from the Neolithic site Korsnäs in Eastern Central Sweden. *Journal of Anthropological Archaeology* 27, 281–297.

Fraser, R.A., Bogaard, A., Heaton, T.H.E., Charles, M., Jones, G., Christensen, B.T., Halstead, P., Merbach, I., Poulton, P.R., Sparkes, D., and Styring, A.K. 2011. Manuring and stable nitrogen isotope ratios in cereals and pulses: towards a new archaeobotanical approach to the inference of land use and dietary practices. *Journal of Archaeological Science* 38, 2790–2804.

Fuller, B.T., Fuller, J.L., Sage, N.E., Harris, D.A., O’Connell, T.C., and Hedges, R.E.M. 2004. Nitrogen balance and $\delta^{15}\text{N}$: why you’re not what you eat during pregnancy. *Rapid Communications in Mass Spectrometry* 18, 2889–2896.

Giorgi, F., Bartoli, F., Iacumin, P., and Mallagni, F. 2005. Oligoelements and isotopic geochemistry: a multidisciplinary approach to the reconstruction of the palaeodiet. *Human Evolution* 20, 55–82.

Hamilton, J. and Hedges, R.E.M. 2011. Carbon and nitrogen stable isotope values of animals and humans from causewayed enclosures. In A. Whittle, F. Healy, and A. Bayliss (eds), *Gathering (p. 379) time: dating the early Neolithic enclosures of southern Britain and Ireland*, 670–681. Oxford: Oxbow.

Hedges, R., Bentley, R.A., Bickle, P., Cullen, P., Dale, C.W., Fibiger, L., Hamilton, J., Hofmann, D., Nowell, G., and Whittle, A. 2013. The supra-regional perspective. In P. Bickle and A. Whittle (eds), *The first farmers of central Europe: diversity in LBK lifeways*, 343–384. Oxford: Oxbow.

Hedges, R.E.M., Saville, A., and O’Connell, T.C. 2008. Characterizing the diet of individuals at the Neolithic chambered tomb of Hazleton North, Gloucestershire, England, using stable isotope analysis. *Archaeometry* 50, 114–128.

Hedges, R.E.M., Stevens, R.E., and Pearson, J.A. 2007. Carbon and nitrogen stable isotope compositions of animal and human bone. In D. Benson and A. Whittle (eds), *Building memories: the Neolithic Cotswold long barrow at Ascott-under-Wychwood, Oxfordshire*, 255–262. Oxford: Oxbow.

Hedges, R.E.M. and Reynard, L.M. 2007. Nitrogen isotopes and the trophic level of humans in archaeology. *Journal of Archaeological Science* 34, 1240–1251.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Herrscher, E. and Le Bras-Goude, G. 2010. Southern French Neolithic populations: Isotopic evidence for regional specifics in environment and diet. *American Journal of Physical Anthropology* 141, 259–272.

Jim, S., Jones, V., Ambrose, S.H., and Evershed, R.P. 2006. Quantifying dietary macronutrient sources of carbon for bone collagen biosynthesis using natural abundance stable carbon isotope analysis. *British Journal of Nutrition* 95, 1055–1062.

Jones, G., and Rowley-Conwy, P. 2007. On the importance of cereal cultivation in the British Neolithic. In S. Colledge and J. Connolly (eds), *Origins and Spread of Agriculture in SW Asia and Europe: Archaeological Investigations of Neolithic Plant Economies*, 391–419. Walnut Creek: Left Coast Press.

Lange-Badré, B. and Le Mort, F. 1998. Isotopes stables du carbone et de l'azote et éléments traces indicateurs du régime alimentaire de la population Néolithique de Khirokitia (Chypre). In G. Camps (ed.), *L'Homme préhistorique et la Mer*, 415–426. Paris: Editions du Comité des Travaux Historiques et Scientifiques.

Le Bras-Goude, G., Binder, D., Formicola, V., Duday, H., Couture-Veschambre, C., Hublin, J.-J., and Richards, M.P. 2006. Stratégies de subsistance et analyse culturelle de populations néolithiques de Ligurie: approche par l'étude isotopique (^{13}C et ^{15}N) des restes osseux. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* 18, 45–55.

Le Bras-Goude, G., Schmitt, A., and Loiso, G. 2009. Comportements alimentaires, aspects biologiques et sociaux au Néolithique: le cas du Crès (Hérault, France). *Comptes Rendus Palevol* 8, 79–91.

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

Lidén, K., Eriksson, G., Nordqvist, B., Götherström, A., and Bendixen, E. 2004. 'The wet and the wild followed by the dry and the tame: —or did they occur at the same time? Diet in Mesolithic-Neolithic southern Sweden. *Antiquity* 78, 23–33.

Lillie, M.C., and Richards, M. 2000. Stable isotope analysis and dental evidence of diet at the Mesolithic-Neolithic transition in Ukraine. *Journal of Archaeological Science* 27, 965–972.

Lindqvist, C. and Possnert, G. 1997. The subsistence economy and diet at Jakobs/Ajvide and Stora Förvar, Eksta parish and other prehistoric dwelling and burial sites on Gotland in long-term perspective. In G. Burenhult (ed.), *Remote Sensing, Vol. I*, 29–90. Stockholm: Dept. of Archaeology, Theses and Papers in North-European Archaeology 13a.

(p. 380) Louwe Kooijmans, L.P. 2007. The gradual transition to farming in the Lower Rhine Basin. In A. Whittle and V. Cummings (eds), *Going over: The Mesolithic-Neolithic transition in north-west Europe*, 287–309. London: British Academy.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Louwe Kooijmans, L.P. 2009. The agency factor in the process of Neolithisation—a Dutch case study. *Journal of Archaeology in the Low Countries* 1, 27–54.

Lubell, D., Jackes, M., Schwarcz, H., Knyf, M., and Meiklejohn, C. 1994. The Mesolithic–Neolithic transition in Portugal: isotopic and dental evidence of diet. *Journal of Archaeological Science* 21, 201–216.

Lübke, H., Lüth, F., and Terberger, T. 2007. Fishers or farmers? The archaeology of the Ostorf cemetery and related Neolithic finds in the light of new data. In L. Larsson, F. Lüth, and T. Terberger (eds), *Non-Megalithic Mortuary Practices in the Baltic—New Methods and Research into the Development of Stone Age Society*, 307–338. Schwerin: Bericht der Römisch-Germanischen Kommission 88.

Lynch, A.H., Hamilton, J., and Hedges, R.E.M. 2008. Where the wild things are: aurochs and cattle in England. *Antiquity* 82, 1025–1039.

Malmström, H., Thomas, M., Gilbert, P., Thomas, M.G., Brandström, M., Storå, J., Molnar, P., Andersen, P.K., Bendixen, C., Holmlund, G., Götherström, A., and Willerslev, E. 2009. Ancient DNA reveals lack of continuity between Neolithic hunter-gatherers and contemporary Scandinavians. *Current Biology* 19, 1758–1762.

McCracken, R.D. 1971. Lactase deficiency: An example of dietary evolution. *Current Anthropology* 12, 479–517.

Milner, N., Craig, O.E., Bailey, G.N., Pedersen, K., and Andersen, S.H. 2004. Something fishy in the Neolithic? A re-evaluation of stable isotope analysis of Mesolithic and Neolithic coastal populations. *Antiquity* 78, 9–22.

Nitsch, E.K., Humphrey, L.T., and Hedges, R.E.M. 2010. The effect of parity status on $\delta^{15}\text{N}$: looking for the ‘pregnancy effect’ in 18th and 19th century London. *Journal of Archaeological Science* 37, 3191–3199.

Oelze, V.M., Siebert, A., Nicklisch, N., Meller, H., Dresely, V., and Alt, K.W. 2011. Early Neolithic diet and animal husbandry: stable isotope evidence from three Linearbandkeramik (LBK) sites in Central Germany. *Journal of Archaeological Science* 38, 270–279.

Papathanasiou, A. 2003. Stable isotope analysis in Neolithic Greece and possible implications on human health. *International Journal of Osteoarchaeology* 13, 314–324.

Price, T.D., Ambrose, S.H., Bennike, P., Heinemeier, J., Noe-Nygaard, N., Brinch Petersen, E., Vang Petersen, P., and Richards, M. 2007. New information on the Stone Age graves at Dragsholm, Denmark. *Acta Archaeologica* 78, 193–219.

Richards, M.P. 2000. Human consumption of plant foods in the British Neolithic: direct evidence from bone stable isotopes. In A.S. Fairbairn (ed.), *Plants in Neolithic Britain and beyond*, 123–135. Oxford: Oxbow.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Richards, M.P. 2008. Hambledon Hill stable isotope values. In R.J. Mercer and F. Healy (eds), *Hambledon Hill, Dorset, England. Excavation and SURVEY of a Neolithic monument complex and its surrounding landscape*, 522–527. London: English Heritage Archaeological Reports.

Richards, M.P., Hedges, R.E.M., Walton, I., Stoddart, S., and Malone, C. 2001. Neolithic diet at the Brochtorff Circle, Malta. *European Journal of Archaeology* 4, 253–262.

Richards, M.P. and Schulting, R.J. 2006. Against the grain? A response to Milner et al. (2004). *Antiquity* 80, 444–458.

Richards, M.P., Schulting, R.J., and Hedges, R.E.M. 2003. Sharp shift in diet at onset of Neolithic. *Nature* 425, 366.

(p. 381) Richards, M.P., and Sheridan, J.A. 2000. New AMS dates on human bone from Mesolithic Oronsay. *Antiquity* 74, 313–315.

Ritchie, A. 1983. Excavation of a Neolithic farmstead at Knap of Howar, Papa Westray, Orkney. *Proceedings of the Society of Antiquaries of Scotland* 113, 40–121.

Salazar-García, D.C., Aura, J.E., Olària, C.R., Talamo, S., Morales, J.V., and Richards, M.P. 2014. Isotope evidence for the use of marine resources in the Eastern Iberian Mesolithic. *Journal of Archaeological Science* 42, 231–240.

Schulting, R.J. 2005. Comme la mer qui se retire: les changements dans l'exploitation des ressources marines du Mésolithique au Néolithique en Bretagne. In G. Marchand and A. Tresset (eds), *Unité et diversité des processus de néolithisation sur la façade atlantique de l'Europe (7-4ème millénaires avant J.-C.)*, 163–171. Paris: Mémoire de la Société Préhistorique Française 36.

Schulting, R.J. 2008. Foodways and social ecologies from the Early Mesolithic to the Early Bronze Age. In J. Pollard (ed.), *Prehistoric Britain*, 90–120. London: Blackwell.

Schulting, R.J. 2011. Mesolithic–Neolithic transitions: an isotopic tour through Europe. In R. Pinhasi and J. Stock (eds), *The bioarchaeology of the transition to agriculture*, 17–41. New York: Wiley-Liss.

Schulting, R.J. 2013. On the northwestern fringes: Earlier Neolithic subsistence in Britain and Ireland as seen through faunal remains and stable isotopes. In S. Colledge, J. Conolly, K. Dobney, K. Manning, and S. Shennan (eds), *The origins and spread of stock keeping in the Near East and Europe*, 313–338. Walnut Creek, California: Left Coast Press.

Schulting, R.J., Bronk Ramsey, C., Reimer, P.J., Eogan, G., Cleary, K., Cooney, G., and Sheridan, A. In press. Dating the human remains from Knowth. In G. Eogan and K. Cleary (eds), *Excavations at Knowth 6: the archaeology of the Large Passage Tomb at Knowth, Co. Meath*. Dublin: Royal Irish Academy.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

Schulting, R.J., Chapman, M., and Chapman, E.J. 2013. AMS 14C dating and stable isotope (carbon, nitrogen) analysis of an earlier Neolithic human skeletal assemblage from Hay Wood Cave, Mendip, Somerset. *Proceedings of the University of Bristol Spelaeological Society* 26, 9–26.

Schulting, R.J., Fibiger, L., Macphail, R.I., McLaughlin, R., Murray, E.V., Price, C., and Walker, E.A. 2013. Mesolithic and Neolithic humans remains from Foxhole Cave (Gower, South Wales). *Antiquaries Journal* 93, 1–23.

Schulting, R.J. and Hamilton, J. 2012. Stable carbon and nitrogen isotope analysis of human and faunal remains from Champ-Durand à Nieul-sur-l'Autize, Vendée. In R. Jous-saume (ed.), *Le site néolithique de Champ-Durand à Nieul-sur-l'Autize (Vendée)*, 527–538. Chauvigny: Association des Publications Chauvinoises.

Schulting, R.J., Murphy, E., Jones, C., and Warren, G. 2012. New dates from the north, and a proposed chronology for Irish court tombs. *Proceedings of the Royal Irish Academy* 112C, 1–60.

Schulting, R.J. and Richards, M.P. 2001. Dating women and becoming farmers: new palaeodietary and AMS data from the Breton Mesolithic cemeteries of Téviec and Hoëdic. *Journal of Anthropological Archaeology* 20, 314–344.

Schulting, R.J. and Richards, M.P. 2002a. Finding the coastal Mesolithic in southwest Britain: AMS dates and stable isotope results on human remains from Caldey Island, Pembrokeshire, South Wales. *Antiquity* 76, 1011–1025.

Schulting, R.J. and Richards, M.P. 2002b. The wet, the wild and the domesticated: the Mesolithic–Neolithic transition on the west coast of Scotland. *European Journal of Archaeology* 5, 147–189.

(p. 382) Schulting, R.J. and Richards, M.P. 2009. Radiocarbon dates and stable isotope values on human remains. In A. Ritchie (ed.), *On the fringe of Neolithic Europe*, 67–74. Edinburgh: Society of Antiquaries of Scotland.

Schulting, R.J., Sheridan, A., Crozier, R., and Murphy, E. 2010. Revisiting Quanterness: new AMS dates and stable isotope data from an Orcadian chamber tomb. *Proceedings of the Society of Antiquaries of Scotland* 140, 1–50.

Schulting, R.J., Tresset, A., and Dupont, C. 2004. From harvesting the sea to stock rearing along the Atlantic façade of north-west Europe. *Environmental Archaeology* 9, 143–154.

Schurr, M.R. 1998. Using stable nitrogen isotope ratios to study weaning behavior in past populations. *World Archaeology* 30, 327–342.

Sealy, J., Armstrong, R., and Schrire, C. 1995. Beyond lifetime averages: tracing life histories through isotopic analysis of different calcified tissues from archaeological human skeletons. *Antiquity* 69, 290–300.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

- Sjögren, K.-G. 2003. Megaliths, settlement and subsistence in Bohuslän, Sweden. In G. Burenhult and S. Westergaard (eds), *Stone and Bones. Formal Disposal of the Dead in Atlantic Europe during the Mesolithic-Neolithic Interface 6000–3000 BC*, 167–176. Oxford: BAR International Series 1201.
- Smits, E., Millard, A.R., Nowell, G., and Pearson, D.G. 2010. Isotopic investigation of diet and residential mobility in the Neolithic of the Lower Rhine Basin. *European Journal of Archaeology* 13, 5–31.
- Smits, L. and van der Plicht, H. 2009. Mesolithic and Neolithic human remains in the Netherlands: physical anthropological and stable isotope investigations. *Journal of Archaeology in the Low Countries* 1, 55–85.
- Tauber, H. 1981. ^{13}C evidence for dietary habits of prehistoric man in Denmark. *Nature* 292, 332–333.
- Tauber, H. 1986. Analysis of stable isotopes in prehistoric populations. *Mitteilungen der Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte* 7, 31–38.
- Thomas, J. 2003. Thoughts on the ‘repacked’ Neolithic revolution. *Antiquity* 77, 67–74.
- Thomas, J. 2004. Current debates on the Mesolithic–Neolithic transition in Britain and Ireland. *Documenta Praehistorica* 31, 113–130.
- Tieszen, L.L. and Fagre, T. 1993. Effect of diet quality and composition on the isotopic composition of respiratory CO_2 , bone collagen, bioapatite, and soft tissues. In J.B. Lambert and G. Grupe (eds), *Prehistoric human bone: archaeology at the molecular level*, 121–155. New York: Springer-Verlag.
- Tresset, A. 2003. French connections II: of cows and men. In I. Armit, E. Murphy, E. Nelis, and D. Simpson (eds), *Neolithic settlement in Ireland and Western Britain*, 18–30. Oxford: Oxbow.
- Van Klinken, G.J., Richards, M.P., and Hedges, R.E.M. 2000. An overview of causes for stable isotopic variations in past European human populations: environmental, ecophysiological and cultural effects. In S.H. Ambrose and M.A. Katzenberg (eds), *Biogeochemical approaches to palaeodietary analysis*, 39–63. New York: Kluwer Academic/Plenum Publishers.
- Whittle, A. 1997. Moving on and moving around: Neolithic settlement mobility. In P. Topping (ed.), *Neolithic landscapes*, 15–22. Oxford: Oxbow.
- Woodman, P.C. 2004. The exploitation of Ireland’s coastal resources—a marginal resource through time? In M.R. González Morales and G.A. Clarke (eds), *The Mesolithic of the Atlantic Façade*, 37–55. Tucson: Arizona State University Anthropological Research Paper No. 55.

Stable Isotopes and Neolithic Subsistence: Pattern and Variation

(p. 383) Wysocki, M., Griffiths, S., Hedges, R., Bayliss, A., Higham, T., Fernandez-Jalvo, Y., and Whittle, A. 2013. Dates, diet, and dismemberment: evidence from the Coldrum Megalithic Monument, Kent. *Proceedings of the Prehistoric Society* 79, 61–90.

Wysocki, M., and Whittle, A. 2000. Diversity, lifestyles and rites: new biological and archaeological evidence from British earlier Neolithic mortuary assemblages. *Antiquity* 74, 591–601. (p. 384)

Rick Schulting

Rick Schulting is Lecturer in Scientific and Prehistoric Archaeology, University of Oxford.