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Surf'n Turf in Doggerland: Dating, stable isotopes and diet of Mesolithic human remains from the southern North Sea

J. van der Plicht^{a,b,*}, L.W.S.W. Amkreutz^c, M.J.L.Th. Niekus^d, J.H.M. Peeters^e, B.I. Smit^f

^a Centre for Isotope Research, Groningen University, Nijenborgh 4, 9747 AG Groningen, The Netherlands

^b Faculty of Archaeology, Leiden University, Einsteinweg 2, 2333 CC Leiden, The Netherlands

^c National Museum of Antiquities, Papengracht 30, 2301 EC Leiden, The Netherlands

^d Stichting STONE/Foundation for Stone Age Research, c/o Lopendediep 28, 9712 NW Groningen, The Netherlands

^e Groningen Institute of Archaeology, Groningen University, Poststraat 6, 9712 ER Groningen, The Netherlands

^f Cultural Heritage Agency of the Netherlands, Smallepad 5, 3811 MG Amersfoort, The Netherlands

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ABSTRACT

The North Sea bed host remains of Pleistocene and Early Holocene landscapes that were, mostly gradually, inundated following the last deglaciation. Archaeological remains from the seabed obtained by fishing, dredging, and sand suppletion include human skeletal remains. Radiocarbon dating reveals that most of these are Mesolithic although a few Late Palaeolithic and historic remains are represented. Samples with known stable isotope ratios $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ show that Mesolithic inhabitants of 'Doggerland' had a significant component of freshwater fish in their diet. This means the ^{14}C dates are subject to a reservoir effect mainly determined by the freshwater bodies at the time. Because of the lack of context, the magnitude of the reservoir effect cannot be derived, so that the ^{14}C dates cannot be precisely calibrated to absolute ages. However, a distinct correlation is observed between the $\delta^{15}\text{N}$ values and the (uncalibrated) ^{14}C dates, suggesting a chronological development.

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1. Introduction

At the end of the last ice age large volumes of water were stored in the ice caps. As a consequence, sea levels were about 70 m lower at the beginning of the Mesolithic than today. At that time, the southern North Sea was a diverse and rich landscape inhabited by hunter-gatherers (Coles, 1998; Gaffney et al., 2009). Although recent investigations have increased our insights into geographical aspects of this now submerged landscape (Gaffney et al., 2007; Sturt et al., 2013; Cohen et al., 2014; van Heteren et al., 2014), we still have little knowledge about the people who occupied the area despite the large quantities of fossil bones and occasional artefacts extracted from the seabed (Glimmerveen et al., 2006; Mol et al., 2008).

The main reason why the Mesolithic occupation of the southern North Sea area—also known as 'Doggerland' (Coles, 1998)—remains rather enigmatic as yet, bears to the fact that most of the finds derive from unknown stratigraphical, palaeogeographical, and archaeological contexts (Peeters et al., 2009; Peeters, 2011). The majority of finds has been brought up in fishing nets, or came ashore in sand dredged from

the seabed for the purpose of coastal reinforcement and land reclamation. Nonetheless, several zones in the southern North Sea, for instance the Brown Bank and Eurogeul, are known as palaeontological and/or archaeological 'hot spots' which have been subject to targeted 'fishing' expeditions. However, the number of locations where research of in situ contexts has been conducted is restricted to Rotterdam-Maasvlakte 2 in the Netherlands (Moree and Sier, 2015). In the English Channel Bouldnor Cliff is a rare example (Momber et al., 2011).

Despite the many restrictions and problems that surround the prehistoric archaeological record of the southern North Sea, there is an increasing effort to gain a better understanding of the significance of the plentiful archaeological finds (Peeters and Momber, 2014; Roebroeks, 2014). This growing effort is both the result of a growing scientific interest, as well as increasing awareness from a heritage management point of view, especially in the light of expanding off-shore activities in the North Sea basin (like wind farms, aggregate industries and gas- and oil platforms), and even current climate change and sea level rise. An important aspect concerns the establishment of the age of these finds. Over the years many samples have been submitted for ^{14}C dating, which has resulted in an important series of dates. Frequently, isotopic analysis of bone collagen has permitted to measure concentrations of the stable isotopes ^{13}C and ^{15}N , which are also proxies for e.g. (palaeo) diet, climate change, and (palaeo) environmental change (e.g. Fry, 2008). It is precisely these kinds of data that permit to draw further inferences with regard to human behaviour in this submerged

* Corresponding author.

E-mail addresses: j.van.der.plicht@rug.nl, j.van.der.plicht@arch.leidenuniv.nl (J. van der Plicht), l.amkreutz@rmo.nl (L.W.S.W. Amkreutz), marcelniekus@gmail.com (M.J.L.T. Niekus), j.h.m.peeters@rug.nl (J.H.M. Peeters), b.smit@cultureelerfgoed.nl (B.I. Smit).

landscape on the basis of (primarily) finds without context. Furthermore, in recent overviews of isotope data, the Southern North Sea is a blank spot on the maps since the majority of available Mesolithic data originates from dry land contexts (Schulting, 1998, 2010). Only recently some information on isotope data from the North Sea was published (Meiklejohn et al., 2015).

This paper presents, for the first time, an overview of Mesolithic human remains from the southern North Sea, and discusses the results obtained from the stable isotope analysis and ^{14}C dating. First we present the find 'locations' and circumstances, as well as the preservation conditions within the broader context of long-term landscape change during the Mesolithic. Next we describe the methods and present the

results in connection to their information value about diet and dating. We will show that when a substantial batch of finds is available, isotope analysis of finds without clear context provides meaningful results which help to enhance our understanding of the Mesolithic as a whole, and the occupation history of Doggerland in particular.

2. Materials and context

This paper deals with the stable isotope data of human bones collected over the years by the Groningen radiocarbon laboratory. All samples were primarily submitted for ^{14}C dating (Table 1).

Table 1

List of human bone samples from the North Sea, sorted to age. The table shows the Groningen laboratory number, skeletal element, location and isotopic measurements. Find type: f—fishing, d—dredging, s—sand suppletion, b—beach find, o—other.

The sample with * was dated in Mannheim (laboratory number M-21,188).

GrA	Skeletal Element	Location	Find type	Age BP	σ	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	C%	N%	C/N
58271	Unknown	Maasvlakte	s	11,050	45	−20.6	9.72	41.6	14.9	3.3
42700	Cranium	Southern Bight	f	10,070	50	−24.7	11.2	36.0	13.3	3.2
42702	Cranium	Southern Bight	f	9440	50	−24.2	13.6	41.5	15.6	3.1
57506	Unknown	North Sea	f	9440	45	−24.4	12.2	40.3	15.1	3.1
50459	Femur	Eurogeul	d	9220	60	−22.8	10.0	35.4	13.1	3.2
62470	Cranium	Maasvlakte	s	9180	50	−23.0	10.3	42.7	16.2	3.1
49638	Unknown	North Sea	f	9150	50	−22.7	4.5	44.5	16.3	3.2
27188	Humerus	SW Brown Bank	f	9140	50	−23.1	10.2	36.4	15.4	2.8
30733	Unknown	SW Brown Bank	f	9080	50	−22.0	11.6	42.6	15.3	3.2
31287	Unknown	SW Brown Bank	f	9035	40	−23.4	11.4	33.2	12.3	3.1
35949	Humerus	SW Brown Bank	f	9005	45	−23.3	10.8	40.7	14.1	3.4
62225	Humerus	Eurogeul	d	8945	45	−13.4	14.1	40.4	15.0	3.1
51669	Unknown	North Sea	f	8910	40	−22.1	9.4	43.7	15.7	3.2
49637	Unknown	North Sea	f	8820	50	−22.5	9.3	44.1	13.9	3.7
67124	Cranium	Zandmotor	s	8680	45	−23.6	12.4	44.0	16.1	3.2
45801	Femur	SW Brown Bank	f	8665	45	−16.5	15.7	43.6	15.3	3.3
54734	Femur	Eurogeul	d	8660	50	−23.9	12.4	46.3	15.0	3.6
54735	Femur	North Sea	f	8660	50	−16.7	13.8	43.1	15.6	3.2
*	Tooth	Hoek van Holland	b	8630	25	−23.4	14.1	51.3	18.0	3.3
57501	Cranium	Maasvlakte	s	8565	45	−23.5	12.7	37.3	14.0	3.1
54733	Femur	Eurogeul	d	8560	50	−24.1	12.4	43.0	15.4	3.3
65508	Maxilla	Slijtgeul	f	8560	50	−19.8	12.9	30.5	11.2	3.2
56366	Tooth	Hoek van Holland	b	8425	40	−21.3	14.9	37.4	14.2	3.1
63432	Skull	Hoek van Holland	b	8375	45	−23.1	12.5	34.0	12.8	3.1
11642	Mandible	North Sea	b	8370	50	−15.4	15.7	39.0	14.3	3.2
56352	Tooth	Burgh Haamstede	b	8290	40	−19.9	15.0	42.0	15.7	3.1
27205	Femur	SW Brown Bank	f	8180	45	−22.6	15.1	40.6	17.7	2.7
65943	Skull	Zandmotor	s	8140	45	−22.5	15.9	39.1	14.0	3.3
51670	Unknown	North Sea	b	7955	40	−21.5	14.6	43.3	15.6	3.2
63431	Tooth	Monster	b	7885	45	−21.3	14.1	38.4	15.0	3.0
63799	Cranium	Maasvlakte	s	7870	45	−23.7	12.9	40.8	15.0	3.2
67123	Cranium	Zandmotor	s	7810	45	−20.9	15.6	41.5	15.1	3.2
65507	Skull	Zandmotor	s	7760	45	−21.6	16.4	36.3	13.1	3.2
65511	Femur	Terschelling	b	2740	35	−20.4	10.2	40.5	14.1	3.4
67067	Vertebra	North Sea	f	2285	30	−20.4	11.3	42.3	15.5	3.2
63619	Unknown	Terschelling	b	1830	30	−19.9	9.9	44.2	16.6	3.1
64747	Femur	Zaandam	o	1805	30	−20.2	9.9	46.4	16.9	3.2
64726	Tooth	Borsele	b	1335	30	−19.4	12.0	41.9	15.2	3.2
50511	Unknown	Southern Bight	f	1260	40	−20.3	8.8	43.3	12.7	4.0
31286	Unknown	Westerschelde	f	1200	25	−19.5	12.0	49.6	17.1	3.4
65510	Skull	Maasvlakte	s	1175	30	−20.6	10.8	47.0	16.0	3.4
66669	Vertebra	den Haag	b	1015	30	−19.7	10.9	46.2	16.7	3.2
67125	Humerus	den Haag	b	875	30	−19.1	11.3	44.4	16.1	3.2
61784	Mandible	Wijk aan Zee	b	485	35	−18.5	13.7	43.4	15.5	3.3
62687	Cranium	Biesbosch	b	470	30	−19.9	13.5	13.3	4.5	3.4
67126	Femur	Den Haag	b	450	30	−18.9	13.4	41.7	15.1	3.2
66670	Vertebra	Den Haag	b	355	30	−20.1	11.4	47.3	17.1	3.2
37072	Humerus	Eurogeul	d	280	35	−18.2	12.2	40.9	13.5	3.5
64893	Tibia	North Sea	b	225	30	−17.0	15.1	44.1	15.5	3.3
63668	Unknown	North Sea	f	205	30	−17.2	11.1	46.8	17.3	3.2
64239	Unknown	North Sea	b	200	30	−19.6	11.9	47.0	17.0	3.2
64895	Tibia	North Sea	b	195	30	−19.2	11.3	44.6	15.1	3.4
65315	Humerus	Bergen aan Zee	b	165	30	−17.4	11.6	41.6	14.5	3.3
64894	Tibia	North Sea	b	120	30	−18.2	11.7	40.8	14.4	3.3
64891	Skull	Waddensea	b	115	30	−19.9	11.2	43.8	15.7	3.3
64892	Skull	Waddensea	b	75	30	−19.6	12.3	45.3	16.2	3.3

As the finds have been brought up in fishing nets or have been collected from dredged sand from the North Sea, exact coordinates of their primary location of origin are not available in most cases. Hence, information about the find 'location' is generally coarse grained. In the worst case we only know that the origin is 'North Sea'; slightly better is the indication that finds originate from a particular section (Southern Bight) or zone (southwest of the Brown Bank, Eurogeul) of the North Sea, or from a sand suppletion area (like Maasvlakte 1, Maasvlakte 2 and Zandmotor). The majority of beach finds (e.g. Hoek van Holland, Terschelling etc.) most probably also originate from sand dredging in the North Sea. In several instances the sand-extraction locations off the Dutch coast are known or can be traced back. A map of the find 'spots' and zones is shown in Fig. 1.

Assuming that most of the human remains, as well as the Stone Age artefacts from the southern North Sea predate their submergence, it is useful to consider the inundation history of the area. Although several models exist with regard to inundation rates and the timing of particular events, the geological data point to an average sea-level rise of 2 m/century for the southern North Sea (Hijma and Cohen, 2010). Inundation of this area progressed from the Strait of Dover and the northern part of the North Sea. Around 7500 BCE the 'two seas' met and the connection between Britain and the European continent ceased to exist. Until about 6500 BCE major elevations like Dogger Bank and Brown Bank existed as islands. An abrupt sea-level jump of about two meters (on top of structural sea-level rise) due to the drainage of Lake Agassiz, followed by the Storegga event (Weninger et al., 2008), led to final

Fig. 1. Schematic map of the North Sea region during the Mesolithic (adapted from Moree and Sier, 2015). Locations of the finds are indicated. 1: Maasvlakte, 2: Hoek van Holland, 3: Monster, 4: Zandmotor, 5: Wijk aan Zee, 6: Bergen aan Zee, 7: Terschelling, 8: Wadden Sea, 9: Borsele, 10: Burgh Haamstede, 11: Eurogeul, 12: Brown Bank, 13: Southern Bight, 14: Westerschelde, 15: Biesbosch, 16: Slijtgeul, 17: Zaandam, 18: Den Haag.

flooding of these islands, and further transgression of the sea between 6500 and 6300 BCE. Along the eastern side of the southern North Sea, the sediment load of the Rhine-Meuse river system would eventually catch up with the now decreasing rate of sea-level rise, resulting in a more stable coastline.

It is clear that the Mesolithic landscape in the southern North Sea area changed dramatically, and transformed from an inland landscape with rivers and lakes, through a semi-marine landscape with estuaries, into a fully marine environment with several islands and a transgressing coast with wide estuaries. Hence it can be expected that generations of hunter-gatherers who populated the area lived under different circumstances. However, we do not know to what extent these people were mobile, and what the extent of their 'active' landscape was. Furthermore we do not know whether they obtained their resources primarily from inland sources and perhaps in course of time, as the inundation progressed, also from coastal (marine) resources. We only know with certainty that formerly inhabitable grounds drowned, and that the coastline shifted in the course of time.

Mesolithic artefacts from the seabed include stone and flint tools like perforated mace-heads and core axes but also an array of bone and antler implements including antler and bone picks, axes and hammers as well as points, harpoons and fishing hooks that are interpreted as hunting/fishing gear (Louwe Kooijmans, 1970/1971; Verhart, 2000, 2005).

Together with human remains and fauna these artefacts were often merely seen as interesting indicators of the Mesolithic occupation of this area, but of limited scientific value, because of the absence of a clear context, or the means to verify (i.e. excavate) such a context. Recent infra-structural works such as the Zandmotor and Maasvlakte 2 projects in the Netherlands however greatly added to the number of finds and provided better indications of their place of origin. This study demonstrates that these increased numbers of material in combination with intensive research adds new information to our knowledge of the Mesolithic occupation of this area.

3. Methods: isotopes

From samples of human and animal bone, collagen was prepared following.

an improved version of the Longin method (Longin, 1971; Mook and Streuerman, 1983). This collagen was used for ^{14}C dating and stable isotope (^{13}C and ^{15}N) analysis. The quality of the bone collagen is assessed by the atomic C/N ratio, as well as its C and N content. These numbers should be in specified ranges (DeNiro, 1985; Ambrose, 1990): the atomic C/N ratio should be ~2.9–3.6, the carbon content of the collagen (C%) should be ~30–45% and the nitrogen content (N%) ~11–16%. Values outside this range may have suffered diagenetic alteration causing changes to the organic composition of the sample.

The samples were ^{14}C -dated by AMS (van der Plicht et al., 2000). The results are reported in conventional radiocarbon years (BP), which includes correction for isotopic fractionation using the stable isotope ratio $^{13}\text{C}/^{12}\text{C}$ to $\delta^{13}\text{C} = -25\text{‰}$, and using a half-life value of 5568 years (Mook and van der Plicht, 1999).

The stable isotopic content of the samples is expressed in delta (δ) values, which are defined as the deviation (expressed in per mil) of the rare to abundant isotope ratio from that of a reference material:

$$\begin{aligned} {}^{13}\delta &= \frac{\left(\frac{{}^{13}\text{C}}{{}^{12}\text{C}}\right)_{\text{sample}}}{\left(\frac{{}^{13}\text{C}}{{}^{12}\text{C}}\right)_{\text{reference}}} - 1 (\times 1000 \text{ ‰}) \text{ and } {}^{15}\delta \\ &= \frac{\left(\frac{{}^{15}\text{N}}{{}^{14}\text{N}}\right)_{\text{sample}}}{\left(\frac{{}^{15}\text{N}}{{}^{14}\text{N}}\right)_{\text{reference}}} - 1 (\times 1000 \text{ ‰}) \end{aligned}$$

For carbon, the reference material is belemnite carbonate (V-PDB); for nitrogen, the reference is ambient air (Mook, 2006). The collagen was combusted into CO_2 or N_2 gas by an Elemental Analyzer, coupled

to an Isotope Ratio Mass Spectrometer (Aerts et al., 2001). The analytical error is 0.1‰ and 0.2‰ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, respectively.

In principle, isotopes are important proxies for topics like migration and diet (e.g., Kohn, 1999; for the Mesolithic see Schulting, 2015; Eriksson et al., 2016 and references therein). The stable isotopes ^{13}C and ^{15}N yield information on the diet of an individual, for bone collagen for roughly the last decade of its lifetime (Katzenbach, 2000; Hedges and Reynard, 2007). In this context, two effects are to be considered: the trophic chain, and type of aquatic food sources.

As the food source that constitutes the main component of a diet passes on to the next trophic level (from producer to primary, secondary or higher order consumers) the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are both raised (Kohn, 1999).

In very general terms, terrestrial herbivores show $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values ranging a few permil around -23‰ and $+4\text{‰}$, respectively, their exact values determined by context (Lanting and van der Plicht, 1999). We only consider C3 vegetation here. The increase in δ value per trophic step is ca. 1‰ for $\delta^{13}\text{C}$, and ca. 3–5‰ for $\delta^{15}\text{N}$ (Bocherens and Drucker, 2003; Hedges and Reynard, 2007).

Organisms living in aquatic reservoirs show specific isotopic effects, depending on the specific reservoir (e.g. Robson et al., 2015). Marine organisms show $\delta^{13}\text{C}$ ranging around -14‰ ; for fresh water, this is about -24‰ typical for the region (Fuller et al., 2012). Their $\delta^{15}\text{N}$ values vary widely and can reach values up to 18‰ for high-trophic level fish and mammals. These are general values, showing a few permil variation. They obviously depend on the aquatic trophic chain.

Aquatic isotope effects also show in the bone collagen of terrestrial organisms, when a significant part of their diet originates from aquatic sources – in particular fish, but perhaps also other fauna like waterfowl, otters etc. The $\delta^{15}\text{N}$ values are then elevated; the $\delta^{13}\text{C}$ values enable a distinction between the sea and rivers.

When the stable isotope values for the food resource is known, the food web can be reconstructed. Many examples are known in the literature. Relevant for our research, for the Netherlands this has been done for the freshwater wetland Mesolithic sites of Hardinxveld (Smits and van der Plicht, 2009), for the Meuse basin in Belgium (Bocherens et al., 2007), and for Denmark, this is done by Fischer et al. (2007).

4. Results and discussion

4.1. The isotope dataset

The results of the analysed human bone finds from the North Sea are presented in Table 1. The data are sorted to age. Only data are shown for which all 3 isotope values (^{14}C , ^{13}C , ^{15}N) are available. We note that the Groningen database does contain more human bone dates measured in the past; for these, no $\delta^{15}\text{N}$ data are available. Most of these ^{14}C dates can be found in Mol et al. (2008), Weninger et al. (2008) and Meiklejohn et al. (2015).

The sample location is stated in general terms. Samples were dredged up by fishing expeditions (Brown Bank, Eurogeul, North Sea in general, etc), obtained by sand suppletion (Maasvlakte 1, Maasvlakte 2, Zandmotor), dredging (the Eurogeul), or are found on the beach (indicated by the name of the towns). The most recent data originate from the Maasvlakte 2 (artificial beach) area, and the suppletion area known as the Zandmotor at the coastline south of Den Haag (The Hague).

Table 1 also shows the bone collagen 'quality parameters' C%, N% and the C/N ratio. They are acceptable except for GrA-62687; it shows a good C/N ratio but both C% and N% values are too low. This is a subrecent sample and not further discussed in this paper; we will focus on the Mesolithic. One Mesolithic sample (GrA-49638) yielded good collagen. However the $\delta^{15}\text{N}$ value is an outlier. Values as low as 4.5‰ are unlikely for humans. Possibly the skeleton element (not specified) is not determined correctly, which requires further investigation. The data are kept in the table for completeness of the record. But both GrA-62687

and 49638 are not further discussed, and are also not included in the graphs below.

In order to evaluate the obtained result for human remains, we will compare these with those of faunal samples available from the Groningen database (Kuitens, 2007; Hebels, 2014). Table 2 shows the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for faunal samples from the southern North Sea, with ^{14}C dates corresponding to the Late Palaeolithic and Mesolithic. As was done for Table 1, the data in Table 2 are also sorted to age. The table includes Mesolithic artefacts made from herbivore bone/antler; one is dated to the Late Palaeolithic (Mol et al., 2008; Amkreutz et al., submitted for publication).

The stable isotope data for all human bone samples are shown in Fig. 2; the Mesolithic results in red, the non-Mesolithic (mostly historic) in blue.

The stable isotope data for fauna is shown in Fig. 3. The latter data comprises elk, red deer, roe deer, reindeer, boar and aurochs. Their isotope values are all in the 'terrestrial herbivore fauna' regime, and are indicated in Fig. 3 by a rectangular box. In addition, the data contain two dogs and one dolphin. This box is practically exactly the same as observed for another Mesolithic/Neolithic site in the Netherlands: Hardinxveld (Smits and van der Plicht, 2009), and is very similar to the one observed for sites in Denmark (Fischer et al., 2007). The relevant Hardinxveld fauna data is from boar, red deer and beaver.

The North Sea dogs are elevated in $\delta^{15}\text{N}$ relative to the terrestrial fauna, and must have had a significant freshwater food component in their diet, similar to the humans they lived with. This observation fits the results published for other Mesolithic assemblages (e.g. Fischer et al., 2007; Smits and van der Plicht, 2009). One North Sea dolphin bone falls in the marine box, as it should. All other faunal samples are clearly terrestrial.

Table 2

List of faunal bone samples from the North Sea, sorted to age. The table shows the Groningen laboratory number, species and isotopic measurements.

GrA	Species	Age BP	σ	$\delta^{13}\text{C}$ ‰	$\delta^{15}\text{N}$ ‰	C%	N%	C/N
25518	<i>Alces alces</i>	10,030	50	-20.8	2.3	44.6	17.2	3.0
36110	<i>Cervus elaphus</i>	10,000	50	-21.1	3.7	44.4	14.8	3.5
27206	<i>Alces alces</i>	9910	50	-20.9	1.7	39.9	16.6	2.8
37796	<i>Cervus elaphus</i>	9815	40	-21.2	3.5	42.9	15.1	3.3
37795	<i>Cervus elaphus</i>	9675	40	-20.8	4.1	43.7	16.5	3.1
37004	<i>Alces alces</i>	9520	50	-23.5	3.4	39.7	14.1	3.3
25506	<i>Alces alces</i>	9460	50	-22.8	4.2	44.9	17.1	3.1
51667	<i>Bos primigenius</i>	9220	40	-22.7	4.9	38.6	14.7	3.1
40524	<i>Cervus elaphus</i>	9070	45	-21.6	3.2	38.1	13.8	3.2
51668	<i>Bos primigenius</i>	8900	40	-22.4	5.2	44.3	15.6	3.3
31283	<i>Capreolus</i>	8880	40	-22.2	2.4	38.9	12.8	3.6
37561	<i>Cervus elaphus</i>	8830	40	-21.7	2.5	44.2	15.2	3.4
20256	<i>Rangifer tarandus</i>	8820	60	-22.7	4.0	40.6	16.8	2.8
25569	<i>Bos primigenius</i>	8800	50	-22.3	5.2	38.2	14.7	3.0
24209	<i>Canis species</i>	8780	50	-25.6	10.2	47.7	16.7	3.3
22998	<i>Bos primigenius</i>	8780	60	-22.5	5.5	36.2	15.5	2.7
36113	<i>Cervus elaphus</i>	8710	50	-22.5	2.2	39.7	13.4	3.5
32600	<i>Sus scrofa</i>	8710	45	-21.2	4.0	41.7	15.1	3.2
25568	<i>Cervus elaphus</i>	8605	45	-21.7	2.1	36.6	13.9	3.1
33949	<i>Capreolus</i>	8405	45	-21.4	3.0	36.8	12.5	3.4
30731	<i>Alces alces</i>	8240	50	-21.2	4.2	45.8	16.4	3.3
51786	<i>Bos primigenius</i>	8175	40	-22.8	6.1	42.8	16.7	3.0
25851	<i>Tursiops</i>	8135	45	-11.4	15.9	40.0	15.6	3.0
22999	<i>Cervus elaphus</i>	8070	50	-20.4	3.4	38.5	15.9	2.8
30721	<i>Sus scrofa</i>	7780	50	-21.9	6.2	31.9	13.4	2.8
20472	<i>Cervus elaphus</i>	7280	60	-21.1	4.4	40.0	14.6	3.2
9645	<i>Bos primigenius</i>	6520	50	-21.3	6.5	41.1	14.7	3.3
9646	<i>Bos primigenius</i>	6420	50	-21.8	6.5	44.0	15.7	3.3
9649	<i>Cervus elaphus</i>	6410	50	-21.8	5.5	43.8	15.8	3.2
9644	<i>Bos primigenius</i>	6260	50	-21.1	5.8	41.5	15.2	3.2
24224	<i>Cervus elaphus</i>	6235	45	-22.1	3.2	38.4	16.2	2.8
9650	<i>Bos primigenius</i>	6210	50	-21.6	6.3	42.3	15.6	3.2
10902	<i>Canis species</i>	5880	60	-20.5	15.0	39.1	13.7	3.3
25524	<i>Alces alces</i>	5770	40	-22.0	3.7	44.5	16.8	3.1
25522	<i>Alces alces</i>	5455	45	-22.4	2.6	40.8	14.7	3.2

Fig. 2. Stable isotope values ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) for ^{14}C -dated human bones from the North Sea, collected from the Groningen database. The data show two groups, Mesolithic and non-Mesolithic. The square box (herbivore terrestrial fauna) is the same as in Fig. 3.

In Fig. 2, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the human bones from the North Sea plot well above the terrestrial/herbivore box shown. This holds for both Mesolithic as well as non-Mesolithic samples. This will be further discussed below.

To guide the eye, general regions are shown by ovals, where stable isotope values are expected for humans with a terrestrial diet, a freshwater diet and a marine diet. These regions generally correspond to those shown by Fischer et al. (2007).

A detailed interpretation of the results is hampered, as the human bone finds from the North Sea are, within certain limits, all stray finds and their specific original archaeological context is unknown. Nevertheless the ^{14}C dates and stable isotope ratios $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ yield useful archaeological information when considered in a broader context of Post Glacial occupation histories and subsistence (Peeters and Momber, 2014). Further research into Post Glacial landscape dynamics (see Gaffney et al., 2007; Sturt et al. 2013; van Heteren et al., 2014) will potentially offer possibilities to contextualise these finds, especially when

Fig. 3. Stable isotope values ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) for animal bones from the North Sea, with ^{14}C dates corresponding to the Mesolithic. A square box is drawn around the herbivore terrestrial fauna and is copied in Fig. 2.

combined with pinpointed geomorphological sampling, ecological research and paleo-environmental reconstruction.

The importance of ^{14}C dates is obvious: only by dating them can it be established that the majority of the human bones is of Mesolithic age. A few appear to be of Late Palaeolithic age; one of these (GrA-58271) will be discussed in detail elsewhere (Amkreutz et al., submitted for publication). Several specimens judged as candidates for being Neanderthal (W. Roebroeks and J. Glimmerveen, pers.comm.) thus far all turned out to be Mesolithic (e.g. GrA-27188 and GrA-35949, both humeri). In this respect it is of interest to note that the Mesolithic human bones are often quite robust (Storm et al., 2014). Apparently, the morphology of these bones and the degree of fossilisation only offer a very limited indication of age. Note that the only confirmed Neanderthal find (right parietal bone) from the North Sea (Hublin et al., 2009) could not be ^{14}C dated, as no collagen was preserved.

4.2. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values

Often, $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ data plots of human bone for coastal regions show a trend between terrestrial and marine regimes. Such observations may allow the determination of mixing ratios between terrestrial and marine food sources. Examples are the extensive datasets for inhabitants of historic and modern Greenland (Buchardt et al., 2007; Nelson et al., 2012), as well as in Mesolithic/Neolithic data (Fischer et al., 2007; Guiry et al., 2015; Eriksson et al., 2016).

Our non-Mesolithic data (mostly historic) more or less follow such a mixing line. This demonstrates that these communities, living at a time when the North Sea shore had more or less reached its current position, were probably characterized by a mixed diet of mostly marine and terrestrial food.

It is immediately clear from Fig. 2, that our Mesolithic human samples from the North Sea show a different picture. They generally fall in the freshwater/terrestrial regime according to their $\delta^{13}\text{C}$ value. Most $\delta^{15}\text{N}$ values are elevated with respect to the terrestrial oval, roughly between 10 and 16‰. This is a clear sign of a strong aquatic dietary component (Schulting, 2015). The samples with $\delta^{13}\text{C}$ values between ca. -10 and -20 ‰ are elevated in $\delta^{15}\text{N}$, corresponding to a mixture of freshwater and marine food with a negligible terrestrial component. Perhaps these humans were coastal dwellers, compared with the main freshwater group. Only a few can be considered terrestrial. When our results are compared with the European overview of Schulting (2015: figs 11.2 and 11.3) it is clear that our results agree with the 'inland' data and disagrees with the 'coastal' data.

Our results hence reflect several dietary groups within the analysed sample. If the diet of Mesolithic hunter-gatherers was directly influenced by 'locally' available food resources, several landscape zones seem to have been exploited to a variable extent: terrestrial environments (dryland), inland aquatic environments (river valleys, lakes), as well as marine/coastal environments (open sea, lagoons, tidal inlets, salt marsh). This is to be expected for finds that, according to the ^{14}C -dates (but see below), cover the time range during which the Post Glacial conditions of the southern North Sea basin transformed from an inland landscape into a full marine environment. On the other hand, there is no reason to assume that the dietary sources were only exploited within a small region: a high mobility range combined with an annual cycle of movement can lead to a mixed diet which leaves behind a mixed isotope signal. Also, we have to bear in mind that socio-cultural factors may have been of influence on specific choices that were made with regard to food.

A further step involves the comparison of the North Sea isotope values with those measured for Mesolithic human bones from other areas: Hardinxveld (Smits and van der Plicht, 2009) and Belgium (Bocherens et al., 2007). The Hardinxveld sites are freshwater wetland sites in the Dutch Rhine-Meuse estuary, and the Belgium dataset consists of inland sites from the Meuse valley (see Fig. 4).

Fig. 4. Stable isotope values ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) for human bones from the North Sea: Late Palaeolithic/Mesolithic bones (same as in Fig. 2) compared with data from the wetland sites of Hardinxveld in the Netherlands, and terrestrial sites from the Meuse valley in Belgium.

The Hardinxveld and Belgium data clearly form two distinct groups. The Hardinxveld $\delta^{15}\text{N}$ values show a major aquatic food component; the $\delta^{13}\text{C}$ values are also freshwater, and not marine. People were living in a freshwater wetland landscape in which the Pleistocene river dunes were the main settlement locations from where resources were exploited (Louwe Kooijmans, 2000; Amkreutz, 2013). In contrast, the Mesolithic human diet in the Belgian Meuse valley was predominantly terrestrial (Bocherens et al., 2007). There is no aquatic influence; the sites are relatively far from the coast, and fish from the Meuse was apparently not a significant food source.

With only a few exceptions, the $\delta^{15}\text{N}$ values of the North Sea Mesolithic humans cover the range between those of Hardinxveld and the Meuse valley, and most of them are in the freshwater region. The $\delta^{13}\text{C}$ values appear generally lower than those of the Meuse valley. The cause for this is impossible to derive without detailed knowledge of the food web.

4.3. Radiocarbon dates

For marine and freshwater reservoirs, the ^{14}C dates are subject to the so-called reservoir effect. The 'modern' ^{14}C concentration in water is lower than in the contemporaneous atmosphere, causing an offset in ^{14}C age between contemporaneous aquatic and terrestrial samples (e.g. Lanting and van der Plicht, 1999). For marine samples, this offset is 400 years for the North Sea; for freshwater reservoirs, the values vary considerably, depending on geochemical circumstances. This effect also shows up in terrestrial organisms when they consume significant amounts of aquatic food. The effect is therefore also known as the 'fish effect' (Lanting and van der Plicht, 1999).

Since the Mesolithic people discussed in this paper were predominantly 'aquatic consumers' according to their stable isotope values, the ^{14}C dates in BP as shown in Table 1 are 'too old'. The ^{14}C age must be corrected for this reservoir effect, before they can be calibrated into absolute (historical) ages. The challenge is to obtain a reliable estimation for the reservoir effect. This can be done for marine (e.g. Arneborg et al., 1999) or freshwater (e.g. Cook et al., 2001) reservoirs, based on the above mentioned mixing parameters, supplemented by paired dating of associated terrestrial and aquatic samples.

For the North Sea data we are dealing with a mixed marine/freshwater complex. In addition, there is currently insufficient contextual information of the samples because of their nature. For example, paired dating of samples (with and without reservoir effect) is not possible.

This makes reliable quantification of the reservoir effect impossible for our North Sea samples.

For Mesolithic Denmark, Fischer et al. (2007) derived the percentage of marine food (based on ^{13}C) and freshwater food (based on ^{15}N). For both isotopes, the reservoir age correction is then determined as the corresponding percentage of a reservoir effect of 400 years. By simply choosing the largest number, the reservoir correction is then determined. Note that this reservoir age of 400 years is taken for both marine and freshwater reservoirs. For the latter, we consider this as a too crude assumption. Freshwater reservoir effects vary widely and can be much larger than 400 years (Lanting and van der Plicht, 1999; Fischer et al., 2007).

Lacking reliable information on the magnitude of reservoir effect, we cannot calibrate the ^{14}C dates for the Mesolithic humans from the North Sea. Absolute ages cannot be established to a reasonable precision. Hence for our dataset, we have to work with (uncalibrated) ^{14}C dates in BP.

It is however clear they are Mesolithic. Moreover, there is a *terminus ante quem*: the Mesolithic samples have to predate the final inundation of the North Sea basin. This appears more likely than to assume they ended up at the bottom of the sea due to off-shore accidents.

We investigated possible correlations between ^{14}C age and other proxies such as the 'find location' but did not find any distinct matches. It should however be mentioned that the two relatively late dates from the Zandmotor (GrA-65507 and 65943, see Table 1) do fit the Later Mesolithic lithic assemblage which was found on the beach. Similarly we could not detect a correlation between 'find locations' and their position in the isotope plot. Without doubt this is partly due to the lack of information on the exact find spots. In addition, a more intensive analysis of our samples in relation to palaeogeographic information and sea-level rise is needed.

There is, however, a correlation between ^{14}C age and diet composition, as shown in Fig. 5. There appears to be a trend in $\delta^{15}\text{N}$ versus age: an increase in the younger direction of about 1‰ per 500 ^{14}C year. A linear fit through the data (the dashed line shown) yields a statistically significant result ($R = 0.66$). This observation does support an increase in aquatic food resources for the Mesolithic inhabitants of the North Sea region over time. It also suggests that the inhabitants did not abandon the area when circumstances changed, but rather adjusted their diet and way-of-life to the changing situation.

A final observation concerning the ^{14}C dates is the 'gap' between the Mesolithic and non-Mesolithic groups, i.e. between 7760 and 2740 BP

(see Table 1). We can only speculate but it would make sense the younger dates represent coastal inhabitants or drowned people.

5. Final considerations and conclusion

The results presented above reveal some patterns with regard to dietary variability among Mesolithic hunter-gatherers that lived in 'Doggerland', the area of the present-day southern North Sea. Their skeletal remains are dated by ^{14}C . We observe that stable isotope ratios $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ indicate the structural inclusion of food resources originating from freshwater, marine/coastal, and terrestrial environments. Marine food components, however, seem to have been less important than freshwater and terrestrial components. To what extent the dominance of Mesolithic human remains with a freshwater aquatic signal is related to taphonomical issues is unclear. We should however bear in mind that the conditions for preservation may have been more favourable in energetically less intense wetland settings in contrast to transgressive coastal settings, or unsheltered upland locations.

We are not able at present to connect the ^{14}C ages to the palaeo-environmental situation of 'find locations' due to the lack of reliable context information. The ^{14}C dates are Mesolithic, but cannot be calibrated into absolute dates. The aquatic diet must have caused a reservoir effect, but its magnitude cannot be established reliably.

Several models of inundation rate do exist (Jelgersma, 1979; Behre, 2007, but see Hijma and Cohen, 2010; Baeteman et al., 2011; Sturt et al., 2013) and differ in various ways due to differences in bathymetric digital models of the Late Glacial and Early Holocene surface, and estimates of subsidence. However, in general terms, these models show that from the start of the Holocene the land between Britain and the continent was gradually engulfed by the sea, transforming the Dover Strait gorge into an estuary which shifted in northern direction and reached the Dutch coast during the Boreal (Hijma and Cohen, 2010, 2011; Peeters and Momber, 2014). From ca. 7000 BCE the sea level rise accelerates, and a clear jump in the sea-level rise around 6500 BCE has been documented as a result of the drainage of Lake Agassiz (Hijma and Cohen, 2010, 2011) and possibly also the influence of a tsunami due to the Storegga landslide (Weninger et al., 2008; Peeters and Momber, 2014). Prior to these 'events', which eventually led to the complete drowning of the southern North Sea, large parts of this area were situated inland. This might explain the closer fit of the older group of North Sea humans with the Belgian data from the Meuse valley. The younger group, then, fits an environmental context which is characterized by the consistent and at times rapid inundation of the south-eastern part of Doggerland and wetlands in the Rhine-Meuse estuary which was transgressing eastward. Around 6500–6250 BCE the coastline had almost reached its present-day position near Rotterdam (Moree and Sier, 2015).

This demonstrates that the inhabitants of Doggerland were capable of adapting to these changing circumstances by shifting their diet towards a more aquatic orientation. The dynamic and changing character of Doggerland therefore seems to have been embraced rather than feared by its occupants (also see Leary, 2009), offering new opportunities in times of change. Apparently there was no need, at least not for all hunter-gatherer groups, to relocate from the North Sea basin to 'dry land' as was suggested earlier (Newell, 1973 but see Lanting and van der Plicht, 1997/1998).

Also it demonstrates that the importance of marine resources of the communities in this drowning area may have been limited. Research of contemporaneous or earlier British and Scandinavian coastal and shell-midden sites has argued in favour of the existence of an important marine orientation for the Mesolithic (Schulting and Richards, 2002a,b; Schulting, 2005, 2007; Fischer et al., 2007; Price et al., 2007; Lidén et al., 2004). This is often in contrast with a distinct shift towards terrestrial resources at the start of the Neolithic (Schulting, 2007, 2011; but see Milner et al., 2004). This juxtaposition between terrestrial and marine resources is also implied in research regarding the now lost coastlines

Fig. 5. Stable isotope $\delta^{15}\text{N}$ values for Mesolithic human bones from the North Sea, plotted as a function of (uncalibrated) ^{14}C age. The dashed line is a linear fit through the datapoints.

of the North Sea (Schulting, 2010, 2011; Conneller et al., 2016). While this may be justified it also colours the debate. Our study underlines that for the drowning Southern North Sea area it was the range of freshwater wetland landscapes that preceded a maritime environment that was of importance, rather than clinging to terrestrial resources or opting for a marine diet.

Much in line with the isotopic and archaeological evidence for the Mesolithic and Neolithic of the Rhine-Meuse delta is the long-term focus on wetland resources (Louwe Kooijmans, 2007, 2009; Smits and van der Plicht, 2009; Amkreutz, 2013). It ranks among the ecologically richest areas for hunter-gatherers worldwide (Binford, 1990, 2001; Nicholas, 1998, 2007).

On the other hand, the fact that the environment provided a broad range of potential food resources does not mean that its full range was exploited. Indeed, why would people in the Meuse valley not be interested in fish? Why did a group of Late Neolithic people with Mesolithic hunter-gatherer ancestry stick to an aquatic/terrestrial diet, whereas other contemporaneous lineages opted for an agricultural diet (Bollongino et al., 2013)? Perhaps this is a matter of persistent traditions (Amkreutz, 2013)?

To conclude, our analyses show that it is relevant and possible to squeeze information from these finds with limited contextual information. This recognition is important for both scientific studies, as well as for claims to secure archaeological finds and contexts from the North Sea basin in light of growing off-shore activities.

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