Journal of Archaeological Science: Reports 35 (2021) 102678

Contents lists available at ScienceDirect

Journal of Archaeological Science: Reports

journal homepage: www.elsevier.com/locate/jasrep

Human and cervid osseous materials used for barbed point manufacture in Mesolithic Doggerland

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ARTICLE INFO

Keywords:
ZooMS
Bone-tool
Bone-point
Human bone
Mesolithic
North Sea
Doggerland
Stable isotopes

ABSTRACT

Barbed bone points originally deposited in Doggerland are regularly collected from the shores of the Netherlands. Their typology and direct ^{14}C dating suggest they are of Mesolithic age. However, the species of which the barbed points were made cannot be identified based on morphological criteria. The bones used to produce the barbed points have been intensively modified during manufacture, use, and post-depositional processes. Here, we taxonomically assess ten barbed points found on the Dutch shore using mass spectrometry and collagen peptide mass fingerprinting alongside newly acquired ^{14}C ages and δ^{13}C and δ^{15}N measurements.

Our results demonstrate a sufficient preservation of unmodified collagen for mass spectrometry-based taxonomic identifications of bone and antler artefacts which have been preserved in marine environments since the beginning of the Holocene. We show that *Homo sapiens* bones as well as *Cervus elaphus* bones and antlers were transformed into barbed points. The ^{14}C dating of nine barbed points yielded uncalibrated ages between 9.5 and 7.3 ka ^{14}C BP. The δ^{13}C and δ^{15}N values of the seven cervid bone points fall within the range of herbivores, recovered from the North Sea, whereas the two human bone points indicate a freshwater and/or terrestrial fauna diet.

The wide-scale application of ZooMS is a critical next step towards revealing the selection of species for osseous-tool manufacture in the context of Mesolithic Doggerland, but also further afield. The selection of *Cervus elaphus* and human bone for manufacturing barbed points in Mesolithic Doggerland is unlikely to have been opportunistic and instead seems to be strategic in nature. Further, the occurrence of *Homo sapiens* and *Cervus elaphus* bones in our random and limited dataset suggests that the selection of these species for barbed point production was non-random and subject to specific criteria. By highlighting the transformation of human bones into barbed points – possibly used as weapons – our study provides additional evidence for the complex manipulation of human remains during the Mesolithic, now also evidenced in Doggerland.

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https://doi.org/10.1016/j.jasrep.2020.102678
Received 17 August 2020; Received in revised form 10 November 2020; Accepted 14 November 2020
Available online 29 November 2020

1. Introduction

Barbed osseous points originally deposited in Doggerland are regularly collected from the beaches of the Netherlands. Doggerland connected Britain to mainland Europe during the Pleistocene and early Holocene (Coles, 1998), and was totally submerged circa 8,000 years ago by the North Sea (Cohen et al., 2014; Hijma and Cohen, 2011, 2019). Doggerland sediments are nowadays mechanically dredged and the sediment collected at the bottom of the southern part of the North Sea is redeposited along the Dutch coastline. In this process, Palaeolithic and Mesolithic artefacts – but also faunal remains and human remains - are recovered (Janse, 2005; Kuitems et al., 2015; Langeveld, 2013; Niekus et al., 2019; Peeters and Mombers, 2014; Peeters et al., 2019; Peeters and Amkreutz, 2020; Van der Plicht et al., 2016; Vervoort-Kerkhoff and Van Kolfschoten, 1988). Over the past years, a large number of barbed points of Mesolithic types have been collected on beach replenishments in the area of The Hague and Rotterdam (Amkreutz and Spithoven, 2019). Many of these barbed points ought to be of Mesolithic age because of their typology and direct ^{14}C dates obtained for six of them (Amkreutz and Spithoven, 2019; Hedges et al., 1990; Verhart, 1988). They appear to be predominantly made out of bone (Amkreutz and Spithoven, 2019; Verhart, 1988), which has been heavily modified during the manufacturing process. Subsequently, the points themselves are also often modified during use, repair, re-sharpening, and as the result of post-depositional processes. As a result, it is generally impossible to identify the species of the bone used to manufacture barbed points based on morphological identification. It was suggested that aurochs (*Bos primigenius*), horse (*Equus* sp.), elk (*Alces alces*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) bones were likely used for bone point production, as they constitute a large portion of the Mesolithic faunal spectrum in Northern Europe (David, 1999; Verhart, 1988; Wild and Pfeifer, 2019; Zhilin, 2017). Yet, until recently only a handful of points had been directly identified to taxon. Two 'harpoons' from Poland and four points from Germany were proposed to be made of red deer and roe deer long bones (Gross, 2017; Osipowicz, 2016) based on morphological criteria. One bone point from Star Carr (United Kingdom) was identified as red deer or roe deer bone – and many other points from the same site were identified as red deer antler (Elliott and Little, 2018). The number of identified barbed points was greatly increased by a recent study on Danish barbed points, which revealed 74 points to be made of cervid, 43 of bovines and three of brown bear (Jensen et al., 2020). The results of the Jensen study fit well with the previous general tendency to view the barbed points as deriving from available herbivore prey species. Although the three brown bear identifications do suggest that there is more to the raw material selection of barbed points than meets the eye.

Here, we use mass spectrometry and collagen peptide mass fingerprinting (commonly referred to as ZooMS) to taxonomically identify ten barbed points collected on replenished beaches in the Netherlands. Due to its triple helical structure, collagen is very resistant to degradation, more so than DNA (Welker et al., 2015a). The amino acid structure of collagen type I typically varies from one taxon to another (Buckley et al., 2010). Depending on the preservation and the specific taxa, ZooMS can in most cases identify up to the genus level, and for some taxa an identification to species level can be made (Welker et al., 2015b). ZooMS is relatively cheap, fast to operate, and requires minimal sampling of the artefact (≈10 mg). Recent developments have also shown that ZooMS can be applied non-destructively by sampling the plastic bag or membrane box which has contained the artefact rather than the artefact itself (Martisius et al., 2020; McGrath et al., 2019). ZooMS has been used for the screening of large quantities of morphologically unidentifiable bone fragments (Sinet-Mathiot et al., 2019) and contributed to the discovery of previously unrecognized human remains (Brown et al., 2016; Charlton et al., 2016; Devièse et al., 2017; Welker et al., 2016). This method has also been applied to distinguish between taxa difficult to separate morphologically (e.g. sheep and goat) (Evans et al., 2016; Pilaar Birch et al., 2018). More recently, ZooMS was also employed to identify the species used for the manufacture of bone tools (Bradfield et al., 2018; Desmond et al., 2018; McGrath et al., 2019). Here, we report on a pilot ZooMS study of barbed points found on the Dutch North Sea coast. Combined with ^{14}C dating and C and N isotope measurements, we contribute to the identification of the taxa used to manufacture bone-points during the Mesolithic.

2. Materials

Around one thousand barbed bone/antler points have been collected from Doggerland and attributed to the Mesolithic (Amkreutz and Spithoven, 2019; Spithoven, 2015, 2018). Our sample consists of 10 barbed points. The recovery locations of these points and their estimated source locations in Doggerland are indicated in Fig. 1. Geologically, the sediments derive from the Rhine and Scheldt delta that evolved from a fluvial valley with lowland marshes to an estuarine and brackish fluvial-tidal inlet during the early Holocene (Hijma and Cohen, 2011).

Most points in our sample appear well-preserved both macroscopically and at low magnification (x10), with either none or minimal parallel cracking of the surface. Two points however are heavily weathered with surface flaking, cracks and pits. A visual inspection indicates that they are all made out of bone except for one specimen, which is produced on antler (Table S1). The types and shapes of the unilateral barbed points are characteristic of the Mesolithic of Northwest Europe, even if they are often smaller than other Mesolithic points found in Europe and can be considered "miniature points" (Spithoven, 2018, 88). They fall in two broad size classes as previously recognized for the Netherlands (Amkreutz and Spithoven, 2019; Verhart, 1988). Six points belong to the smaller points (i.e. $<$ 89 mm) and four to the class of larger points. Possible retrieval marks are present on the large points and indicate that some examples were probably repaired, re-sharpened and curated (Spithoven 2018). These points were likely used for hunting as impact scars are present on some of the tips (Hartz et al., 2019; Spithoven, 2018) and they were probably hafted on a bevelled shaft using bindings and pitch or tar, as indicated by organic residues and microwear (Spithoven, 2018).

3. Methods

3.1. ZooMS

Each bone point was analysed according to two ZooMS protocols: the cold acid protocol (Buckley et al., 2009; Van Doorn et al., 2011) and the ammonium-bicarbonate (AmBic) protocol (Van Doorn et al., 2011). Two samples of 10–20 mg were taken from each barbed point using a scalpel, pliers or a fretsaw. The first sample was treated according to the cold acid protocol (Van Doorn et al., 2011) and the second sample according to the AmBic protocol (Van Doorn et al., 2011). The samples designated for the cold acid protocol were demineralised in 250 μL 0.5 M HCl for 40 h. Once demineralisation had finished the acid was removed and the samples were neutralised by adding 200 μL of ammonium bicarbonate (AmBic, NH_4HCO_3, 50 mM, pH 8, Sigma-Aldrich). The samples were then vortexed and centrifuged at 10,000 RPM for 1 min. After centrifugation, the NH_4HCO_3 was removed. The neutralisation step was repeated three times.

Then, the cold acid protocol samples as well as the non-demineralised AmBic samples were incubated in 100 μL of AmBic buffer (50 mM, pH 8) at 65 °C for one hour. Afterwards, the samples were centrifuged at 10,000 RPM for one minute. The collagen in the samples was digested by adding 1 μL of trypsin (Promega). Digestion occurred at 37 °C and was stopped after 17 h 15 min by adding 1 μL of 20% TFA (trifluoroacetic acid). The collagen peptides were filtered from the samples using C18 ZipTips (Thermo) and eluted in 0.1% TFA.

After filtration, each sample was spotted on a MALDI Bruker MTP384 target ground steel plate in triplicate. Of each sample, 1 μL was spotted

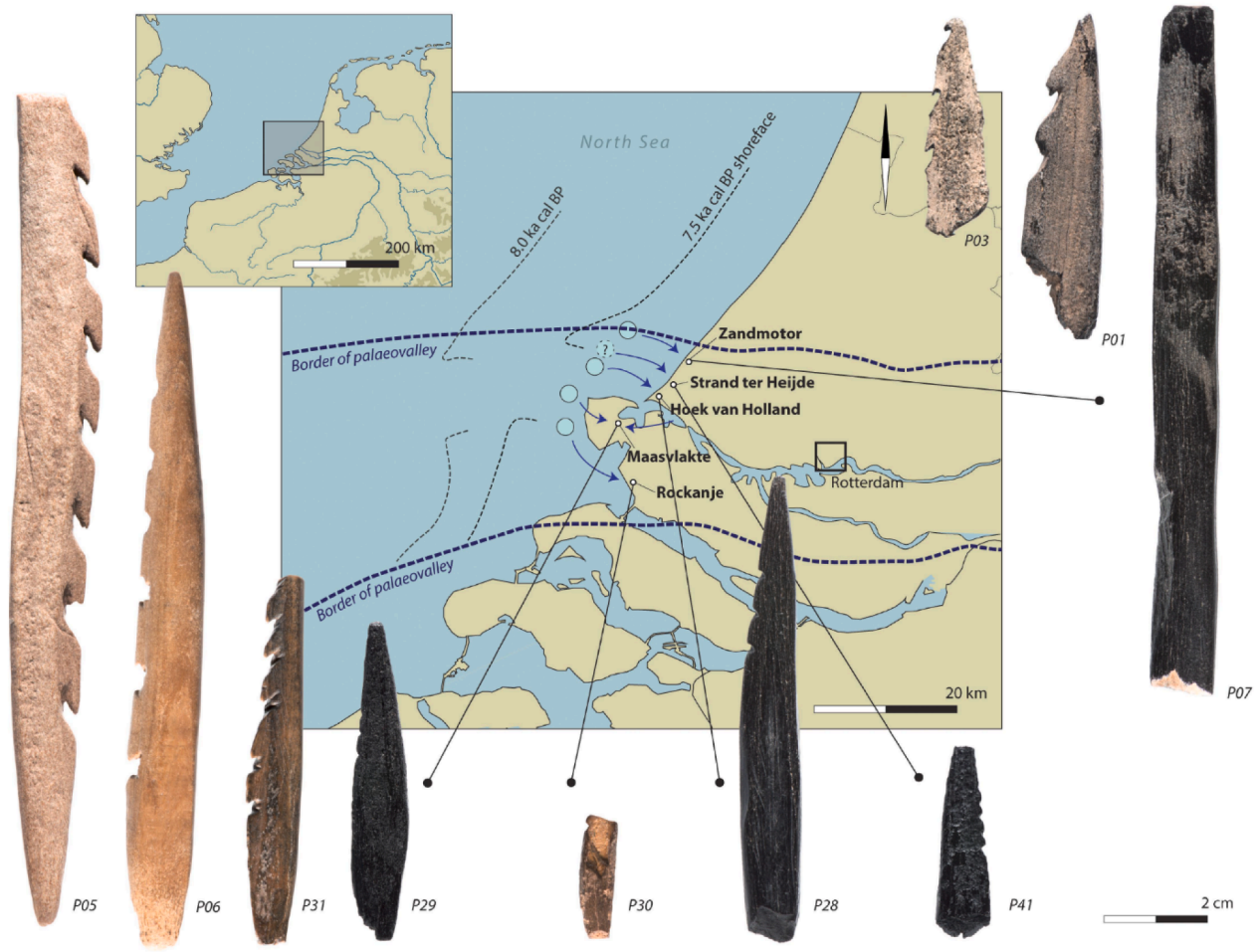

Fig. 1. The discovery locations of the barbed points and their probable sand source locations beneath the North Sea. The specimens are identified by ZooMS number; P29 and P03 are the points identified as made of human bone (map after Hijma and Cohen, 2011; photos R.J. Looman, RMO, Leiden; graphic design by J. Porck).

and 1 μL of α-cyano-4-hydroxycinnamic acid (CHCA; Sigma) was added as sample matrix. The samples were analysed with an autoflex LRF MALDI-TOF (Bruker) set to reflector mode, positive polarity, matrix suppression of 590 Da and collected in the mass-to-charge range 700–3500 *m/z*. The raw data was converted by Flex Analysis (Bruker) into .txt files. The triplicate spectra were merged for each sample

Table 1
Results of ^{14}C dating and stable isotopes from the barbed points. ZM = Zandmotor; MV1 and MV2 = Maasvlakte 1 and 2; HvH = Hoek van Holland; Ro = Rockanje; StH = Strand ter Heijde (for locations, see Fig. 1). E = empty, i.e. no collagen preserved, Coll. = collagen. * radiocarbon ages cannot be calibrated because of the unknown reservoir effect of humans consuming aquatic resources in the Dutch deltas (Van der Plicht et al., 2016). Calibrated age range: calibrated with OxCal v4.3 (Bronk Ramsey, 2009), using IntCal13 atmospheric curve (Reimer et al., 2013); age range for 95,4% probability.

ZooMS number	Database number	Find location	Identification	Groningen lab number	^{14}C age (yrBP)	Calibrated age range (yrBP)	Coll. Yield (%)	%C	%N	C: N	δ^{13}C (‰)	δ^{15}N (‰)
P01	28.1	ZM	*Cervus / Alces*	GrM-19216	7,335 ± 40	8,293–8,021	1.5	31.8	12.0	3.1	−22.3	5.5
P03	28.3	ZM	*Homo sapiens*	GrM-19217	7,410 ± 40	*	6.9	42.5	15.9	3.1	−21.7	10.5
P05	86.1	MV2	*Cervus elaphus*	GrM-19218	9,495 ± 40	1,1071–1,0601	5.0	43.4	15.7	3.2	−21.3	2.8
P06	1000.1	MV2	*Cervus elaphus*	GrM-19219	9,415 ± 40	1,0749–1,0555	4.8	42.1	15.0	3.3	−21.8	4.3
P07	27.1	ZM	*Cervus elaphus*	GrM-19221	7,315 ± 40	8,190–8,020	2.7	39.4	14.2	3.2	−21.5	3.3
P28	37.4	HvH	*Cervus elaphus*	GrM-19226	8,260 ± 40	9,410–9,093	3.2	37.7	14.4	3.0	−21.6	2.4
P29	34.1	MV1	*Homo sapiens*	GrM-19229	8,295 ± 40	*	2.6	38.4	14.0	3.2	−23.2	12.7
P30	14.121	Ro	E	X	X	X	X	X	X	X	X	X
P31	30.1	MV2	*Cervus elaphus*	GrM-19230	9,505 ± 40	1,1075–1,0606	4.7	40.7	15.4	3.1	−22.0	4.3
P41	41.3	StH	*Cervus elaphus*	GrM-19231	7,920 ± 40	8,978–8,607	1.5	30.0	11.9	2.9	−22.3	4.8

through R (version 3.5.1) (R Core Team, 2018), and taxonomic identifications proceeded, using mMass (Strohalm et al., 2010), through peptide marker mass identification in comparison to a database of peptide marker series for all European, Pleistocene medium to large size mammals (Welker et al., 2016).

3.2. ^{14}C dating, $\delta^{13}C$ and $\delta^{15}N$ analysis

Isotopes were analysed at the Centre for Isotope Research of the University of Groningen, the Netherlands (Dee et al., 2020). A solid fragment of bone of between 100 and 270 mg was extracted from the points (see Table S2) as solid chunks tend to have higher collagen yields than bone powder (Dee et al., 2020).

Collagen was extracted from the bone samples and used for ^{14}C dating, $\delta^{13}C$ and $\delta^{15}N$ analysis following the methods described in Van der Plicht et al. (2016). The collagen yield, C:N ratio, %C and %N were used as quality controls (see Table 1). Following Van Klinken (1999) and Van der Plicht et al. (2016) measurements were considered valid when the collagen yield was higher than 0.5%, the C:N ratio was between 2.9 and 3.6, the carbon content (%C) was between 30 and 45% and the nitrogen content (%N) was between 11 and 16%.

The age bracket derived from ^{14}C dating was important for the interpretation of the ZooMS spectra because specific species can be excluded based on the extinction dates during the Late Pleistocene to Holocene transition.

$\delta^{13}C$ and $\delta^{15}N$ were used to check that the main protein source (terrestrial, freshwater, marine) and the trophic level of each individual was coherent with the species identified using ZooMS. A previously published stable isotope dataset of Mesolithic humans and animal remains from the North Sea was used as a reference set (Van der Plicht et al., 2016).

4. Results

The results of the taxonomic identification through ZooMS as well as the ^{14}C dates, quality control parameters and stable isotope data are presented in Table 1. The sample P30 is a small, degraded fragment of a barbed point that did not yield collagen suitable for either ZooMS, radiocarbon or stable isotope analysis. The other nine samples provided sufficient collagen to allow a taxonomic identification and measurement of the ^{14}C, $\delta^{13}C$ and $\delta^{15}N$ values. All of the isotopic quality indicators are within the acceptance ranges.

4.1. Species identifications and their diet

Nine of the ten bone points subjected to the cold acid and AmBic sampling protocols were identified. There were no taxonomic discrepancies between the results obtained via different protocols for the same artefact. Using the standard peptide marker series seven bone specimens were identified as *Cervid/Saiga* and the other two specimens were identified as human (*Homo sapiens*) (Fig. 2). In the context of these bone points, "*Cervid/Saiga*" refers to a group of the following species: elk (*Alces alces*), giant deer (*Megaloceros giganteus*), fallow deer (*Dama dama*), red deer (*Cervus elaphus*) and saiga antelope (*Saiga tatarica*). On the basis of its geographic range during the early Holocene, fallow deer can be excluded (Baker et al., 2017). Although fallow deer is found in northern Europe throughout much of the Pleistocene (Kosintev, 2008; Markova and Puzachenko, 2008), it was confined to Southern Europe

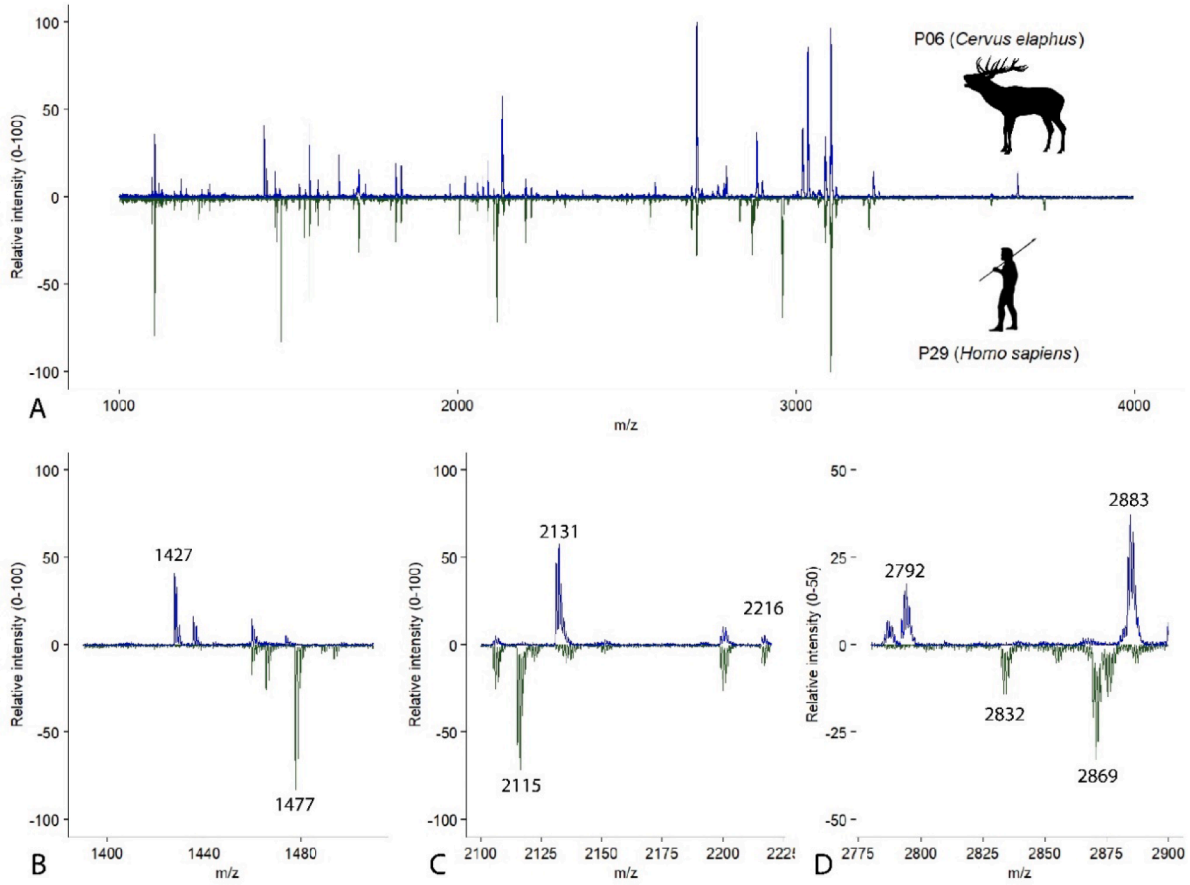

Fig. 2. Comparison of MALDI-TOF MS spectra for barbed bone points P06 (*Cervus elaphus*) and P29 (*Homo sapiens*). A. Full spectra. B-D. Close-up of peptide markers around 1400–1500 *m/z* (B), 2100–2200 (C), and 2790–2890 (D). *m/z* = mass to charge ratio. Y-axis indicates relative intensity, 0–100%, scaled relative to the most intense peptide peak in either spectrum.

and Anatolia at the end of Pleistocene (Chapman and Chapman, 1980). Fallow deer is only found in Northern Europe again during Antiquity (Sykes, 2004). Considering that the giant deer and the Saiga antelope went (locally) extinct in Northwest Europe during the Late Glacial, they are unlikely for points directly dated to the early Holocene (Lister and Stuart, 2019; Nadachowski et al., 2016). Therefore, two species are left as likely candidates: elk and red deer. However, the recent proposal of a new biomarker at a *m/z* of 2216 (Jensen et al. 2020) enables us to further specify the identification of six barbed points to red deer (Table 1). As the distinction between the closely related red deer and elk does not impact some of our arguments and since one barbed point can be made of either elk or red deer, we will use the notation *Cervus/Alces* to refer to all seven red deer and/or elk barbed points.

The identification of two of the bone points (P29 and P03) as human was unexpected and raised the question of contamination. The biomarkers for the identification of humans are unique and not shared with other species present in Mesolithic Northwest Europe. However, organic material deriving from humans is a common contaminant in biomolecular studies (Hendy et al., 2018). Following Buckley et al. (2009), several measures were taken to ensure the authenticity of the results of this study: 1) each extract was analysed in triplicate, reducing the risk of contamination during MALDI-TOF MS analysis, and these replicates all produced identical results; 2) each specimen was analysed using two extraction protocols in parallel, and produced identical results; 3) the destructive samples consisted of both inner and outer layers of the bone, reducing the influence of surface contamination. Furthermore, the $\delta^{13}C$ and $\delta^{15}N$ values measured on the two bone points identified by ZooMS as human are in accordance with other North Sea human bones values. They significantly differ from the animal bone values recovered in the North Sea (Fig. 3). Therefore, we consider the identification by ZooMS of two barbed points made of human bones as reliable.

The *Cervus/Alces* bone and antler points $\delta^{13}C$ and $\delta^{15}N$ values fall within the range of values for herbivores recovered from the North Sea. The values for the points overlap with the data for North Sea red deer and elk (Fig. 3). The $\delta^{13}C$ and $\delta^{15}N$ values for the human bones are clearly separated from the values for terrestrial fauna and fall in the cluster of North Sea humans. One of the individuals (P29) signals a clear freshwater diet, and the other one (P03) is in-between values for a fresh water and a terrestrial fauna diet. These results are in line with previous $\delta^{13}C$ and $\delta^{15}N$ signatures from Mesolithic Doggerland human remains (Van der Plicht et al., 2016).

4.2. Dating

The uncalibrated ages of the barbed points range between 9.5 and 7.3 ka ^{14}C BP which correspond to an age of roughly 11,000 to 8,000 years ago, confirming their attribution to the Mesolithic period. The ^{14}C ages obtained on bones from animals feeding on terrestrial resource can be calibrated. The isotopic values recorded on our sample of *Cervus/Alces* indicate they had a terrestrial diet, as well as other roe deer, red deer and elks from the North Sea (Van der Plicht et al., 2016). In turn, no reservoir effect needs to be included in the calculation of the real age. However, the human bones in our sample indicate a fresh-water diet. A so-called reservoir effect or "fish effect" must in turn be subtracted from

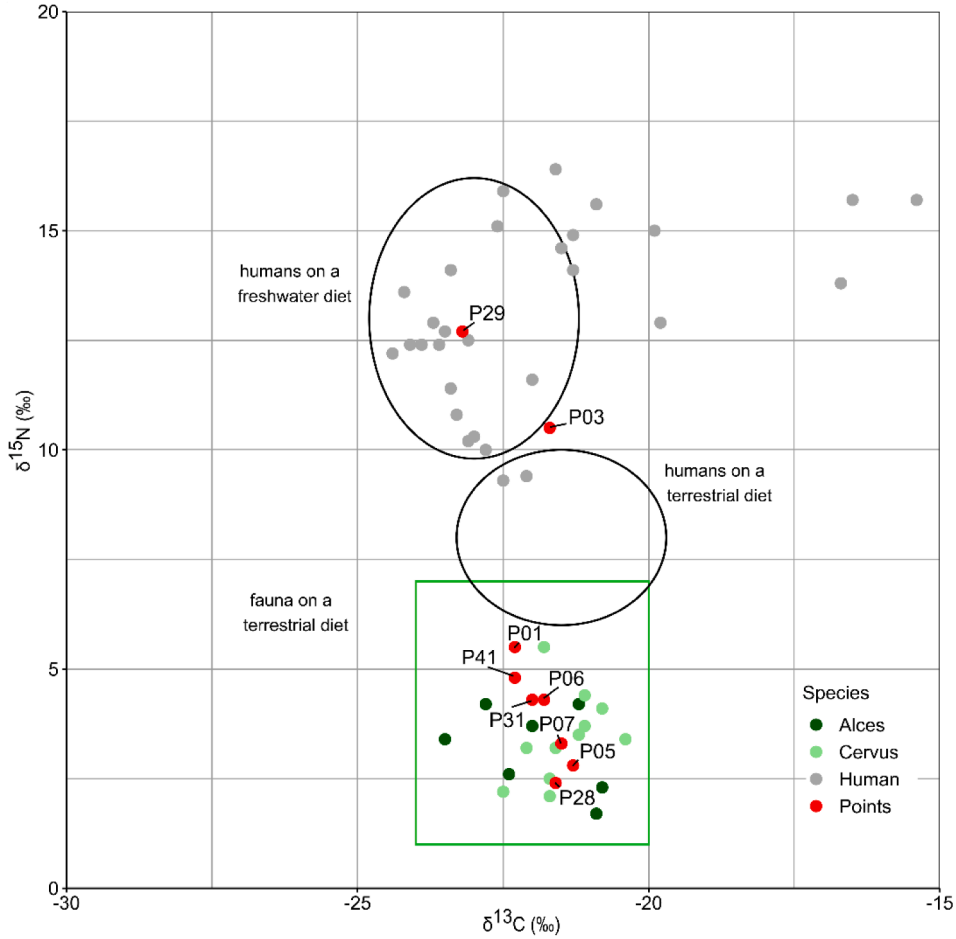

Fig. 3. $\delta^{13}C$ and $\delta^{15}N$ values for the barbed points compared with the ranges for terrestrial fauna and human remains from the North Sea. The specimens are indicated in red and identified by ZooMS number; P29 and P03 are the points identified as made of human bone (other data and ranges from Van der Plicht et al., 2016). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the ^{14}C ages (Lanting and van der Plicht, 1998). Such reservoir effect is often thought to be 400 years, but can be larger (Van der Plicht et al., 2016; Philippsen and Heinemeier, 2013). Yet, it seems that it is for now impossible to obtain a reliable estimation of the reservoir effect for humans living on the Dutch coast considering the mixing of fresh-water and marine signal in deltas (Van der Plicht et al., 2016). Nevertheless, it is clear that these humans are Mesolithic. Their absolute age cannot be older than circa 11,000 years and must pre-date the final inundation of the North Sea basin that is currently dated to around 8,000 years ago (Hijma and Cohen, 2011, 2019).

5. Discussion

The barbed points studied here likely come from different Mesolithic find locations as they were collected on several artificial deposits spread along circa 20 kms of coast, and their colour and density indicate they have experienced different diagenetic histories (Fig. 1). Their ^{14}C ages indicate that they mainly date to the Early Mesolithic. In turn, our sample of barbed points is to be seen as a random sample of Mesolithic barbed points from the Dutch shore. Being a random sample, it is interesting that it only consists of several *Cervus elaphus*, one *Cervus elaphus/Alces alces* and of *Homo sapiens*. As elk might be represented by only a single barbed point or could altogether be absent, we will not consider the one *Cervus elaphus/Alces alces* point in further discussion.

It is possible that the use of red deer osseous material for the production of barbed bone simply reflects the availability of this species in the original faunal assemblage, i.e. an opportunistic selection among the hunted faunal assemblage. Considering that the points were not found in association with faunal assemblages, and in order to test the hypothesis of an opportunistic selection of red deer, we review the taxonomic composition of the North-western Europe Mesolithic faunal assemblages (Tables S3 and S4). Red deer is commonly found, but the same applies for aurochs (*Bos primigenius*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). Aurochs, roe deer, red deer as well as elk are considered suitable sources of bone for the production of barbed points (Verhart 1988). Table S3 shows that the average percentage of red deer bone is 42.9%, although there is a large amount of variation between sites (range: 0–92.3%). Thus, we assume that, if the raw material selection for the bone points purely reflects the availability of local fauna, there is a 42.9% chance that a bone point is made from red deer bone. As each bone point can be seen as an independent data point randomly drawn from the larger Mesolithic faunal assemblage, the probability to find six red deer barbed points equals $0.429^6 = 0.00623$. In turn, it is unlikely that the raw material selection for barbed points reflects the abundance of animal taxa available in the environment.

In addition, if there was no selection, it is probable that all other bone tools would also be made of the hunted fauna without species selection. It seems however that this is not the case. Louwe Kooijmans (1971) mentions five axes/adzes/picks from the North Sea, all made of aurochs (identification was possible because only one end of the heavy tool was modified), plus three worked aurochs bones and one worked red deer antler. The faunal assemblage and bone tools from the late Mesolithic site Hardinxveld Polderweg (the Netherlands) show a similar species distribution with red deer being dominant, followed by small numbers of roe deer and elk (Louwe Kooijmans, 2001). Rensink (2006) mentions nine Mesolithic axes/adzes from the Netherlands, that derive from one aurochs, three elks, and five red deer. In the wider context of early Mesolithic well-preserved sites in Denmark and Sweden, there are many indications of selection for bone-tool manufacture (David, 1999). We conclude that a random and opportunistic selection of red deer is unlikely and that, to the contrary, a strategic selection of red deer bone to produce bone points at several sites seems the most plausible way to explain the proportion of species observed here.

The human barbed points were excluded from Table S3, as opportunistic selection of human bone can safely be excluded. Ethnographic data on hunter-gatherers, who employ an immediate return foraging style, show that the amount of animal resources exploited is several orders of magnitude higher than the biomass of the hunter-gathers themselves (Stutz, 2020). In other words, human bones ordinarily compose only a miniscule fraction of the total amount of bones available to hunter-gatherers. Although there are examples of Mesolithic sites where disarticulated human remains are quite common, it is not always clear how these should be interpreted. In some cases the disarticulated remains are hypothesised to be the result of violence or special treatment (Petersen et al., 2015) while in other cases these likely represent remains from older graves disturbed to make room for new burials (Stutz et al., 2013). Experimental evidence indicates that fresh bone is better suited for tool production than dry bone (Isaakidou, 2003) which makes the opportunistic usage of loose dry human remains less likely. Additionally, the availability hypothesis is based on the routine availability of animal remains, whereas dry human remains only became available at burials. Therefore, it is reasonable to assume that opportunistic selection for human bone is highly unlikely.

The reasons for the strategic selection of red deer or human bones can be related to the biomechanical properties of the selected bones including bone dimensions, cortical bone thickness and overall bone shape and morphology. In faunal assemblages where the fauna is fragmented and mixed, it is likely that bones cannot be diagnosed and related to a specific species. There are cases in the Palaeolithic for instance where human remains seems to have been treated in the same way as any other medium size mammal remains and were likely mixed up with other mammal remains (Verna and d'Errico, 2011). In that case, bones of specific species would have been selected not because they were of a specific species, but because of their biomechanical properties. However, there is little evidence to indicate that the stiffness and toughness of red deer bone is superior to the bone of any other species (Currey, 2004; Currey et al., 2009; Margaris, 2006; Wild and Pfeifer, 2019). There are in fact large differences in the values reported for the same skeletal element from the same species (Currey, 1988, 1990; Currey et al., 2009; Kieser et al., 2014). Despite the many inconsistencies in the biomechanical literature it is clear that the toughness of antler is consistently significantly higher than that of bone – whatever species the bone is (Chen et al., 2008; Currey, 1990; Margaris, 2006). In consequence, if bone toughness was the only and main selection criteria, antler would have been more suitable for the production of projectile points than any type of bone. Thus, it seems that toughness cannot be used to explain the selection of red deer, or human bone.

Another variable that may have influenced the suitability of osseous remains for barbed point production is skeletal element dimensions. It may be that the bones of some species could more easily be transformed into barbed points because of their specific shape and size. It is unfortunately not possible anymore to identify the skeletal elements selected for the manufacture of the bone points as they were heavily transformed. Further analysis would be required to test if size and shape may have played a role in the selection process.

We should consider the possibility that such a non-opportunistic selection was also driven by culture-specific meanings or symbolism attributed to a particular species. There are several ethnographic accounts for the usage of animal remains to signal group identity, gender or to invoke the stereotypical abilities of a species (e.g. the deer's light-footedness) (Choyke, 2013; Conneller, 2004; Hachem, 2018; McGhee, 1977; Peres and Altman, 2018; Soderberg, 2004). Human remains appear to have been used in a similar way, although it appears that they often represent the personal identity of the used individual, rather than referring to the stereotype of the human species (Cobb and Gray Jones, 2018; McNiven, 2013). Some ethnographic accounts state that only weapons made from the remains of certain species could be used to hunt particular prey species (McGhee, 1977). And it seems that culturally determined preferences for certain species or skeletal elements are quite strict and slow to change (Choyke, 2013). Further adding to the symbolic dimension of animal remains is the practice of acknowledging certain species as other-than-human persons. This belief seems to be

rather widespread, although its particularities vary between cultures (Conneller, 2004; McGrath et al., 2019; Peres and Altman, 2018). It would be interesting to explore if and to which species this concept could be applied to in the Mesolithic. Conneller (2004) investigated the barbed points at Star Carr and argued that symbolic reasons drove the selection of antler for their manufacture. Antler may have been preferred over bones for its stronger link to the essence of the animal (Conneller, 2004). However, the barbed points studied here are predominantly made from bone and we have yet no indication that the selection of red deer bone during the Mesolithic in Doggerland was driven by a culture-specific meaning.

As for the use of human remains for barbed point production, it is possible that they were selected for ritual or symbolic reasons, for example as part of mortuary practices. Selection of skeletal elements for secondary burial and modification of human skeletal parts like the breakage of long bones are documented for the Mesolithic (Cauwe, 2001; Cobb and Gray Jones, 2018; Louwe Kooijmans, 2007; Schulting et al., 2015). There are also a few examples of pierced human teeth (David, 1999) and one Mesolithic human ulna from Loughlan Island, Ireland, was shaped into a point (Woodman, 2015). To our knowledge, no transformation as intensive as turning a human bone into a barbed point has yet been documented in the Palaeolithic or in the Neolithic. There is evidence which indicates that Upper Palaeolithic humans and Neandertals were at least occasionally breaking apart human bones, cutting or biting them (Bello et al., 2017), and sometimes utilising them as retouchers (Rougier et al., 2016; Verna and d'Errico, 2011). However, in more recent contexts, some 14th-16th century Iroquoian points were made out of human bone (McGrath et al., 2019) and the tip of Chamorro spears too (Kerner, 2018). Ethnographic examples of human bone used for tools including both utilitarian and ritual contexts such as initiations are also known (Kerner, 2018).

It is interesting to note that use-wear and rounding localised on the distal part of one of the human bone points (P29) is consistent with the usage of the points as weapon tips (see details in Spithoven, 2018). Mesolithic barbed points are thought to have been used (although maybe not exclusively) for killing purposes (Hartz et al., 2019). This could represent a case of specific mortuary practices where human remains are transformed into weapons which were subsequently used.

To summarise, because our sample comes from several different locations, it appears that red deer and human bones were often selected in a non-opportunistic manner to be transformed into bone points. Because neither red deer nor human bones seem to have specific biomechanical properties that would explain their selection over other species of comparable size, other factors than biomechanical (or functional) should instead account for the selection of these species. Though the function of the Mesolithic barbed points – as projectile tips for fishing and/or hunting – is still debated, and because at least one of the human points seems to have been used as a projectile, we emphasize the possibility that the choice of human bone was likely associated with symbolic reasons rather than solely practical factors.

6. Conclusion

The most important result of this study was the ZooMS identification of Mesolithic barbed points produced from human bones. Additionally, the remaining barbed points were produced on bone and antler from red deer. These identifications were corroborated by the measured carbon and nitrogen values, which also indicate a freshwater diet for one of the humans (P29), and a fresh water and/or a terrestrial fauna diet for the other one (P3). Radiocarbon dating further secured the chronological placement of the barbed osseous points in the Mesolithic.

Because the sample of points studied here is a small random sample, drawn from a dataset of around a 1,000 barbed points, from different localities and since it seems that neither red deer nor humans were the most abundant bone species available at Mesolithic sites, we suggest that these species were likely regularly selected to be transformed into barbed points. We also suggest that the preferential selection of red deer and human remains was not due to their specific biomechanical properties, but that other culturally specific reasons were likely driving their selection for barbed point manufacture. By highlighting the potentially regular transformation of human bones into barbed points – subsequently likely used as weapons – our study also highlights a complex manipulation of human remains in Doggerland during the Mesolithic.

The reconstruction of the cultural meaning of osseous artefacts depends on robust correlations between the presence of certain species and particular contexts. Systematically combining ZooMS taxonomic identifications with the deciphering of the cultural biography of bone artefacts may contribute to a better reconstruction of the symbolic meaning of Mesolithic bone-tools.

CRediT authorship contribution statement

Joannes Dekker: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Virginie Sinet-Mathiot:** Methodology, Validation, Formal analysis, Investigation, Writing - review & editing, Visualization. **Merel Spithoven:** Conceptualization, Investigation. **Bjørn Smit:** Investigation, Writing - review & editing. **Arndt Wilcke:** Resources. **Frido Welker:** Methodology, Writing - review & editing, Visualization, Supervision. **Alexander Verpoorte:** Writing - original draft, Visualization, Supervision. **Marie Soressi:** Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors thank the collectors Aad Berkhout, Rick van Bragt, Maarten Drummen, Gideon de Jong, Mirjam Kruizinga, Trudy Langeveld, Erwin van der Lee, Sibo van Maren, Johan Passchier, Maarten Schoemaker, Peter Soeters and Willy van Wingerden for their permission to study the objects, dr. S. Palstra for advice and assistance in sampling and for the analysis at the Centre for Isotope Research, University of Groningen, the Netherlands, Prof. dr. J.J. Hublin for support and use of facilities of the Max Planck Institute for Evolutionary Anthropology, Leipzig, E. Mulder and Prof. dr. A. van Gijn for assistance and use of facilities of the Laboratory for Artefact Studies, Faculty of Archaeology, Leiden, dr. J. Laffoon for the use of equipment and assistance with sampling, I. Djakovic for editing the language, dr. H. Peeters, University of Groningen, the Netherlands for constructive comments, K. Lönnquist for assistance, R.J. Looman (RMO, Leiden) for the photographs, and J. Porck (Leiden) for design of the figures. We thank the Max Planck Society and the Cultural Heritage Agency of the Netherlands for supporting this research. We would also like to thank the organisers and participants of the Meso2020 conference for fruitful discussions. We would also like to thank the two anonymous reviewers for their very useful comments.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2020.102678.

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