

MAKING SILENT BONES SPEAK: THE ANALYSIS OF ORPHANED OSSEOUS TOOLS ILLUSTRATED WITH MESOLITHIC STRAY FINDS

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Abstract

Orphaned osseous tools are very often perceived as having a high aesthetic value, but are usually under-examined. This article illustrates the research potential of these artefacts, with a case study of Mesolithic stray finds from Lithuania. Four bone points from the River Šventoji, Vaikantonys, Obšrūtai and Kamšai were subjected to AMS dating, tandem mass spectrometry for animal species identification, and technological and use-wear analysis. The results revealed that all four bone points could be dated to the Boreal period, and imply an Early to Middle Mesolithic date. Harpoons from the River Šventoji and Kamšai were most likely made of aurochs bones. All of the bone points were produced from long sections of tubular long bones, and three of the points show signs of reuse. Overall, the analysis revealed similarities with contemporaneous material in northern Europe. Within the context of the present research, the paper briefly describes other scientific methods which could be applied to orphaned bone and antler tools, including biomolecular and stable isotope analysis. Digital recording methods can be useful for bone artefact recording. This is relevant today, as the demand for good-quality digital representations is increasing, in order to apply software for further analysis, such as geometric morphometrics. As a result, more widespread and systematic applications of these new methods to orphaned osseous finds would lead to a significant activation of these finds in a scientific and outreach context.

Key words: Mesolithic, osseous tools, AMS dates, protein-based analysis, use-wear.

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Introduction

Many thousands of osseous objects lie in museum collections, and many new objects are found every year. However, all too often these objects, especially those found either during older excavations without modern methodology and recording, or as stray finds, languish under-utilised, under-researched and often undisplayed in museum storerooms. Such stray or orphaned objects often have an intrinsic aesthetic value, but are commonly under-studied, or not studied at all. At best, minimal information is inferred from casual typological comparison. The under-researched nature of these objects can be attributed to a lack of funding, a lack of knowledge regarding applicable methods, and the idea that these objects, especially those from older excavations and stray finds, have had their research potential stripped by the passing of time since they were recovered, partly due to a lack of records or known find contexts (Voss 2012).

In the light of recent methodological developments, we see this disregard of orphaned osseous objects as unwarranted. The focus of this paper, therefore, is to illustrate the significant research potential of such osseous tools, even those lacking any detailed information regarding find context, and to outline a number of both conventional and rapidly developing scientific methods that can be used to study recently excavated finds, *as well as* objects lacking any contextual information. This will be illustrated by a series of analyses of four osseous points from Lithuania. The specific objects studied as part of this research were chosen because they also represent Mesolithic osseous objects with little information on the find circumstances, and inconsistent interpretations regarding their cultural and chronological associations. Thus, the results of our analyses contribute significantly to the clarification of previously ambiguous interpretations. They also contribute important new knowledge to our understanding of Mesolithic bone technology in Lithuania vis-à-vis contemporaneous osseous tool technologies in northern Europe.

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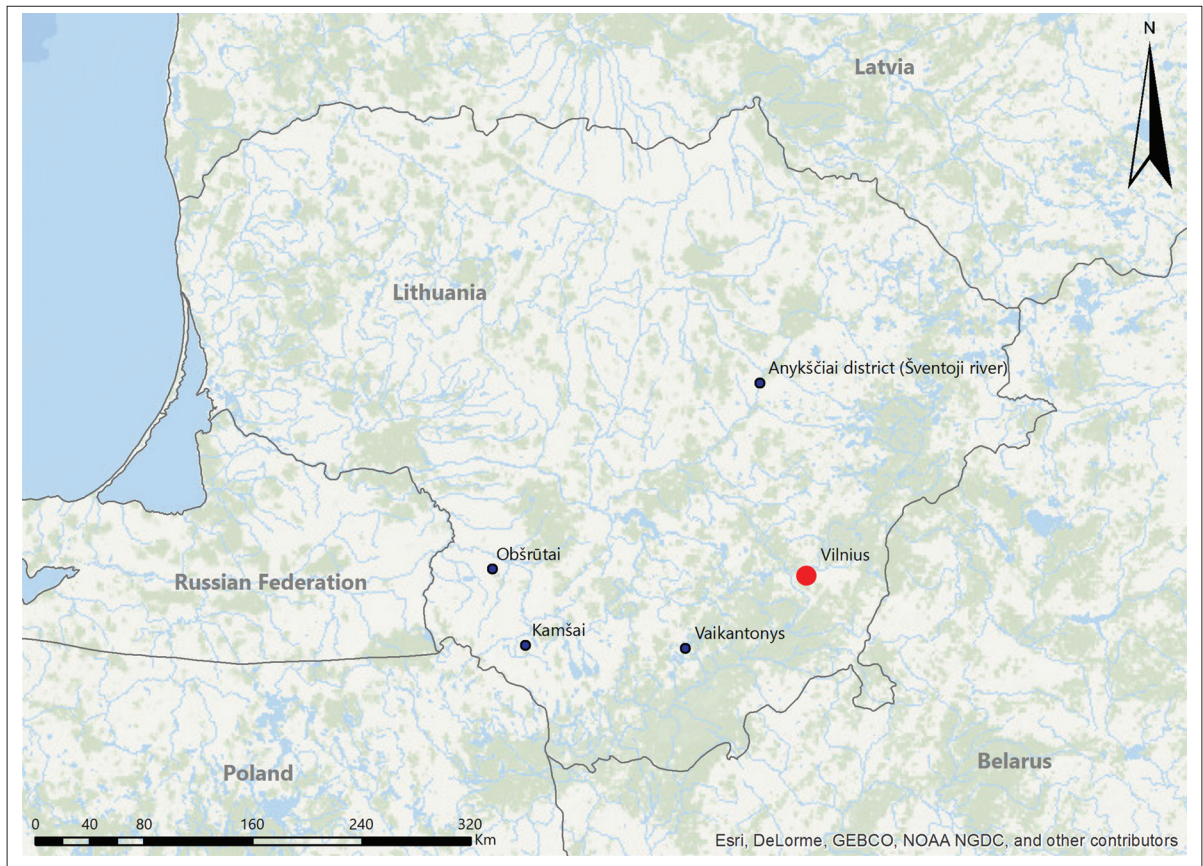


Fig. 1. Map showing the locations of the Mesolithic bone point finds presented in the text.

The background of the case studies

The four objects presented in the paper are currently held at the Vytautas the Great War Museum (VDKM), and are all stray finds from peat digging. The find circumstances of these objects are not unusual. In fact, they match the majority of Lithuanian prehistoric bone and antler artefacts, which are also stray finds from wetland environments, and which were most often found during peat digging and other agricultural work during the interwar period (Fig. 1). This situation is also true of prehistoric osseous objects elsewhere in northern Europe.

One slotted bone point (VDKM: AR 6) is currently on display. The remaining artefacts are held in storerooms. None of these objects have previously been studied in any detail, they have been part of the museum displays, and are shown in publications as examples of characteristic Mesolithic object types (Rimantienė 1996; Girininkas 2009; Galiński 2013).

These four objects were chosen as case studies primarily since very few osseous tools in Lithuania are known from the earliest periods of prehistory. This rarity alone makes these objects valuable scientifically, as they may be able to provide important insights into

the early occupation and osseous technology of Lithuania in a northern European context (Fig. 2). In addition, our analysis aimed to illustrate the usefulness and timeliness of analysing orphaned organic artefacts in the light of recent methodological developments.

The first artefact (VDKM: AR 2437) is a fragment of a harpoon found in 1978 on the right bank of the River Šventoji in the vicinity of Kavarskas (Anykščiai district). Only the distal portion of a uniserial harpoon with three large well-distinguished barbs remains. Dimensions: L= 10.5 centimetres, W= 2.4 centimetres, T= 0.8 centimetres, with an ancient oblique fracture at the current base of the harpoon. The stray find has not been published before.

The second artefact (VDKM: AR 6) is a slotted bone point found near Vaikantonys. Currently, nine flint inserts remain intact, although originally almost the entire side of the point would have been flint-edged. With a modern slight break at the tip, and an older break near the base, the current dimensions are L= 24.5 centimetres, W= 1.8 centimetres, T= 0.6 centimetres. It was found during drainage work 0.5 metres deep, close to the River Varėnė (Rimantienė 1974, p. 75).

The third artefact (VDKM: AR 7) is also a slotted bone point with flint inserts from Obšrūtai (Vilkaviškis



Fig. 2. The Mesolithic barbed and slotted bone points analysed in this paper, from top to bottom: River Šventoji (VDKM: AR 2437), Vaikantonys (VDKM: AR 6), Obšrūtai (VDKM: AR 7), Kamšai (VDKM: AR 1) (photograph by Iga Kuriata, Moesgaard Museum).

district). The current dimensions are $L=21.4$ centimetres, $W=1.5$ centimetres, $T=0.7$ centimetres. The basal part features a modern break, implying that the original length would have been greater. Only three lithic inserts remain, two of which are still inserted into the lateral groove. The remaining insert has fallen out, but is stored with the object. Like the other slotted bone point from Vaikantonys, this point would also have had one edge almost entirely flint-edged. It was found in Eksnė peat bog, 2.5 metres deep, on gravel underneath the peat layer. There is a note that the slotted bone point was found together with a flint knife, but there are no further details regarding this knife, and its current location is unknown (Rimantienė 1974, p. 60).

The fourth artefact (**VDKM: AR 1**) is a barbed point from Kamšai. This uniserial barbed point, with a missing base, has nine well-distinguished convex barbs. The current dimensions, with a break near the basal part, are $L=21.5$ centimetres, $W=1.2$ centimetres, $T=0.8$ centimetres. At the base of the point, three large chop marks are present. It is unclear how these chop marks were caused. Clearly, they were applied with significant force with a wide-angled edge when the bone was soft. We hypothesise that either this reflects ancient preparation with an axe-like tool, perhaps to aid in hafting; or, more likely, it occurred accidentally around the time of discovery whilst the point was waterlogged. The harpoon was found in a peat bog 1.6 metres deep, close to the River Kirsna in the Marijampolė district during peat-cutting. According to the finder, the harpoon was found together with human, animal and fish bones, an antler axe, and other flint tools. Sadly, only the harpoon and the antler axe ever made it to the museum, and there is no additional information regard-

ing the location of the remaining artefacts (Rimantienė 1974, p. 41).

The selected artefacts were previously dated only by typological comparative studies of analogous material in other regions. The dating brackets for barbed points as well as slotted bone points are quite wide (for barbed points, see Ciesla, Pettitt 2003; Andersen, Petersen 2009; for slotted bone points, see Knutsson et al. 2016), making such typological inferences exceedingly imprecise. The museum labels associated with these four analysed objects only note that they date from the seventh or sixth millennium BC. Rimantienė (1996) ascribes the harpoon from Kamšai (VDKM: AR 1) and the two slotted bone points to Mesolithic Kunda culture. In contrast, Galiński (2013) attributes the harpoon from Kamšai (VDKM: AR 1) to the Final Palaeolithic and Epipalaeolithic periods, based on similarities to Maglemosian harpoons from Star Carr (Clark 1954), and both of the slotted bone points to Mesolithic Kunda culture. Girininkas (2009) classifies the harpoon from Kamšai as Maglemosian. It is problematic in this context that several studies highlight the evident co-existence of different types of harpoons at the same time (Andersen, Petersen 2009; Savchenko et al. 2015). While direct radiocarbon dating cannot clarify the cultural associations of these objects, it can, as an important first step in our analytical protocol, provide firm chronological anchors. In the following section, we report this dating exercise and other supplementary archaeometric analyses (protein-based species identification and use-wear) to shed additional light on these orphaned osseous objects.

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Methods and results

In order to specify the chronology, as well as to gain more detailed knowledge of bone point technology in the eastern Baltic, a series of analyses were carried out, including AMS dating, protein-based species identification, and technological and use-wear analysis.

AMS radiocarbon dating

In contrast with older radiocarbon dating methods (beta-counting), where approximately five grams of pure carbon was required for a single date, accelerator mass spectrometry (AMS) dating requires very little organic material, and hence allows the sampling of even delicate osseous tools without significant damage. AMS dating requires 100 to 800 milligrams of bone, depending on the preservation, or only three to 20 milligrams of charcoal. Furthermore, sampling techniques are constantly being refined. Currently, several methods are available, such as cutting a small piece or drilling small holes in the surface. The second technique is often the one chosen, as it allows sampling without obscuring the object's dimensions or overall form, and can be applied to any part of the object.

In the case of the two barbed points, however, small slices were cut. A sample of 646.4 milligrams was taken from VDKM: AR 1, and 269.9 milligrams was taken from a fragment of VDKM: AR 2437. To date the slotted bone points (VDKM: AR 6; VDKM: AR7), the tar (organic glue) attached to the objects was sampled in order to minimise the impact on the osseous tools themselves. Both slotted bone points held sufficient amounts of well-preserved tar, of which approximately three milligrams was extracted from each. On closer inspection, some of the artefacts showed signs of possible unrecorded conservation treatment. All bone and tar samples were therefore cleaned with different organic solvents and ultrasound prior to the application of standard pre-treatment procedures. The tar samples were pre-treated with a standard ABA method (acid-base-acid). Collagen was extracted from the bones using a modified Longin procedure with ultrafiltra-

tion (cf. Brown et al. 1988; Jørkov et al. 2007; Longin 1971; the authors can provide detailed method descriptions on request).

The dates fall clearly into two sets, but all fall within the Boreal period, and imply Early to Middle Mesolithic affiliations (Table 1 and Fig. 3). The barbed points are older than the slotted bone points. The oldest date is from the Kamšai (VDKM: AR 1) barbed point, although it still postdates the Starr Carr material by a few hundred years, despite evident similarities. Unexpectedly young dates were obtained for the barbed point fragment from the River Šventoji (VDKM: AR 2437), which, based on typology, was expected to fall into the transitional period between the Late Pleistocene and Early Holocene.

The similarities between the slotted bone points in date and form are notable. But further studies are needed to determine if there is any chronological and/or spatial patterning in this slotted bone technology. Overall, the dates agree with the typological and radiocarbon dating of slotted bone points elsewhere in the region (Knutsson et al. 2016).

These newly obtained dates have significantly tightened up the dating of the four osseous objects. To date, only a few osseous tools in northern Europe, let alone Lithuania, have been directly dated, and, evidently, typological dating approaches fall short of providing suitable accurate or precise chronological handles.

Protein analysis and tandem mass spectrometry-based identification of animal species

Osseous tools are often heavily worked, leading to a loss of distinctive morphological characteristics that may assist in determining the species from which the object's raw material derives. Therefore, in order to identify the type of animal that the two harpoons were made from, a novel protein-based species identification method was applied. The two slotted bone points were not analysed using this method, as no bone samples had been taken.

Table 1. Results of AMS dating

AAR	Museum no.	¹⁴ C age	δ ¹³ C (‰ VPDB)	δ ¹⁵ N (‰ AIR)	C/N ratio
25551	VDKM : AR 1	8972±46	-22,21±0,11	4,74±0,56	3,38±0,01
25552	VDKM : AR 2437	8874±38	-23,11±0,11	4,06±0,56	3,36±0,01
25553	VDKM : AR 7	8328±49	-28,00±1,00 (AMS)	N/A	N/A
25554	VDKM : AR 6	8345±43	-29,00±1,00 (AMS)	N/A	N/A

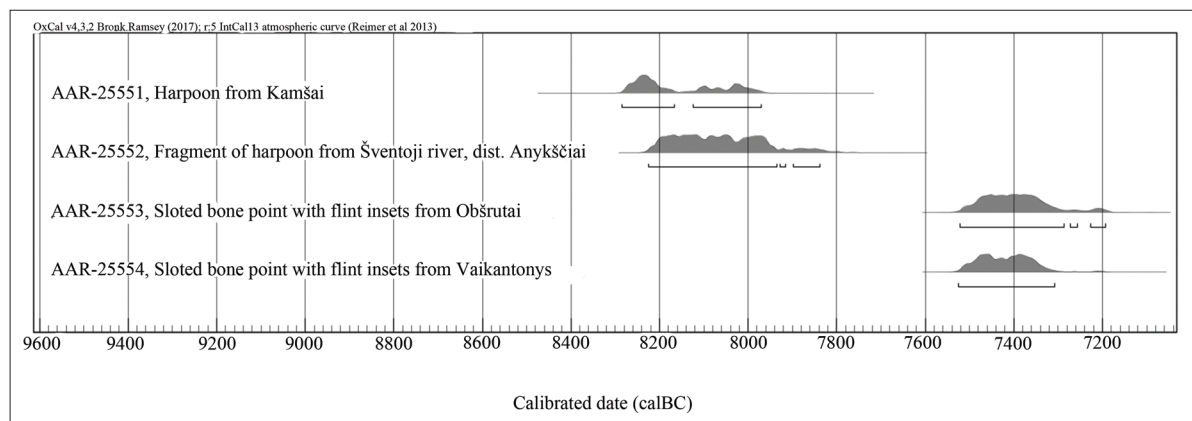


Fig. 3. Calibrated ^{14}C results of the four Lithuanian bone points using OxCal v 4.2 (Bronk Ramsey 2009) and the IntCal13 calibration curve (Reimer et al. 2013).

After death, enzymes degrade the DNA and most proteins, and the sequence information necessary for species identification is lost. However, a family of proteins called collagens are resistant to enzymatic degradation. In addition, they are the most abundant proteins in animals, accounting for around 30% of the total protein content. These proteins are found in connective tissues, like the skin, tendons and ligaments, but also in hair, teeth and bones. Because of this resistance to degradation, it is sometimes possible to extract collagen from archaeological material of biological origin. In archaeology, mainly collagen type 1 is of interest, because it is the predominant collagen found in bone. The extracted collagen can be analysed by tandem mass spectrometry, a method that can sequence minute amounts of collagen. By comparing the obtained sequence with all known protein sequences through a database search, it is possible to identify even the animal species of tiny bone fragments or bone and antler artefacts that are not identifiable by traditional methods. As this method requires only a nano-gram (10^{-9} gram) of material, it is minimally destructive.

Because the methods are very sensitive, it is important that the samples are collected carefully, using tools, surfaces and collection tubes that have not been used for sampling other bones. The method is also not useful for distinguishing individuals of the same species, as the collagen sequences will be identical. Similarly, closely related species can only be distinguished if the collagen sequences are different.

The first protein analyses of the barbed points from Kamšai (VDKM: AR 1) and the River Šventoji (VDKM: AR 2437) were based on sawdust collected during sampling for radiocarbon dating and stable isotope analysis. Somewhat surprisingly, the analysis revealed the presence of sheep collagen type 1. The analysis covered 22% of the sheep collagen sequence;

however, the same data set also covered 19% of the cow sequence. In this case, a peptide reading AGEVGPP-GPPGPAGEK representing sheep collagen was found. The corresponding peptide in cow (PGEVGPPGPPGPAGEK) was not detected. Therefore, based on these data, it would normally be concluded that the specimen is from a sheep. This interpretation is based on the assumption that the sample is homogeneous and only contains collagen from a single species.

Since these artefacts may have been treated with a bone-based glue applied to the surface during preservation, it is likely that the sample is contaminated with unrelated collagen. A strong argument for the possibility of contamination is the fact that the earliest evidence for sheep (*Ovis aries*) in the eastern Baltic (Daugnora, Girininkas 2004) as well as in the western Baltic (Sørensen 2014) postdates our samples by several millennia.

To circumvent the contamination issue, material collected from inside the bone (collagen extracted from a piece of bone after physically cleaning the surface) was also analysed. The quality of the sample in the second analysis was much higher, and provided a significantly higher sequence coverage. However, both cow and sheep still matched the data set (Fig. 4). In the second analysis, the collagen sequences were covered with 48% for cow and 45% for sheep. Each species was identified by a unique peptide; however, the amount and quality of the cow identifying peptide were higher. These data indicate that the sample is bovine, and was possibly conserved with sheep-based bone glue. In conclusion, the origin of the harpoon is a cloven-hoofed, ruminant mammal, and it is most likely a cow or cow-related species, including the aurochs. Given the lack of domesticated cows, as well as any known wild sheep population in Lithuania during the first half of the Mesolithic, the interpretation of the harpoon be-

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SP P02453 CO1A1_BOVIN	GPRGPAGPPGRDGIPGQPLGPPGPPGPPGLGGNFAPQLSYGYDEKS	171
TR W5P481 W5P481_SHEEP	PPQGAGPPGRDGIPGQPLGPPGPPGPPGLGGNFAPQLSYGYDEKS	179
	*.*****	
SP P02453 CO1A1_BOVIN	TGISVPGMGPSPRGLP PPGAGPQGF QGGPPGEPGEPGASGPMGR PPGPPGKNGDD	231
TR W5P481 W5P481_SHEEP	TGISVPGMGPSPRGLP PPGAGPQGF QGGPPGEPGEPGASGPMGR PPGPPGKNGDD	239

SP P02453 CO1A1_BOVIN	GEAGKPRPGERGPPGQARGLPGTAGLPGMKGHRGFSGLDGAKGADAGPAGPKGEPGSP	291
TR W5P481 W5P481_SHEEP	GEAGKPRPGERGPPGQARGLPGTAGLPGMKGHRGFSGLDGAKGADAGPAGPKGEPGSP	299

SP P02453 CO1A1_BOVIN	GENGAPQMGRPLPGERGRPGAPGARGNDGATGAAGPPGPTGPAGPPGFPGAVGAK	351
TR W5P481 W5P481_SHEEP	GENGAPQMGRPLPGERGRPGAPGARGNDGATGAAGPPGPTGPAGPPGFPGAVGAK	359

SP P02453 CO1A1_BOVIN	GEGGPQGRGSEGPQGVREGEPPGAPAGAAGPAGNPGADGQPGAKGANGAPGIAGAPGFP	411
TR W5P481 W5P481_SHEEP	GEAGPQGRGSEGPQGVREGEPPGAPAGAAGPAGNPGADGQPGAKGANGAPGIAGAPGFP	419
	** *****	
SP P02453 CO1A1_BOVIN	GARGSPGQPSGPPGPKNSGEPGAPGSKGDTGAKGEPGPTGIQGGPPGAGEEGKRGAR	471
TR W5P481 W5P481_SHEEP	GARGSPGQPSGPPGPKNSGEPGAPGSKGDTGAKGEPGPTGIQGGPPGAGEEGKRGAR	479

SP P02453 CO1A1_BOVIN	GEPGAPGLPGERGPPGSR GFPADGVAGPK GPAGERGAPGAPGKSPGEAGRPGEA	531
TR W5P481 W5P481_SHEEP	GEPGAPGLPGERGPPGSR GFPADGVAGPK GPAGERGAPGAPGKSPGEAGRPGEA	539

SP P02453 CO1A1_BOVIN	GLPGAKGLTGSPGSPDGKTGPPGAPQDGRPPGPPGARGQAGVMGFPGPKGAAGEP	591
TR W5P481 W5P481_SHEEP	GLPGAKGLTGSPGSPDGKTGPPGAPQDGRPPGPPGARGQAGVMGFPGPKGAAGEP	599

SP P02453 CO1A1_BOVIN	GKAGERGVPPGAVGPAGKDGEAGAQQPPGAPAGERGEQGPAGSPGFQGLPGPAGPP	651
TR W5P481 W5P481_SHEEP	GKAGERGVPPGAVGPAGKDGEAGAQQPPGAPAGERGEQGPAGSPGFQGLPGPAGPP	659

SP P02453 CO1A1_BOVIN	GEAGKPGEQVPGDLGAPGSPGARGERGFPERGVQGGPPGAPRGANGAPNDGAKGDA	711
TR W5P481 W5P481_SHEEP	GEAGKPGEQVPGDLGAPGSPGARGERGFPERGVQGGPPGAPRGANGAPNDGAKGDA	719

SP P02453 CO1A1_BOVIN	GAPGAPGSQGAPGLQGMGERGAAGLPKGDGRDAGPKGADGAPKDGVRGLTGPIGPP	771
TR W5P481 W5P481_SHEEP	GAPGAPGSQGAPGLQGMGERGAAGLPKGDGRDAGPKGADGAPKDGVRGLTGPIGPP	779

SP P02453 CO1A1_BOVIN	GPAGAPGDKGEAGSPGAPPTGARGAPDRGEPGPPGAPFAGPPGADGQPGAKGEPGDA	831
TR W5P481 W5P481_SHEEP	GPAGAPGDK GETGSPGAPPTGAR GAPDRGEPGPPGAPFAGPPGADGQPGAKGEPGDA	839

SP P02453 CO1A1_BOVIN	GAKGDAGPPGAPGAPPPGPIGNV GAGPKGARGSAGPPGATGFPGAAGRVP GPPSGNA	891
TR W5P481 W5P481_SHEEP	GAKGDAGPPGAPGAPPPGPIGNV GAGPKGARGSAGPPGATGFPGAAGRVP GPPSGNA	899

SP P02453 CO1A1_BOVIN	GPPGPPGAPKESKGRGETGPAGRPGEVPPGPPGAGEKGAPGADGPAGAPGTPGPQ	951
TR W5P481 W5P481_SHEEP	GPPGPPGAPKESKGRGETGPAGRAGEVPPGPPGAGEKGAPGADGPAGAPGTPGPQ	959

SP P02453 CO1A1_BOVIN	GIAGQRGVVGLPQQRGERGFPLPGPSGEPGKQGPSGASGERGPPGPMGPPGLAGPPGES	1011
TR W5P481 W5P481_SHEEP	GIAGQRGVVGLPQQRGERGFPLPGPSGEPGKQGPSGASGERGPPGPMGPPGLAGPPGES	1019

SP P02453 CO1A1_BOVIN	GREGAPGAEGSPGRDGPAGKGDGETGPAGPPGAPGAPGAPGVPAGKSGDRGETGPA	1071
TR W5P481 W5P481_SHEEP	GREGAPGAEGSPGRDGPAGKGDGETGPAGPPGAPGAPGAPGVPAGKSGDRGETGPA	1079

SP P02453 CO1A1_BOVIN	GPAGPIGPVARGPAGPQGRGDKGETGEQDGRGIKGHRGFSGLQGGPPGPP	
TR W5P481 W5P481_SHEEP	GPAGPIGPVARGPAGPQGRGDKGETGEQDGRGIKGHRGFSGLQGGPPGPP	

Fig. 4. Sequence alignment of cow and sheep collagen alpha1-(I). Identical residues are indicated with (*) below the sequences. Cow and sheep unique peptides identified by mass spectrometry are highlighted in bold red.



Fig. 5. Stacked photographs using the extended depth of field feature on a dinolite microscope of polishing on barbs on a harpoon from the River Šventoji (VDKM: AR 2437) (A at 40x), and manufacture tool marks on the same harpoon (B at 20x).

ing produced from aurochs is most likely. This result corresponds neatly with observations from the western Baltic, where aurochs were one of the five main species used for bone tool production (David 2009; Leduc 2012).

Technological analysis using optical microscopy

As part of the analysis, all four bone points were analysed by optical microscopy using a portable digital microscope (dino-lite AM4815ZTLx with 20-140x magnification). By examining osseous tools for different tool marks that may be difficult or impossible to see macroscopically using an optical microscope, it is possible to better understand their manufacturing process (cf. Gramsch 1990). By better understanding the manufacturing process, it might be possible to understand the object, the site, the regional or chronological differences in this tool class, its attendant technology, and craft organisation (David 2003; 2006; 2009). The use of a microscope with an inbuilt camera, such as affordable and portable USB microscopes, or a microscope with a camera attachment, facilitates high levels of photographic recording of these features.

Based on a visual inspection of the four bone points, the following manufacturing processes could be identified: all of the bone points were produced from long sections of tubular long bones that had been split. Given the length and regularity of the bone points, it is likely that the groove-and-splinter technique was used for at least the two slotted bone points and the fine-toothed barbed point from Kamšiai (VDKM: AR 1). These pre-forms were then further worked using dif-

ferent tools, including burins, blades and occasionally scrapers to shape the pre-forms.

Next, barbs were cut into the barbed points. These barbs were cut into the harpoon by engraving intersecting diagonal lines into both sides of the bone using a burin. The barbs on the large point from the River Šventoji (VDKM: AR 2437) were further shaped, and the inside edge was even polished and rounded, most likely in order to make it less susceptible to fracture, and to make the harpoon more aerodynamic and hydrodynamic (Fig. 5). The barbs that were cut into the barbed point from Kamšiai (VDKM: AR 1) were incised using a similar technique, but they do not appear to have been polished.

Turning to the slotted bone points, it is evident that once the overall form of the slotted bone points was finished, a groove was cut along one side using a burin. This groove extended across the central portion of the point only. They were then further worked and shaped to remove any sharp edges from the groove.

Next, a viscous black pitch-like material (that visually appears to be similar to birch bark tar) was placed in the slot, and then the flint inserts were placed in this pitch. It is possible to determine that this pitch was very viscous, possibly still warm, when the inserts were emplaced, as the pitch filled small gaps between the inserts, and in some places flowed outside the slot. A similar black pitch-like material is present on the base of the point from Vaikantonys (VDKM: AR 6), suggesting that this may have been used to secure the point's hafting arrangement (Fig. 6).

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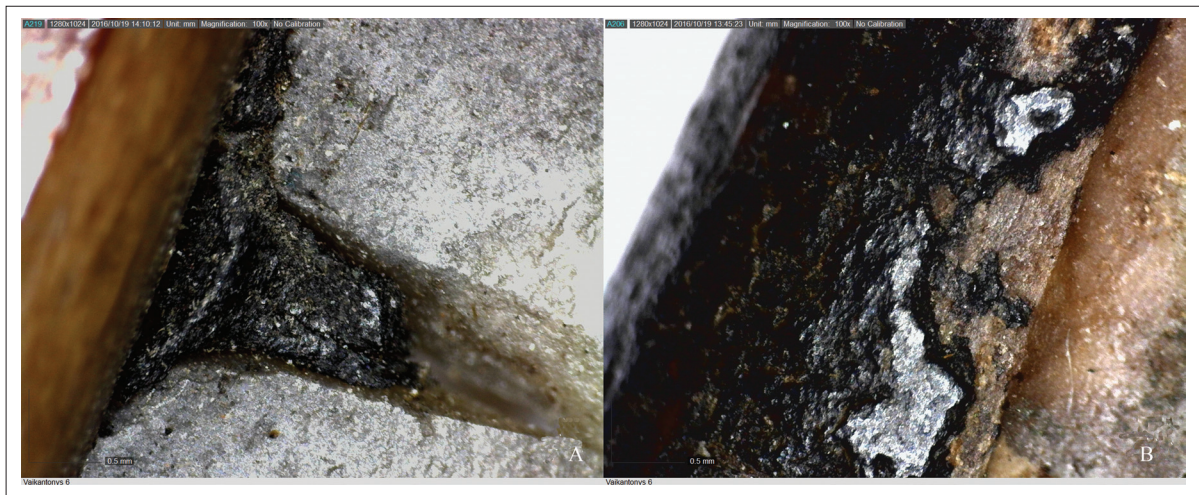


Fig. 6. Photographs using a dinolite microscope of the black pitch used to attach inserts (A at 100x), and on the base of the slotted point from Vaikantonys (VDKM: AR 6) (B at 100x).

Use-wear analysis

It is also possible using an optical microscope (as well as scanning electron microscope) to identify any microscopic and macroscopic traces of use, such as polishes, striations and edge rounding (Jensen 1988; 2000). By comparing these observed archaeology use-wear traces to similar traces formed during experimental research, it can be possible to determine how a tool was used, and what material it was used on, thus adding a vital part to our understanding of the biography of individual tools. Often, tool use is inferred on morphology and casual comparisons with ethnographic or recent tools only (cf. Gebauer 1987). Use-wear can here provide important confirmation of such assessments, or instead provide direct clues to object uses that differ from those observed ethnographically or historically.

A full use-wear analysis of the four points addressed here was not attempted. However, during the microscopic analysis aimed at elucidating the manufacturing process, it was noted that the tip of the large barbed point from the River Šventoji was slightly fractured (Fig. 7). The break may have originated when the harpoon hit a hard material like stone or bone, causing the tip to chip off. Interestingly, the edges of this break are slightly rounded, suggesting that the harpoon may have been used a number of times after the tip broke. At a later stage, the harpoon broke again, resulting in a large oblique fracture that is a typical impact fracture seen on many bone and antler points. This large oblique fracture probably led to this tip of the harpoon being lost, either at the bottom of the river or inside whatever animal was being hunted.

In addition to the limited use-wear analysis of the harpoon, the flint inserts of the two slotted bone points

were also analysed for use-wear traces, such as polishes, striations, edge rounding and edge damage. Unfortunately, the objects could not be washed due to museum policy, making it impossible to positively identify any use-related polish or striations. In addition, a large amount of glue-like material was present on the flint inserts, probably from the conservation of the bone, which further obscured potential micro-wear. However, some of the flint inserts on both slotted bone points did have slight edge rounding, which suggests repeated use of the slotted bone points (Fig. 8). This finding is further supported by the presence of extensive edge damage on many of the inserts, further suggesting that these two points had seen regular use.

Other possible methods

In the previous section, all the methods that were applied to the four osseous points from Lithuania are described in detail and their results presented. These methods are straightforward, follow mostly quite well-established analytical protocols, and are applied in a straightforward and cost-effective way. But there are a number of other scientific methods, including zooarchaeology by mass spectrometry, aDNA and stable isotope analysis, investigation on artefact taphonomy, recording methods, and morphometric analyses, which can also be applied to better understand the life histories of osseous tools. Thus, the following section will shortly summarise other emerging and established methods, and highlight how they can be integrated into dynamic research designs related specifically to past bone and antler objects.

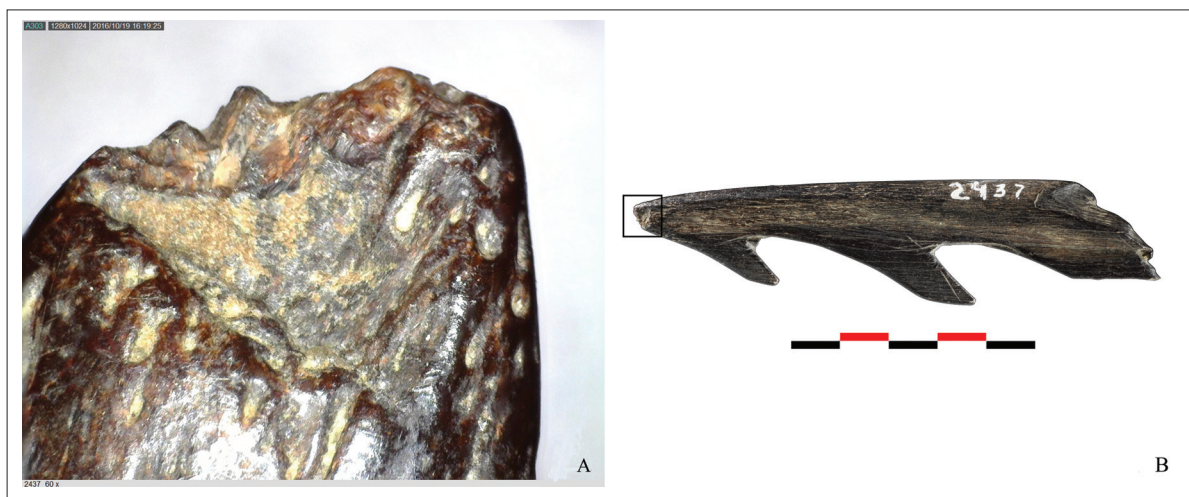


Fig. 7. Photographs at 60x of the broken tip of the harpoon from the River Šventoji (VDKM: AR 2437) (A), and of the oblique fracture on the same harpoon (B) (photograph by Iga Kuriata, Moesgaard Museum).

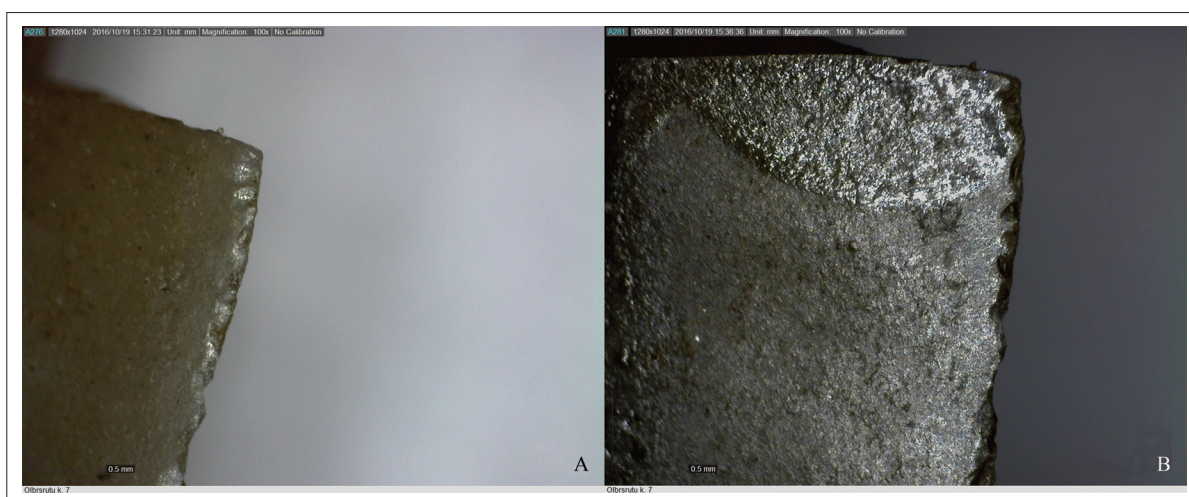


Fig. 8. Photographs at 100x of edge damage and rounding on flint inserts in the slotted bone points from Obšrūtai (VDKM: AR7) (A), and glue-like material on flint inserts from the same slotted bone point at 100x (B).

Biomolecular analysis

ZooMS (zooarchaeology by mass spectrometry) is rapidly developing a protein-based biomolecular method, which analyses peptide fragments in the protein collagen (e.g., Welker et al. 2015; Charlton et al. 2016). It is based on the fact that every animal family group has a unique presence and combination of certain masses, and these differences in mass can be used for taxonomic identification when comparing a sample and the reference collection. Thus, a rich reference collection is important for ZooMS.

This method allows species identification based on very small fragments of bone or antler, and in the total absence of any diagnostic morphological features, as is often the case on highly worked osseous tools. In some cases, however, where collagen sequences are

very similar, only genus-level identification can be achieved. For instance, red deer, fallow deer and elk cannot be differentiated (Ashby et al. 2015). Importantly, this method does allow for discrimination between sheep and goat, which can be very difficult with standard zooarchaeological methods.

A key advantage of this technique is the very small sample size. Only five to ten milligrams of bone is necessary, thus making it possible to sample and analyse even the most delicate osseous tools without significant damage. Furthermore, ZooMS allows for the rapid analysis of a large number of samples at relatively low cost: hundreds of samples can be processed in a day at a cost of <15€ per sample (van Doorn 2014). Furthermore, under favourable post-depositional conditions, collagen can survive thousands of years, and peptide

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mass fingerprinting can be applied to archaeological material from various periods (Buckley, Collins 2011).

ADNA

While aDNA can be used for taxonomic identification, it has rarely been used for this purpose, as it is significantly more expensive than protein analysis. Ancient DNA sequences are also significantly more susceptible to degradation. When well-preserved aDNA sequences are retrieved, however, they are powerful tools for identifying a wide variety of characteristics, such as species, sex, kinship and ancient disease load, and individual-level traits (hair colour, eye colour, etc), as well as addressing evolutionary questions (Malmström 2007; Der Sarkissian 2011; Nikulina, Meadows 2013). In contrast to analyses focused on proteins, aDNA analysis is at present both considerably more expensive and slower, but swift developments in laboratory techniques and sequencing technology might soon allow a more routine application of these techniques.

Isotope analysis

Stable isotope analysis is a rapidly developing technique that can be used for a wide variety of different

research questions: it has most often hitherto been used to explore diet and the mobility of prehistoric humans and animals based on the specific affordances of different isotopes (Table 2) (Drucker et al. 2011; Slovak 2011; Clementz et al. 2012; Makarewicz, Sealy 2015). Fundamentally, it is also necessary to analyse the carbon isotope ratios in bone samples in order to determine if the radiocarbon dates need to be compensated for marine reservoir effects. The marine reservoir effect is caused by a difference in the content of ^{14}C in the ocean compared to the atmosphere. This difference results in an age offset between marine samples and individuals who have consumed large amounts of marine food, thus making marine samples appear older than they actually are (Heinemeier et al. 1993). Disturbingly, the same may be true of some freshwater sources (Philippsen 2013). The carbon isotope ratios are therefore routinely analysed as part of ^{14}C dating of bone material, and may potentially provide additional information about dietary composition by enabling discrimination between terrestrial, freshwater and marine food intake. An awareness of the necessity to potentially correct for marine and freshwater reservoir effects is particularly important for Mesolithic researchers, given the importance of marine and freshwater resources in this period.

Table 2. List of the most often used stable isotopes for analysing osseous material. ¹(Makarewicz and Sealy 2015), ²(Reynard and Hedges 2008), ³(van der Sluis et al. 2016), ⁴(Bartelink et al. 2014), ⁵(Clementz et al. 2012), ⁶(Leyden et al. 2006), ⁷(Mannino et al. 2015), ⁸(Eerkens et al. 2011), ⁹(Drucker et al. 2011), ¹⁰(Pellegrini et al. 2016), ¹¹(Slovak 2011), ¹²(Nehlich 2015), ¹³(Jaouen and Pons 2016)

Element	Isotopes	Obtained from	What can we learn from them?
Hydrogen	^1H ^2H (=D)	Bone collagen	Diet (e.g. trophic level) ¹⁻³ , climate (e.g. relative temperature) ^{1,2,4-6} and mobility (e.g. isotopic composition of meteoric waters) ^{1,4-6}
Carbon	^{12}C ^{13}C ^{14}C	Bone collagen, dentinal collagen	Diet (i.e. ecosystem of origin mainly of dietary protein) ^{1,4,7,8} and environments (especially in the case of herbivores) ^{1,5,9}
Nitrogen	^{14}N ^{15}N	Bone collagen	Diet (i.e. trophic level of origin of dietary protein) ^{1,4,7,8} and environments (especially in the case of herbivores) ^{1,5,9}
Oxygen	^{16}O ^{17}O ^{18}O	Bone dental enamel (phosphate)	Climate (i.e. isotopic composition of rainfall) ^{1,5,9} and mobility (e.g. isotopic composition of meteoric waters of the locality of origin) ^{1,4,10}
Strontium	^{88}Sr ^{86}Sr ^{84}Sr ^{87}Sr	Bone dental enamel	Mobility (e.g. origin of the individual) ¹¹
Sulphur	^{32}S ^{33}S ^{34}S ^{36}S	Bone collagen	Diet (i.e. ecosystem of origin of dietary protein) ^{3,7,9,12} , environments ^{9,12} , and mobility (e.g. coastal versus inland) ^{9,12}
Zinc	^{64}Zn ^{66}Zn ^{67}Zn ^{68}Zn ^{70}Zn	Dental enamel, bone apatite	Diet (e.g. trophic level) ¹³

The application of isotope analysis of specifically osseous tools is just in its infancy. However, it can potentially reveal exciting insights into the possible movement of objects and raw material, and thus offer possible insights into past culture contact and/or migration.

Taphonomy

In the analysis of osseous tools, new information can be added by considering their taphonomic history (Hedges 2002). Taphonomy encompasses the time gap between the death of the animal that provided the raw material for the tool and the eventual retrieval of the artefact. Zooarchaeologists mostly consider the taphonomic history of sites rich in faunal remains (Lyman 1994). New studies (Gummeson et al. 2017) indicate a strong correlation between bone artefact surface characteristics and artefact age, animal species, and the level of bone modification, opening up the possibility of qualifying taphonomy vis-à-vis single finds as well.

Bone surface characteristics, including traces of weathering, abrasion and heating, can provide important information. Weathering of the bone surface might give information about how long an artefact has been exposed on the surface, about soil matrix characteristics, and about the duration of deposition. The colour and degree of artefact degradation are important in determining the depositional environment, in waterlogged, desiccated or acidic soils, with important implications for the likelihood of successful downstream biomolecular analyses. Another important factor is bone surface abrasion, which can be caused by animal or human trampling, eolian or fluvial processes, or other factors (Lyman 1994). These processes might mimic anthropogenic abrasion, and hence are important to account for. In addition to looking for macro and microscopic traces of heating, it may be possible to obtain further insights into the manufacture and use of the investigated objects (Roberts et al. 2002; Koon et al. 2003; Nicholson 1993). For example, were the bones fresh when they were worked, or had they been boiled, roasted, etc. prior to manufacturing? In principle, only once these taphonomic changes are accounted for can we engage in substantial cultural interpretations of orphaned osseous objects (cf. Hedges 2002).

Digital recording methods

Recent advances in digital recording are increasingly being applied in archaeology (Dodd 2014; Meijer 2015; Jensen 2017), including the study of artefacts (Mudge et al. 2005; Malzbender et al. 2001; Jones et al. 2015; Jones 2017). There is little doubt that the application of digital recording methods also has the

potential to make a positive contribution to the study of osseous tools. Methods can be broadly divided into two categories: photogrammetry and laser scanning. Within each family, there is a variety of sub-methods. Therefore, the methods discussed here are by no means exhaustive.

Of the many methods that comprise the photogrammetric family, techniques such as Reflectance Transformation Imaging (RTI) and Structure from Motion (SfM) are the front runners. RTI, as the name suggests, measures the reflectance of an object in relation to a moving light source. A stationary camera takes a series of photographs of an object, as the light source is moved slightly between each shot. This provides a digital representation, based on how light behaves as it hits an object. This method allows us to re-light an object from any direction, to enhance and capture different surface details, including manufacturing traces, ornamentation, use-wear, surface damage, and colour (Fig. 8). Additionally, high and low pass filters are applied to each pixel in each digital photograph, in order to enhance the differences and allow the user to modify the apparent surface properties (Malzbender et al. 2004; Jones 2017).

The SfM method has increasingly been used in archaeology to create accurate photo-textured 3D models of objects, features and entire sites. Here, a sequence of overlapping photographs are taken and automatically compared, to identify common feature points in order to create a 3D point cloud, which can be used to create a photo-textured 3D mesh and model. This may be interactively explored and re-used in any 3D software. Another common use of SfM in archaeology is the creation of geometrically true orthophotos: an illustration with the optically induced perspective deviations created by parallax removed from the image. This may, to some extent, either replace or provide the backdrop for traditional 2D line drawings or standard photographs. However, SfM is challenged by very homogeneous or reflective/transparent surfaces, as it is based on matching identical pixels in each photograph. It is therefore important that lighting and shadows do not change notably between the images. Furthermore, it is often difficult to control the depth of field when photographing smaller objects or on a macro scale. The results of both RTI and SfM rely on lens and photograph quality, but both are cost-effective ways of creating digital representations of objects for surface analysis and interactive geometry exploration. Basically, only a digital camera and software is needed, and both commercial and free/open source options are available (Agisoft PhotoScan/VisualSFM).



Fig. 9. An example of a comparison between high resolution standard photography (A) (Rógvi Johansen, Moesgaard Museum) and RTI imagery (B) (Unit of Archaeological IT, Aarhus University) of a bone figurine dated to 1034-1204 AD found as a stray find from Museum Skanderborg, Denmark (Ahlqvist & Bjørnevad 2017). In RTI images, it is significantly easier to identify different tool marks that are not as visible in either a standard photograph or with the naked eye (reproduced with permission from Museum Skanderborg).

Perhaps the most promising opportunities at present are offered by laser scanning. Although the costs of owning a scanner, computer and associated software are high, it is possible to hire companies to undertake smaller jobs. The accuracy of a laser scanner can be higher than with optical photographic methods, up to 0.2 millimetres at the point where the scan is initialised; however, the accuracy can vary significantly, depending on the model of laser scanner used. Scanning small objects takes seconds. The advantages of hand-held laser scanning over photogrammetry can be summarised as higher accuracy, faster data acquisition (as little as a few seconds), and ease of use.

The outcome of both these technologies is a highly visual end-product, which encourages an interactive and explorative approach, rather than a quantitative analy-

sis. Thus, the dissemination potential is substantial, and several online 3D-viewers are already available for embedding 3D models into webpages. Interactive RTI-viewers are also available, most recently seen applied to the Mesolithic pendant from Starr Carr (Milner et al. 2016). The applications within archaeology are currently at an early stage, while the analytical potential is likely to be lurking in the very near future. However, the 3D models created from SfM or laser scanning are increasingly being used in 3D morphometric analysis, as described above. In addition, RTI can be used to identify surface modifications, such as engravings, manufacturing traces or traces from use that may not be visible to the naked eye or in standard photographs, which can have significant analytical potential (Newman 2015). Researchers are looking closely at techniques already in existence, and investigating if and

how existing methods can be applied, or whether new analyses and technologies need to be developed.

Arguably, hand-held laser scanning and photogrammetric methods such as SfM and RTI still lack the resolution of optical microscopic analysis as demonstrated in this study. However, as time progresses, it is highly likely that scanning or photogrammetry will be able to offer the same or even higher levels of detail than photo-microscopy.

Geometric morphometrics

Geometric morphometrics, at its core, isolates and quantifies shape variance/covariance, through the collection and analysis of landmark, outline or surface data obtained through two-dimensional approaches (illustrations and photographs), and three-dimensional approaches (scans and SfM models, see above). As these methodologies benefit any research field which depends on comparative morphology, it is no surprise that geometric morphometrics has been implemented in a wide variety of archaeological applications. These include questions associated with ceramic (Wilczek et al. 2014), lithic (Buchanan 2006; Costa 2010; Picin et al. 2014; Serwatka and Riede 2016), osteological (Kubicka et al. 2016) and zooarchaeological (Cucchi et al. 2016) material.

With respect to osseous tools specifically, geometric morphometrics has the potential to aid a variety of questions associated with their manufacture and use, in terms of their shape and form. This includes a rigorous statistical examination of whether two groups of osseous tools are different, whether these differences correspond to a particular hypothesis or archaeological model, notions of stylistic variation, and how aspects of shape are related to the chronological period, region or tool function. In addition, morphometrics has been applied to cut marks on the osseous material to determine what type of tool was used to produce the cut marks (e.g. Dominguez-Rodrigo 1997; Boschin and Crezzini 2012). These questions can be in relation to single stray finds in conjunction with larger collections (for any statistical analysis to be robust), allowing for a meaningful analysis of almost all osseous material culture. However, issues of fragmentation and the necessity for analyses to incorporate complete or near-complete specimens may arise, depending on the question and shape of the data under investigation. Despite this, geometric morphometrics can have great potential in the analysis and understanding of osseous tool manufacture and use, building on the aforementioned techniques and providing a different perspec-

tive on the social biography of osseous tools, to which these methods remain to be applied.

Discussion

By applying close observation and a variety of novel and established archaeometric methods, this paper has sought to outline and illustrate the currently mostly untapped analytical potential inherent in osseous finds, including specifically those found in older excavations or as stray finds. Osseous tools are all too often either typologically dated or are characterised by their presumed function based on analogical objects. This is especially true of the many orphaned legacy objects that often lie under-utilised in museum collections. Despite the fact that these objects commonly afford substantial aesthetic value and are even regularly displayed to the public, we often know next to nothing about them. Yet, as is demonstrated in this paper, a wide range of rapidly advancing scientific methods is available for the analysis of such objects.

Advanced archaeometric methods can provide significant new information on such legacy objects, illustrated here by our analyses of four Mesolithic osseous tools that can now be much more securely tied into ongoing research projects about the colonisation of Lithuania and northern Europe, and the spread of different technologies in the wider region. It is worth noting that most of the methods referred to in this paper are relatively inexpensive, easy to apply, and often minimally destructive. Many of these methods may not be available to a single researcher, but by cultivating collaborative research, especially through international collaborative projects, such multi-method studies can rapidly become routine and yield exciting results (Oras et al. 2017). Table 3 provides a (by no means exhaustive) facet of methods, their benefits and weaknesses, which can be used as a checklist for any researcher wishing to design analytical projects involving orphaned or excavated osseous tools or assemblages thereof. Depending on the questions to be addressed and the resources and expertise at hand, all or some of these methods may be used.

Conclusions

In a case study of four Mesolithic osseous tools from Lithuania, we followed a suggested sequence of analysis, starting with non-destructive methods like high-definition photography and use-wear analysis, and then sampling for AMS dating and tandem mass spectrometry. The analysis facilitated critical cross-checking of previous dating by typological inference, and has re-

Table 3. Applicable methods for osseous tool analysis, listed with their benefits and weaknesses

Method	Function	+	-
AMS C14 dating	Absolute dating	Minimally destructive and accurate up to within a few decades	Destruction relies on collagen preservation
Tandem mass spectrometry	Species ID	Minimally destructive, cheap, quick	Sample must be uncontaminated, needs to be sent to specialist lab, not all species can be differentiated and reliant on collagen preservation
ZooMS	Species ID	Minimally destructive, cheap, quick	Sample must be uncontaminated, needs to be sent to specialist lab, not all species can be differentiated
aDNA	Species ID as well as numerous other traits	Tremendous amounts of information can be identified with aDNA	aDNA often not well preserved and can be very expensive, sample must be uncontaminated, needs to be sent to specialist lab
Isotope Analysis	Object/material mobility, animal diet, create an isotope baseline, prehistoric hunting and craft strategies	Can be minimally destructive, addresses many questions that cannot be addressed any other way	Destructive, reliant on collagen preservation, requires pre-existing isotope studies in region
Optical microscopy and scanning electron microscope	Manufacture and use-wear traces	Non-destructive method	Special training is needed to analyse use-wear and manufacture traces
Geometric morphometrics	Artefact shape analysis	Most of the software packages required for analysis are open-source	Larger sample size is needed to make statistical examination, requires complete or near-complete specimens
Reflectance Transformation Imaging (RTI)	Digital recording method to capture surface details and colours	Cost-effective method, accessible open-source software	Might lack resolution
Structure From Motion (SfM)	A digital recording method for photo-textured 3D models	Cost-effective method, accessible open-source software	Might be inconvenient to use on uniform or reflective/transparent surfaces
Laser scanning	Digital recording method for creating 3D models	High accuracy and time-efficient	High cost
Taphonomic analysis	Reconstruction of depositional processes	Can provide with additional information on pre- and postdeposition environment	

vealed very different dates of barbed and slotted bone points. Both the barbed points are younger than typological dating suggested, while the slotted bone points fit well into a wider regional context. Protein analysis of the two barbed points revealed the high possibility that aurochs bones were the source material. The manufacture techniques applied, as shown through

macro and microscopic observation, show a great resemblance to other bone points from this period, and add further information on the spread of people and technologies in the Boreal. The use-wear analysis revealed that the barbed point from the River Šventoji (VDKM: AR 2437) had also been used after the tip flaked off, probably from hitting some hard material

like bone or stone, but that the object was eventually lost or discarded following a large oblique fracture. The presence of possible edge rounding and clustered edge damage on the inserts on both slotted bone points from Vaikantonys (VDKM: AR 6) and Obšrūtai (VDKM: AR7) indicates that they had both been used repeatedly and over longer periods, and that they had come into contact with some relatively hard material (e.g. bone).

The results of our analyses confirm that orphaned and context-poor stray osseous finds can be informative on their own, especially when they come from regions where such finds are rare, or where they have only rarely been analysed. A well-conducted analysis of single finds can be correlated to existing studies, and thereby reveal similarity or difference within a broader context. For chronological studies, it is paramount to add further dots on our maps, and to provide as many radiocarbon dates as possible, in order to aggregate them into statistically sound samples at regional and supra-regional levels. We realise, of course, that all archaeological research operates under the ever-present constraints of time and money, but we highlight in this paper a battery of established and emerging observational and archaeometric techniques that are rapid and cost-effective in their application, and hence optimise the cost-benefit ratio of time/money spent in relation to knowledge gained. More widespread and systematic applications of such methods to orphaned osseous (and other) finds would lead to a significant activation of this otherwise sorely overlooked find category in a scientific and outreach context.

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SIEKIANT PRAKALBINTI TYLIUS KAULUS: ATSITIKTINIŲ KAULO-RAGO DIRBINIŲ ANALIZĖ, REMIANTIS MEZOLITO DIRBINIŲ PAVYZDŽIU

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Santrauka

Atsitiktiniai kaulo-rago dirbiniai dažnai vertinami dėl estetinės išvaizdos, tačiau vyrauja nuomonė, kad jie turi labai minimalią informacinę vertę archeologijos mokslui. Didelė dalis kaulo-rago dirbinių, rastų Lietuvoje, panašiai kaip ir Šiaurės Europoje, aptikta pavieniui atsitiktiniai. Jie naudojami dažniausiai tik kaip graži iliustracinė medžiaga publikacijoms ar ekspozicijoms. Per pastaruosius kelis dešimtmečius mokslinių metodų taikymas archeologijos srityje labai pažengė ir leidžia tirti net ir nedidelius kaulo-rago dirbinius, be-

veik jų nepažeidžiant. Šiais metodais buvo atlikta išsami keturių Vytauto Didžiojo karo muziejuje saugomų mezolito kaulinių antgalių analizė. Kauliniai antgaliai iš Šventosios upės, Vaikantonių, Obšrūtų ir Kamšų buvo datuoti AMS metodu, taip pat baltymų analize buvo nustatyta gyvūno, iš kurio kaulų pagaminti antgaliai, rūšis, atlikti trasologiniai tyrimai. Datavimo rezultatai atskleidė, kad abu kauliniai žeberklai yra ankstyvesni nei antgaliai su įstatomais titnaginiais ašmenėliais, tačiau visi keturi radiniai datotini borealio laikotarpiu, o tai reiškia ankstyvuojų–viduriniu mezolitu. Remiantis baltymų analize, didžiausia tikimybė, kad abu žeberklai buvo pagaminti iš tauro kaulų. Visiems keturiems kauliniams dirbiniams naudoti ilgieji gyvūnų kaulai. Trasologiniai tyrimai parodė, kad antgaliai buvo naudoti ne vieną kartą. Apibendrinant analizės rezultatus, galima teigti, kad kauliniai antgaliai iš Šventosios upės, Vaikantonių, Obšrūtų ir Kamšų, remiantis tiek gamybos technologija, tiek gyvūno rūšies pasirinkimu, tiek jų amžiumi, atitinka platesnį vienalaikį mezolito kontekstą.

Svarbu paminėti, kad tai yra tik labai nedidelė dalis atsitiktinai rastų kaulo-rago dirbinių, todėl, norint susidaryti detalesnį vaizdą apie mezolito kaulo-rago dirbinių technologiją, reikia gausesnės duomenų bazės. Dėl to nemaža šio straipsnio dalis yra skirta kitiems metodams trumpai pristatyti, nes juos galima gana lengvai pritaikyti kaulo-rago dirbinių analizei. Tai biomolekuliniai metodai arba stabiliųjų izotopų analizė, kurių taikymas gali padėti atsakyti į svarbius archeologų keliamus klausimus. Straipsnyje įvardijami ir kaulo-rago dirbiniams labiausiai tinkami fotofiksacijos metodai, kurie ne tik leidžia gauti aukštos raiškos vaizdą, bet ir įgalina šią medžiagą toliau tirti naudojant kompiuterines programas, pavyzdžiui, analizuojant dirbinių geometrinę morfometriją. Plačiai ir sistemškai taikant šiuos metodus kaulo-rago dirbinių analizei, galima sudaryti gausnę duomenų bazę, kuri būtų pagrindas platesnėms apibendrinančioms išvadoms.