



A Protocol to Identify the Wear Traces on Osseous Points Used for Fishing

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Abstract

The ability to distinguish osseous points used for hunting in aquatic and terrestrial environments is key to understanding the economies of hunter–gatherer societies (and beyond) and the typological diversity of such tools observed worldwide. In this article, we present an analytical protocol for wear analysis that enables the identification and correct interpretation of microwear traces generated on osseous points as a result of fishing. A starting point of our studies, which were conducted using optical and confocal microscopy, as well as microcomputed tomography (microCT), was the analysis of 72 experimental osseous points, which were used 1208 times in hunting experiments, where the targets were 110 kg of fish of various species and the bodies of terrestrial animals such as red or roe deer. We constructed a classification of wear traces formed on osseous points after fishing based on the results of an analysis of 169 wear observation areas on the barbed points used in such experiments. This classification significantly diverges from previous findings on wear patterns typical of projectile points, where impact fractures play a crucial role. Moreover, it demonstrates that in the case of fishing, other, previously undistinguished categories of microtraces, such as compression traces, osteon structure highlighting, specific polish, and several types of perpendicular linear traces, are of primary importance. We then tested the analytical protocol developed based on this analysis by analyzing 35 prehistoric osseous points from 11 sites located in Poland, Lithuania, and Latvia. These studies fully confirmed its effectiveness.

Keywords Wear analysis · Fishing · Osseous barbed points · Reflected light microscopy · Microcomputed tomography · Confocal microscopy

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Introduction

Hunting weapons in the form of points (barbed and without barbs) made from osseous raw materials were an essential element of hunters' equipment in the Stone Age. The oldest example of this type of artifact may be a semifinished product resembling an unfinished barbed spearhead, discovered at the WK East A, Bed IV site in Olduvai Gorge, Tanzania. It is attributed to *Homo ergaster* and dated to ca. 1.4 Ma (Pante *et al.*, 2020). More numerous osseous barbed points are represented in the African Middle Stone Age and are associated with anatomically modern humans (*e.g.*, Yellen, 1998; Yellen *et al.*, 1995).

The earliest unequivocal and securely dated European osseous points bearing deliberately carved barbs belong to the early Upper Magdalenian and date to approximately 16.0–15.5 ka cal BP. They are known from sites Fontalès, d'Espalunge and Isturitz in France and Tito Bustillo in northern Spain, marking the emergence of unilaterally and bilaterally barbed projectiles in the Franco-Cantabrian region (Langley *et al.*, 2016; Pétilion *et al.*, 2015; Szmidi *et al.*, 2009; Tisnérat-Laborde *et al.*, 1997). Earlier Gravettian evidence should be distinguished from these artefacts. The specimen from Les Prés de Laure, dated to approximately 23.5 ka cal BP, was a composite bone point equipped with lithic barbs (Tomasso *et al.*, 2018), whereas several Gravettian forms interpreted as “self-barbed” antler points (Goutas, 2004; Petillon, 2009; Goutas, 2016), are not equivalent to implements with barbs carved directly into the osseous blank. By approximately 15 ka cal BP, unequivocal osseous barbed points are also documented at Vlakno in the eastern Adriatic, demonstrating the wider Late Glacial distribution of this technological concept (Vitezović *et al.*, 2024).

In the Late Pleistocene and Early Holocene, osseous projectile points, both barbed and unbarbed, began to be widely used to arm arrows (Aleo *et al.*, 2023), as bow hunting began to dominate other previously known hunting techniques (Cattelain, 1997; Yaroshevich *et al.*, 2010). However, some researchers suggest that bow–arrow technology could even have been used in the African Middle Stone Age (Bradfield *et al.*, 2020).

The use of barbed osseous points extends well beyond the periods considered in this study. This technological tradition persists into later prehistory and even historic periods across various regions (*e.g.*, Ramseyer, 1988; Baron *et al.*, 2023; Luik, 2006; Mitelsztet, 2023). The artifacts of this type are also well documented in ethnographic contexts, particularly among ingenious hunter–gatherer communities in South America (Christensen *et al.*, 2016) or Australia (*e.g.*, Allen *et al.*, 2016). In Arctic and Subarctic regions, barbed bone and antler points continued to be used into the recent past, as evidenced in ethnographic and archaeological records (*e.g.*, Aigner, 1966; McGhee, 1974; Weniger, 1992; Mason, 1998).

Research on osseous points has a long history and is an integral part of the study of prehistoric societies. Since the early twentieth century, such artifacts have been analyzed morphologically and typologically (*e.g.*, Clark, 1936; Gramsch, 2003; Galiński, 2013; Orłowska & Osipowicz, 2022), and the knowledge thus acquired is used to develop the chronological and cultural classifications

necessary for the periodization of human prehistory (e.g., Kozłowski, 1969; Galiński, 2013). Technological studies conducted to date have allowed for a precise analysis of the techniques and tools used to produce and decorate these artifacts (e.g., Zhilin, 1998, 2017; David, 2005; Lozovskaya & Lozovski, 2013; Langley, 2016; Orłowska & Osipowicz, 2018; Osipowicz *et al.*, 2020b). Moreover, they have constituted the basis for interpretations covering the symbolic activity of the Stone Age population (e.g., Płonka, 2003; Osipowicz *et al.*, 2019).

A crucial part of contemporary research on the osseous elements of projectile weapons is the study of their function. These studies began in the 1980s and have been primarily based on experimental archaeology (Pétillon *et al.*, 2016, and further references therein). Their methods and specific goals have varied considerably (e.g., Carrère & Lepetz, 1988; Knecht, 1991; Stodiek, 1993; Pétillon *et al.*, 2016), but ultimately, they have typically led to inferences about prehistoric hunting techniques (e.g., Cattelain, 1997) or, for example, the function of camps (Piličiauskas *et al.*, 2023).

Since the early twentieth century, there has also been an ongoing debate regarding the function of osseous barbed points. Their use has been inferred, as a rule, based on direct and indirect connections with faunal remains (e.g., Clark, 1936, 1948; Julien, 1982; Verhart, 2000; Pétillon, 2009; Gramsch, 2000, 2011) or ethnographic analogies (e.g., Mason, 1902; Weniger, 1992; Julien, 1982; Pétillon, 2009; Christensen *et al.*, 2016) and only sporadically based on somewhat limited experimental studies and related wear analysis (e.g., Buc, 2011; Aleo *et al.*, 2023). Over the years, osseous barbed points have often been attributed to the role of weapons used for hunting in aquatic environments (e.g., Hyades & Deniker, 1891; Osgood, 1970; Pétillon, 2009; Torres, 2009; Christensen *et al.*, 2016). However, no one has yet conducted more detailed experimental and wear studies that would lead to the creation of even a preliminary classification of microwear traces typical for points used in this manner, which could confirm such suggestions. Moreover, no one has developed an analytical protocol that would allow the identification of this type of trace. The research reported in this article aimed to fill this gap.

During wear analysis carried out as part of an international research project entitled *Life and death written in bones. The technological and functional aspects of the osseous artifacts of Early and Middle Holocene hunter–gatherer–fisher communities inhabiting the East Baltic Plain*, we have observed that the majority of the analyzed prehistoric osseous points, which were found in lakes and rivers, lack macroscopically visible wear damage (impact fractures). On the other hand, microscopically, they exhibited use modifications that differed in many aspects from those typical of osseous points used for hunting terrestrial animals. This led to the hypothesis that these points could be used for hunting in aquatic environments, probably for fishing, and that this use of osseous points generates on their surface characteristic microwear traces that can be identified and classified, enabling the recognition of tools used in this manner in prehistory and history. This hypothesis was tested through experimental and wear studies (qualitative and quantitative), supplemented by microcomputed tomography (microCT) studies. Their results are presented in this article.

Current Knowledge on the Characteristics of Wear Traces Visible on Osseous Points Used for Hunting

Experimental studies have demonstrated the high resistance of osseous points to damage resulting from their use as hunting weapons (e.g., Tyzzer, 1936; Guthrie, 1983; Knecht, 1991; Pokines, 1998; Bertrand, 1999; Pétilion, 2006; Foletti, 2012). Accompanying wear traces studies have allowed the development of a relatively coherent classification of the wear traces characteristics of this function. Based on these experiments, in which osseous points primarily targeted the bodies of terrestrial animals, so-called diagnostic impact fractures (DIFs) were identified as their primary category. DIFs are understood as evidence for impact use in the form of fracture types that are unlikely to have originated in any way other than through forceful longitudinal collisions (cf. Barton & Bergman, 1982; Moss & Newcomer, 1982; Bergman & Newcomer, 1983; Fischer *et al.*, 1984; Bradfield & Lombard, 2011; Foletti, 2012; Pétilion *et al.*, 2016). DIF classification includes several categories of major destruction types, including *beveled breaks* (bending fractures; oblique fractures that start on the side of the point, break off the distal part of it, and show a step-, hinge- or bevel-shaped proximal termination), *splitting* and *shattering* (longitudinal breaks, originating from the tip and dividing the point in two halves) and *breaks at the base* (breaks on the proximal, hafted part of the points) (cf. Tyzzer, 1936; Fischer *et al.*, 1984; Arndt & Newcomer, 1986; Bergman, 1987; Stodiek, 1993; Nuzhnyi, 1998; Pétilion, 2005, 2006; Bradfield & Lombard, 2011; Pétilion *et al.*, 2011, 2016). To other characteristic impact tip damage belong *crushing* (so-called *chipping* by Tyzzer, 1936; simple crushing of the tip, destroying only the last few millimeters of the point; Arndt & Newcomer, 1986; Bergman, 1987; Stodiek, 1993; Nuzhnyi, 1998; Pétilion, 2005, 2006; Bradfield & Lombard, 2011), and *mush-rooming* (flattening of the tip of the point which occurs only on antler points; Arndt & Newcomer, 1986; Bergman, 1987; Stodiek, 1993). However, according to recent opinions expressed by some researchers, the only diagnostic impact fractures (DIFs) resulting from longitudinal impact on the osseous points are *spin-off fractures* larger than 6 mm and bifacial spin-off fractures (Bradfield, 2015; Bradfield & Brand, 2015; Bradfield & Lombard, 2011).

Detailed microCT studies have also been conducted on internal microfracture patterns connected to high-velocity impact (Bradfield, 2013; Bradfield *et al.*, 2016). These studies have demonstrated the significant diagnostic value of certain categories of such traces (primarily longitudinal cracking and subsurface damage) for identifying osseous artifacts used as hunting weapons.

In addition to macroscopic DIF marks, several categories of microscopic damage have been identified on osseous points used as heads of hunting weapons, such as microfractures and edge chipping, surface microcracks, polish, scratches, and abrasion understood as localized friction-induced flattening and partial smoothing of the bone surface microrelief (cf. LeMoine, 1994; Buc, 2011; Buc & Loponte, 2007; Cristiani & Boric 2016; Siebrecht & Pomstra, 2020; Aleo *et al.*, 2023). However, these types of destruction have received little attention and are usually treated as secondary. Reporting on the results of her research using bone points, Buc characterizes the polish observed on them as irregular, with heterogeneous microtopography and

rounded high points of relief (Buc, 2011). In turn, Zhilin, reporting on his experiments and studies on bone arrowheads from the Volga–Oka interfluvium, describes the polish visible on them as “hide” polish, beginning from the tip and gradually disappearing (Zhilin & Ruev, 2025).

In the case of striations, Buc states that they do not occur on osseous points used as hunting weapons, classifying the examples she observed as resulting from factors other than contact with meat and bone (Buc, 2011). In the works of Zhilin, fine and sometimes coarse striations are characteristic, running from the tip along the axis of the arrowhead and/or at an acute angle to it (Zhilin, 2019; Zhilin & Ruev, 2025; Zhilin *et al.*, 2023).

From the perspective of this article, it is also worth paying attention to the surface microcracks observed by Buc on one of her experimental points, which, according to her description, take the form of “short, transverse marks” and arise as a result of stress concentration during impact, the so-called “mechanical stress” (Buc & Loponte, 2007).

Previous experimental studies using barbed points for fishing and associated wear analyses are very rare and have been limited in scope. They have been summarized in only two studies. The first is the study by Buc, in which a fish (*Megaleporinus obtusidens*) was placed in a plastic barrel and hit directly (Buc, 2011). The experiment employed two antler barbed points, which made 100 impacts. As a result of the wear analyses conducted after the experiments, the author noted no differences between the wear traces created on the tested points and the points used for experimental imaging of terrestrial animals.

Aleo *et al.* (2023) reported the second study in this area. Citing two experimental points that were used to hit salmon carcasses (unfortunately, no detailed information about these experiments is available), the microwear characterizing the bone heads of hunting weapons used for fishing was described as follows: (...) a “corrugated” polish is visible on the active part. The polish is mainly dull, rough, and greasy, but with smooth, matte, and bright spots. On this basis, some of the osseous barbed points discovered in Doggerland have been linked to fishing.

Materials and Methods

Experiments Conducted

The selection of forms for the experimental points and their dimensions was grounded in observations of archaeological assemblages of osseous artifacts from northeastern Europe, including sites in Poland, Lithuania, Latvia, and Estonia (*e.g.*, Vankina, 1999; Orłowska & Osipowicz, 2022; Osipowicz *et al.*, 2020a). A direct analogy here is the points from the collections of archaeological artifacts analyzed in the article. Long bones of cervids were used for the production of experimental points, as they represent one of the most commonly identified raw materials for Mesolithic and Subneolithic osseous points (David, 2005; Osipowicz *et al.*, 2020a). In addition, red deer antler was also included, reflecting its well-documented use in analogous artifact categories (Cristiani & Borić, 2016). The applied manufacturing

techniques of the experimental points were designed to replicate those observed in the archaeological record (David, 2005; Orłowska & Osipowicz, 2018; Osipowicz et al., 2020a), thereby providing a reliable comparative framework for the wear analysis. The points used in the experiments, therefore, have close formal, raw material, and technological analogies with the archaeological artifacts considered in the work.

Detailed information on the experimental osseous points used, including their photographs, as well as the conditions and results of each experiment, is included in Supplementary Information (SI) 1.

The experimental research, which was the starting point for the reported wear studies, was conducted on the Vistula River, near Toruń (Poland), in September 2024 and October 2025. Twenty-seven barbed points (Po 1–27) were used in these experiments, including 13 specimens with one row of barbs and 14 with two rows of barbs (cf. SI1, Table 1).

Two large uniserial barbed points (Po 1 and Po 2), ten smaller points of that type (Po 11, 13–17, 19–21, 24), and eight smaller biserial barbed points (Po 10, 12, 18, 22, 23, 25–27) were manufactured from the metapodial bones of red deer (*Cervus elaphus*). Four biserial barbed arrowheads (Po 4–7), along with one larger uniserial barbed point (Po 3), were produced from the metapodial bones of roe deer (*Capreolus capreolus*). Additionally, two barbed arrowheads (Po 8 and 9) were crafted from red deer antlers.

The red deer metapodial bones used to produce points Po 10–27 were fresh. The bones used in the other experiments were not fresh. All soft tissues, including the periosteum, were stripped 3 years before the use of the bones. Bones used to produce points Po 1, 2, 6, and 7 remained unprocessed until these points were made. The yellowish coloration observed at these points is attributed to oils from marrow that remained inside the bones until processing. In contrast, bones used for points Po 3–5 were segmented into blanks shortly after procurement, preventing marrow oils from penetrating the bone. Owing to the dryness of the raw material, these bones were characterized by internal cracks and were already subject to accidental breakage during the points production process.

All experimental points were carved from a single piece of raw material. The initial stage of blank production involved modern equipment, specifically an electric rotary saw, to section the bone and antler. Subsequent shaping of the barbs and final surface finishing were conducted exclusively with flint tools and a grinding stone. First, both the external (periosteal) and internal (medullary) surfaces of the experimental points were ground flat on sandstone. The direction of grinding was varied, resulting in a regularized morphology and a relatively even surface topography. Subsequently, the entire pieces were further refined by longitudinal scraping with a flint blade. This operation smoothed and homogenized the surfaces. The barbs were additionally emphasized through careful whittling and scraping: the lower portions were sharpened, the dorsal ridges were worked longitudinally, and the inner edges were also shaped by controlled whittling and finishing scraping.

All points were used as distally hafted tips with an axial position (Tydgadt & Rots, 2025). The hafting area was formed by making a single-sided, perpendicular incision approximately half the shaft's thickness deep, approximately 3–5 cm from its tip (depending on the point size), and removing unnecessary wood by splitting

and whittling. In beveled shafts made this way, the points were placed with their base resting on the step created by the incision (*cf.* Aleo *et al.*, 2023). No adhesive was used to attach the points; only a wrap made of a leather strap. Only in the case of the singular leister prong of the experimental sample (*cf.* SI1, Table 1) was it replaced with hemp string. This method of attaching the points is supported by ethnographic observations (*cf.* Mason, 2007) and proved fully sufficient for the experiments. It also enabled quick and easy replacement of points on the shafts' tips during the experiments, which was crucial given their complexity and long duration. All experiments were conducted within a few days of shaping the points.

Three barbed points (Pos 1–3) were used as spearheads. They were mounted atop an approximately 2-m shaft to strike the target from close range (direct impact; *cf.* Figure 1a and b). The remaining barbed points were used as



Fig. 1 Experimental works conducted for the study

arrowheads. They were embedded in pine arrow shafts approximately 80 cm long, which were shot at the target with a straight bow with a draw weight of approximately 15 kg from a distance of approximately 2–3 m (Fig. 1d and f). Fifty-eight dead bream (*Abramis brama*), weighing approximately 1.5–2 kg (approximately 90 kg of fish), are used as targets and mounted between metal rods, as shown in Fig. 1d and e. Each fish was shot/struck no more than 10 times.

Additionally, in the wear studies reported here, we included a middle spike from a leister prong used in the experimental work conducted in September 2025 in Lithuania (Fig. 1j and k). This tool was used to make approximately 120 hits on fish species, including perch (*Perca fluviatilis*), pike-perch (*Sander lucio-perca*), bream (*Abramis brama*), and roach (*Rutilus rutilus*), with a maximum weight exceeding 3 kg (in total, approximately 20 kg of fish).

For ethical reasons, only dead fish (caught and killed by professional fishermen) were used in the experiments, which may affect the results and the characteristics of the microtraces generated on the points. Certainly, in the case of hunting live animals, the percentage of missed shots (and therefore, for example, hitting the river bottom) would be higher. However, the changes in the characteristics of the microtraces generated on the points as a result of this fact may actually be much less significant than they may seem. During the experiments, it was observed that water rapidly slows down the impact force of shafted hunting weapon projectiles, causing them (especially in the case of arrows) to usually not reach the bottom (even at shallow depths). Therefore, they do not generate the typical DIF traces associated with such contact, which is confirmed (as will be demonstrated later in the article) also on prehistoric material, *i.e.*, in the case of artifacts used for hunting live targets.

The wear traces produced during the experiments described above were compared with damage typical of bone points used for hunting terrestrial animals, which are described in the literature (*cf.* “Introduction” Section). However, for a direct comparative analysis, we also used points from our earlier archery experiments, in which the targets were the bodies of red deer (five specimens; Fig. 1l and m) and baby roe deer (22 specimens; Fig. 1n and o). All the arrowheads used in these experiments were made from metapodial bones from red deer. They were mounted on approximately 70 cm long beechwood arrow shafts and shot from a distance of approximately 10–15 m using a bow with a draw weight of 16 kg. Comparative studies also included spearheads and arrowheads used in recently published studies on the origins of perforations identified in prehistoric seal scapulae from Šventoji, Lithuania (Osipowicz *et al.*, 2025). Table 1 in SI1 provides detailed information on the points from these experiments that were used directly in the studies presented in this article (see infrasections “Studies of the polish texture via confocal microscopy” and “Microcomputed tomography (microCT)”).

In summary, the experimental group used in the reported studies consisted of 72 points, of which 28 were used in experiments with fish (633 hits in the targets) and 44 were fired at the bodies of terrestrial animals (573 hits in the target).

Archaeological Material

The findings obtained during the study of the experimental material were applied to the microscopic analysis of 35 prehistoric osseous points of different morphological forms from sites located in Poland, Lithuania, and Latvia (*cf.* Figure 2; SI2). Most of this collection (19 specimens) consists of points from the Lake Lubāns site in Latvia (*cf.* Vankina, 1999). These are stray finds (artifacts out of archaeological context) that lack direct radiocarbon dating, but they can be linked to hunter–gatherer–fishermen groups of the Early and Middle Holocene. These artifacts are stored in the Museum Storage Facility of the National History Museum of Latvia in Riga. Nine of



Fig. 2 Locations of the archaeological sites where the analyzed osseous points were found and examples of the points analyzed in this study: (1) Lake Lubāns (A.10120:74), (2) Lake Lubāns (A.9415:4), (3) Lake Lubāns (A.10120:130), (4) Lake Lubāns (A.10045:8), (5) Pabiržulis (EM 2391), (6) Lake Lubāns (A.10120:82), (7) Wiele (MOB/A-4644), (8) Mirakowo-Grodno (202/03), (9) Mirakowo-Grodno (13/01), (10) Rūdninkai (EM 2069:1), (11) Karaviškės (EM 2015), (12) Švenčionėliai, (13) Lake Lubāns (A.10120:76), (14) Lake Lubāns (A.10120:81), (15) Kaitanēnai (1306), and (16) Žemaitiškē 2 (EM2430:31)

the analyzed points come from Lithuanian sites. These are two Subneolithic points from Šventoji (Osipowicz *et al.*, 2020a; Rimantienė, 2005), a Mesolithic point from the Pabiržulis site, undated points from the Rūdninkai and Karaviškės sites (Rimkus *et al.*, 2023), and two Subneolithic barbed points from Žemaitiškės 2 (Piličiauskas, 2012; Piličiauskas *et al.*, 2011). The last two artifacts are new finds (not published yet) discovered at the Kaltanėnai (Piličiauskas, *et al.*, 2020) and Švenčionėliai sites. They are all stored in the National Museum of Lithuania in Vilnius. From the area of Poland, the study included a Final Paleolithic bone point from Lisi Ogon, site 13 (Orłowska & Osipowicz, 2019), two Mesolithic barbed points from Wiele, site 33 (Orłowska & Osipowicz, 2022; Osipowicz, 2016), and four arrowheads from the Lusatian culture stronghold Mirakowo-Grodno (site 6; Gackowski, 2003, 2009). The points from Lisi Ogon and Wiele are currently stored in the Leon Wyczółkowski District Museum in Bydgoszcz, and artifacts from Mirakowo-Grodno are stored at the Institute of Archaeology, Nicolaus Copernicus University in Poland.

The choice of points was dictated by several factors. The context of waterlogged deposits in which the artifacts were found was the most significant, increasing the probability of their connection to fishing (lake and river finds). The primary criteria also included the availability of the points for analysis, the state of preservation, and the type of preservatives used (or preferably their lack). Points from the Lake Lubāns artifact collection were selected at random.

Points from sites located in Poland and Latvia have no recorded history of consolidates or preservative treatment. In the case of Lithuanian artifacts, the preservatives used did not visibly affect the legibility of wear traces on their surfaces.

Wear Studies Employing Optical Microscopy

For the purposes of the analyses conducted in this study, the criteria for wear identification and the terminology employed draw on selected approaches developed within osseous wear research (*e.g.*, Maigrot, 1997, 2003; Christidou, 1999; Legrand, 2007; Buc, 2011). These works are treated as complementary methodological reference points rather than a unified framework, reflecting differences in analytical scale and observational protocols.

A distinct strand, drawn upon here in the assessment of impact-related damage, focuses on diagnostic impact fractures (DIF) and associated wear patterns on osseous projectile points like crushing (*e.g.*, Bradfield & Lombard, 2011; Bradfield, 2015; Pétilion *et al.*, 2016). Due to the characteristics of the observed diagnostic impact fractures (DIFs), *i.e.*, their very small sizes (below 4 mm) and the defined characteristic of crushing (multiple, small, uneven overlapping step-like fractures... destroying only the last few millimeters of the point; Pétilion *et al.*, 2016), in this work, both types of impact damage are grouped into one analytical category. Methodologically, small DIFs (<4 mm) are often morphologically indistinguishable in the analyzed material from fine chipping described as crushing, and no clear metric or morphological threshold separates these forms. Instead, a continuous spectrum of damage was observed, making any formal distinction arbitrary and difficult to reproduce. Given their very low frequency in the assemblage (their statistical

insignificance), separating both types of wear traces is also not justified from the perspective of the purposes of the studies, as it would not affect the interpretations made (and would multiply the analytical data with no reasonable reason). Accordingly, all minor edge and tip damages were analyzed within a single, broadly defined category of impact damage (*cf.* Pétillon *et al.*, 2016).

In our terminology, “abrasion” refers to mechanical surface modification caused by frictional contact, leading to the flattening and partial smoothing of the upper parts of the microrelief. We follow the broader wear and tribological understanding of abrasion as a process of progressive surface alteration through friction and material removal, where polish may be considered a particular manifestation of abrasion (*e.g.*, LeMoine, 1994). In contrast to well-developed polish, these traces retain a more heterogeneous and irregular surface topography and often display slightly rough textures.

The term compression traces is understood as modifications of tool surfaces not related to hafting and binding impressions (*cf.* Cristiani & Borić, 2016; Aleo *et al.*, 2023), but originating from the local compression of bone fibers on the tools’ contact surfaces (points’ tips) resulting from striking the target (fish).

The terminology applied to linear traces follows descriptive approaches commonly used in osseous use-wear studies (*e.g.*, LeMoine, 1994; Legrand, 2007; Buc, 2011; Bradfield, 2015).

Selected descriptors from lithic wear studies (terms flat and pitted, *cf.* Vaughan, 1985; van Gijn, 1989; Juel Jensen, 1994; Osipowicz, 2010) are used where they provide a precise (supplementing) vocabulary for describing polished surface general appearance and microtopography, complementing terminology specific to osseous materials.

To simplify (where possible) the description of the degree of development of wear traces observed at experimental and archaeological points, the following terms were used:

- *Well-developed wear traces*—wear completely covers the surface relief of the raw material and manufacturing traces, completely changing the primary microtopography of the surface.
- *Weakly developed wear traces*—the natural surface relief of the raw material or manufacturing traces is still quite clearly visible; however, all important types of distinctive wear traces are readable.
- *Initial wear traces*—the natural surface relief of the raw material/manufacturing traces dominates over the usage modifications. Only some types of typical wear traces are readable.

The wear analyses were performed using two microscopes. Initial analysis of the wear traces was performed using a Nikon SMZ-745 T stereo microscope (zoom range $0.67\times$ – $6.3\times$; working distance 115 mm; field of view ca. 3.5–32.8 mm with $10\times$ eyepieces, FN 22), equipped with a Delta Pix Invenio 6EIII camera. Detailed polish observations (topographies, texture, *etc.*) were conducted using a Zeiss Axiotech 5 Vario microscope, used with incident light, and equipped with Zeiss EC Epiplan objectives ($5\times/0.13$, $10\times/0.25$, $20\times/0.40$). The corresponding working

distances of this equipment are approximately 18.5 mm (5×), 11.0 mm (10×), and 3.0 mm (20×). The field of view (with 10×eyepieces, FN 22) is approximately 4.4 mm, 2.2 mm, and 1.1 mm for the 5×, 10×, and 20×objectives, respectively. The microscope is equipped with an Axiocam 208 camera. One of the points from Lake Lubāns, Latvia (A10120:125; SI2, Plate 12) was analyzed with the use of a Motic AE2000MET microscope with a Moticom 5+ camera. This microscope is equipped with the Motic LM Plan objectives (5×/0.13, 10×/0.25, 20×/0.40). The corresponding working distances are approximately 20.3 mm (5×), 17.5 mm (10×), and 8.1 mm (20×). The field of view (with 10×eyepieces, FN 20) is approximately 4.0 mm, 2.0 mm, and 1.0 mm for the 5×, 10×, and 20×objectives, respectively.

To determine the frequency of occurrence of the wear traces on the analyzed experimental barbed points, the tips of each point and each barb were treated as independent wear observation areas (WOAs). We have chosen them to analyze because, as microscopic observations have shown, wear traces develop here the fastest and most intensively. In the case of the points used in the fishing experiments, a total of 169 areas of this type were analyzed (*cf.* SI1, Table 2).

The main section of the article presents only selected micrographs of the most characteristic wear traces observed on the WOAs. Complete documentation of wear modifications recorded on all WOAs (including micrographs of 71 WOAs before the experiments) is included in SI1.

Some of the micrographs included in the article show fish residues. These were not intentionally removed from the points, as their characteristics and distribution will be the subject of independent studies.

Studies of the Polish Texture via Confocal Microscopy

The potential of quantitative texture analysis of 3D images obtained through confocal microscopy in the context of osseous tools has already been demonstrated in a few studies (*e.g.*, Stemp *et al.*, 2016; Watson & Gleason, 2016; Martisius *et al.*, 2018; Martisius, 2022; Ma *et al.*, 2023; Clemente-Conte *et al.*, 2024). In our work, we conducted confocal microscopy analysis to verify the existence of differences in the roughness of the polish formed on bone points used for fishing and hunting terrestrial animals.

The points selected for this study were those that had been repeatedly used and exhibited well-developed microwear traces, as previously verified through wear analysis. The measurement places with a confocal microscope were located in all cases in similar locations, *i.e.*, in the areas with the best readable microwear, on the flattest possible sections of the surface relief, covered with a visible polish, and as far away as possible from natural modifications of the raw material's relief, such as Haversian canals. In each of these areas, 10 measurements were taken at different locations, which served as the basis for the statistical calculations.

We analyzed four specimens, two of which (Po 1 and Po 4) were barbs no. 2 taken from the points used in the fishing experimental program. Samples "14.1" and "14.2" were fragments of points used in archery experiments, where a roe deer was used as a target.

The confocal microscopy images were recorded using a Lext OLS 4000 device from Olympus equipped with a 405-nm laser. Two objectives of magnification ($\times 5$ and $\times 20$) were used for the measurements, yielding scanned areas of $2574\ \mu\text{m} \times 2574\ \mu\text{m}$ and $645\ \mu\text{m} \times 645\ \mu\text{m}$, respectively. A Gaussian filter of $80\ \mu\text{m}$ was applied as a cutoff to remove waviness from the roughness. The average surface roughness (S_a), root mean square roughness (S_q), skewness (S_{sk}) and kurtosis (S_k) were calculated according to the ISO 25178 norm.

Statistical analyses comparing the examined groups were performed using STATISTICA 13.3 PL (StatSoft, Poland) software. The significance level was set at $p < 0.05$. Owing to the lack of a normal distribution, as determined by the Shapiro–Wilk test, the median (Me) and quartiles (25% and 75%) were used in the descriptive statistics. Box plots were used to illustrate the distributional characteristics of the data. Intergroup comparisons of the distribution of the surface texture parameters were conducted using the nonparametric Kruskal–Wallis test.

Detailed data on the analysis conducted in this study with the use of a confocal microscope are provided in SI3.

Microcomputed Tomography (microCT)

As mentioned above, microCT scanning has already been used in the past to examine internal microfracture patterns on bone points used as hunting weapons (Bradfield, 2013; Bradfield *et al.*, 2016). These studies demonstrated the method's high usefulness in identifying this type of functional damage.

In our studies, two Bruker Sky Scan microtomographs were used: models 1272 and 1273. A Bruker Sky Scan 1272 microtomograph with voxel sizes of 2 and $3.5\ \mu\text{m}$ was used for most of the scans. Owing to the limited size of the device's scanning chamber, only fragments of selected experimental points (fishing experiments, Po 1, 6–9, 28; terrestrial hunting experiments, 14.1, 14.16, 14.17, 14.23, 14.24) and smaller archaeological artifacts (a point from Kaltanėnai, and two arrowheads from Mirakowo-Grodno, inv. no. 37 and 17.01) were examined. Scanning was conducted in the Department of Surface Science, Bydgoszcz University of Science and Technology (Poland). The scanning results of one of the points from the Šventoji site (Lithuania) were obtained using a Bruker SkyScan 1273 in the Faculty of Medicine, Translational Health Research Institute, Vilnius University (Vilnius, Lithuania).

Results

Experimental Points Efficiency

A detailed description of the experimental results is provided in SI1, Table 1. All the points used as spearheads, arrowheads, and leister prongs easily penetrated the fish bodies and were suitable for repeated use (Fig. 1d–f, i, and k). No invasive damage was observed in most of them by the end of the experiments. The only exceptions

to this rule were the points made from overdried bones, one of which (Po 3) broke at the base after only seven uses. However, this was not due to the impact on hard targets, such as the river bottom, but to a natural crack in the raw material used for its production. A similar situation occurred with another point made from overdried bone, Po 5, which was completely destroyed (fragmented) after only four uses as an arrowhead, without any apparent reason like striking a hard target. Among the arrowheads made of overdried raw material, only point Po 4 proved to be useful, as it broke only after 42 uses as a result of hitting the river bottom.

The use of antler arrowheads was also interesting. Their tips quickly softened and became pliable, allowing them to be bent in various directions. Despite this, their penetrating power remained unchanged throughout the experiments.

Results of the Wear Analysis

Classification of the Wear Traces Observed on the Experimental Points

As demonstrated in the wear studies, clear wear traces appear on osseous points used for hunting fish after only 5–10 uses (more on this in the “Frequency of occurrence of the wear traces on experimental points” Section). Moreover, they significantly modify the original surface of the raw material (*cf.* SI1–WOA before and after the experiments), creating a relatively uniform group of wear marks. They have been classified into the following types:

1. Impact damage (ID): The traces of this category observed on bone points used in the reported hunting experiments, where fish were the targets, are specific and very delicate. DIFs clearly deviate from the typical invasive damage observed on points used in the terrestrial environment. These are essentially only minor fractures with additional crushing on the last 1–2 mm of the point tip (Fig. 3e and g–i), as well as (much less frequently) isolated fractures (mainly bending fractures with step terminations and burination; *cf.* Bradfield & Lombard, 2011), with scar lengths no longer than 4 mm (Fig. 3c and d). Slightly more invasive damage was observed only in one case (Fig. 3f). On antler points, crushing and bending of the raw material fibers occurred (Fig. 3a and b). None of the fractures identified can be considered diagnostic for osseous projectile point function according to current knowledge (Bradfield, 2015; Bradfield & Brand, 2015; Bradfield & Lombard, 2011).
2. Rounding (R): This type of trace consists of macroscopically and/or microscopically readable rounding of the points' tips or barbed edges (*e.g.*, Fig. 4a; SI1, Plate 1a and b).
3. Compression traces (CT): These traces feature small (approximately 20–50 μm) and usually shallow, oval or irregular depressions in the polished surface, resulting from compression of bone fibers in areas most exposed to the influence of usage factors (Fig. 4b; *cf.* SI1, Plate 2c and d). In their well-developed form, they give the polished surface a pitted (still homogeneous) microtopography (Fig. 4b; *cf.* SI1, Plate 1e and f, tips; Plate 1 g and h, barbs). It seems that a significant

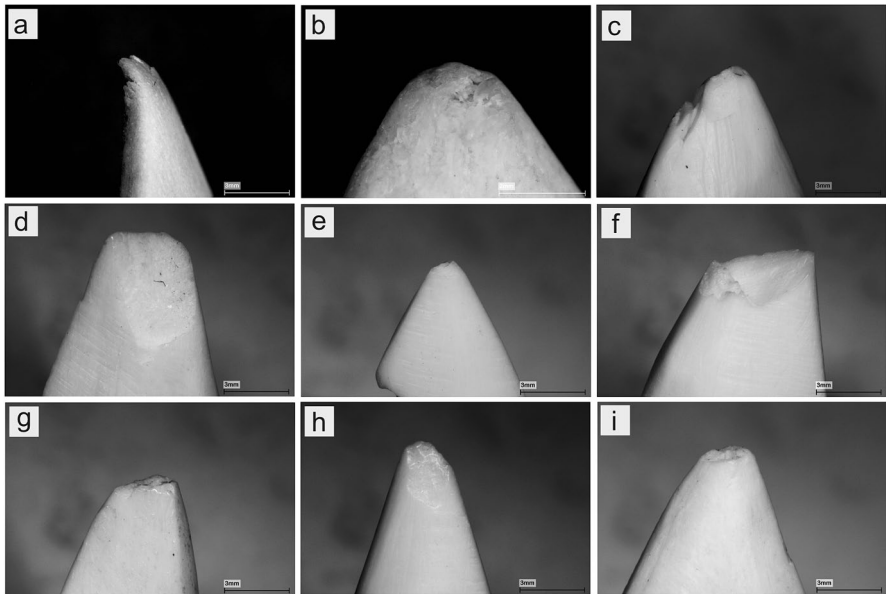


Fig. 3 Impact damage (ID) observed on analyzed experimental points: DIF-type traces (**c**, **d**, and **f**), minor fracturing with crushing (**a**, **b**, **e**, and **g–i**). **a** point 8, **b** point 9, **c** point 10, **d** point 11, **e** point 12, **f** point 13, **g** point 16, **h** point 17, and **i** point 20. All micrographs were obtained with the use of the Nikon SMZ-745 T stereo microscope

role in the creation of these types of traces is played by the softening of the bone surface due to its use in an aquatic environment.

4. Osteonstructure highlighting (OH): These traces comprise modifications to the bone and antler surface, resulting in increased readability of the osteon network and its structure. Three types have been distinguished:
5. OH1: The appearance of the singular osteons is changed. Their Haversian canals are clearly visible; the structure of the lamellae becomes better readable (highlighted), as a result of a slight collapse of the interlamellar matrix (Fig. 4c; cf. SI1 Plate 1a, i, and j). The structure of the osteon network is therefore gently highlighted, slightly different from the standard structure (cf. Kim *et al.*, 2007; Fig. 4).
6. OH2: The structure of the osteon network is strongly highlighted (Fig. 4d; cf. SI1, Plate 1 k–o). The Haversian canals and the structure of the lamellae are clearly visible because of the strong collapsing of the interlamellar matrix (lamellae are less visible in the case of antlers, SI1, Plate 1o). The highlighting of the osteon network strongly affects the microrelief and topography of the raw material surface.
7. OH3: The structure of the osteon network is strongly highlighted, primarily due to the increased visibility of natural openings such as Haversian and Volkmann's canals and blood vessels, and, at the same time, with the almost complete degradation and obliteration of the lamellae network and their collapse along with the interlamellar matrix (Fig. 4e; cf. SI1 Plate 1p). Unlike OH2-type traces,

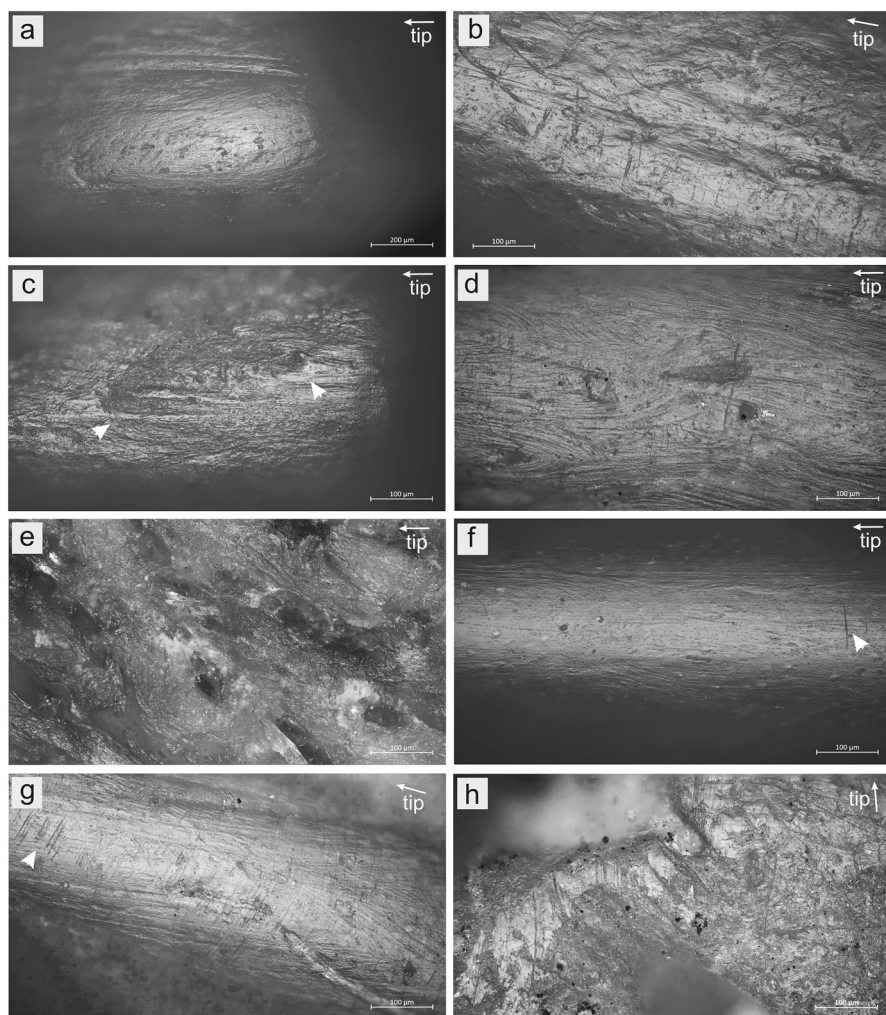


Fig. 4 The examples of diagnostic wear traces observed on experimental barbed points: **a** rounding (R); **b** well-developed compression traces (CT), pitted microtopography; **c** osteon highlighting of the OH1 type; **d** osteon highlighting of the OH2 type; **e** osteon highlighting of the OH3 type; **f** polish type P1; **g** polish type P2; and **h** polish type P3. In micrographs (f) and (g), white arrows indicate linear traces of the LT2 type. All micrographs were obtained with the use of the Zeiss Axiotech 5 Vario microscope

where other categories of wear traces (such as polish) are clearly legible, clear surface degradation (erosion) is also visible, resulting in the destruction of other microwear and manufacturing traces.

8. Polish (P): Three types of use polish were observed at the analyzed experimental points.
9. P1: A pale, “melted” polish covering the primary surface (natural surface relief of the bone or manufacturing traces). However, it is the most developed and

legible in the upper parts of the surface relief (particularly if weakly developed). Its characteristic feature is a lack of linearity (the apparent linearity of the polish visible in some micrographs results solely from the linearity of the scraping traces it covers; once these are erased, the linearity disappears). The polish has generally flat appearance, and homogeneous microtopography (in some cases pitted, when compression traces are well-developed). The microrelief of the polished surface is regular, and the high points are usually flat. The polish texture is generally completely or almost completely smooth, lacks clearly visible roughness, granular irregularities, or sharply protruding asperities (Fig. 4f; *cf.* SI1, Plate 1e, f, r–t), although in some cases, a slightly rough texture was also observed due to surface erosion (mostly on the archaeological artefacts, where postdepositional factors influenced the polish).

10. P2: A polish with characteristics identical to those described for type P1 but linear, with an orientation perpendicular to the direction of the point's impact. The linearity of the polish is the result of smoothing the linear traces of types LT1 and LT2 (*e.g.*, Fig. 4g; *cf.* SI1, Plate 1c, u, w; Plate 2c).
11. P3: Bright, usually linear polish/abrasion, oriented according to the direction of the point's impact (or close to it). This polish type covers mainly the upper parts of the surface relief. Its microtopography is usually more heterogeneous, and the microrelief is more irregular, than in the case of polish types P1 and P2. The texture of the polish may be slightly rough, and the high points of the microrelief are flat or (often) slightly rounded (Fig. 4h; *cf.* SI1, Plate 5a, b).
12. Linear traces (LTs): Seven types of linear traces were identified on the experimental barbed points analyzed, most of which are oriented perpendicular to the direction of the points' impact. Transverse cracks resulting from "material stress" when the tip impacts the target are also included, as they are not always clearly distinguishable from ordinary striations.
13. LT1: Very shallow, hairline scratches oriented perpendicular to the direction of impact on the target. They occur primarily at the top of the barbs, within the polish, singly or in groups. Their length is usually approximately 30–100 μm , and their width is less than 1 μm (Fig. 5a; *cf.* SI1, Plate 1c–e, r, and u; c and d).
14. LT2: Scratches oriented perpendicular to the direction of impact on the target, resembling incisions with a V-shaped cross-section, quite regular edges, and much greater depth than linear traces of the LT1 type (Fig. 5a and b). Their length is usually approximately 50–80 μm , and their width is 1–3 μm (usually 2–3 μm). They occur mainly on the tops of the barbs, within the polish, as single striations (*e.g.*, Fig. 5a; SI1, Plate 1n) or in groups (*e.g.*, Fig. 4g; SI1, Plate 2e–g).
15. LT3: A broad group that includes various types of short scratches and microcracks with relatively great depth and orientation perpendicular or slightly oblique to the direction of impact with the target. Their lateral edges are usually uneven and torn, and their ends are irregular. Their cross-sections can vary (irregular, U-shaped, and V-shaped). These traces occur singly or in groups at the tops of the barbs. Their length is approximately 20–70 μm , and their width is usually approximately 3–6 μm (*e.g.*, Fig. 5c; *cf.* SI1, Plate 2 h–l). Some LT3-type striations were probably created due to the "material stress" as a result of

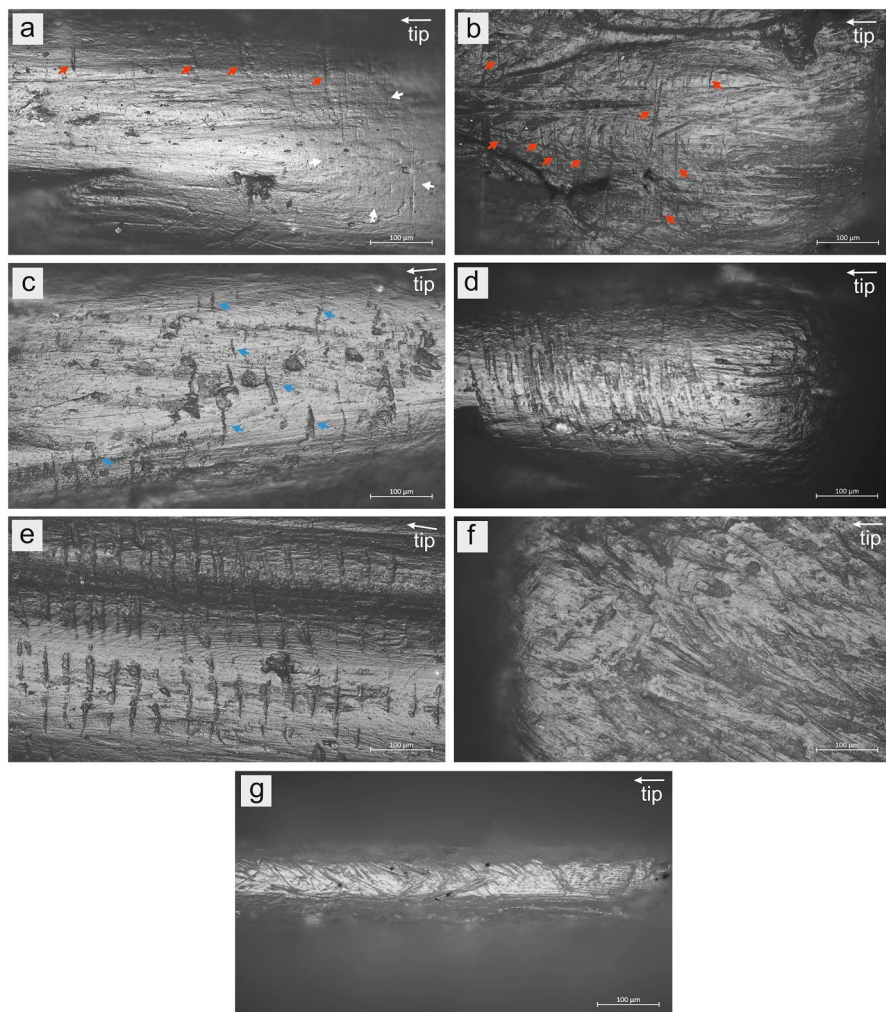


Fig. 5 The examples of diagnostic wear traces observed on experimental barbed points: **a** linear traces type LT1 (white arrows); **a** and **b** linear traces type LT2 (red arrows); **c** linear traces type LT3 (blue arrows); **d** linear traces type LT4; **e** linear traces type LT5; **f** linear traces type LT6. Micrographs taken on points: 1 (**a**), 3 (**d**), 6 (**c**), 7 (**e**), 9 (**b**), 17 (**f**), and 26 (**g**). All micrographs were obtained with the use of the Zeiss Axiotech 5 Vario microscope

hitting the target and/or drying out the raw material used in the water condition (which, of course, requires confirmation with proper material studies). In the case of others, their origin remains unclear due to modifications resulting from the development of use polish and smoothing.

16. LT4: Much longer than in the case of LT3-type traces, perpendicular scratches observed in clusters. They have uneven edges and strongly roughened bottoms

Table 1 General characteristics of the wear traces observed on experimental points (detailed data on this topic, describing the observations made on individual WOAs, can be found in S11 and Table 2)

Wear traces WOA	ID	R	CT	Highlighting of the osteons structure			Type of polish			Linear traces						
				OH1	OH2	OH3	P1	P2	P3	LT1	LT2	LT3	LT4	LT5	LT6	LT7
Total in WOAs (%)	7.7% (Tips: 46.4%) N: 169	95.3%	73.4%	27.8%	42.6%	1.8%	95.3%	7.7%	4.7%	33.1%	24.2%	22.5%	2.4%	13%	5.3%	10.1%
N: 169	N: 161	N: 124	N: 47	N: 72	N: 3	N: 161	N: 13	N: 8	N: 56	N: 41	N: 38	N: 4	N: 22	N: 9	N: 17	N: 17
	N: 13			N: 118 69.8%						66.3% (N: 112); perpendicular: 58.6% (N: 99); other: 13.6% (N: 23)						

- (Fig. 5d; SI1, Plate 2 m). Their length is usually approximately 100–200 μm , and their width reaches approximately 20 μm .
17. LT5: Microchatter marks (Fig. 5e; cf. SI1, Plate 1 l; Plate 2n–p). Regular, deep cuts oriented perpendicular to the direction of impact on the target. They occur both on points' tips and on barbs, where they can be observed on both their tops and side surfaces (here, their orientation may be other than perpendicular). The length of individual cuts, for marks visible on tips, is usually approximately 200 μm , and their width is 10–20 μm . Cuts visible on barbs are generally approximately 110–120 μm long and approximately 10 μm wide. This group of linear traces also included individually observed serial scratches in the bone surface with similar regularity, orientation and characteristics, but with a longer length of up to approximately 500 μm (SI1, Plate 2p).
 18. Traces of this type are undoubtedly of functional origin. The “technological” chatter marks visible on the analyzed barbed points were erased by traces of use and had no apparent effect on their characteristics (e.g., SI1, Point 6 (Plate 8), barbs 3 and 4).
 19. LT6: Linear traces of various types with orientations consistent with the direction of impact of the point on the target (Fig. 4h; 5f; cf. SI1, Plate 1i).
 20. LT7: Linear traces of various characteristics and random orientation, which cannot be classified as one of the types of regularly oriented traces described above (Fig. 5g; SI1, Plate 1c).

Frequency of Occurrence of the Wear Traces on Experimental Points

Summarizing data on the occurrence of individual types of wear traces on the analyzed experimental points is reported in Table 1. Detailed data on this topic, describing the observations made on individual WOAs, can be found in SI1, Table 2.

The share of ID in the WOAs examined is relatively low, especially considering that some points were used 60 or even 120 times (cf. SI1, Table 1). They were observed in only 13 cases (7.7% of the WOA), exclusively at the tips of the points. This means that approximately 46% of the tips of the analyzed points bear IDs. However, these very subtle and specific types of damage are visible mainly under a microscope and are distinctly different from typical invasive IDs resulting from terrestrial hunting. Additionally, most of them resulted from the accidental impact of the arrow on sand/gravel at the river's bottom; thus, they cannot be directly treated as being the result of hitting water prey.

Among the usage damage observed on the analyzed points, the rounding characterizing tips and barbs constitutes an essential category. It occurred on more than 95% of the WOA, allowing us to consider it a permanent element of wear observed on bone points used for fishing. Compression marks (CT) constitute only a slightly smaller share, as they were identified on as many as 73.4% of WOAs.

A particularly significant category of usage damage is osteon structure highlighting (OH). This type of modification was observed on 69.8% of the WOAs. It should be noted, however, that in the case of long barbed points (length more than

10 cm, point nos. 1–3), OH-type traces occurred only on the first four to six barbs of these points (which most often had direct contact with the target, *cf.* Fig. 6e). This increases the percentage of OH-type traces for WOAs in this location. The type of OH observed appears to depend on the type of raw material used to produce the points. OH3-type modifications were observed exclusively on points made of antler.

Similar to rounding (R), P1 polish was identified in more than 95% of WOAs, which also allows it to be treated as a relevant element of microwear observed on osseous points used for fishing. P2 polish occurred on 7.7% of WOAs, whereas P3 polish was observed on only 4.7% of them (primarily on the tips of the points and less frequently used on barbs).

In the case of linear traces, the exceptionally high proportion of various striations oriented perpendicular to the direction of the points' impact, reaching 58.6% of the WOAs, is indeed surprising. These traces are usually absent at the tips of the points (except for microchatter marks) and are typical primarily of barbs. Among them, the most significant are LT1 striations, identified (confidently) on 33.1% of the WOAs. However, it should be noted that on some points (*e.g.*, Po 1–Po 4), they occurred on most of the barbs. LT2 traces, a “deeper” version of LT1 striations, occurred on 24.2% of the WOAs, and similar to LT1, on some points (*e.g.*, Po 2 and Po 4), they were observed on most of the barbs.

The LT3 and LT5 traces are also undoubtedly highly significant. The former occurred on 22.5% of the WOAs, whereas the latter occurred on 13%. If we assume that both mark categories are largely material stress-related, then modifications of this origin were observed on 31.9% of the analyzed WOAs (with some barbed points, such as Po 3, 4, 7, and 8, where they are visible on almost half or half of the barbs). This finding indicates that they are a significant component of the wear traces typical of osseous tools featuring the functional profile studied.

Linear traces of LT4 were observed in only four cases. More numerous are striations oriented in the direction of impact (LT6), which occurred on 5.3% of WOAs. Multidirectional LT7 striations were observed on more than 10.1% of WOAs.

No linear traces were observed on 33.7% of WOAs. If we include WOAs where this type of modification is represented exclusively by LT3 and LT5 (*i.e.*, not typical striations but material stress-induced traces), the percentage of WOAs without classic linear traces increases to 49.1%. This is undoubtedly a significant figure.

As experimental and wear studies have shown that projectile points, even from the same experimental series, can exhibit a very high degree of variability, more so than for any other activity (Rots & Plisson, 2014). However, in the case of analyzed experimental osseous points, a fairly uniform and repeatable set of functional modifications was observed.

The rate of wear trace development and spread on osseous points used for fishing is quite rapid, and after just a few “uses,” they cover the point's surface that came into contact with the target. After only about 4–5 hits, the tip of the point and the barbs' tips develop rounding (R), compression traces (CT), slight osteon highlighting (OH1 and OH2), P1-type polish (also P3 on the tips), and hair-like LT1-type linear traces (Fig. 6a). This wear, however, does not completely cover the primary surface (natural surface relief of the bone or manufacturing traces), but appears mostly in its upper locations.

Fig. 6 Diagram of the organization and development of the wear traces on the experimental points after 5 (a), 10 (b), 30 (c), and 50 (d and e) hits in fish. Next to each drawing is a list of wear traces (their symbols) that were identified on points used a given number of times. Degree of wear trace development: (1) well-developed wear traces, completely covering the surface relief of the raw material/manufacturing traces; (2) weakly developed wear traces, the natural surface relief of the raw material or manufacturing traces is still quite clearly visible; and (3) initial wear traces, the natural surface relief of the raw material/manufacturing traces dominates over the usage modifications

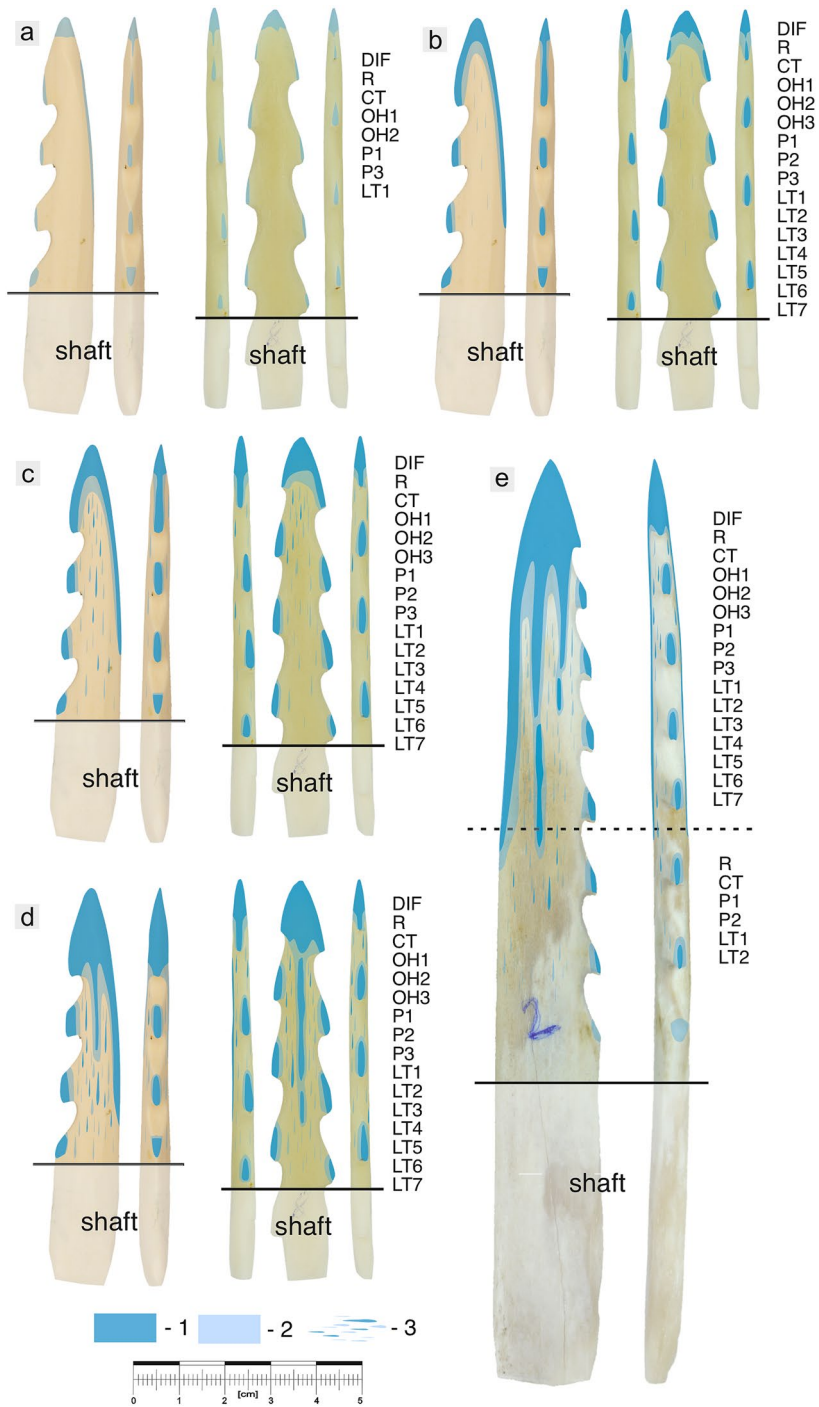
After ten hits, wear traces on the points' tips and barbs are already very well-developed, completely covering the natural surface relief of the raw material and/or manufacturing traces. Ten hits in fish are sufficient for all distinguished types of wear damage to develop on the point, allowing for their reliable classification and interpretation (Fig. 6b).

Further stages of wear trace development on points used in this manner involve a gradual increase in the extent of the wear modifications completely covering the surface relief on the points' tips and barbs, and a slow development of wear traces on the points' shafts (Fig. 6c). The characteristics of the wear traces themselves and their composition do not undergo any significant changes. After approximately 50 hits, wear traces cover approximately 2/3 of the surface relief of the raw material on the short (up to approximately 10 cm) points' shafts (Fig. 6d). For longer specimens, the situation is somewhat different, as the most intense wear traces occur in the first 8–9 cm of their length. All of their distinguished categories can be observed here (Fig. 6e). On the barbs located further from the tip, OH-type traces or linear LT3–LT7-type traces were not recorded, which is likely due to the fact that these parts of the points did not regularly interact directly with the target fish.

It has been observed that the development of wear modifications on points' shafts is highly dependent on their cross-section. In the reported experiments, relatively flat points were used, which resulted in weaker wear trace development in areas closer to the center of the point. Using tools with a more oval cross-section would likely result in faster and more intense wear trace development in these areas.

Most categories of distinguished wear traces develop in a way that prevents the determination of their variability over time. For the same reasons, it is also impossible to determine the factors influencing their presence on the points and their intensity at this stage of research. This is the case for P2 and P3 polish, as well as all types of distinguished linear traces. The occurrence of IDs depends on random factors, such as hitting hard material (the bottom of a water body or a larger fishbone). The appearance of rounding (R) was observed after just four hits. In locations on the surface of the points that come into most intense contact with the target, P1 polish destroys (covers) the surface relief of the raw material after just 7–10 hits, completely altering its original topography (natural or created by manufacturing processes). Changes occurring within these areas through continued use of the points are not significant enough to allow for their classification (apart from the above-mentioned increase in the range of such zones).

OH-type traces are, as noted, directly related to impacts on fish, but a linear progression from OH1 to OH3 was not observed. The factors influencing the presence of specific modification categories on individual points are undetermined at



this stage of research and may result from both the characteristics of the raw material used to produce them (*e.g.*, degree of desiccation, type of raw material) and the number or quality of hits. OH3-type modifications were observed only on points made of antler, and they appear to be characteristic of this type of osseous raw material due to its susceptibility to structural damage (fiber disruption) when softened as a result of contact with water.

The development and characteristics of compression traces (CT) likely depend primarily on their location (the degree to which a given part of the point is exposed to contact with the target) and the type and characteristics of the raw material from which the point was made. Certainly, such traces are not the result of applying the manufacturing techniques (scraping and whittling), as evidenced by micrographs of WOAs before experiments (SII, Plates 3–11). The experiments conducted showed that the intensity of such marks is not dependent on the number of hits on the target, although their most developed form was observed on a spike with a leister prong used over 120 times (*cf.* Figure 4b).

Results of the Polish Texture Analysis using a Confocal Microscope

For each investigated object, the surface roughness of the material was quantitatively assessed using the S_a , S_q , S_{sk} , and S_k parameters. The median, first quartile, third quartile, minimum and maximum values are presented in the boxplot in Fig. 7a–d. The highest S_a values (Fig. 7a) were found for specimen Po 4, with a median value of $Me=0.15\text{ }\mu\text{m}$, a maximum of $0.17\text{ }\mu\text{m}$, and first and third quartiles of 0.07 and $0.16\text{ }\mu\text{m}$, respectively. This distribution of roughness, also reflected in the S_q parameter (Fig. 7b), indicates the presence of two distinct roughness regimes on the surface, suggesting that two different factors influenced the surface topography. The lowest S_a median value ($Me=0.08\text{ }\mu\text{m}$) was observed for Po 1, which is a more homogeneous surface than Po 4. The roughness values for specimens 14.1 and 14.2 were lower than those of Po 4 and slightly higher than those of Po 1. The negative median values of S_{sk} for all the specimens (Fig. 7c) indicate asymmetric right-skewed deviations from the normal distribution. A detailed analysis using the Shapiro–Wilk test revealed that the roughness parameters that most deviated from normality were those of Po 4 and 14.2. However, no statistically significant differences were found between the roughness values obtained for the investigated specimens. The results of the Kruskal–Wallis test indicated no significant difference between the specimens for the S_a , S_q , S_{sk} , and S_k parameters, with p values of 0.172, 0.134, 0.733 and 0.575, respectively.

Results of the MicroCT Analysis of the Experimental Points

As a result of the microCT studies, in addition to natural (Haversian and Volkmann’s canals, blood vessels) and pathological (voids) “holes” in bones (Bradfield, 2013; Kim, *et al.*, 2007), as well as cracks that may result from desiccation of the bones used in some experiments (covering entire objects), a number of

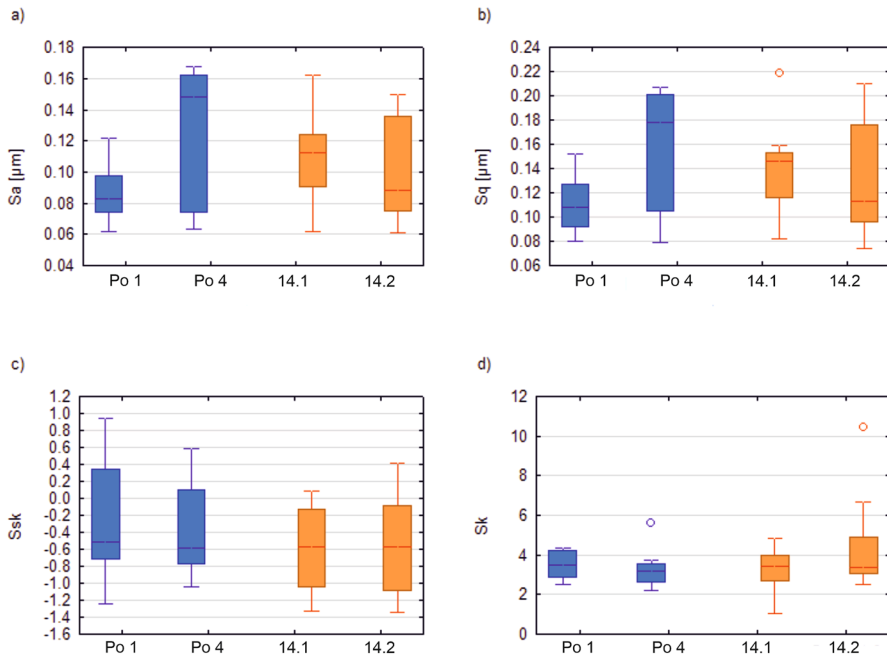


Fig. 7 Polish texture analysis using a confocal microscope. Boxplot of roughness values determined for the four tested samples: **a** average surface roughness (Sa), **b** root mean square roughness (Sq), **c** skewness (Ssk), and **d** kurtosis (Sk)

types of damage were identified. These types of damage differ significantly in the case of experimental points used for terrestrial and fishing.

With respect to the tools used in the aquatic experiments, significant subsurface compression of bone fibers was observed at the tips of the points, whereas no internal cracks that could have formed during impact with the target were observed (Fig. 8a–f). This compression (evident in grayscale scans as white areas and in color scans as yellow and even blue areas) is apparent when comparing scans taken at the tips of the points with reference scans taken at the bottoms of selected specimens, where the compressed areas are not visible at all (*cf.* Po 7 and Po 9: reference). Additionally, on points made from antler used for fishing, a modification not present in the bone points used in this manner was observed. It is visible as bending and separation (but not cracking) of the raw material fibers resulting from their softening.

Typical internal cracks of different types resulting from impact (*cf.* Bradfield, 2013; Bradfield *et al.*, 2016) were observed on all the points used in the terrestrial hunting experiments (Fig. 8g–k), even those targeting the very delicate body of a baby roe deer (Fig. 8i). Additionally, the points used in these experiments showed almost complete removal of areas of raw material fiber compression by rapidly progressing DIFs (Fig. 8g and h). The compression traces are visible only on the arrowhead shot at the body of a baby roe deer, where the after-impact surface

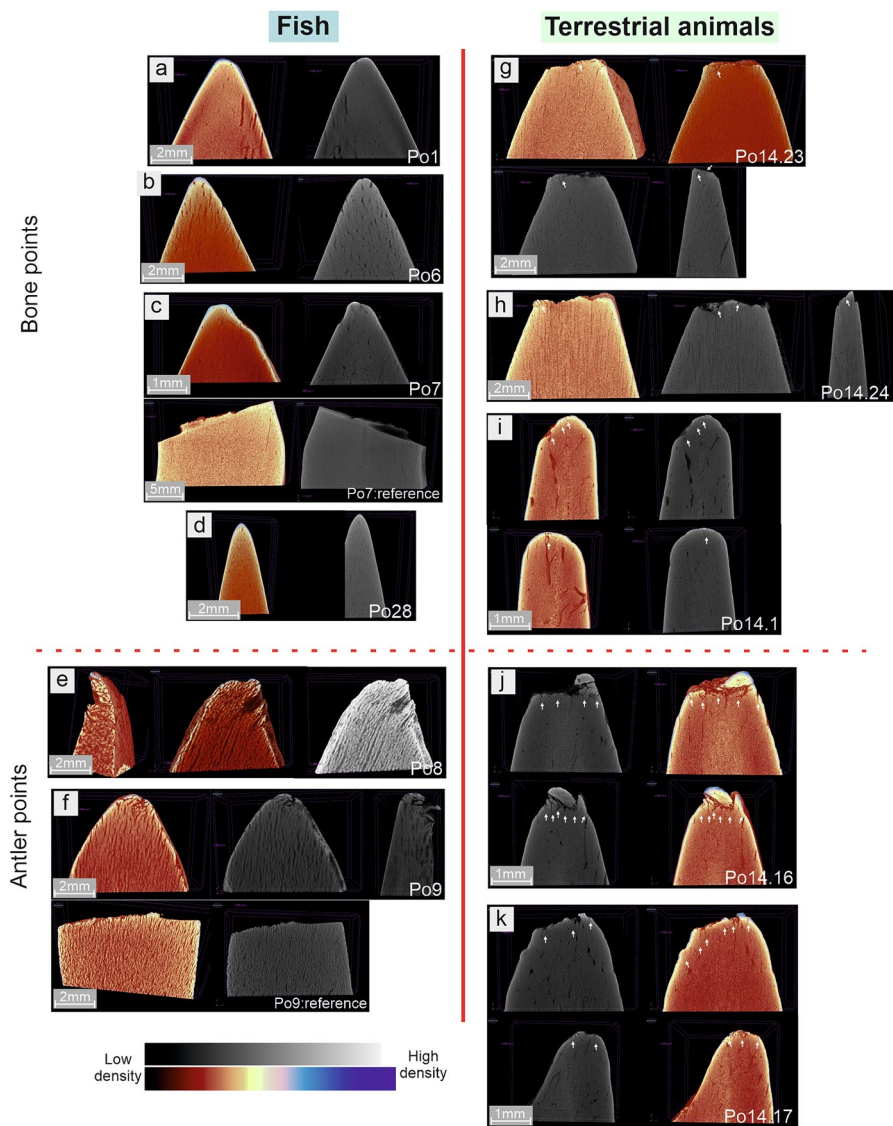


Fig. 8 Results of the microCT studies of the experimental points. The scans were made with the use of a Bruker Sky Scan 1272 microtomograph

removals are very delicate (Fig. 8i), and on one of the antler arrowheads, where a fragment of compressed fibers “stuck” to the tip (Fig. 8j).

Discussion

Classification of the Defined Fishing Wear Traces Created on Osseous Points in the Context of the Current Knowledge of the Issue

One of the basic aims of the research reported in this article was to formulate a classification of the wear traces created on osseous points as a result of their use for fishing. However, an essential difficulty in achieving this goal objectively is that the state of research on microtraces created on osseous points used for hunting terrestrial animals is insufficient. This makes it difficult to make a complete comparison of the observations made here with the results of wear analyses of tools used in this manner. Therefore, the findings presented below should be considered as still requiring verification. We consider it possible that some of the wear traces described here as distinctive for points used in fishing may also be identified on points used in terrestrial hunting under specific conditions. The important unknown here is, for example, the wear traces created on osseous points used for hunting small aquatic mammals, *i.e.*, animals that combine terrestrial and aquatic environments. However, investigating this problem requires independent, specialized studies.

As presented in the Introduction, previous experimental studies and related wear analyses have shown that DIF damage is the most distinctive feature in distinguishing osseous heads of hunting weapons, with modifications observable at the micro-wear level playing a secondary role. However, these studies were primarily based on analyses of tools used in hunting experiments conducted in terrestrial environments, most often involving the bodies of large mammals. The results of the wear studies reported in this article are quite different.

First, it should be noted that in the case of osseous points used for fishing, ID traces are of less significance, as they are rare or minimally invasive. Most of the observed damage of this type was not caused by impacts with fish but by accidental contact with the river bottom. Furthermore, this is a very specific damage, identified primarily microscopically (minor fracturing with or crushing), whose presence does not prevent further use of the points, as is usually the case with DIFs associated with hunting terrestrial animals. These types of damage usually blur quickly with further use and do not affect the points' penetration capabilities. Their subtlety can result in them being illegible on prehistoric artifacts due to the surface modifications resulting from postdepositional changes. The essential type of wear damage in the case of antler points used for hunting fish can be bending and separation of the raw material fibers at their tips. However, confirming this observation requires more experiments involving the use of antlers from different species under various conditions.

One of the key elements of usage damage occurring on osseous points as a result of fishing is compression traces (CTs), a type of trace “equivalent” to DIF traces typical of terrestrial hunting, replacing them in this case as the main category of impact damage recorded on points. This situation is caused (as it seems, but it still

must be confirmed by detailed analysis) by the progressive softening of the bone material in an aquatic environment, which increases its plasticity (reducing the possibility of impact fracture while improving the compressive properties of the fibers). An essential step in analyzing this type of damage is microCT examination, which enables the identification of compression traces within the points and their counterparts in cases of terrestrial hunting, such as the removal of fragments of compressed surfaces and internal cracks.

Additionally, highlighting the structure of the osteons (OH), which (similar to compression traces) has not been previously mentioned in the literature in this context, is highly important for identifying points used for fishing. These traces do not appear to be solely related to tool use in an aquatic environment; however, their genesis is directly related to the discussed function (fishing) because (as mentioned earlier), in the case of the experimental long points, they were formed only on the first 4–6 barbs of the tools that had direct and prolonged contact with fish.

The P1-type of polish, characterized by a lack of linearity, may also be crucial for the osseous points used in this manner. However, “nonlinear” polish was also mentioned by N. Buc in the context of the general characteristics of wear traces typical of osseous points used for hunting and therefore also for those used for hunting in a terrestrial environment (Buc, 2011). It is difficult to clearly determine whether and to what extent the polish described by Buc corresponds to the P1-type of polish identified here, as her cited article lacks a microphotograph of it. Buc characterizes it as irregular, with heterogeneous microtopography and rounded high points of relief. This description differs significantly from the characteristics of the P1-type of polish, which we defined as generally flat, having homogeneous (sometimes pitted) microtopography (with a “melted” appearance), regular microrelief, and usually flat high points. As a result of terrestrial hunting experiments conducted by our team, a rather dull nonlinear polish was also observed on some of the bone points used, corresponding to the description by Buc (Fig. 9c). However, it is quite different from the P1 polish and corresponds rather to what Zhilin describes as “hide”-type polish (Zhilin & Ruev, 2025). It covers only the upper parts of the surface relief (Fig. 9a and b) and may also have linear characteristics consistent with the direction of the point’s impact (Fig. 9d and e), thus corresponding to the P3-type polish described above. This polish occurs both on the tips of the points (Fig. 9d) and on the barbs (Fig. 9e). It is only one of many versions of polish recorded on points used for terrestrial hunting, which can also be much brighter (Fig. 9f and h), highly abrasive (Fig. 9i), or take the form of bright spots (Fig. 9g).

Considering the wide optical variability of polish identified on points used for terrestrial hunting, the results of analyses conducted for this study using a confocal microscope are interesting. They revealed no differences in the roughness of the polish formed on points used in experimental fishing and terrestrial hunting. However, this analysis utilized points from experiments where the target was a baby roe deer, the body of which was very soft (also because the animal had died many days earlier), which resulted in only limited ID formation on the points used here. Moreover, the resulting polish is very bright and, in some respects (only the slightly marked linearity and penetration of deeper sections of the microrelief), resembles the P1 polish (Fig. 9h). Therefore, the observed lack of differences may be due to the

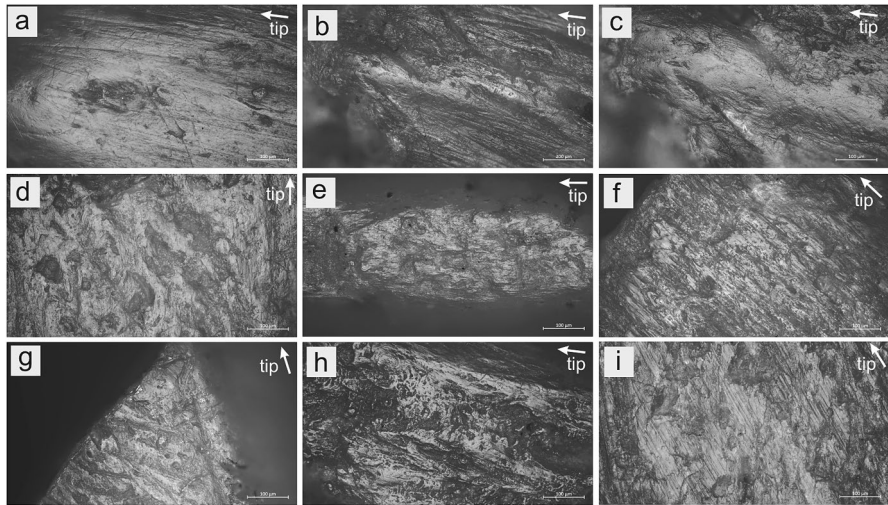


Fig. 9 Examples of microwear traces observed on osseous points used in terrestrial hunting experiments (cf. S11, Table 1): **a**, point 14.2; **b** and **c**, point 14.22; **d** and **e**, point 14.23 (**d**, tip; **e**, barb); **f**, point Ł2/2; **g**, point Ł2; **h**, point 14.17; **i**, 14.24. All micrographs were obtained with the use of the Zeiss Axiotech 5 Vario microscope

specificity of the target being shot at; thus, analysis of a larger number of specimens is necessary for full statistical validation of the results obtained by confocal microscopy. Unfortunately, such an analysis is not currently possible.

The situation with linear traces is also interesting. According to Buc's (2011) findings, this type of damage is generally not present on the osseous points of hunting weapons. This suggestion is confirmed in our study in only 17.9% of the analyzed WOAs. This finding is contradicted primarily by the number and diversity of linear traces oriented perpendicular to the axis of the analyzed barbed points, which were observed on as many as 60% of WOAs. Such a high rate of this type of damage, in the absence of broader literature data on its occurrence on osseous points used in experiments conducted in terrestrial environments, allows us to initially consider them a significant distinguishing feature of osseous points used for fishing.

Unfortunately, not much can be said about the significance of the distinguished types of perpendicular linear traces for the classification of wear traces typical of osseous points used for fishing. This is because of the generally still poor understanding of the category of damage under discussion.

In the wear publications on osseous heads of hunting weapons, we found no confirmation of identifying linear traces of types LT1 and LT2 on other experimental tools. However, we observed them on points 14.1 and 14.2 studied in this article, indicating that they also occur on points used for hunting terrestrial animals. We also found no information on traces analogous to the damage types LT3 and LT5 identified here. In her studies, Buc also mentions transversal traces originating from "mechanical stress" present on the osseous heads of hunting weapons. However, she considers damage with different characteristics

Table 2 Characteristics of the wear traces observed on included prehistoric osseous points

No	Site	Inv. no	ID	R	CT	Highlighting of the osteons structure			Type of polish			Linear traces			Possible function/comments (figure)			
						OH			P			LT						
						OH1	OH2	OH3	P1	P2	P3	Other	LT1	LT2		LT3	LT4	LT5
1	Wiele 33	MOB/A-4644	-	+	+	-	+	-	+	-	-	+	+	+	-	-	+	Fishing (Fig. 13)
2	Wiele 33	MOB/A-4644	-	+	+	+	-	-	+	-	-	+	+	+	-	-	-	Fishing? (SI2, Plate 2)
3	Lisi Ogon 13	MOB/A-959	-	+	N	+	-	-	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:1)
4	Mirakowo-Grodno 6 37		+	-	-	-	-	-	-	-	-	+	-	-	-	+	+	Terrestrial hunting (Fig. 14:1)
5	Mirakowo-Grodno 6 17/01		+	-	-	-	-	-	-	-	-	+	-	-	-	+	-	Terrestrial hunting (Fig. 14:2)
6	Mirakowo-Grodno 6 13/01		-	+	+	-	-	-	-	-	+	-	-	-	-	+	+	Ambiguous (terrestrial hunting?) (SI2, Plate 4:1)
7	Mirakowo-Grodno 6 202/03		-	+	+	-	-	-	-	-	-	+	-	-	-	-	+	Ambiguous (terrestrial hunting?) (SI2, Plate 4:2)
8	Šventoji	EM2136:173	-	+	+	-	+	-	+	-	-	-	+	-	-	-	-	Fishing (Fig. 12 (2))
9	Šventoji	-	-	+	-	-	-	-	-	-	-	+	-	-	-	-	-	Ambiguous, not hunting? (SI2, Plate 6)
10	Pabiržulis	EM2391	+	+	+	-	+	-	+	-	-	-	-	-	-	±	-	Fishing (Fig. 12 (1))
11	Rūdinkai	EM2069:1	-	N	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:2)
12	Karaviškės	EM2015	-	+	-	-	-	-	+	-	-	+	-	-	-	-	+	Ambiguous (SI2, Plate 8)
13	Žemaitiškė 2	EM2430:31	-	N	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:3)
14	Žemaitiškė 2	EM2430:25	+	N	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 9)
15	Kaltanėnai	1306	-	+	-	-	-	-	-	-	-	+	-	-	-	-	+	Ambiguous (SI2, Plate 10)

Table 2 (continued)

No	Site	Inv. no	ID	R	CT	Highlighting of the osteons structure	Type of polish				Linear traces							Possible function/com- ments (figure)
							OH				LT							
							OH1	OH2	OH3	P1	P2	P3	Other	LT1	LT2	LT3	LT4	
16	Švenčionėliai	-	-	+	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:4)	
17	Lake Lubāns	A10120:131	N	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:9)	
18	Lake Lubāns	A10120:127	+	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:8)	
19	Lake Lubāns	A10120:145	-	+	+	+	-	+	+	+	-	-	-	-	-	-	Fishing (SI2, Plate 11)	
20	Lake Lubāns	A10120:125	-	+	+	+	-	+	+	+	-	-	-	-	-	-	Fishing? (SI2, Plate 12)	
21	Lake Lubāns	A10120:129	-	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:10)	
22	Lake Lubāns	A12120:134	-	+	+	+	-	+	+	-	-	-	-	-	-	-	Ambiguous, heavily destroyed postdepo- sitionally (SI2, Plate 13)	
23	Lake Lubāns	A10120:130	-	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:6)	
24	Lake Lubāns	A10120:80	-	+	+	-	+	+	+	+	-	-	-	-	-	+	Fishing (SI2, Plate 14)	
25	Lake Lubāns	A101120:83	-	+	+	+	+	+	+	+	-	-	+	+	+	-	Fishing (Fig. 10)	
26	Lake Lubāns	A10120:74	-	+	+	+	-	+	+	-	-	-	+	+	-	-	Fishing? destroyed postdepositionally (SI2, Plate 16)	
27	Lake Lubāns	A10120:76	-	+	+	-	-	+	+	-	-	-	-	-	-	-	Wear traces weakly developed, used for very short time (SI2, Plate 17:1)	
28	Lake Lubāns	A10120:81	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Not used/lost on first use (SI2, Plate 17:2)	
29	Lake Lubāns	A10120:75	-	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:7)	

Table 2 (continued)

No	Site	Inv. no	ID	R	CT	Highlighting of the osteons structure	Type of polish				Linear traces				Possible function/com- ments (figure)		
							OH1	OH2	OH3	P1	P2	P3	Other	LT1		LT2	LT3
30	Lake Lubāns	A10120:79	-	+	+	+	+	-	+	+	+	+	-	-	-	-	Fishing Point repaired (secondary scraped on the tip) (SI2, Plate 18)
31	Lake Lubāns	A10120:73	+	+	-	-	-	-	+	-	-	-	-	-	-	+	Ambiguous, destroyed postdepositionally. wear traces weakly developed (SI2, Plate 19)
32	Lake Lubāns	A10120:82	+	N	N	N	N	N	N	N	N	N	N	N	N	N	n/a (SI2, Plate 1:5)
33	Lake Lubāns	A10045:8	-	+	+	+	+	-	+	+	+	-	-	-	+	+	Fishing (SI2, Plate 20)
34	Lake Lubāns	A10051:25	N	+	+	-	+	-	+	+	+	-	-	-	+	-	Fishing (Fig. 11)
35	Lake Lubāns	A9415:4	-	+	+	+	-	-	+	-	-	+	-	-	-	+	Ambiguous (fishing?): heavily destroyed postdepositionally (SI2, Plate 22)

N, observations were not possible due to the destruction of the artifact surface by postdepositional factors or its coverage by preservatives; SI2, supplementary information 2

occurring at the tip (Buc & Loponte, 2007, Fig. 26; Buc, 2011, Fig. 14D). Therefore, given that we failed to observe LT3- and LT5-type traces on other osseous points used during the hunting experiments conducted under “land” conditions, we tentatively assume that these points may also be essential features for distinguishing barbed points used for fishing.

Zhilin reported that striations with an orientation consistent with or slightly oblique to the axis are characteristic of the osseous heads of hunting weapons (Zhilin, 2019; Zhilin & Ruev, 2025; Zhilin *et al.*, 2023). These traces correspond to the definition of type LT6 striations, which were rarely identified on the analyzed experimental tools and observed primarily on the tips. Taking this into account, traces of this type (such as multidirectional type LT7 striations) cannot be considered a significant indicator for distinguishing osseous points used for fishing (particularly because they are visible also on points used in terrestrial experiments—Fig. 9a, f, g, and i). However, they may help confirm the use of the point for hunting purposes.

Protocol to Identify the Wear Traces on Osseous Points Used for Fishing

In accordance with the findings of the conducted studies, a protocol for wear analysis aimed at identifying osseous points and wear traces resulting from fishing should include the following analytical steps:

- Step 1: Examination of macrotraces using a stereoscopic microscope. Indicators of the discussed function: (a) absence of IDs or their very “delicate” characteristic, (b) distinct rounding of the points’ tips and barbs, and (c) traces of use-related softening of the raw material (bending and separating of fibers; the case of antler specimens).
- Step 2: Microwear analysis using a metallographic microscope. Indicators of the discussed function: (a) highlighting of the osteon structure in the apical part of the points (over all the points except for the base in the case of small specimens); (b) presence of compression traces (CT) and P1-type polish, usually closely interconnected; (c) absence of any linear traces; (d) presence of linear traces oriented perpendicular to the points’ axis, particularly of the types LT1 and LT2 but also LT3 and LT5 striations.
- Step 3: microCT scanning and analysis of the internal structure of the points. Indicators of the discussed function: (a) clearly visible fiber compression on the tips, (b) absence of internal cracks and surface removal, and (c) separation and bending of the raw material fibers (antler samples).

Some categories of the wear traces mentioned can probably be found incidentally (under the influence of nonstandard functional conditions) and on points used for terrestrial hunting. However, in accordance with the findings of the reported studies, confirmation of the presence of all or most of these indicators suggests that the analyzed point could be used for fishing.

Application of the Protocol on Archaeological Osseous Points

Any classification of wear traces based on experimental research will be meaningless if these traces cannot be identified on prehistoric artifacts. Contrary to appearances, this is a significant problem, as in the case of objects made of organic materials, such as bone, the traces generated during use can be easily erased or altered by postdepositional processes, especially if these modifications are superficial. Therefore, verifying the findings in the reported studies required precise, experimental data-based wear studies of prehistoric artifacts, as well as a detailed application of the research protocol created.

As a result of such microscopic analyses, the states of preservation of 11 of the 35 prehistoric points included in the study precluded proper and reliable verification studies (*cf.* Table 2). Ambiguous wear traces were found on another eight specimens. However, their characteristics allowed us to suggest a possible connection with terrestrial hunting in two cases (Mirakowo-Grodno, site 6, inv. no. 13/01 and 202/03), in one case with fishing (Lake Lubāns, inv. no. A9415:4), and in one case with an activity other than hunting (Šventoji, without inv. no.). An excellent example of a specimen with such an (uncertain) functional profile is a barbed point from Kaltanėnai (inv. no. 1306). In this case, microCT scans allowed the observation of damage typical of points used for fishing (firm compression of fibers on the tip, no microcracks); however, these modifications were not confirmed by the traces of use observed on the postdepositionally altered surface of the specimen (*cf.* SI2, Plate 10).

Two of the analyzed points from the Lake Lubāns collection turned out to be unused or used very briefly (A10120:81, A10120:76, *cf.* SI2, Plate 17). Virtually no traces of use were observed on their surfaces (in the case of artifact A10120:76, these are rudimentary). Nevertheless, manufacturing traces (remains of scraping) are clearly visible. These points are crucial for the analyses presented here because, being of the analogous chronology as the specimens from Lake Lubāns described below and coming from the same depositional context, they demonstrate minimal impact of postdepositional processes on the well-preserved artifacts from this site, indirectly confirming the functional origin of the modifications observed on their surfaces.

Wear studies of the remaining 14 points (40%) from the collection considered in this article led to the identification of traces of use that allow us to suggest their original function with a high degree of probability. In twelve cases, this is fishing (Table 2). These points originate from various sites and have different typological characteristics but are characterized by very uniform wear traces, in most cases fully corresponding to the wear observed on the experimental tools used in this manner.

The most abundant morphological form among them is the uniserial barbed points with short, blunt, widely spaced barbs from the Lake Lubāns site (*cf.* Vankina, 1999). The presence of most or all the distinguished fishing indicators was confirmed on these points (especially for specimens A.10120:79, A10120:80, and A.10120:83). An example here is point A101120:83 (Fig. 10). This specimen did not exhibit DIF damage (Fig. 10a) but exhibited very strong rounding of the tip of the point and all the barbs (Fig. 10a and b). The polished surfaces are

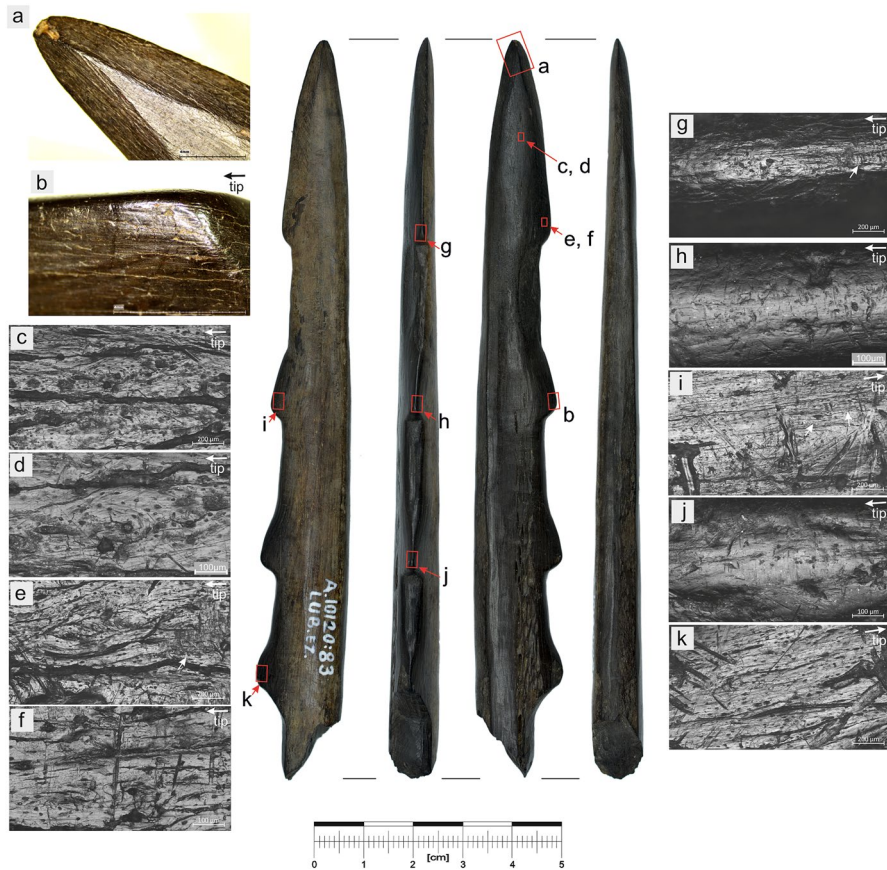


Fig. 10 Point from site in Lake Lubāns, Latvia (A101120:83). Example micrographs of the identified wear traces (arrows: **e**, linear traces LT4; **g**, micro chatter marks LT5; **i**, osteons highlighting of the type OH1). Micrographs were obtained with the use of Nikon SMZ-745 T stereo microscope (**a** and **b**) and Zeiss Axiotech 5 Vario microscope (**c–k**)

characterized by very clear compression marks (Fig. 10c, d, g, h, and j). In the apical part of the points, distinct osteon highlighting of the OH2 type was also observed (Fig. 10c–f), which disappeared approximately halfway along its length (here, poorly marked OH1, Fig. 10i). In places where the strongest compression traces and the most distinct osteon highlighting are present, numerous postdepositional cracks are visible, most likely resulting from the drying of the raw material (Fig. 10d–f). Modifications of this kind are even more legible on other points of this morphological type, for which a fishing function has been suggested (SI2, Plate 14c–e; 16c; 18e), as well as on points of a different form used in this way (discussed below). On almost the entire point surface, P1-type polish is visible (Fig. 10c–h), as is P2-type polish (Fig. 10j). All distinctive categories of linear traces were also observed, *i.e.*, LT1 and LT2-type striations (Fig. 10f), LT4-type linear roughening (Fig. 10e, cf. Figure 5d; SI1, Plate 2 m), LT5-type microchatter

marks (Fig. 10g), and LT3-type linear marks (Fig. 10h and j, *cf.* Figure 5c; SI1, Plate 2 h).

An interesting specimen of the discussed morphological type is point A10120:79 (SI2, Plate 18), on which the remains of repair (scraping) of the tip were observed (SI2, Plate 18a), which “removed” damage typical for fishing (CT, OH1, P1, P2?, LT1–LT3; *cf.* SI2, Plate 18e); its repeated use destroyed manufacturing traces (SI2, Plate 18b).

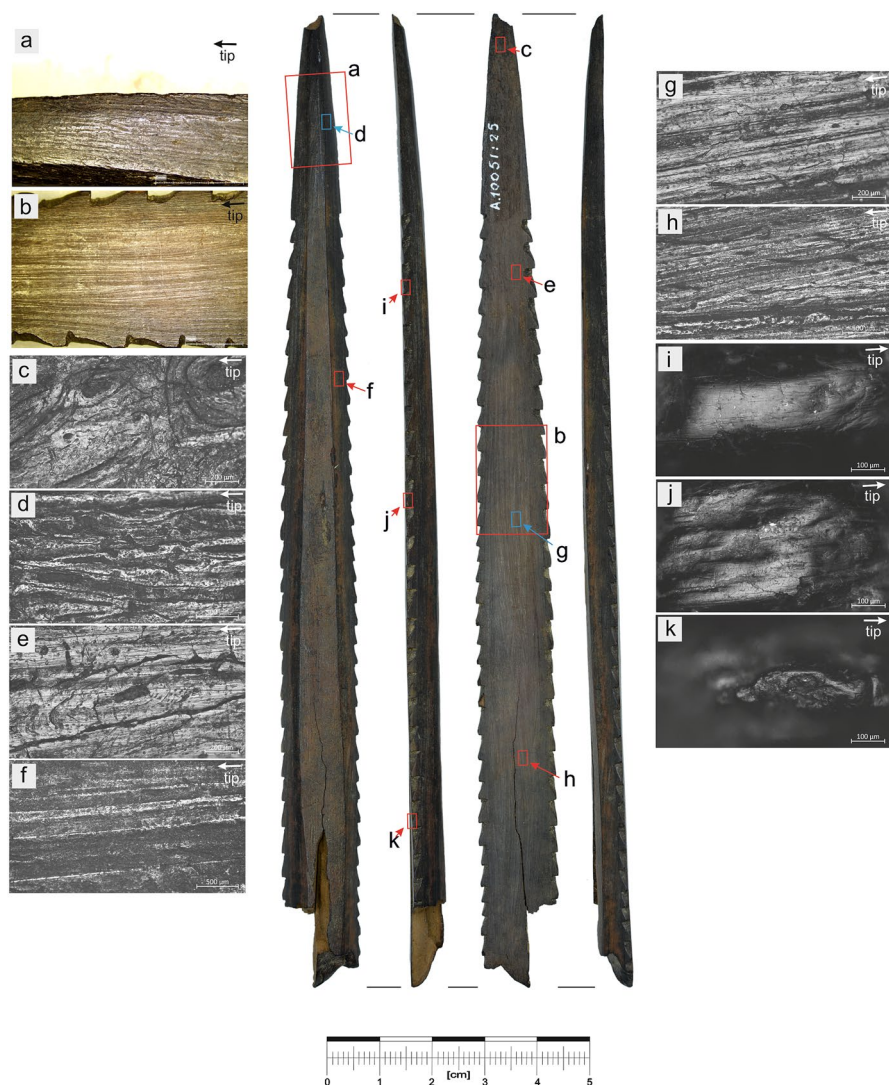


Fig. 11 Point from a site in Lake Lubāns, Latvia (A10051:25). Example micrographs of the identified wear traces. Micrographs were obtained with the use of Nikon SMZ-745 T stereo microscope (**a** and **b**) and Zeiss Axiotech 5 Vario microscope (**c–k**)

Very clearly legible traces of use corresponding to damage indicative of the fishing function were identified on two analyzed tanged points with triangular cross-sections with notched edges from Lake Lubāns (A10051:25, A10045:8; cf. Vankina, 1999). The tip of the first of the mentioned tools was damaged by postdepositional fracture (Fig. 11). However, in the case of the second one, ID traces were not noted (SI2, Plate 20). In the apical parts of both specimens, compression damage (CT), P1 polish, and OH2 osteon highlighting are clearly visible (Fig. 11c and d; cf. SI2, Plate 20d, e), which in the case of specimen A10051:25 gradually disappears after approximately 7 cm, indicating manufacturing traces (Fig. 11f–h). On specimen A10045:8, OH-type modifications are legible for approximately 2/3 of its length, disappearing only at the base (SI2, Plate 20f vs. 20c). On both points, very distinct postdepositional cracks were observed in areas of the strongest compression traces and the most pronounced osteon highlighting, often coinciding with the arc of the lamellae (Fig. 11c and e; cf. SI2, Plate 20d, e). In both cases, linear traces typical of fishing were also confirmed, although on specimen A10051:25, they were noted only at the tops of the barbs. These are striations of types LT1 and LT2, and on specimen A10045:8, also LT3 (Fig. 11i and j; cf. SI2, Plate 20d, e). Additionally, linear traces of types LT6 and LT7 occurred on the tools. When discussing these artifacts, it is worth noting the interesting technological practice observed on their surfaces, consisting of intentionally polishing only one (flat) surface of the points (Fig. 11e and g; SI2, Plate 20f). However, explaining the reasons for this feature requires further in-depth study.

Among the points from the Lithuania area that showed the presence of fishing traces, the most legible wear was observed on the specimens from Pabiržulis (EM2391) and Šventoji (EM 2136:173).

Typologically, the Pabiržulis artifact (Fig. 12 (1)) corresponds to barbed points that are finely toothed by oblique notches (Clark's No. 6; Clark 1936). The specimen exhibited probable ID traces (Fig. 12a), although a postdepositional origin of this fracture cannot be ruled out. OH2 osteon highlighting and strong compression marks, intensified by postdepositional drying processes, were observed in the first few centimeters of the apical part of the point (Fig. 12b–d). The OH traces gradually fade and are no longer legible halfway along the point (Fig. 12e). P1 polish was noted on most surfaces of the specimen (Fig. 12b–e), including its barbs, where it was sometimes accompanied by single filled-in striations consistent with the point orientation (Fig. 12f and g). There were no other linear traces, apart from single scratches of clearly postdepositional origin.

The Šventoji point (Fig. 12 (2)) is a burrless plain point of a circular section (Clark's No. 1; Clark, 1936). Typical usage damage, quite analogous to that seen on the Pabiržulis specimen, was observed here: compression marks CT, P1-type polish, and OH2-type osteon highlighting that disappeared at some distance from the tip (Fig. 12i–k). Furthermore, this specimen did not exhibit ID traces but rather a distinct rounding of the tip (Fig. 12h) and LT1- and LT2-type linear traces (Fig. 12k). This specimen is significant for the present study because its small size allowed for microCT scanning (Fig. 12l). The results revealed clear fiber compression at the tip, with a simultaneous absence of DIFs and internal (usage) cracks. This characteristic

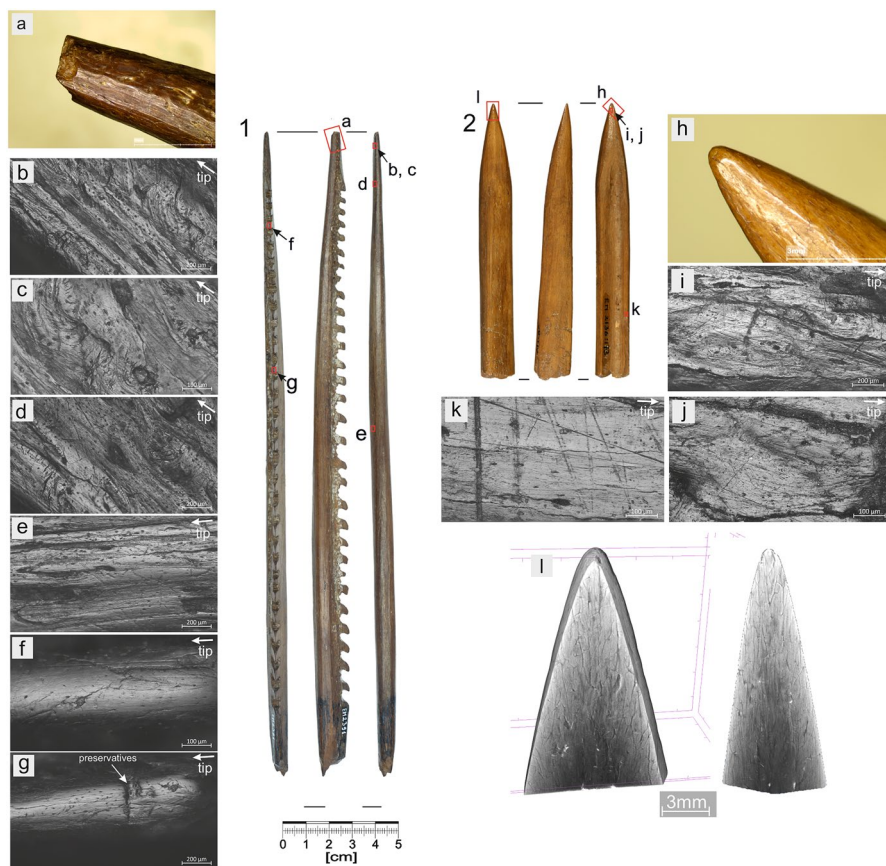


Fig. 12 Points from sites in (1) Pabiržulis (EM2391) and (2) Šventoji (EM 2136:173), Lithuania. Example micrographs (a–k) and microCT scans (l) of the identified wear traces. Micrographs were obtained with the use of Nikon SMZ-745 T stereo microscope (a and h) and Zeiss Axiotech 5 Vario microscope (b–g and i–j). A microCT scan (l) was made with the use of a Bruker Sky Scan 1273 microtomograph

corresponds perfectly with the wear observed on the point's surface, supporting its connection with fishing.

In the case of tools from Poland, wear indicators typical of fishing were identified on specimens from Wiele (MOB/A-4644), typologically corresponding to single-barbed points (Clark's No. 5; Clark, 1936). The points on which wear traces are better developed (Fig. 13) show legible compression damage (Fig. 13a), osteon highlighting of the OH2-type (Fig. 13b), P1-type polish (Fig. 13b–d), and strongly developed linear traces of types LT1 and LT2 (Fig. 13a and b), LT3 (Fig. 13c), and LT7 (Fig. 13a). As with most other points used for fishing, the osteon highlighting gradually fades away from the tip of the points and becomes invisible halfway along its length (Fig. 13d). Approximately two cm below, the P1 polish also disappears, giving way to manufacturing traces (remains of scraping, Fig. 13e). This part of the point was in the shaft. The application of the developed analytical protocol in the



Fig. 13 Point from Wiele, site 33, Poland (MOB/A-4644). Example micrographs of the identified wear traces. All micrographs were obtained with the use of the Zeiss Axiotech 5 Vario microscope

new (verifying) wear studies of the points from Wiele forces us to change our previous opinion that they were not used, which was based on classical indicators of the function of projectile points (Osipowicz 2016).

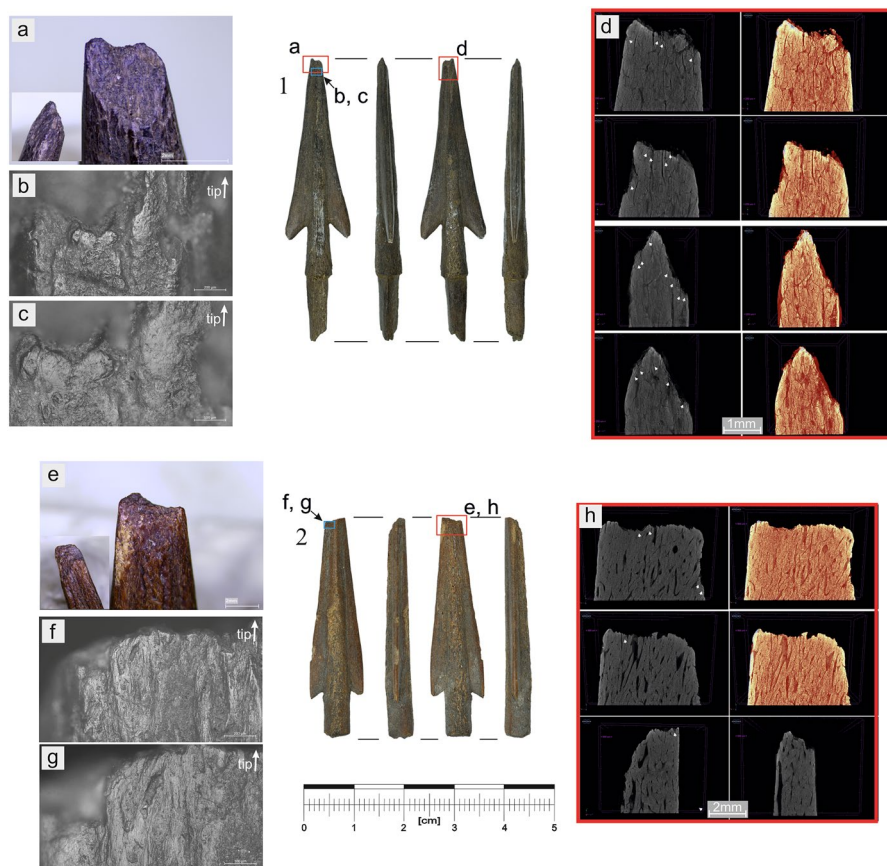


Fig. 14 Points from Mirakowo-Grodno, site 6, Poland: (1) inv. no. 37 and (2) inv. no. 17/01. Example micrographs (a–c and e–g) and microCT scans (d and h) of the identified wear traces (d and h, arrows mark micro cracks). Micrographs were obtained with the use of Nikon SMZ-745 T stereo microscope (a and e); Zeiss AxioTech 5 Vario microscope (b, c, f, and g). The microCT scans (d and h) were made with the use of a Bruker Sky Scan 1272 microtomograph

Completely different usage damage from that described previously was observed on two arrowheads from Mirakowo-Grodno, site 6 in Poland (inv. no. 37 and 17/01). In their case, analyses conducted according to a protocol developed to identify wear traces typical for fishing revealed a complete absence of indicators characteristic of this function. However, very clearly legible DIF damage in the form of beveled breaks with spin-off fractures was observed here (Fig. 14a and e). A hide-like polish covering the upper parts of the raw material surface relief and rounding its uppermost areas is also visible. Its more abrasive variety is observed on arrowhead no. 37 (Fig. 14b and c) corresponds perfectly to the experimental polish documented in Fig. 9b and c. The polish variant legible on point inv. no. 17/01 (slightly similar to the P3-type polish; Fig. 14f and g) is essentially identical to the experimental polish visible in Fig. 9d. Linear traces

consistent with their orientation (LT6) and less frequent multidirectional LT7-type traces are also clearly visible on both points. MicroCT scanning revealed a large number of internal cracks of postdepositional origin for both artifacts. In addition, however, numerous microcracks of usage origin also occurred near the edges (Fig. 14d and h). The virtually complete removal of areas of compressed raw material fibers by postimpact breakage was also observed.

Considering the study results reported in this article, this characteristic of wear traces is far from typical for fishing but entirely consistent with the damage generated during terrestrial hunting. This is how the function of the artifacts from Mirakowo-Grodno should be interpreted.

The wear analysis of the archaeological artifacts conducted here unequivocally argues the correctness of the classification of the wear traces on osseous points used for fishing, as well as the possibility of their identification and reliable interpretation using the developed analytical protocol. The wear marks observed on most of the analyzed archaeological specimens have the same characteristics, configuration, and distribution as those produced during experimental fishing. Importantly, identical wear with the discussed characteristics was observed on points of different chronologies, originating from various archaeological sites and different depositional contexts. These traces clearly differ from those produced on osseous tools during other activities (including terrestrial hunting), allowing for their reliable differentiation. Moreover, their characteristics are sufficiently uniform and unique that they cannot be confused with damage of postdepositional origin. It is worth adding here that, as a result of the wear and taphonomical research to which the authors of this article subjected prehistoric (unused) bones from many European sites, no postdepositional modifications corresponding to the use traces typical of fishing classified in this article were identified.

However, as a result of the conducted studies, some minor discrepancies were also observed between wear traces produced during experimental fishing and those visible on archaeological artifacts for which such a function has been suggested. These discrepancies consist of two elements. The first is the frequency of microchatter marks (LT5), which were observed relatively frequently on experimental points, whereas in the case of archaeological artifacts, their presence was recorded only once. The reason for this situation is unclear. These differences may result from the type of raw material used to produce the points, the species of fish targeted, or the hunting technique employed (*e.g.*, distance from the target and bow strength). This topic certainly requires further research.

The second discrepancy is much more significant. It is the presence of distinct cracks (usually following the line of osteon lamellae) on archaeological artifacts, where compression marks and osteon highlighting are most visible. These cracks likely arose from rapid postdepositional drying of the points, which widened the microcracks (generated as a result of the compressive forces upon impact) and contributed to delamination of the raw material inside them. These cracks should undoubtedly be considered additional indicators of the distinctive fishing function of archaeological artifacts.

Conclusions

The results of the conducted studies provide a significant analytical tool, enabling the distinction between points used for terrestrial hunting and fishing. This is a critical issue for prehistoric research, as it will enable a more responsible analysis of the economies of communities inhabiting different ecological niches and their relationships with the aquatic environment, which is considered crucial, for example, in the case of the Mesolithic, as noted by Crombé & Robinson (2014). The developed analytical protocol will also likely enable a much more valid and precise analysis of the functions of various types of osseous points and the enormous variation in this regard observed among hunter–gatherer societies.

Notably, the developed wear analysis protocol does not always allow for the fully reliable identification of fishing wear on osseous points. Its effectiveness is crucially influenced by the state of preservation of the analyzed artifacts (mostly, the degree of erosion of their surface) and the degree of development of wear traces on their surfaces. Perhaps, through further analysis, a sphere of activity generating indirect traces of use will also be established between fishing and terrestrial hunting (*i.e.*, possibly hunting small aquatic mammals). However, verifying its existence is a postulate for the future, the implementation of which will most likely detail the reported studies, not contradict them.

We should certainly continue our research using microCT and confocal microscopy, which, for objective reasons, we were unable to conduct on a larger scale. However, our most important goal for the near future is to test the protocol presented here on as many diverse archaeological materials as possible, which will allow for statistical verification of its suitability for studying diverse artifact collections.

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Author Contribution G. O. is the principal author of the study, responsible for conceptualization and the use-wear analysis. He wrote the main manuscript text and prepared Figs. 1, 3–6, 8–13, as well as all Supplementary Information. G. O. and J. O. conducted archaeological experiments. J.O. conducted a literature review and prepared Fig. 2. Ł. S. performed confocal microscopy studies; G. B-C. performed statistical analyses related to confocal microscopy studies and prepared Fig. 7. M.C., Z.S., and Gie. P. performed microCT scans. G. P. acquired points from Kaltanėnai and Švenčionėliai during fieldwork and provided information about them. All authors reviewed the manuscript.

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Data Availability The microcomputed tomography (microCT) and confocal microscopy datasets supporting this study are openly available in the Zenodo repository under the link: <https://doi.org/10.5281/zenodo.21307852>.

Declarations

Competing Interests The authors declare that they have no competing interests.

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