Research Article

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Fish Processing in the Iron Gates Region During the Transitional and Early Neolithic Period: An Integrated Approach

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Abstract: It is well known that many Mesolithic and Early Neolithic sites were uncovered during the past century in the Iron Gates region of the North-Central Balkans. The application of diverse analyses on the bioarchaeological remains and artefacts raised many questions, but also offered new ideas about the Mesolithic–Neolithic transitional period in the Middle and Lower course of the Danube. Communities in the Iron Gates consumed fish and exploited the riverbank in prehistory. The stable isotope analyses are implying that these human groups fed on aquatic resources in some periods more than others. Fish remains were also found in settlements, and based on fish-related imagery on sculpted boulders and other artefacts, the bond between the people, river, and the ecosystem was compelling. The idea of this article is to present the possible ways of fish processing at Lepenski Vir using chipped stone tools. Three integrated methodologies, with high levels of interpretation, were applied: use-wear, residue, and archaeozoological analyses. Use-wear and residue analyses were performed on both archaeological and experimental chipped stone tools. The results are considered together with the traces of butchery observed on archaeological samples of fish bones, creating a more coherent picture of the everyday habits of the Iron Gates populations.

Keywords: use-wear analysis, residue analysis, chipped stone tools, fish, experimental archaeology, Iron Gates, Lepenski Vir, Mesolithic–Neolithic transition, Early Neolithic

1 Introduction

In the last century, during the sixties and seventies, in the course of the rescue excavations, many sites were discovered in the Iron Gates region indicative of human presence during the Late Glacial and Early–Mid Holocene (Bonsall, 2008; Borić, 2011). Among them, many prehistoric settlements, belonging to the Mesolithic and Early Neolithic periods, were found at the terraces of the Danube river, such as Lepenski Vir, Padina, Vlasac, and Hajdučka Vodenica (Figure 1).

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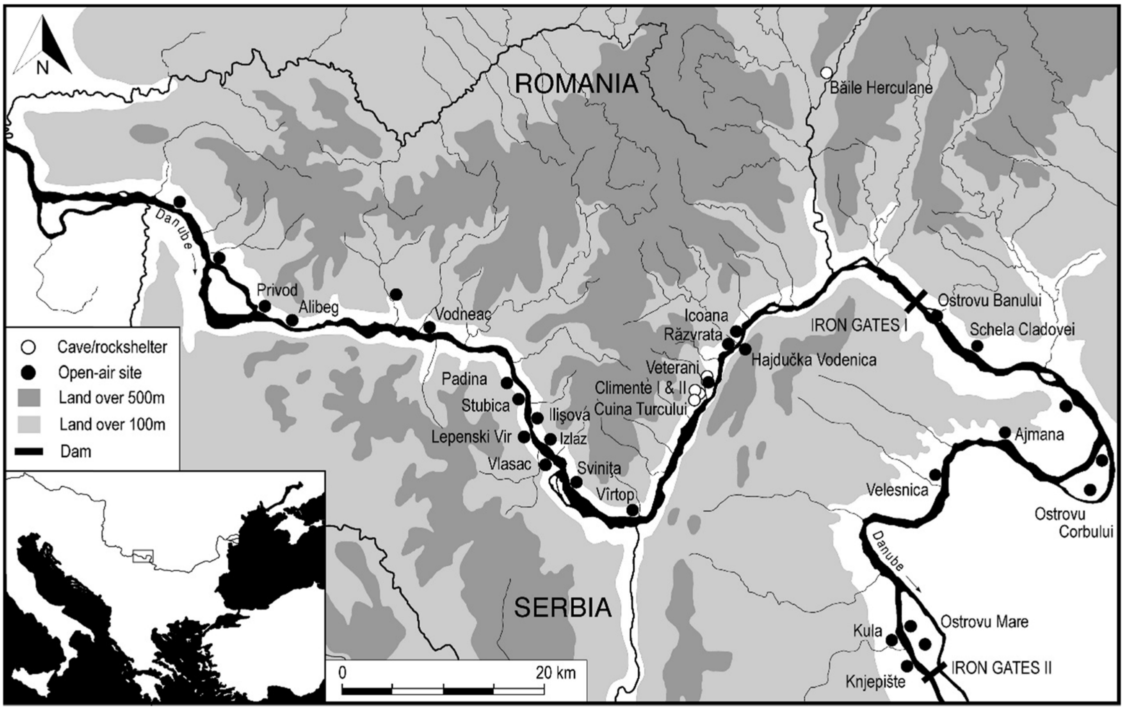


Figure 1: Map of Iron Gates region (after Bonsall, 2008. Courtesy of the authors).

The Mesolithic–Neolithic transition and the Early Neolithic phases, relevant for this study, coincide with the establishment of the hunter-fisher-gatherer settlement with trapezoidal-base buildings, stone-lined hearths, sculpted boulders and pottery (c. 6170–5940 cal BC), and the appearance of a greater number of non-local individuals, first domesticates, pit features, and the use of the abandoned trapezoidal dwellings as burial grounds (c. 5990–5660 cal BC) (Borić et al., 2018).

New methods and studies of the artefacts enabled the researchers to explore the everyday life of the hunter-fisher-gatherer groups who inhabited the Iron Gates area (e.g. Antonović, 2006; Borić, 2016; Borić et al., 2018; Cristiani, Radini, Edinborough, & Borić, 2016; Kozlowski & Kozlowski, 1984; Radovanović, 1996; Radović & Stefanović, 2015).

As many fish remains were found at Iron Gates sites (Bartosiewicz, Boroneanţ, Bonsall, & Stallibrass, 2001; Bökönyi, 1972, 1978, Clason, 1980; Živaljević, 2017), the need to explore the manner of their preparation for consumption, and to test the possibility that chipped stone tools were involved in these activities became obvious. The archaeozoological and isotopic data indicate that during the transitional period (c. 6170–5940 cal BC, Borić et al., 2018) subsistence strategies were based on the consumption of both terrestrial and aquatic resources (Bonsall et al., 1997; Borić & Dimitrijević, 2005; Borić, Grupe, Peters, & Mikić, 2004; Dimitrijević, Živaljević, & Stefanović, 2016; Dimitrijević, 2000, 2008; Greenfield, 2008; Grupe, Peters, & Mikić, 2003; Jovanović et al., 2019; Nehlich, Borić, Stefanović, & Richards, 2010; Živaljević, 2017). Fishing could have been taking place for the most part of the year, given the presence of freshwater species such as common carp (*Cyprinus carpio*) and many other smaller cyprinids, Wels catfish (*Silurus glanis*), and huchen (*Hucho hucho*), which were available for prolonged periods of time. However, it would have been particularly intense in spring and autumn, coinciding with the spawning runs of sturgeons, the beluga (*Huso huso*), Russian sturgeon (*Acipenser gueldenstaedtii*), fringebarbel sturgeon (*Acipenser nudiventris*), starry sturgeon (*Acipenser stellatus*), as well as the cyprinid vyrezub (*Rutilus frisii*) from the Black Sea (Table 1), (Živaljević, 2017). It might be suggested that during peak times of seasonal migrations of anadromous fish, the fishers would have been engaged in laborious work lasting from several days to several weeks. The setting and the emptying of traps, pulling nets ashore, stunning large fish, and cleaning the catch and preparing it for consumption probably involved a large part, if not the whole community.

Table 1: Taxonomic composition of the fish faunal assemblage related to the Mesolithic–Neolithic transitional and the Early Neolithic phase of occupancy of Lepenski Vir (cf. Živaljević, 2017)

Taxon		NISP		Weight	
		n	%	*g*	%
Acipenseridae	Russian sturgeon (*Acipenser gueldenstaedtii*)	38	5.0	452.3	5.6
	Fringebarbel sturgeon (*Acipenser nudiventris*)	3	0.4	80.4	1.0
	Sterlet (*Acipenser ruthenus*)	8	1.1	11.4	0.1
	Starry sturgeon (*Acipenser stellatus*)	7	0.9	35.9	0.4
	Acipenser sp.	10	1.3	37.0	0.5
	Beluga sturgeon (*Huso huso*)	48	6.4	2411.6	30.1
	Acipenseridae indet.	26	3.5	235.1	2.9
Clupeidae	Pontic shad (*Alosa immaculata*)	1	0.1	0.6	0.0
Cyprinidae	Common carp (*Cyprinus carpio*)	62	8.2	210.6	2.6
	Asp (*Aspius aspius*)	2	0.3	1.7	0.0
	Ide (*Leuciscus idus*)	1	0.1	0.1	0.0
	Sichel (*Pelecus cultratus*)	1	0.1	0.1	0.0
	Vyrezub (*Rutilus frisii*)	234	31.1	220.5	2.8
	Cactus roach (*Rutilus virgo*)	1	0.1	0.1	0.0
	Vimba bream (*Vimba vimba*)	1	0.1	1.2	0.0
	Cyprinidae indet.	158	21.0	191.2	2.4
Siluridae	Wels catfish (*Silurus glanis*)	91	12.1	3962.1	49.4
Esocidae	Northern pike (*Esox lucius*)	1	0.1	0.4	0.0
Salmonidae	Huchen (*Hucho hucho*)	59	7.8	155.1	1.9
	Black Sea salmon (*Salmo labrax*)	1	0.1	6.0	0.1
	Total identifiable	**753**	**100**	**8013.4**	**100**
	Pisces indet.	184		478.2	
	TOTAL	**937**		**8491.6**	

The use of chipped stone tools for processing animal materials, in the same chronological frame, on the sites in the Iron Gates is very high (Petrović, 2021). However, these traces indicate various activities, among them groups of polish that could be interpreted as fish processing. These observations supported the idea to test the possibility to identify fish processing or any part of this unique activity, and categorizing the specific traces or polish left on the knapped artefacts.

Additionally, butchery traces were observed on a small sample of fish bones recovered from Lepenski Vir and Padina (Živaljević, 2017). The connection between the cut marks on fish bones and the traces found on the chipped stone tools urged the idea to combine the experimental approach, the use-wear and residue analyses and to recreate the processing and preparation techniques of various fish species.

Previous experimental trials (Clemente-Conte et al., 2020; García Díaz & Clemente-Conte, 2011; Moss, 1983; Van Gijn, 1984/85/86,) showed that some characteristic traces on chipped stone tools could be noted. Two studies, based both on experimental trials and the analysis of the archaeological sample, were helpful in the process of identifying the traces and polish, and they were used as a methodological basis for our research as well.

Van Gijn (1984/85/86) recognised three types of polish as a result of fish cleaning:
- Type A: rough, ridge-like positioned greasy polish, not connected to any task in specific, but very common for fish processing;
- Type B: matt polish, randomly distributed linear streaks, connected to the removal of hard scales only; and
- Type C: smooth bright polish, which is a result of working with fish bones.

A recent study (Clemente-Conte et al., 2020), based on additional experimentation, confirmed previous results and summarised the new insight as:
- Scaling: rough and greasy appearance of micro polish adapted to the topography of the flint (Figures (2c and d) and (3f) in Clemente-Conte et al., 2020).

– Decapitation: flat polish, as a result of contact with the bones, compact, positioned along the edge (Figures (2f) and (3e and h) in Clemente-Conte et al., 2020).
– Filleting and gutting: both activities leave similar traces, a combination of polish characterised by a rough and greasy appearance (contact with the meat and skin) and spots of more compact, flat polish (contact with bone). Fine striations in the inner surface occur as a result of the contact with fish vertebrae during gutting (Figures 2 (g, d, and h) and 3 (a–e, and g) in Clemente-Conte et al., 2020).

Various studies focused on the integration of use-wear analysis and protein residue analysis showed interesting results (Högberg, Puseman, & Yost, 2009) together with FTIR analysis (Monnier, Frahm, Luo, & Missal, 2018). All these studies produced various promising results, but they still leave their application to the archaeological sample to be proven in the future. These encouraging studies were one of the reasons to employ an integrated approach in our research, and to examine both use-wear and residue traces.

The study is composed of two parts: an experimental trial and the analysis of the archaeological sample of both chipped stone tools and traces of modification on fish bones. It is of utmost importance to mention that the experimental study was conducted only after the specific, peculiar traces were observed on the chipped stone artefacts from Lepenski Vir. The experimental results represented by macro and micro traces were compared to the use-wear traces found on the archaeological sample creating a fruitful base for discussion of various ways of fish processing during the Mesolithic–Neolithic transition (c. 6170–5940 cal BC) and the Early Neolithic (c. 5990–5660 cal BC) in the Iron Gates region. Furthermore, the study was reinforced by observing the use-wear traces on experimental tools used for processing various fish species from reference collection at the Laboratory of Technological and Functional Analysis of Prehistoric Artefacts (LTFAPA) at the Sapienza University of Rome. The implements from the reference collection helped us understand diverse stages of work, as it was needed to observe a larger number of tools to better understand the trace formation and distinctive aspects of this trace type.

2 Materials and Methods

Low- and high-power approaches were combined and applied to the experimental and archaeological chipped stone tools at the LTFAPA at Sapienza University of Rome, using Stereomicroscope Nikon SMZ-U with reflected light (×0.5 objective, ×10 oculars, range of magnifications from ×0.75 to ×7.5×), Metallographic microscope Nikon Eclipse ME 600 (×5, ×10, ×20, ×50 oculars), and digital microscope Hirox RH 2000.

Traces observed on the fish bones from various contexts from Lepenski Vir were observed with Nikon SMZ18 (range of magnifications from ×7.5 to ×30) at the Faculty of Agriculture, University of Belgrade.

Regarding the residue analysis, FTIR spectra of chipped stone tools were collected with a Bruker Optic Alpha-R portable interferometer with an external reflectance head covering a circular area of about 5 mm in diameter, and SEM-EDX analysis was completed with a digital microscope HITACHI TM3000. Both residue analyses were done before the cleaning of the samples.

A standard cleaning procedure of the LTFAPA Laboratory was used consisting of 15 min of cleaning in an ultrasonic tank with a mixture of demineralised water and Derquim® soap. A second wash was done with the demineralised water in the ultrasonic tank for 10 min.

The total sample of 393 chipped stone tools from Lepenski Vir assemblage was observed in the wider study together with artefacts from the sites of Padina and Vlasac (Petrović, 2021). The sampling was done based on the availability of absolute dates with the aim to trace the human activities during the transitional period.

In the preserved, hand-collected faunal sample from Lepenski Vir, a total of 1,347 fish bone specimens were identified, originating from contexts related to the Early–Middle Mesolithic, Mesolithic–Neolithic transitional, and the Early Neolithic phase of occupancy of the site (Živaljević, 2017). Given the overlap between the latter two phases, the fish faunal assemblage collected from both the floors and the infills of the buildings, as well as from Neolithic pits, is presented here as a whole, comprising of 937 specimens (Table 1).

Thus, not only the chronological frame for both the wider studies but also the context that will be discussed and highlighted, based on the information they provide about the processing of the fish, is the end of the seventh to mid-sixth millennium BC.

3 Experimental Framework

One of the most important observations and elements of previous use-wear studies is the *fish polish*, as it has been called by colleagues (Clemente-Conte et al., 2010). This specific polish is a consequence of different activities such as decapitation, scaling, gutting, and filleting, which produce diverse wear patterns that could be noted after fish processing. Accordingly, the characteristics of all three types of materials could be observed (soft, medium, and hard), since fish processing includes various cleaning tasks. In addition to the *fish polish* categorisation, some scholars suggest that a single tool could have been used in all activities, in cases where people had to work fast when a large number of fish is caught in a short period, for example during their seasonal spawning runs (Van Gijn, 1984/85/86). This tempo of work could have been very intensive, in particular during the peak of fish migration, and it could have lasted for hours, days, and even weeks (*cf.* Hewes, 1948).

In the absence of a complete petroarchaeological analysis of geological sources of the raw materials present at the Iron Gates sites (*cf.* Gurova et al., 2016, Šarić, Šarić, & Cvetković, 2021) we used raw materials from Vrelo Marice (eastern Serbia) to produce the replicas of chipped stone tools.

Two flakes of different sizes were used in the experimentation with the common carp. The process of scaling was singled out and one tool was used for this activity. All other tasks (decapitation, gutting, and filleting) were done by another flake. This way, the specific characteristics of fish polish resulting only from the contact with the scales could be observed. The main reason for this kind of *division of labour* between two experimentally produced flakes emerged with an idea that some of these specific polish attributes could be noticed in the archaeological sample as well. In this manner, the fish processing could become more traceable in the archaeological context.

The first step included the scraping of the scales from their root in the opposite direction (Figure 2a). The skin was cleaned, and all scales were removed after 30 min.

The second step included a set of various activities such as decapitation (Figure 2b), splitting the fish open (Figure 2c), and removal of the organs (gutting). Then, the skin was carefully removed by scraping motions, and the meat was cleaned from bones and filleted (Figure 2d).

The scaling of the fish was done by an unretouched flake with a convex edge which was used only for this activity. Usually, fish scaling is performed in an opposite direction to the root of the scale. In our case, this was helpful on the upper part of the fish, near the head, but on the medium part and near the tail it was more convenient to first put pressure on the root of the scale and then slide it towards the tail. As mentioned, it took 30 min to clean the skin from all the scales, and during the process, the tool was in contact with the working surface on its ventral side. The tool was still efficient after its use.

The scaling produced an edge rounding and snap and half-moon scars with localised distribution (Figure 3a). The observed polish is very rough, dull, with flat topography, sometimes domed in the areas where it was not well developed and greasy in the most pronounced areas (Figure 3b). A similar polish description of the experimental tools was reported by other colleagues (Clemente-Conte et al., 2020; Van Gijn, 1984/85/86).

The tool was observed by the FTIR micro-spectroscopy on two occasions. The first time, just a couple of days after the experimentation, and the second time 16 months later. The tool was not cleaned and residues were visible and noted as larger patches of grease and fibres (Figure 4a and b). The analysis was repeated with the idea to observe the possible transformation of the residues (collagen) to the adipocere.

In Figure 4c, the spectra show a few points located in the various areas of the tool compared to the spectrum of pure flint. The absorption peaks observed in the 1,650–1,500 cm^{-1} range can be attributed to

Figure 2: (a) Scaling, (b) decapitation, (c) splitting the fish open before gutting, and (d) the removal of skin, organs, and filleting (photo A. Petrović and A. Vinet).

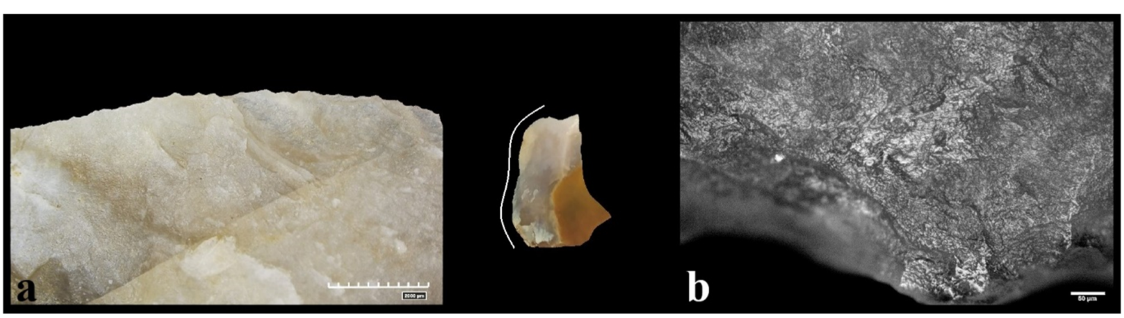
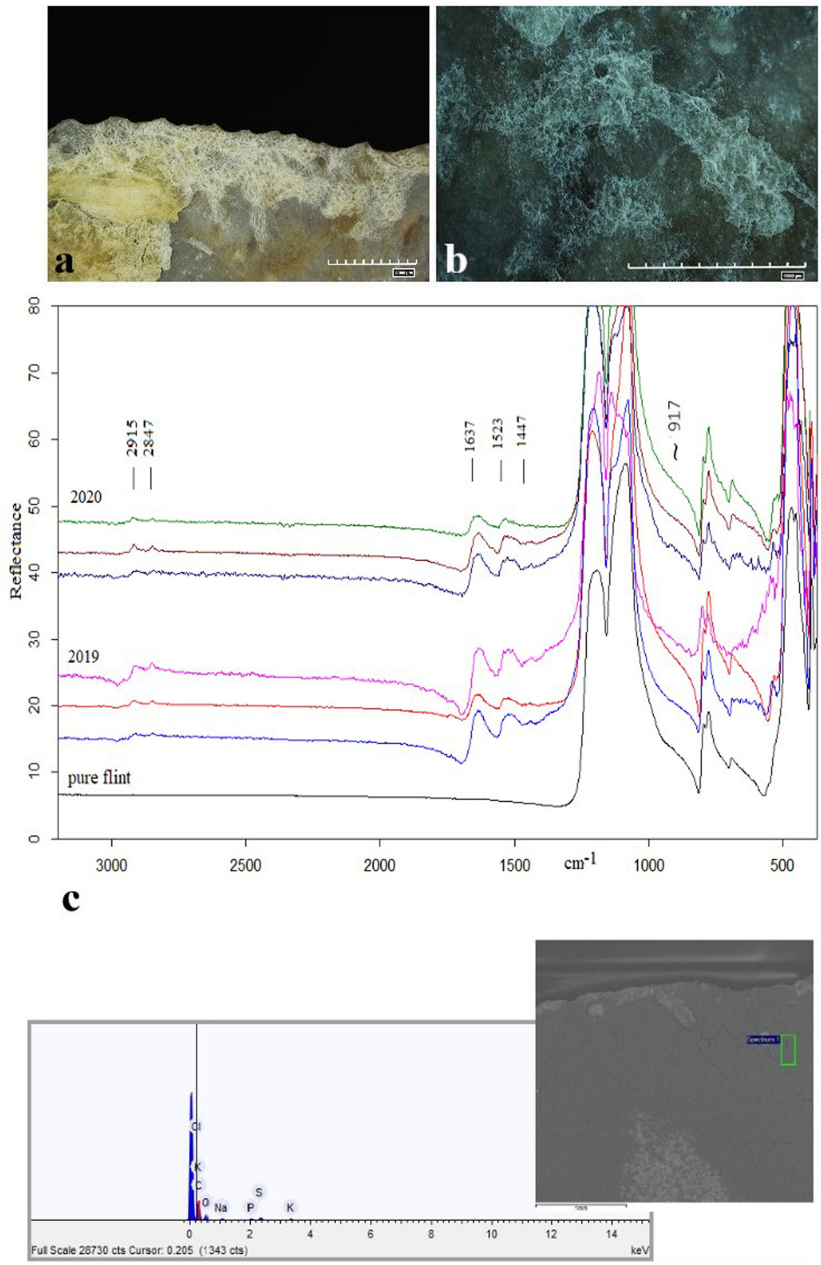


Figure 3: (a) Macro snap and half-moon scars and localised distribution and (b) greasy polish with flat topography (photo A. Petrović).

Amide I and II modes of proteins composing the collagen (Chadefaux, Ho, Bellot-Gurmet, & Reiche, 2008). A weak shoulder at ~917 cm^{-1} is sometimes observed suggesting the existence of hydroxyapatite, the mineral component of bones (Stiner & Kuhn, 1995).

This is an expected situation considering that scales have both proteinic and bone-like composition. These results represent an important indication and the direction in the tracing of the fish activities on the chipped stone tools.



Element	Weight %	Weight % σ	Atomic %
Carbon	39.596	2.723	49.647
Oxygen	46.079	2.131	43.374
Sodium	2.893	0.211	1.895
Phosphorus	2.392	0.173	1.163
Sulfur	4.511	0.257	2.119
Chlorine	1.447	0.135	0.615
Potassium	3.082	0.200	1.187

d

Figure 4: Residues left after scaling, both on the edge (a) and the surface area (b), (c) FTIR analysis showing collagen, done 5 days after the experimentation (March 2019), and the second analysis, done after 1.4 years (July 2020), spectra showing AMIDE I and II from collagen and bone (917 cm^{-1}), and (d) SEM-EDX results, the flake used for scaling (FTIR spectra S. Nunziante Cesaro, photo A. Petrović).

SEM-EDX analysis showed, among other elements, the presence of sodium, phosphorus, sulphur, potassium, and aluminium (Figure 4d). The specimen was tested by three points. The mentioned elements are a part of the animal material composition. The sulphur and potassium are probably a result of contact with the skin during the scaling process (Hayes, Cnuts, & Rots, 2019, p. 122).

A large flake with an unretouched edge was used for all other activities such as decapitation, skin removal, gutting, and filleting. These tasks were performed in a total of 1 h and 50 min. At first, it was a bit unclear what would be the easiest way to process a large-sized fish such as carp without any previous experience. The head cutting was the most challenging task, but it was observed that the easiest way was to cut the skin and meat around the bone and then to break it off with hands.

The flake produced snap and step scars with oblique direction and close regular distribution (Figure 5a). The polish is characterised by granular topography, and the smooth texture is a result of the contact with bone, which, in our case, was 60% of the total time (Figure 5b). The topography was not as flat as it usually is, in the cases when the tool comes in the contact with the mammal bone. However, it is important to mention that fish bones are generally smaller and more fragile compared to mammal bones. This is the reason why the topography was not equally developed. Additionally, the observed traces could mimic the working of any mammal bone for a shorter period of time. All these attributes were similar to the polish features produced after any other animal resource processing activity and based on the macro and micro traces, no specific characteristics were noted which could be attributed exclusively to the contact with fish bones, meat, or organ removal.

The infrared spectra of the points in the residue zones (Figure 6a) manifest the absorption peaks attributable to collagen proteins (Figure 6b). However, bands suggesting the existence of micro residues of the mineral component of bones are not observed. This absence, even after the tool was in contact with fish bone, is likely due to their porosity, or it can be a result of a small quantity of the residue, which was not substantial enough to be preserved or detected by the spectroscopic analysis.

The tool showed very similar results to the previous one, with some changes in the quantity of phosphorus and potassium depending on the test zone. For this reason, two out of three points will be shown for a better understanding of the SEM-EDX analysis and by this we can utilise the data. The first results refer to the chosen zone on the dorsal side, right in the area where the residues were preserved, and it showed very similar results to the flake used for scaling (Figure 7a). The second point was placed on the group of collagen fibres, also on the dorsal side. This testing showed great amounts of potassium and phosphorus (Figure 7b).

In addition to the flakes, we have also chosen to test chemically the scales (Figure 8a–d). FTIR analysis suggests the presence of proteins (1,600–1,400 cm^{-1}), oxidised proteins (1,700–1,600 cm^{-1}), and hydroxyapatite at 1,025 cm^{-1} (Figure 8c).

Calcium and phosphorous were found to be the dominant inorganic matters based on SEM-EDX analysis (Figure 8d). The condensation of those elements might be responsible for the hardness of the external region. Fish scales contain collagen fibrils and calcium phosphates, particularly hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$; HAp) crystals (Okuda et al., 2009) which corresponds to our results. Similar conclusions were obtained by Hayes and Rots (2019, (Figure 13u), where large amounts of calcium and phosphorus were

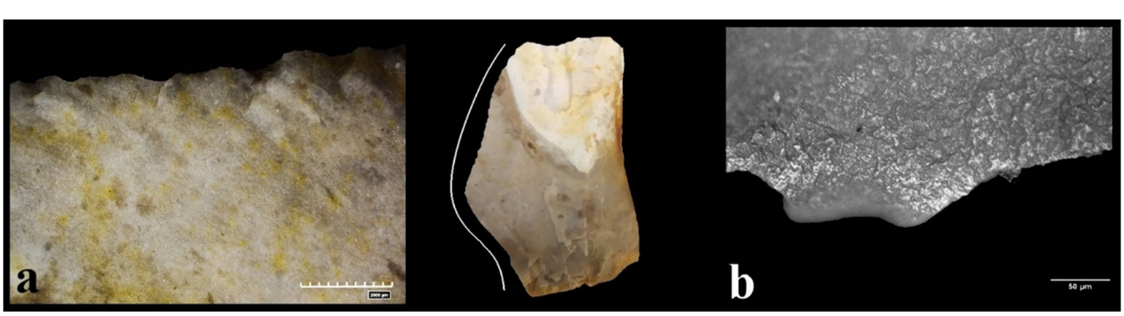


Figure 5: (a) Edge rounding and macro traces and (b) granular polish after 1.5 h of work (photo A. Petrović).

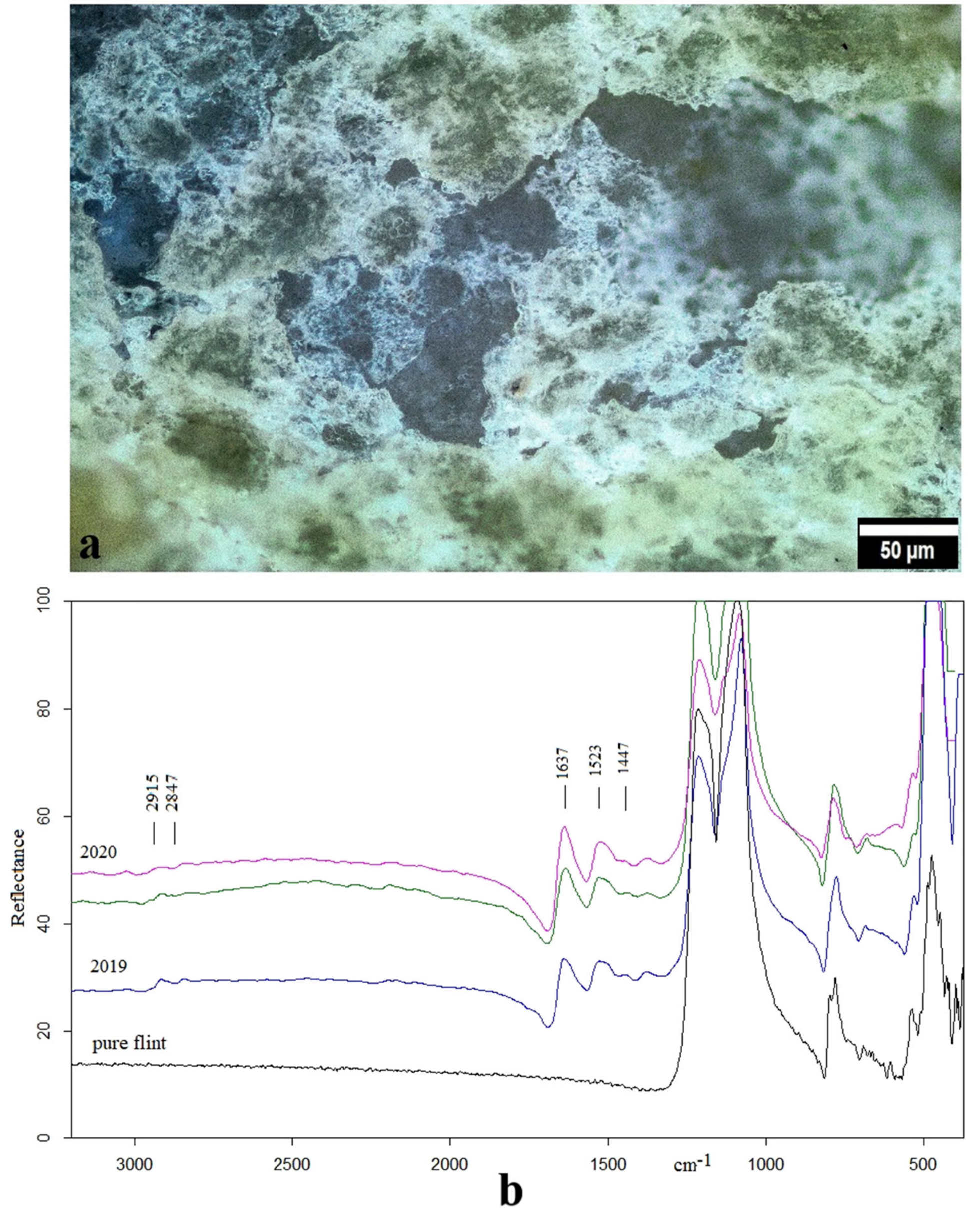
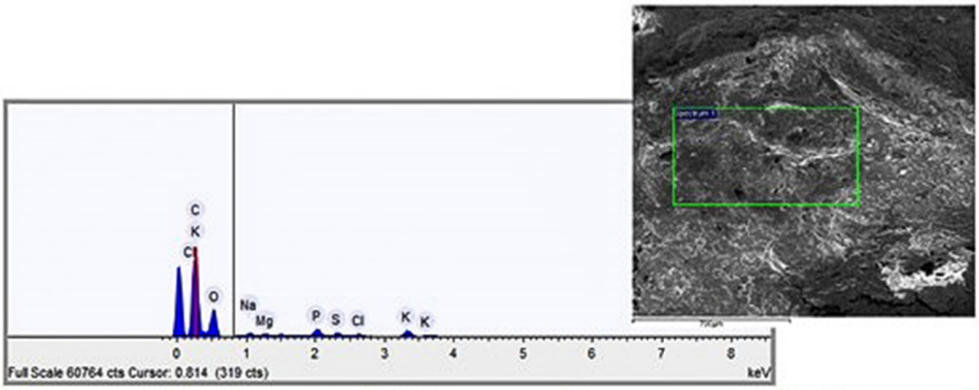


Figure 6: (a) Residues, (b) FTIR spectra showing collagen, the analysis done 5 days after the experimentation (March 2019), and the second analysis, done after 1. 4 years (July 2020) – AMIDE I and II from collagen and working of the meat and organs (FTIR spectra S. Nunziante Cesaro, photo A. Petrović).

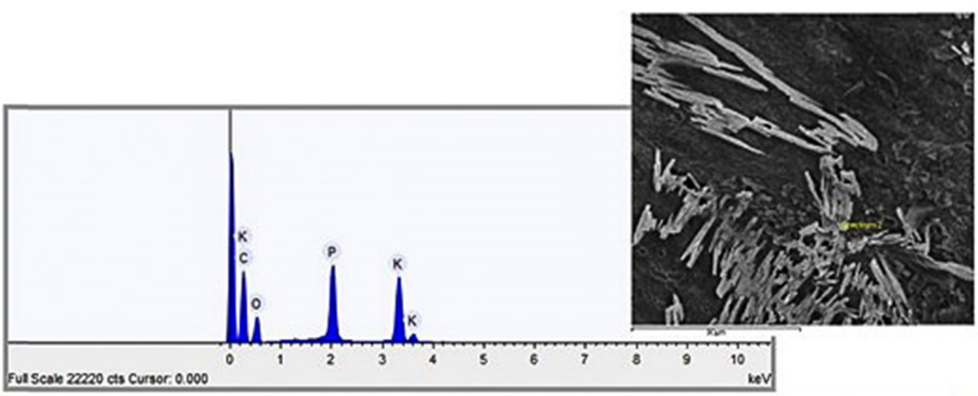
detected on the fragment of a fish scale. In addition, the mentioned study recorded the underlying collagen (Hayes & Rots, 2019, Figure 13v) with the small peaks of sodium and phosphorus which in the case of our trial was not visible in the SEM-EDX spectra of the scale itself. However, the presence of sodium and phosphorus was obtained in the residues found on the edges of the tools used in both stages of experimentation (Figures 4d and 7a).

The differentiation between scales and bone viewed by the proposed methods is almost impossible, having in mind that the ratio of calcium and phosphorus found in the scales is 2:1, which is the same proportion found in the bone composition (Acerbo, Lawrence Carr, Judex, & Miller, 2012; Garimella, Bi, Anderson, & Camacho, 2006, Ming-Guo, 2012).



Element	Weight %	Weight % σ	Atomic %
Carbon	37.337	1.003	46.730
Oxygen	50.648	0.829	47.589
Sodium	1.487	0.064	0.972
Magnesium	0.693	0.043	0.428
Phosphorus	3.247	0.077	1.576
Sulfur	1.587	0.052	0.744
Chlorine	0.940	0.044	0.399
Potassium	4.063	0.088	1.562

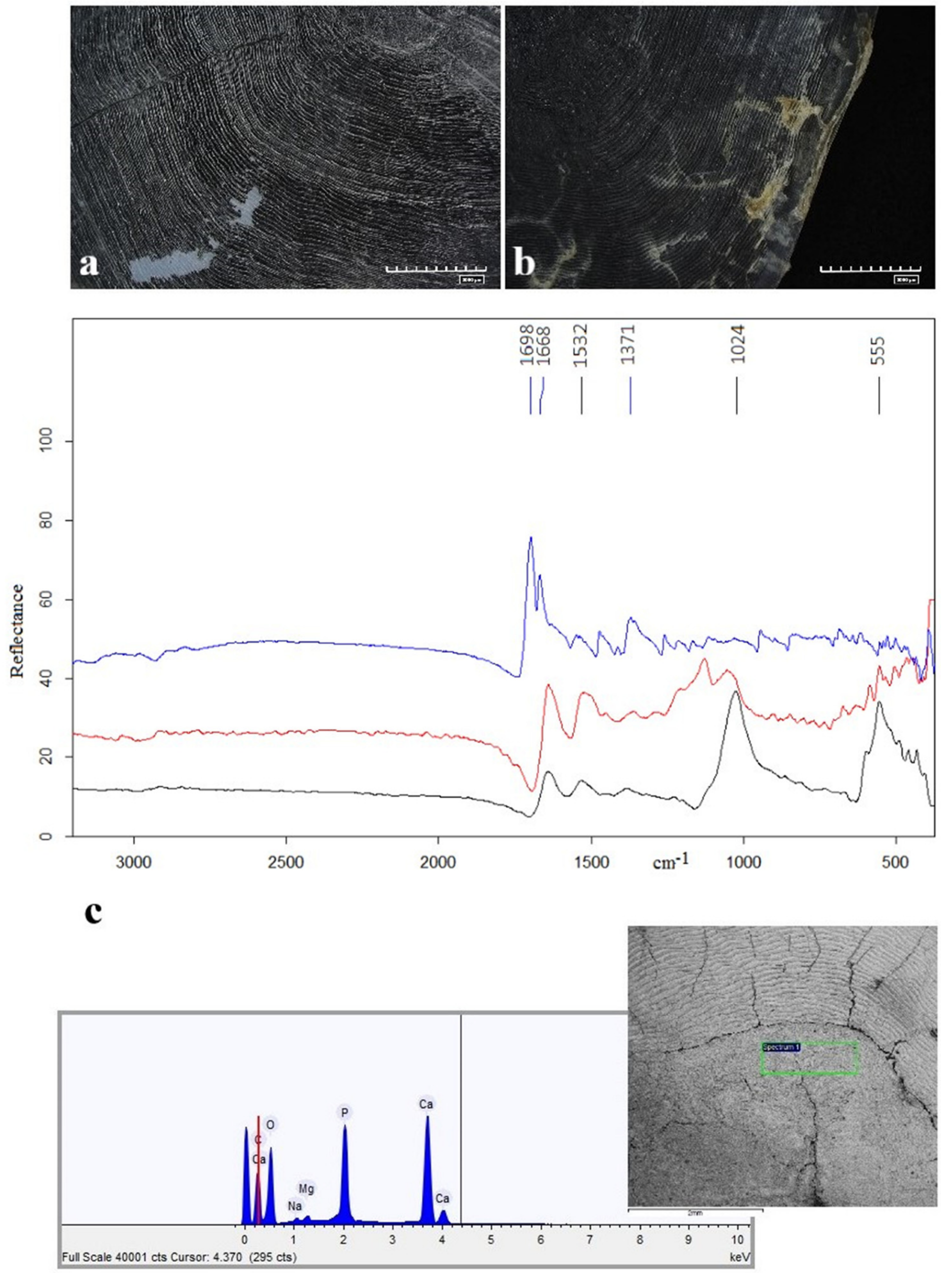
a



Element	Weight %	Weight % σ	Atomic %
Carbon	26.486	1.250	40.207
Oxygen	34.939	0.674	39.817
Phosphorus	16.246	0.303	9.564
Potassium	22.328	0.408	10.412

b

Figure 7: (a) 1st point and (b) 3rd point, collagen fibres.



Element	Weight %	Weight % σ	Atomic %
Carbon	26.999	0.167	38.668
Oxygen	44.162	0.169	47.483
Sodium	0.401	0.022	0.300
Magnesium	0.468	0.017	0.331
Phosphorus	9.616	0.051	5.341
Calcium	18.353	0.077	7.877

d

Figure 8: (a), (b) Fish scale under the digital microscope and skin residues, (c) FTIR results – apatite, (d) SEM-EDX analysis, the ratio of phosphorus and calcium, fish scale (FTIR spectra S. Nunziante Cesaro, photo A. Petrović).

4 Results

4.1 Archaeological Evidence on Chipped Stone Tools, Lepenski Vir

Out of the total of 393 sampled tools from Lepenski Vir, only two specific artefacts showed traces that could be connected specifically to fish processing. General results regarding all the analysed sites in Iron Gates show a preference towards animal processing, and the variety of the worked materials is broad. Bone, antler, various phases of hide working, butchering, and the processing of meat and other animal tissues were noted at the Lepenski Vir in particular (Petrović, Lemorini, Nunziante Cesaro, & Mihailović, 2021).

A scraper made of the grey flint used for fish processing was found on the floor of building 32. This building is the youngest in the sequence whose construction damaged building 20 that was partly overlapped by the limestone floor of building 33 (Borić & Dimitrijević, 2005), and it is dated in the range 6061–5902 cal BC (Borić & Dimitrijević, 2007). The use of the scraper was confirmed with the additional experiments previously described. At first, the traces were complex to identify, but based on experimental trials and results from previous studies (Clemente-Conte et al., 2020; Van Gijn, 1984/85/86), the process was accelerated. Macro traces were mostly regular continuous steps (Figure 9a). The edge rounding is formed and the polish penetrated the scars (Figure 9b). The polish has granular topography with half-tight to tight linkage, which can be related to meat processing. However, the diffusion of the polish inside the edge fracture is distinctive, and it was not observed previously in the Lepenski Vir assemblage. This characteristic was noted on the experimental tools and archaeological samples from Vale Marim and Vale Pincel (Clemente-Conte et al., 2020), and the same polish penetration is also visible on the experimental flake used for gutting in our study (Figure 5b). Apart from the polish resulting from meat processing, there was another area of work present on the scraper where the situation was a bit more complicated (Figure 9c). Here some ulterior indications and elements are connected to other materials as well. The presence of rough texture and striations on the domed to flat topography on the outer edge indicates contact with a bone-like element. The striae have an oblique bidirectional trend. The visible slightly abrasive film could either be connected to the contact with the bone or could be a result of the working surface being close to the ground.

A number of points of the flint tool were spectroscopically analysed (Figure 10). The presence of calcium carbonate ($CaCO_3$), mainly on the dorsal surface, is ascertained by the observation of a broad peak around

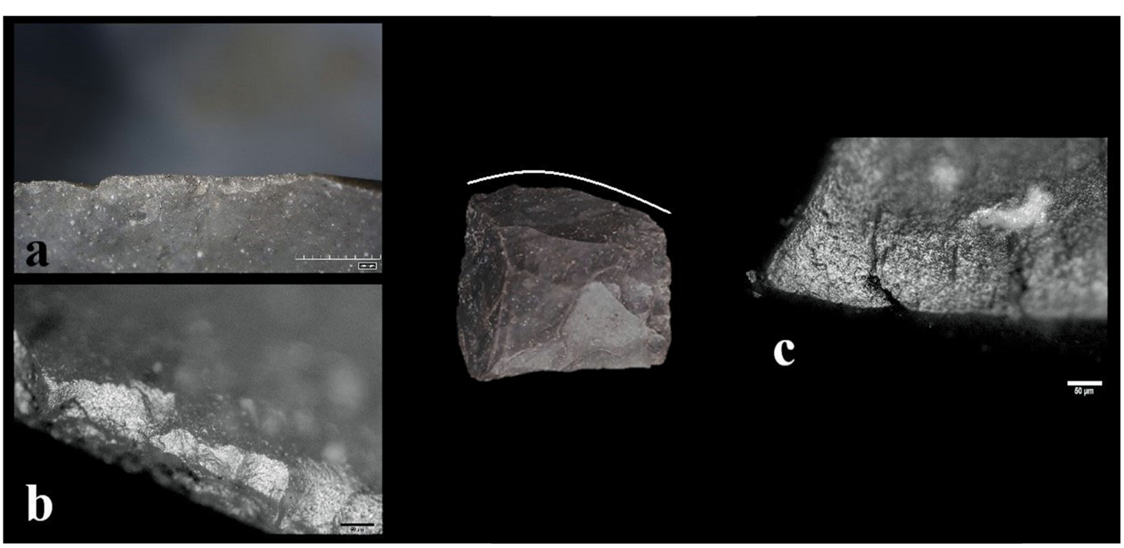


Figure 9: (a) Edge rounding and step, regular continuous scars, (b) polish that penetrated the scars, and (c) mixture of diverse materials, flat topography scaling (photo A. Petrović).

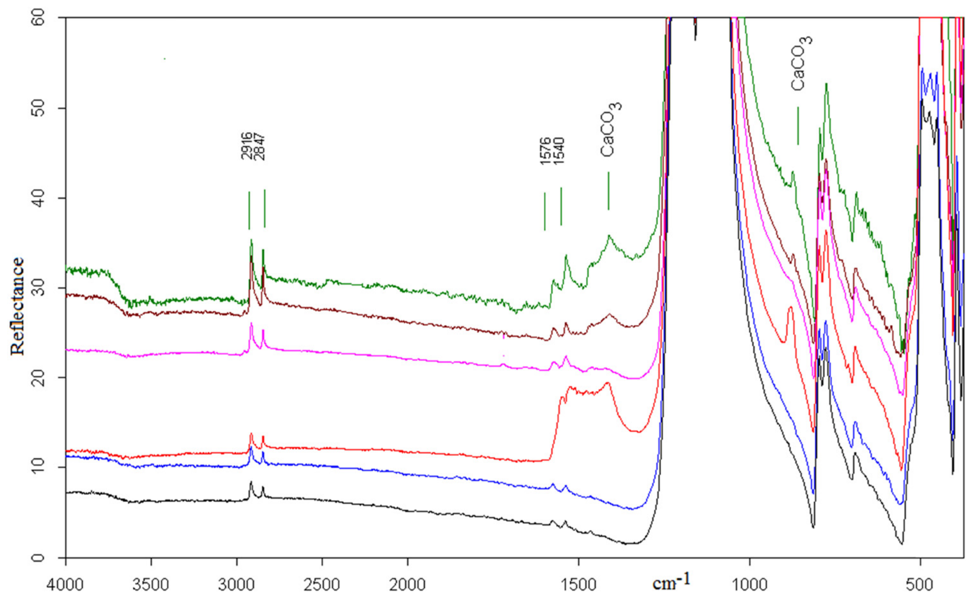


Figure 10: Micro FTIR spectrum of dorsal and ventral points of a scraper from building 32 (FTIR spectra by S. Nunziante Cesaro).

1,400 cm^{-1} together with the sharp one at 870 cm^{-1}. Calcium carbonate can not only be correlated with the bone residues but also with modern contamination (Figure 8 in Pedergnana & Ollé, 2018).

In addition, the doublet at 1,570\1,540 cm^{-1} indicated the existence of fatty acid residues due to the anaerobic bacterial hydrolysis of fat tissues mainly of animal origin (adipocere) (Forbes, Matthew, Wilson, & Stuart, 2011). The observed bands show the presence of elements connected to the processing of the animal resources containing fat acids. These peaks isolated from the use-wear traces cannot be directly associated with fish working alone.

The second example comes from building 35, another feature associated with the transitional period. A bone from the hearth of building 36 was dated in the range 6198–5928 cal BC (Borić & Dimitrijević, 2007), which was superimposed by object 35, a younger building, where various animal remains were recorded (Dimitrijević, 2008). Building 35, with the already mentioned objects 32 and 36, is considered as one of the main knapping spots (Mitrović, 2018), which highlights the role of this building in the settlement. The tools found within this building were used as well, mainly in the processing of bone, animal tissues, meat, fresh, and dry hide, but some of them were used for scraping fresh wood and vegetable-based materials.

The flake from building 35 was used in fish processing, but these traces differ from the ones observed on the scraper from building 32. Traces connected to scaling and a greater involvement of areas implied in the activity connected to the bone-like material are notable on the sample from the house of 35. Macro scars are snap and large with an oblique bidirectional and transitional course, indicating a mixed activity of scraping and cutting (Figure 11a). The polish is present on the outer edge, and edge, creating flat topography, tight linkage and striae. Domed topography is present in the zones where the polish did not develop due to insufficient contact with the scales (Figure 11b and c). The polish is overall greasy and there are more abrasive areas. The same characteristics are notable on the experimental flake used in scaling (Figure 3b).

Figure 12 shows the infrared active vibrations detected on a number of ventral and dorsal spots of a flake from building 35. In all spectra, broad peaks in the 1,500–1,400 cm^{-1} range suggest the presence of residues of sparitic limestone, a carbonate sedimentary residue. The assignment is supported by the observation of the weak band at 875 cm^{-1} assigned to the same compound (Poduska et al., 2012). The weak doublet around 3,000 cm^{-1} indicates the existence of organic micro residues. Only one spectrum is shown, and in addition, a weak broadband approximately at 1,600 cm^{-1} supports the hypothesis and indicates the probable existence of collagen traces.

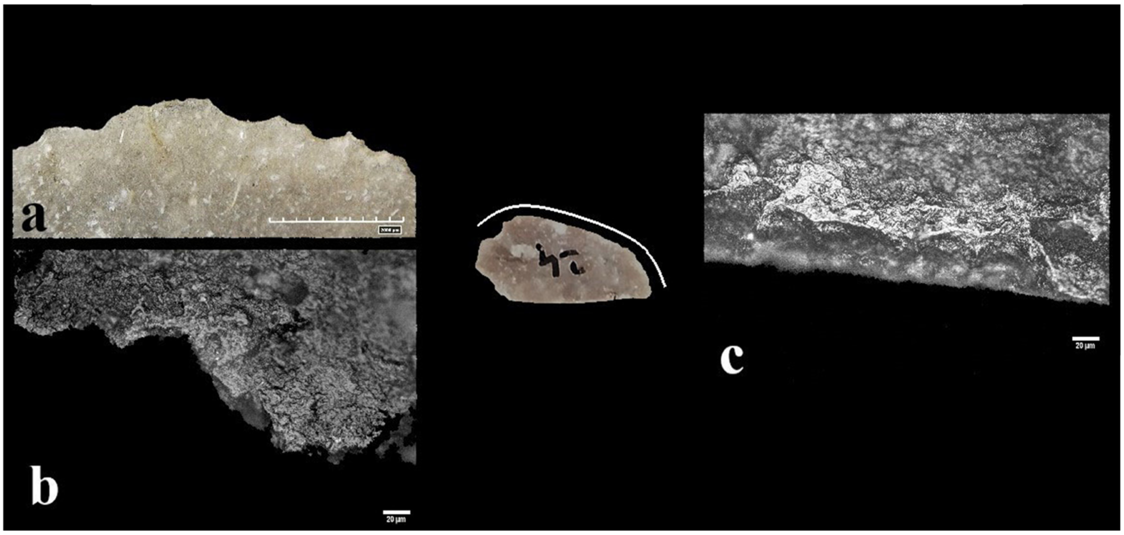


Figure 11: (a) Macro traces, (b) micro polish, and (c) micro polish, detail (photo by A. Petrović).

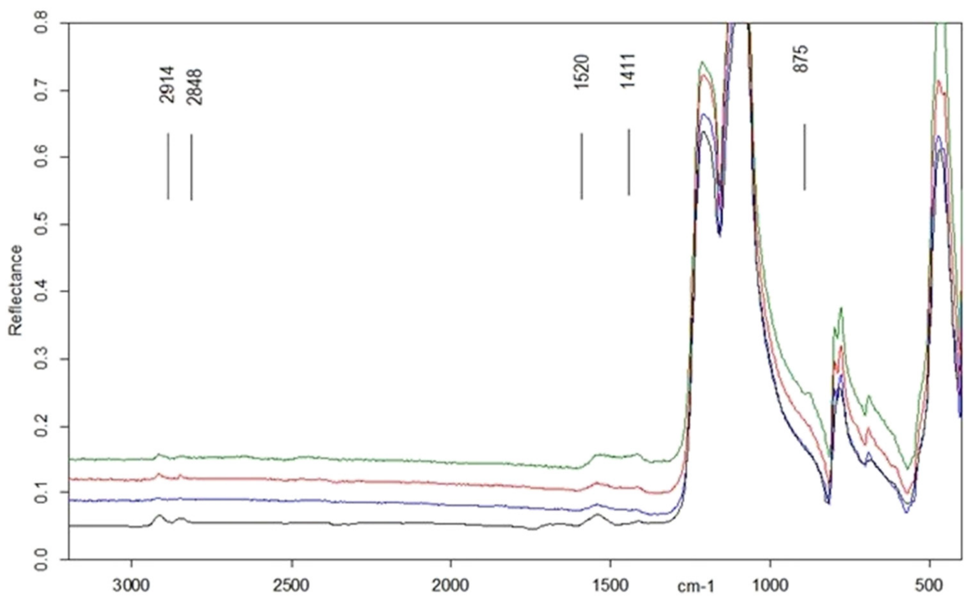


Figure 12: Micro FTIR spectrum of dorsal and ventral points of a flake from building 35 (FTIR spectra by S. Nunziante Cesaro).

4.2 The Evidence of Processing on Fish Bones at Lepenski Vir

Cut marks inflicted by chipped stone tools are often obscured by particular features of fish bones, namely, their porosity. During the experimental trial described in this study and a previous experiment involving the processing of a recent catfish specimen with unretouched flakes, undertaken by I. Živaljević and M. Mitrović, it was observed that chipped stone tools leave irregular traces on fish bones, and cause them to flake off and break more easily. Moreover, many processing activities – such as scaling, splitting, and gutting – would not necessarily involve contact with the bone. Consequently, in the fish faunal sample from Lepenski Vir, cut marks were recognised on 11 bones only (0.8%) (Živaljević, 2017), which does not imply that other fish remains were not treated in a similar manner. It should also be noted that bones with cut marks mainly originated from large species and/or individuals – probably due to their overrepresentation as a result of hand-collection, but also because their preparation for consumption most likely required more effort. This is especially the case with large sturgeons, the enormous beluga in particular, whose estimated total length (TL) ranged between c. 101 and 566 cm (mean value = 291 cm). The mean TL of Russian sturgeon and fringebarbel sturgeon was c. 135 and 215 cm, respectively, (Živaljević et al., 2021). The sturgeon skeleton is largely cartilaginous, the only ossified elements being the dermal plates, scutes arranged in five longitudinal rows, the parasphenoid, and some elements of the mouth cavity and the pectoral girdle (Brinkhuizen, 1986). In the case of sturgeons, cut marks were observed on the bones of the neurocranium and branchiocranium, one of the few ossified elements in the members of this family. Given that sturgeon elements composing the vertebrae are cartilaginous, i.e. they are not likely to survive in the archaeological record, there is no evidence regarding the treatment of the postcranial skeleton. Nevertheless, as shown by van Gijn (1984/85/86), while these fishes can be easily butchered by cutting from the ventral side, avoiding the ventral row of scutes, the plating on the dorsal part of the body would represent a greater obstacle. As for other, bony fish, they too were represented by fairly large individuals: the mean TL of catfish, carp, and vyrezub in the Lepenski Vir sample was c. 178, 66, and 65 cm, respectively, (Živaljević, 2017). Unlike cyprinids, characterised by firm scales (Figure 2a), the body of catfish is scaleless but its skin is particularly thick, sluggish, and difficult to remove, as shown by our previous experiment.

The cut marks on the Lepenski Vir specimens were mainly noted on the elements of the neurocranium, branchiocranium, and the pectoral skeleton: on two parasphenoid bones of Russian sturgeon, one

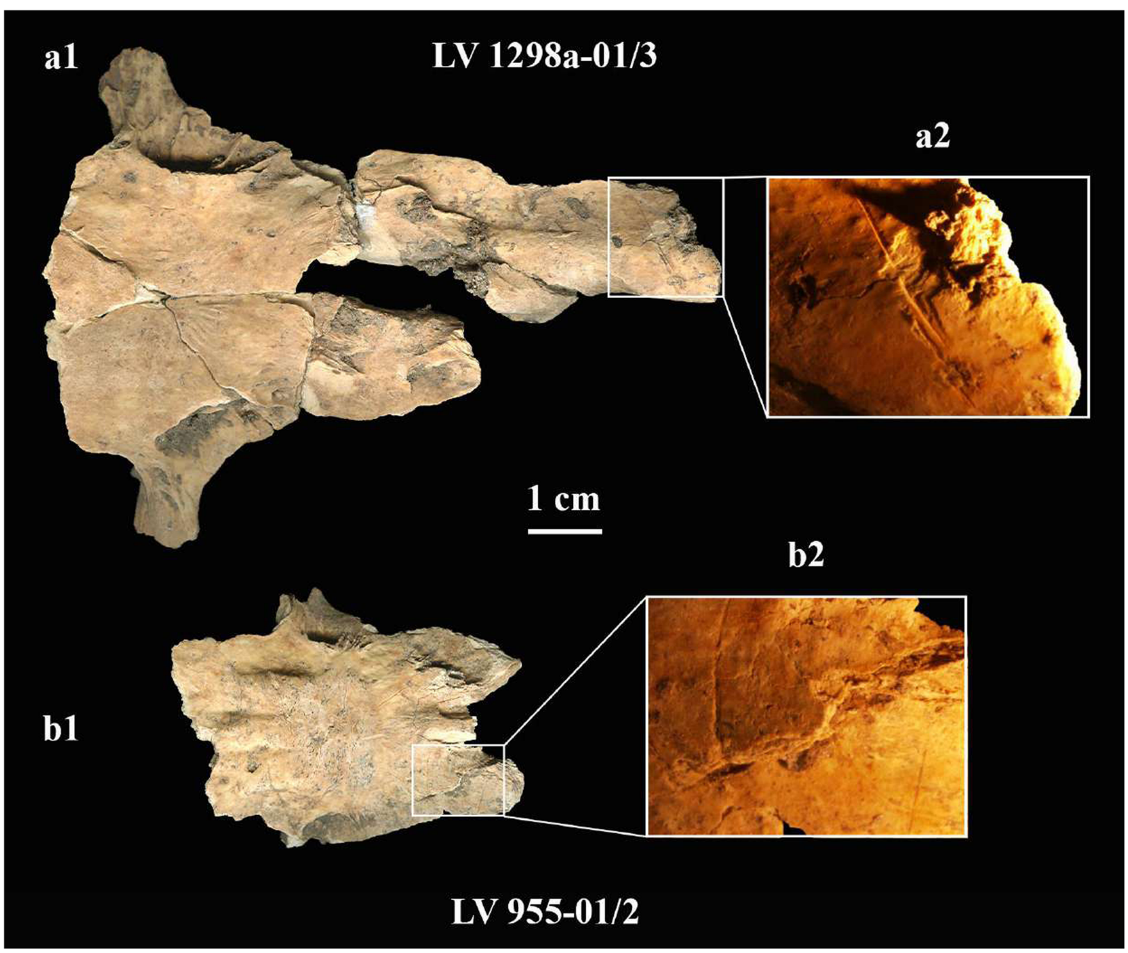


Figure 13: LV 1298a-01/3: (a1) fragment of a Russian sturgeon parasphenoid (found between superimposed floors of buildings 21, 22, and 30, transitional phase), with 2–3 long diagonal cut marks on the ventral side, 7.5× magnification (a2); LV 955-01/2: (b1) fragment of a Russian sturgeon parasphenoid (sq. c/I–III, spit X, Early Neolithic), with a long transverse cut mark on the ventral side, 10× magnification (b2) (Figure 9.16 in Živaljević, 2017).

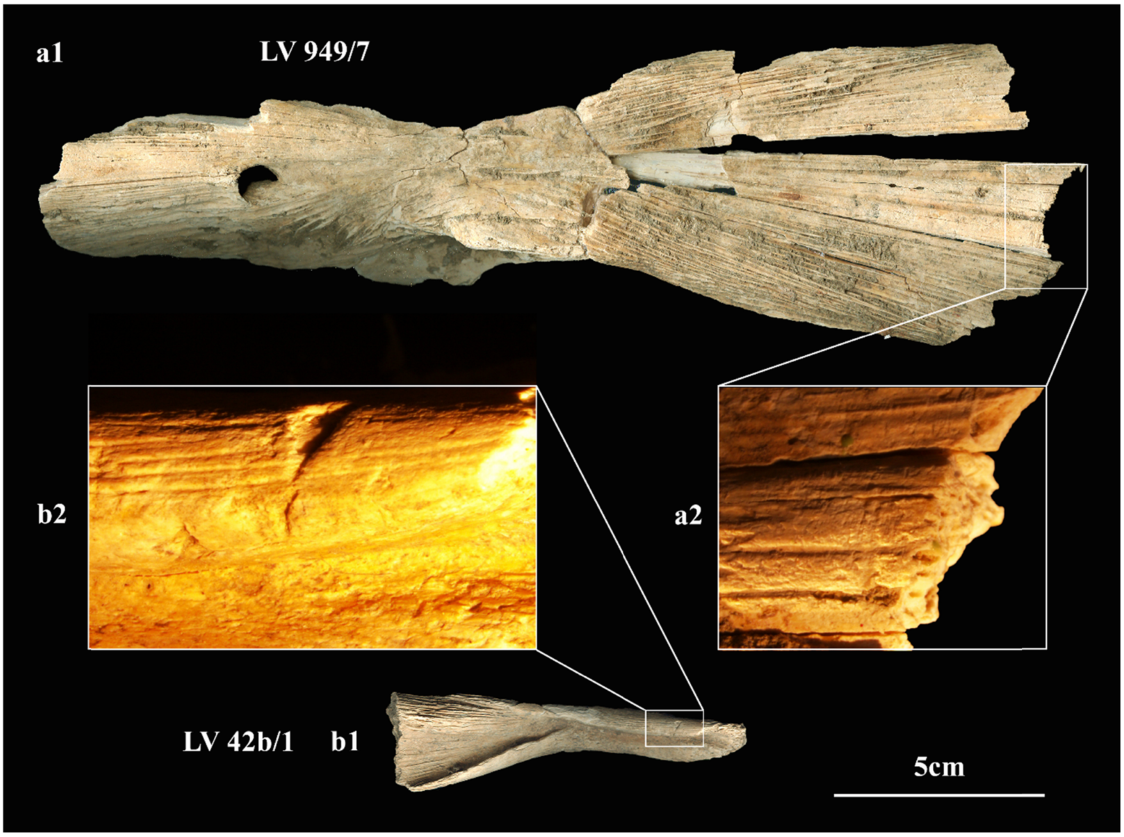


Figure 14: LV 949/7: (a1) beluga sturgeon parasphenoid (sq. C/III, spit IX, probably Early Neolithic), with several transverse cut marks on the ventral side, 7.5× magnification (a2); LV 42b/1: (b1) beluga sturgeon left dentary (burial 42b, Early Neolithic), with a chop mark on the medial side, 10x magnification (b2) (Figure 9.17 in Živaljević, 2017).

parasphenoid, one palatopterygoid, one maxillary, and one dentary of beluga sturgeon, one pharyngeal bone of vyrezub, one ceratohyal and two cleithra of catfish, and on one bone of an unidentified fish. All the cuts on parasphenoid bones of Russian sturgeon and beluga were located on the ventral side of the bone (Figures 13 and 14a1–2), and probably occurred during the disarticulation of the neurocranium from the branchiocranium and further portioning of the head into smaller pieces. A chop mark on the medial side of a beluga dentary (Figure 14b1–2), several cut marks on the medial side of a palatopterygoid and one cut on a maxillary bone of the same species, and transversal cut marks on both sides of a catfish ceratohyal can probably be attributed to similar activities, or perhaps to tongue/cheek removal (*cf*. Barrett, 1995, 1997).

Short oblique and transversal cuts, close to the fracture, were noted on the lateral side of two catfish cleithra (one of them shown in Figure 15a1–2). According to previous studies (Barrett, 1995; Brinkhuizen, 1989, Afb. 9.7) and the experiment involving a recent catfish specimen (Figure 15b1–3), the location of the cuts and the fracture itself most likely resulted from decapitation. Such breakage patterns were also recorded in other catfish cleithra from the site, with no visible traces of butchery. This is in accordance with the observation by van Gijn (1984/85/86) and Brinkhuizen (1989, Afb 9.7) that the head can be broken off from the body more easily after most of the meat has been removed.

5 Discussion

The results of the use-wear analysis of chipped stone tools found in buildings 32 and 35 are very important, as these are the only two artefacts displaying the characteristic types of traces and polish that are

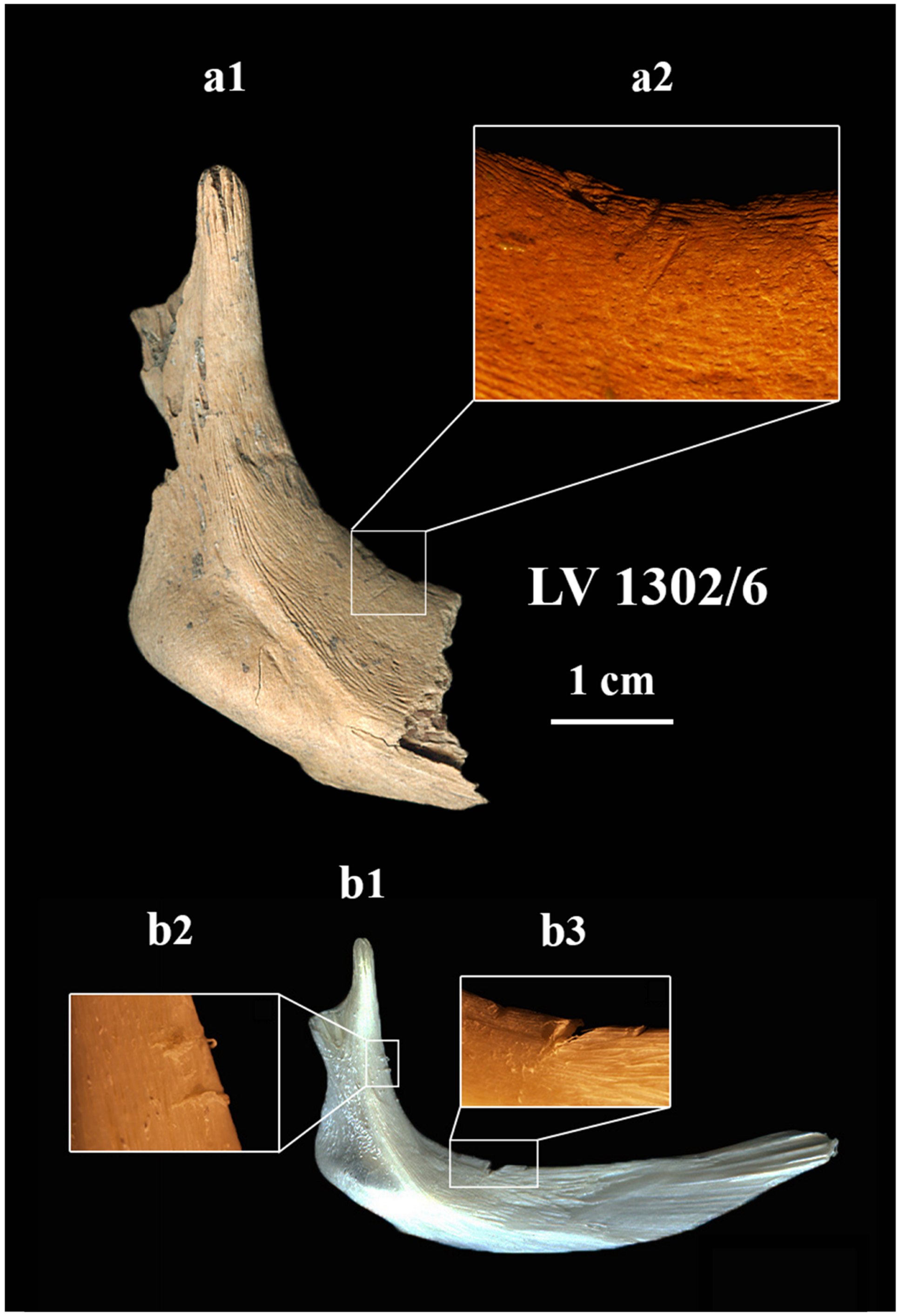


Figure 15: LV 1302/6: (a1) fragment of a catfish right cleithrum (found under the floor of building 26, transitional phase), with several short oblique cut marks on the lateral side, 10× magnification (a2); (b1) comparison with a recent catfish right cleithrum, with cut marks on the lateral side resulting from experimental decapitation with unretouched flakes, (b2) 30× magnification, and (b3) 15× magnification. Apart from the corresponding cut marks, the fracture on the archaeological specimen LV 1302/6 is most likely also a consequence of decapitation (Figure 9.18 in Živaljević, 2017).

exclusively related to the fish processing. The value of these results is even more highlighted having in mind that traces of fish processing are known to be very difficult to recover. The additional evidence was obtained after the observation of traces on experimental tools, which corresponded to those on archaeological samples. The supplementary data on the complete process of fish working yielded information on social behaviour and the complexity of certain tasks. The cut marks on fish bones from transitional and Early Neolithic contexts from Lepenski Vir further support the use of chipped stone tools in the activities of the preparation of fish.

This specific study, as well as previous research, brought different kinds of data and unambiguous evidence of fish processing at the Iron Gates. However, there are a couple of hypotheses and research questions that should be addressed and discussed further.

Based on the presented results, a very limited number of tools were used for processing fish. However, it should be considered that only a part of the chipped stone assemblage from Lepenski Vir was analysed. Another important indication is obscured in the general results. A large number of tools used in the processing of animal materials, among them meat, are not only found in the Lepenski Vir assemblage but also in the assemblages from Padina and Vlasac. In terms of polish characterisation, meat is usually very distinguishable and easy to recognise; however, it is limited to meat in general, or it can be found mixed with other materials such as tendons, bone, or skin. Even though the characterisation of meat processing traces is recognisable, it is not possible to distinguish between types of meat and animal species. In our case, it was not possible to distinguish between the traces of processing fish and meat of other animal species. This represents an obstacle to a better understanding of fish processing in the case of the Lepenski Vir site, leaving the vast number of meat processing traces in a general characterisation. Hence, many of these traces could have resulted from the contact with fish meat as well.

Regarding the observed traces and their interpretation, we should revise the idea of using one tool alone for processing fish at specific times (*cf*. Van Gijn, 1984/85/86). Archaeological traces which could confirm this hypothesis were found on the blades from La Esparragosa (Clemente-Conte et al., 2010). The concept of using a single tool in diverse fish activities should not be excluded as one of the scenarios in the case of the Iron Gates communities in general. In the case of the tools with superpositioned traces, it is quite attainable that some of the secondary matters and the activities covered or cancelled previous uses, and that fish processing is among those.

Even though for the most part, fish processing behaviour is not detectable in the lithic tools, the specific situation in the case of the Iron Gates leaves a couple of possible scenarios, for example, the use of some other kinds of tools for fish cleaning. This should not be excluded, given the wealth of osseous material from Lepenski Vir and other Iron Gates sites in the region (Mărgărit & Boroneanţ, 2017; Vitezović, 2011, 2017). Even though the osseous tools were probably more related to the fishing itself (as suggested by the sporadic presence of harpoons and bone hooks), some of them – such as boar tusk tools – could have also been used in the cleaning and preparation process (Bačkalov, 1979; Borić, 2003; Boroneanţ, 1989; Srejović & Letica, 1978). Their sharp point could have been used to cut and split open the fish, whereas the working edge could have served in scaling. On the other hand, some of the more recent studies indicate that they could have been used in woodworking (Boroneanţ & Mărgărit, 2017; Boroneanţ, Mărgărit, Bălăşescu, & Bonsall, 2018). However, based on the experimentations, it should be noted that lithic tools would have been among the most efficient ones in the cleaning process. Even in a situation where the person involved with this process had little or no experience, a chipped stone tool would have an advantage considering its sharp edges. During the peaks of the fishing season, the Iron Gates communities would have a great amount of prey to process and not all people would have the same knowledge or practice and the use of chipped stone tools would be practical.

Given the possibility that different kinds of tools were used in fish processing, and given that there is an obvious lack of individual fish polish, other ways of processing and conservation should also be considered. The fermentation of fish was suggested in other Mesolithic contexts, such as the site of Norje Sunnasund in Sweden. Here such practices were suggested on the basis of a gutter feature with a large assemblage of fish bones, differing from other fish remains at the site in terms of its taxonomic composition and taphonomy. Among other elements, the gutter assemblage contained collapsed vertebrae, indicating that they had been subjected to acid (Boethius, 2016). No such features or taphonomic processes have been identified in the Iron Gates setting. However, the occurrence of hearths within the buildings at Lepenski Vir suggests that the possibility of smoking and drying the fish should not be excluded (*cf*. Bonsall, 2008, Borić, 2003, 2007). Also, recent analyses of lipid residues have shown that the earliest pottery in the Iron Gates (already present in the transitional phase buildings) was mainly used for processing aquatic resources (Cramp et al., 2019). Nevertheless, it might be assumed that such activities would require at least some degree of prior processing, such as cutting large fish into appropriately sized pieces.

Since residue analysis became well incorporated in the use-wear analysis in the last decades, this can also be one of the keys to gain new insights into the preparation of fish and fishing practices in general. Calcium and phosphorus are the most abundant minerals in fish, humans, and other organisms, and they are mostly present in the bones. Calcium is needed to form bones and regulate functions. Phosphorus is a major component of bone and teeth and is a regulator of energy metabolism. Given that the same/similar amount of these elements is present in fish bones, scales, and carnivore bones, they are not very indicative for our study and sufficient enough to distinguish between the two types of residues.

However, apart from these elements, there are a couple of others whose values are higher than usual and which could be indicative of fish residues. Potassium, chloride, and sodium are electrolytes that carry out osmoregulation, the regulation of acid-base balance. Potassium promotes cellular growth and helps maintain normal blood pressure, while chlorine allows the maintenance of the electrolyte balance. Fresh seafood is low in sodium, but the content of this mineral increases during processing by the addition of salt or sodium-containing compounds. There is a wide variation in the sodium content of fish. The sodium content is 60 mg/100 g in freshwater and marine fish and 120–140 mg/100 g in shellfish, while the potassium concentration is reported to be higher than the sodium, ranging from 198 to 440 mg/100 g in seafood (Gokoğlu, 2002). The presence of these chemical elements in the residues can indicate fish meat, and combined with the use-wear traces support the interpretation.

Based on the obtained results, we would suggest the creation of an FTIR reference collection for various fish and carnivore meat types as the next step of our research. The key elements and values that should be observed carefully are sulphur and potassium. Both are noted in carnivore and fish meat residues, but a more thorough micro-study could aim for more precise results.

Another interesting observation is the incompatibility of the contexts where chipped stone tools with clear fish traces (building 32 and 35) were found and the areas where fish bones with cut marks were noted. The fish remains are present in the mentioned buildings, but they do not bear evident traces of butchery. However, it should be noted that fish bones do not have the same structure as mammal bones and the butchering traces are less commonly observed on the former. Additionally, chipped stone tools leave a worn trace that makes a bone flakier due to which these traces are often overlooked. This suggests that even if the butchering traces are not visible, it does not mean that the fish were not prepared for consumption. On the other hand, fish bones with cut marks resulting from decapitation were found in various contexts of the transitional phase, such as between the floors of buildings 26 and 26′, below the floor of building 26, on the floor 26′, between the floors of buildings 21, 22, and 30, 23, 18, building 43, and the floor of building 65/XXXVI (Živaljević, 2017), where traces on the recovered chipped stone tools did not bear any specific characteristic indicative of fish processing itself. As already noted, this can be due to the fact that meat processing traces can be attributed to the fish meat as well, and due to the mobility of the lithic tools.

Regarding the general use-wear results, which were beyond the scope of this study, the traces of meat and fresh hide processing were detected on tools found on and under the floor of building 26, and in and under the building 26′ where bones with cut marks were also found. This suggests that some of these traces could be a result of fish meat processing as well. However, while these finds reveal possible activities in the mentioned buildings, they do not exclude the possibility that the fish were processed elsewhere and brought to these areas to be consumed or their remains discarded. Fish bones were found all over the site, in all buildings and outside of them, and no specific areas associated with fish processing could be isolated.

Accordingly, it is possible that the prehistoric groups in the region used tools made in another location, and that their final context of deposition was not indicative of the exact area where the specific activity took place. Additionally, if one hypothesises that the fish-related activities were carried out, in most of the cases, in the close vicinity of the river, it can be suggested that designated tools could have been left on the river bank for future tasks. However, having in mind the superposition of the traces, multifunctionality and the utilisation of the tools to their maximum, specifically at Lepenski Vir (Petrović, 2021), it is more probable that fish traces are disguised with other activities or materials. Having separate tools appointed only for fish working is something that does not seem plausible for the economical dynamics of the Iron Gates communities, but the particular emphasis on fish in the diet and its significance in the social domain allows for this possibility.

6 Conclusion

Apart from identifying parts of the operation chain of fish processing at the site of Lepenski Vir, this study bears important implications for a better understanding of fish cleaning and preparation processes based on the conducted experimental trial. The purpose of this study was twofold, to characterise the fish polish on archaeological samples of chipped stone tools, and to gain additional knowledge about the visibility of this kind of activity based on other materials, such as cut marks observed on fish bones.

A very small number of chipped stone tools bore traces specifically related to fish processing. However, numerous tools found in all areas of the site had traces of animal processing, among them traces of meat processing which could also include the fish.

Residue FTIR analysis has proven to possess great potential regarding the detection of fish remains. By tracing the values of various elements of different fish species, we should be able to create a reference collection of FTIR spectra in the near future.

Based on various types of archaeological evidence, from fish bones to osseous and stone tools, and having in mind the salient symbolism of fish related imagery, it might be concluded that the Iron Gates communities held fishing in great regard and that they prepared their meals using chipped stone tools. Even though this type of activity is notable only on a limited number of lithic tools, the results presented in this article offer more insight into fish processing techniques at Lepenski Vir and can provide more clues for tracing similar activities at other sites in the region.

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