Beneath Still Waters - Multistage Aquatic Exploitation of *Euryale ferox* (Salisb.) during the Acheulian

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Summary

Remains of the highly nutritious aquatic plant Fox nut – *Euryale ferox* Salisb. (Nymphaeaceae) – were found at the Acheulian site of Gesher Benot Ya'aqov, Israel. Here, we present new evidence for complex cognitive strategies of hominins as seen in their exploitation of *E. ferox* nuts. We draw on excavated data and on parallels observed in traditional collecting and processing practices from Bihar, India. We suggest that during the early Middle Pleistocene, hominins implemented multistage procedures comprising underwater gathering and subsequent processing (drying, roasting and popping) of *E. ferox* nuts. Hierarchical processing strategies are observed in the Acheulian lithic reduction sequences and butchering of game at this and other sites, but are poorly understood as regards the exploitation of aquatic plant resources. We highlight the ability of Acheulian hominins to resolve issues related to underwater gathering of *E. ferox* nuts during the plant's life cycle and to adopt strategies to enhance their nutritive value.

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(underwater) manipulating a large basket (*Auka*) in which nuts are collected. Note the two hands at the edge of the basket. (Image credit: authors)

Figure 6: Procedures involved in the collection of *E. ferox* nuts, Madhubani District, Bihar, India: (A) Diver with the basket that is rotated within water to cleanse the nuts; (B) Divers bring the basket to the shore to complete the process of cleansing the nuts; (C) Close-up of the collected nuts; (D) View of the *E. ferox* nuts with associated molluscs; (E) Trampling helps remove the pulp; F) A mound of nuts piled up near the water body ready for transport to the village. (Image credit: authors)

Figure 7: Procedures involved in processing of *E. ferox* nuts, Madhubani District, Bihar, India: (A) *E. ferox*nuts are spread out to dry in the sun in the village; (B) The nuts are sorted into differing size ranges using sieves of different dimensions; (C) The nuts are roasted and stirred using bamboo sticks; (D) Popping of the*E. ferox* nuts immediately after roasting; note the wooden anvil and hammer; (E) View of the popped *E. ferox* nuts ready to be eaten. (Image credit: authors)

Figure 8: Hammer and anvil used for popping the dried and roasted *E. ferox* nuts in traditional practices in Madhubani District, Bihar, India: (A) General view of a wooden hammer (*Thaapi*) (photograph: Gabi Laron); (B) A wooden anvil (*Aphara*); (C) Measurements of a typical hammer; (D) Close-up of an anvil used for popping *E. ferox* nuts. (Image credit: authors)

Figure 9: Debris of *E. ferox* nuts after popping: (A) A handful of nuts (eight in number) generally popped together (N=50 fragments varying from 1mm to 1cm, the rest being <1mm). At the top right of the image, note a complete roasted nut of the same size group (diameter=11.49mm) as well as the final popped*Makhana*; (B) Close-up of nut fragments showing inner concave side; (C) One roasted *Makhana* nut (N=5 fragments) after popping. (Image credit: authors)

Figure 10: Anvils at the site of Gesher Benot Ya'aqov: A) Pitted anvils; B) Thin anvil. (Image credit: authors)

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1. Introduction

Studies of the evolution of hominin cognitive abilities and the origins of intelligence and language focus primarily on stone tool manufacture and on the exploitation of medium-sized to large terrestrial mammals. Here, we examine additional aspects of these cognitive abilities as reflected in a little-known example of skilled behaviour patterns: the exploitation of aquatic flora and fauna in the wetland habitats of paleo-Lake Hula. Although wetlands play an important role in supplementing human diet and enhancing its nutritional balance (Joordens *et al*. 2009; Wrangham *et al*. 2009; Cunnane and Steward 2010), few studies have explored the nutritional and/or medicinal properties of wetlands plants in the archaeological context (Stewart 1994; 2010; Colonese *et al*. 2011; Cortés-Sánchez *et al*. 2011; Hardy and Moncel 2011; Verhaegen and Munro 2011).

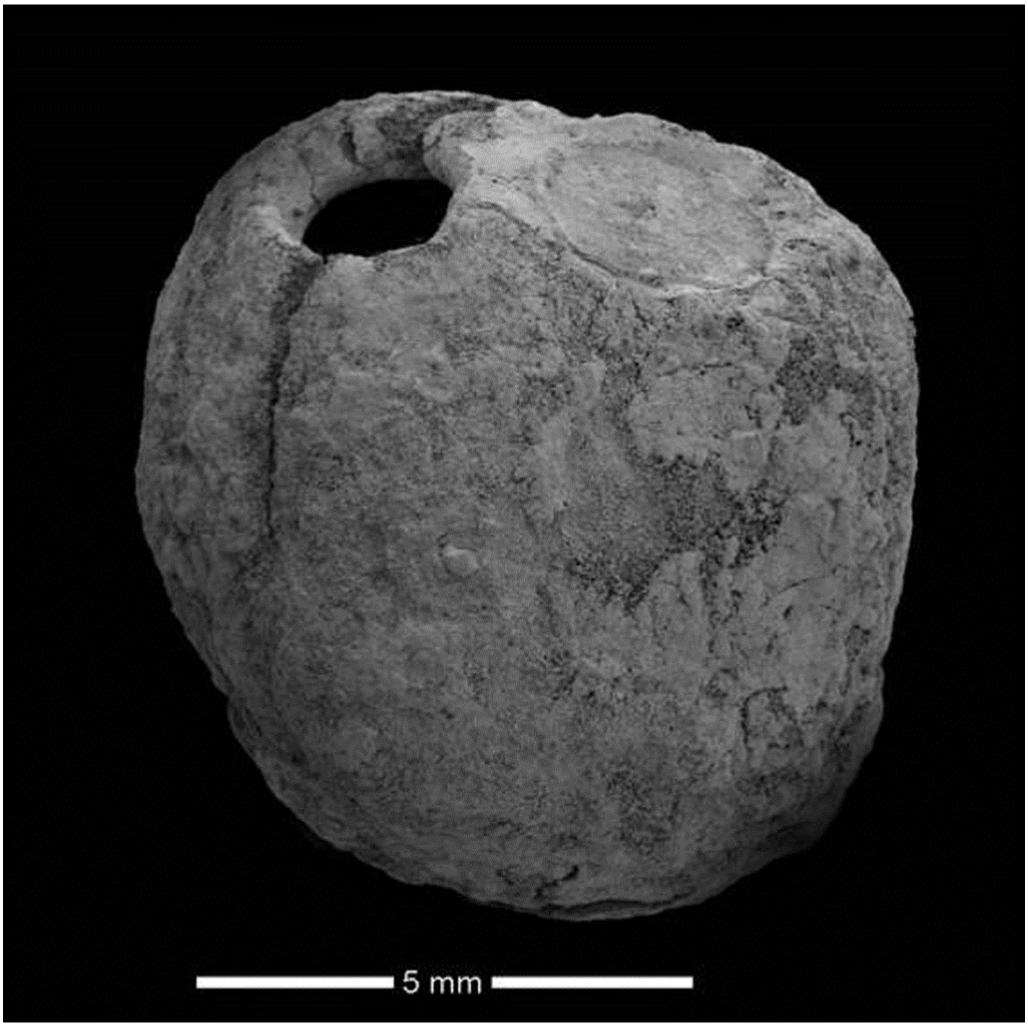

Figure 1: Fox nut (*E. ferox*) from Gesher Benot Ya'aqov Layer II-6 Level 1, complete seed with its characteristic germination aperture and attachment scar (*hilum*). (Image credit: authors)

Nuts of the aquatic plant *Euryale ferox* Salisb. (Nymphaeaceae) (common names: Fox nut, Gorgon nut, Prickly water lily and *Makhana* in Bihar, India) (Figure 1) were identified in Early to Middle Pleistocene deposits (Marine Isotope Stages 18–20) at the site of Gesher Benot Ya'aqov (GBY), Israel (Goren-Inbar *et al*. 2000; Feibel 2004; Sharon *et al*. 2011) (Figure 2). Along with *Trapa natans* (Water chestnut), they formed part of the botanically rich aquatic habitat of paleo-Lake Hula, comprising over 24 species of water plants (Table 1). Both species are currently extinct in the Levant (Melamed 2003; Melamed *et al*. 2011). *E. ferox* and *T. natans* are floating annual aquatic plants that grow in low-energy or still-water bodies generally around 1.5m deep, occurring within a wetlands ecosystem that was exploited by the GBY Acheulian hominins (Melamed 2003; Ashkenazi *et al*. 2005; Ashkenazi *et al*. 2009; Spiro *et al*. 2009; Mienis and Ashkenazi 2011; Zohar and Biton 2011). The prickly nature of *E. ferox* renders gathering and processing its nuts far more difficult in comparison with those of *T. natans*, thus providing us with an opportunity to explore the ways in which this species was exploited at GBY.

Here, we present novel evidence for advanced cognitive abilities of Acheulian hominins at GBY as attested by their adoption of complex multistage procedures for collecting and processing *E. ferox* nuts. *E. ferox* is widely prevalent in tropical and subtropical regions in ecological contexts similar to those of the paleo-Lake Hula environment. In many such places, it is collected and processed using traditional methods by predominantly freshwater fishing communities (Jha *et al*. 1991; 2003). The range of these strategies, particularly evident in the water bodies of northern Bihar (Madhubani District, India) (Figure 2), is of immense relevance when examining the archaeological context of *E. ferox* nut remains at GBY.

The Acheulian site of GBY, situated within the Benot Ya'akov Formation (Belitzky 2002), is located on the shores of paleo-Lake Hula in the Upper Jordan Valley, Dead Sea Rift (Goren-Inbar *et al*. 2000). This Early to Middle Pleistocene sedimentary sequence documents an oscillating freshwater lake and represents ~100,000 years of hominin occupation (Marine Isotope Stages 18–20) beginning earlier than 790,000 years ago (Feibel 2001; 2004). Studies of the 15 excavated archaeological horizons indicate that Acheulian hominins repeatedly occupied lake margins, produced stone tools, systematically butchered and exploited animals, gathered plant food, and controlled fire (Goren-Inbar *et al*. 1994; 2002a; 2002b; 2004; Rabinovich*et al*. 2008; Alperson-Afil *et al*. 2009).

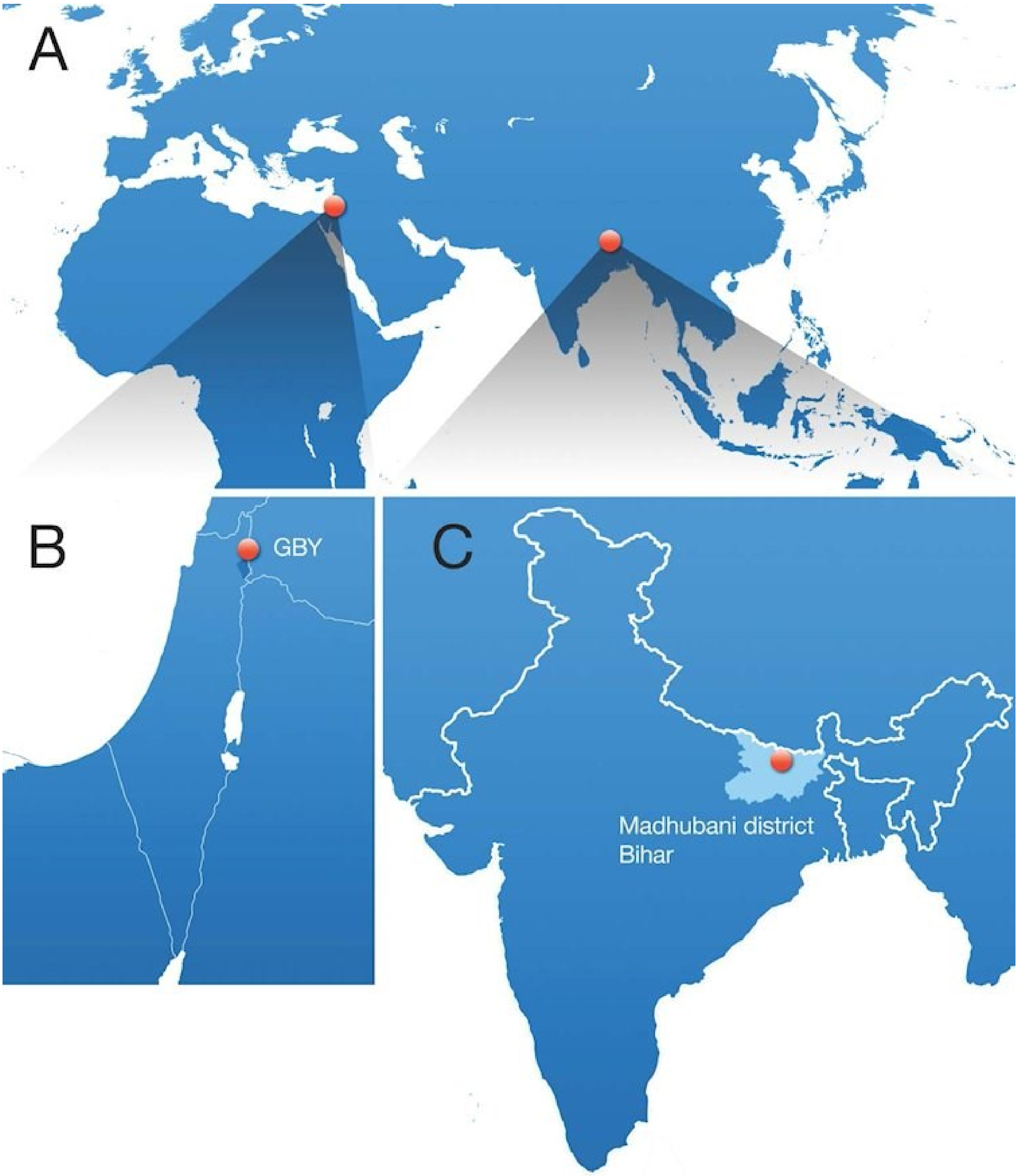

Figure 2: Map showing: (A) General view of the location of the regions studied in Israel and India; (B) Location of the Acheulian site of Gesher Benot Ya'aqov, Israel (33°00'30''N, 35°37'30''E) and; (C) Location of water bodies in Madhubani District, Bihar, India where traditional methods of gathering and processing *E. ferox* are practiced. The water bodies studied are located within a radius of 10km south and east of the town of Madhubani (26°22' 0'' N, 86°5'0'' E). (Image credit: authors)

2. *Euryale ferox* (Salisb.)

Remains of *Euryale ferox* nuts (seeds in botanical terminology) at GBY were identified by their characteristic features such as the prominent longitudinal ridge (raphe), shape and location of the *operculum* and *hilum*, as well as the structure of the seed surfaces (Figures 1, 3). These characteristics distinguish *Euryale ferox*from related fossil genera such as *Palaeoeuryale* and *Pseudoeuryale* (Miki 1960).

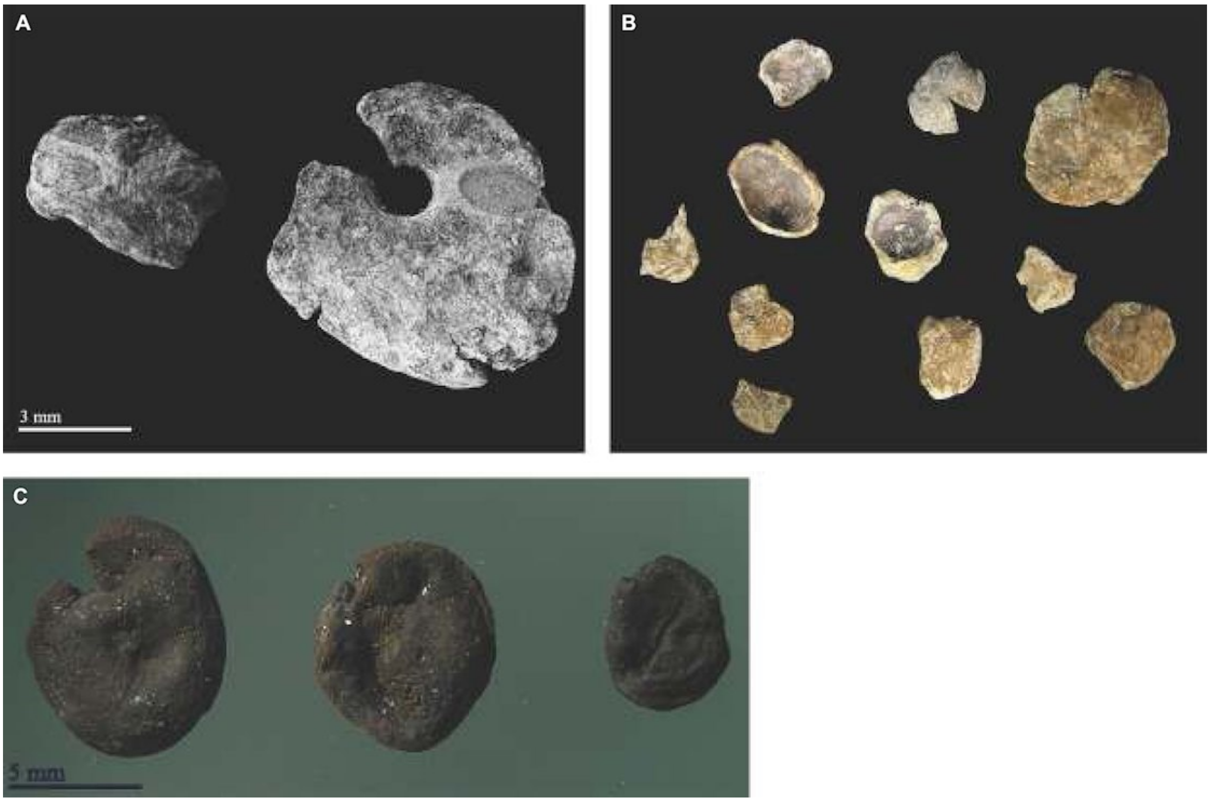

Figure 3: *E. ferox* seed remains from GBY: (A) Fox nut (*E. ferox*, GBY Layer II-6 Level 1), seed coat fragments easily identified by their characteristic attachment scar (*hilum*) close to the germination aperture (appears in the right fragment) (SEM); (B) Fox nut (*E. ferox*, GBY Layer II-6 Level 1), seed coat fragments, eight showing the convex outer side and three the concave inner side; (C) Fox nut (*E. ferox*, GBY Layer III-7), complete and compressed seeds. (Image credit: authors)

The prickly water-lily is an annual or perennial plant with long-petiole leaves whose large rounded blades (normally up to 1.3 and occasionally 2.4m in diameter) float on the water surface. The long petiole and veins that protrude from the bottom of the blade are densely covered with sharp prickles. The rhizome is sunk deep in the ground with the help of groups of thick and fleshy roots. The plant develops approximately 15–20 spongy fruits, each of which contains 30–40 nuts. When the fruit is ripe it dehisces and releases the nuts, which are covered by a mucilaginous arillus (Jha *et al*. 1991).

The plant grows in shallow stagnant water generally 0.3–1.5m deep and at a neutral pH. In the study region in Madhubani District, Bihar, water depths reach a maximum depth of around 3.5m. Flowering occurs in April–May and the fruits ripen and dehisce between June and August, when spherical nuts are released. The nuts have a mucilaginous arillus that holds them above the water surface for several days, after which they sink to the bottom of the water body. The plant germinates in early winter and grows with surprising speed, the biomass doubling each month from January to July. The maximal biomass found in a pond in India was 1.7kg/m^2 fresh weight in July. Temperature has a profound effect on the rate of biomass production (Jha *et al*. 1991).

As regards their nutritional value, *E. ferox* nuts contain 12.8% moisture, 9.7% protein, 0.1% fat, 0.5% minerals, 76.9% carbohydrates, 0.9% phosphorus, 0.02% calcium and 1.4 mg/100g carotene. The calorific value is 362 kcal/100g for raw *E. ferox* and 328 kcal/100g for popped nuts (see below for description of the processing techniques of these nuts). Popped nuts are comparable with staple food such as wheat and rice. The essential amino acid indices (EAAI) in the raw and popped parts of edible *E. ferox* nuts are 93% and 89%, respectively. These are higher than the values for rice (83%), wheat (65%), Bengal grain (81.55%), soya bean (85.6%), amaranth (57.5%), human milk (81.55%), cow's milk (88.8%), fish (89.2%) and mutton (87.24%) (Jha *et al*. 1991; Jha and Barat 2003; Ghosh and Santra 2003). *E. ferox* nuts are superior to dry fruits such as almonds, walnuts, coconuts and cashew nuts in terms of sugar, protein, ascorbic acid and phenol content (Jha *et al*. 1991; Jha and Barat 2003; Ghosh and Santra 2003).

E. ferox was present in Europe in the geological past, becoming extinct during the Quaternary (Simpson1936; Miki 1960; Soboleweska 1970; Jha *et al*. 1991; Ghosh and Santra 2003). Fossil nuts of this species have been reported from the Pleistocene in Poland (Soboleweska 1970) and England (Gibbard *et al*. 1996), and from the Oligocene in Scotland (Simpson 1936). Evidence of *E. ferox* is also noted in Tertiary deposits in Kolkata, India (Jha *et al*. 1991; Ghosh and Santra 2003). Nuts of several extinct fossil *Euryale* species, including *E. europaea* Weber, *E. lissa* Reid and *E. nodulosa* Reid, were found in geological layers in Europe and Japan (Miki 1960). At present, *E. ferox* is the only surviving species of the genus, which is the only recent genus of the subfamily *Euryaloideae*.

3. Materials and Methods

The methodology for calculating the number of *Euryale ferox* and *Trapa natans* nuts in the archaeological record at GBY was as follows:

***E. ferox* – calculation of nut numbers:** The number of complete nuts (Table 1) was calculated for each excavated unit by estimating the number of fragments that could be conjoined to form a single nut coat. When this estimate suggested the presence of more than one nut, the number was rounded up to two, and so forth. However, some units yielded fragments including characteristic structures such as the attachment scar (*hilum*) or germination aperture of the nuts. In such cases, their number was compared to the estimated value derived from the conjoined fragments and the higher value was considered to represent the minimum number of complete nuts in the assemblage.

***T. natans* – calculation of nut numbers:** The nuts of *T. natans* (Table 1) consist of a single nut enclosed within a bony calyx. The calyx bears four lateral spines, a typical depression at the base and an aperture surrounded by an extended rim at the tip. Most of the *T. natans* remains from GBY are fragments of the nut wall, while others are spines, apertures or bases. Hence, the number of nuts in each layer/level was calculated by estimating the number of fragments that could be conjoined to form a single nut wall. In addition, for layers/levels that also contained spines, apertures and bases, each structure was counted separately and the number of spines was divided by four. In such cases, as for *E. ferox*, their number was compared to the estimated value derived from the conjoined fragments and the higher value was considered to represent the minimum number of complete nuts in the assemblage.

Table 1: Nuts and shell fragments of *E. ferox* and *T. natans* at GBY (updated from previous work). Apart from layers/levels noted below, pitted stones (without botanical remains) were also found in Layer V-4: N=1; Layer V-5: N=4; Jordan Bank (Layers V-5 and V-6 excavated together under water): N=7+2 anvils; Layer II-6 Level 4b: N=26+2 anvils

Layer	*Euryale ferox*			*Trapa natans*			Pitted stones/ anvils	Approximate sample volume (in litres)
	No. of fragments	No. of complete nuts	Calculated no. of nuts	No. of fragments	No. of complete nuts	Calculated no. of nuts		
VI-2				11		3		0.35
VI-3				1		1		0.3
*V-6	2		1	391		51	3	374.4
VI-4				59		9		2.2
VI-5				6		2		0.3
VI-6				7		2		0.8
*I-4	4		1	176		28		308.75
*I-4 + I-5	16		9	1320		108		1137.5
VI-7				16		3		0.9
*I-5				30		4		190
VI-8				6		1		0.7
*II-2	69		46	72		6		879.1
VI-9				2		1		0

*II-2/3	27		17	63		6	2	341.25
II-3	8		3	15		2		117.5
VI-10	9		3	7		2		0.8
II-3/4				3		1		8.75
II-4	8		4	16		2		291.25
II-4/5				13		2		151.25
*II-5	752		222	920		69	3	4635
VI-12			1	3		1		1.5
*II-5/6	58		25	38		5	1	751.97
*II-6 L1	654	2	204	414		27	23/8	4333.75
*II-6 L2	128	1	45	60		4	228/8	1263.75
*II-6 L3	15		8	1		1	12/5	501.25
*II-6 L4	9		5	8		1	37/7	653.75
*II-6 L5	4		1	0		0	7/1	107.5
*II-6 L6				0		0	32/6	81.25

*II-6 L7	131		18	4		1	28/5	488.6
IV-6				1		1		5.74
II-7				33	1	7		10.71
IV-7				30		9		10.8
II-8				16		2		9.36
II-9	3		1	61		11		2.34
II-10	5		3	20		5		0.99
II-11				18		5		2.5
III-4				4		1		3.24
III-5	8	1	5	0		0		3.96
III-6				3		1		2.16
III-7	123	3	19	27		26		9.72
III-9				2		2		1.44
Total	**2033**	**7**	**641**	**3877**	**1**	**413**		**16687.38**

4. The Context of *E. ferox* Remains at GBY

The identification of complete and fragmentary remains of *E. ferox* within waterlogged archaeological horizons at GBY necessitated study of the site's taphonomy, with particular attention to the degree to which hominins were the agents responsible for the accumulation, spatial patterning and physical condition of the remains.

Examination of site formation processes at GBY indicates that the archaeological horizons were sealed rapidly, demonstrating a high integrity of preservation and an excellent context for studies of spatial patterning (Alperson-Afil *et al*. 2009). Observations from several archaeological horizons at the site may be summarised as follows:

a. Intact embryos and faecal pellets of two extinct freshwater molluscs, *Viviparus apameae galileae* and *Bellamya* sp. (Ashkenazi *et al*. 2009) were present, together with packstone of the molluscs (Sharon and Goren-Inbar 1999; Goren-Inbar and Sharon 2006; Rabinovich *et al*. 2012), in a single layer at GBY in association with thousands of stone artefacts and fossil mammal bones. Trampling and other post-depositional agents would not have left the embryos and faecal pellets intact.
b. The record of organic material comprises wood, bark, seeds and fruits (Goren-Inbar *et al*. 2002b; Melamed 2003), signifying minimal exposure to atmospheric conditions and hence minimal presence of bacterial activity that would have destroyed the anatomical structure and resulted in decomposition.
c. The preservation of medium-sized and large mammal bones at the site is excellent and hominin-induced markings (cut marks, percussion marks and hack marks) are discernible on them (Rabinovich *et al*. 2008; 2012). Experimental studies of faunal remains support these observations (Gaudzinski-Windheuser *et al*. 2010; Rabinovich *et al*. 2012). Further evidence includes the presence of conjoinable bones in some levels and layers, indicating that taphonomically the bones underwent minimal reorganisation (Goren-Inbar *et al*. 1994).
d. Fish remains at the site demonstrated differential preservation, being deposited either as a natural death assemblage (Zohar and Biton 2011) or in association with remains of hominin activities (Alperson-Afil *et al*. 2009).

e. The presence and spatial clustering of flint, basalt and limestone microartefacts is a clear indication that taphonomic processes at GBY had a minimal effect on archaeological horizons. The unique record of the burned flint component (microartefacts) viewed as 'phantom hearths' further confirms the excellent preservation of archaeological and associated materials/features. In these cases, spatial patterning reflects the time of abandonment. The lack of sedimentary obstacles, linear deposition or winnowing, and the spatial association of finds (Alperson-Afil and Goren-Inbar 2010), emphasise the absence of discernible taphonomic processes.

Table 1 presents the occurrence and frequencies of the two types of water nuts at GBY. Both *E. ferox* and *T. natans* nuts are present in both archaeological horizons and geological layers, the latter being devoid of lithic artefacts. The marked difference between archaeological and geological layers in quantities of *E. ferox* and *T. natans* arises primarily from different sampling strategies. Geological layers were minimally sampled along the walls of the trenches (Trenches II–VI) as compared to the extensive studies conducted on archaeological horizons. Within geological layers, there are differences in the occurrences of the two types of nuts. In Layer III-7, both nuts are well represented with *E. ferox* predominating. In other layers, *T. natans* is the dominant seed, with its highest occurrence being in Layer II-9, a gray mud sediment characteristically deposited under the highest water column and which represents the deepest part of the paleo-lake. Sedimentologically, a group of geological layers (Layers II-9, II-10, II-11, III-7) with a high occurrence of *T. natans* represent coquinas. The absence of lithics in these layers does not necessarily mean that they are archaeologically sterile. Although this may appear to be a contradiction, our experience at the site leads us to suggest that layers that are apparently archaeologically sterile may bear artefacts further along the strike, beyond the boundaries of excavated areas. In some cases (e.g. Layer II-12 in Goren-Inbar *et al*. 2002b, 81), an isolated microartefact indicated the presence of an as yet unknown and unexcavated archaeological horizon. Thus, the presence of seeds in archaeologically sterile layers may be explained in two ways; as a natural occurrence or as a result of human behaviour. In the absence of further excavations, neither possibility can be confirmed.

Remains of *E. ferox* are extremely abundant in the rich archaeological horizons (Table 1, rows marked by *). They occur in varying frequencies in these layers, as well as within the archaeological complex of Layer II-6. Hominin activities varied significantly between the 15 rich archaeological horizons, as reflected by differences in the presence and frequencies of finds (stone artefacts, fossil bones and organic remains). Here, we propose the hypothesis that the spatial patterning, physical condition and concentration of *E. ferox* nut fragments at the site is the result of intentional hominin gathering and processing rather than of natural factors. The key evidence for this is the co-occurrence of nuts and their fragments with phantom hearths and pitted stones (Goren-Inbar *et al*. 2002a), which occur in 10 of the 15 archaeological strata containing *E. ferox* remains (Figure 3). One possible use of the pitted stones was as 'anvils' for popping nuts. On the basis of ethnographic parallels discussed below, we believe that the association of many *E. ferox* fragments with pitted stones and phantom hearths is an indication of intentional roasting followed by popping to extract the nut from its hard shell and exploit its maximum nutritive value (Jha and Barat 2003). A new type of anvil, a component of the percussive tool assemblage, was recently identified at GBY (Goren-Inbar *et al*. in prep). These passive (dormant) percussive tools (de Beaune 2000) consist of thin natural basalt slabs with two flat surfaces that are sometimes broken, probably as a result of use. This is the first report of such thin anvils from an Acheulian site. They are characterised by the presence of pits and other abrasive damage marks on one or both flat surfaces and sometimes on the thin edges. Such anvils are not found at the lake's edge but were selected for their particular morphology and specific characteristics (e.g., hardness and non-vesicular nature) and brought from exposures of basalt flows that are currently unknown in the vicinity of the site. The total number of these anvils at GBY is 36, 26 of which are pitted. Along with pitted stones (the latter primarily of basalt but also of limestone), these anvils occur diachronically throughout the cultural sequence of the site (Table 1). The same is true for pitted stones, although their availability was most probably more extensive since their morphology is more varied (Goren-Inbar *et al*.2002a). Together, these percussive tools form the bulk of the tools that we propose were used to pop the*E. ferox seeds* and crack other types of nuts.

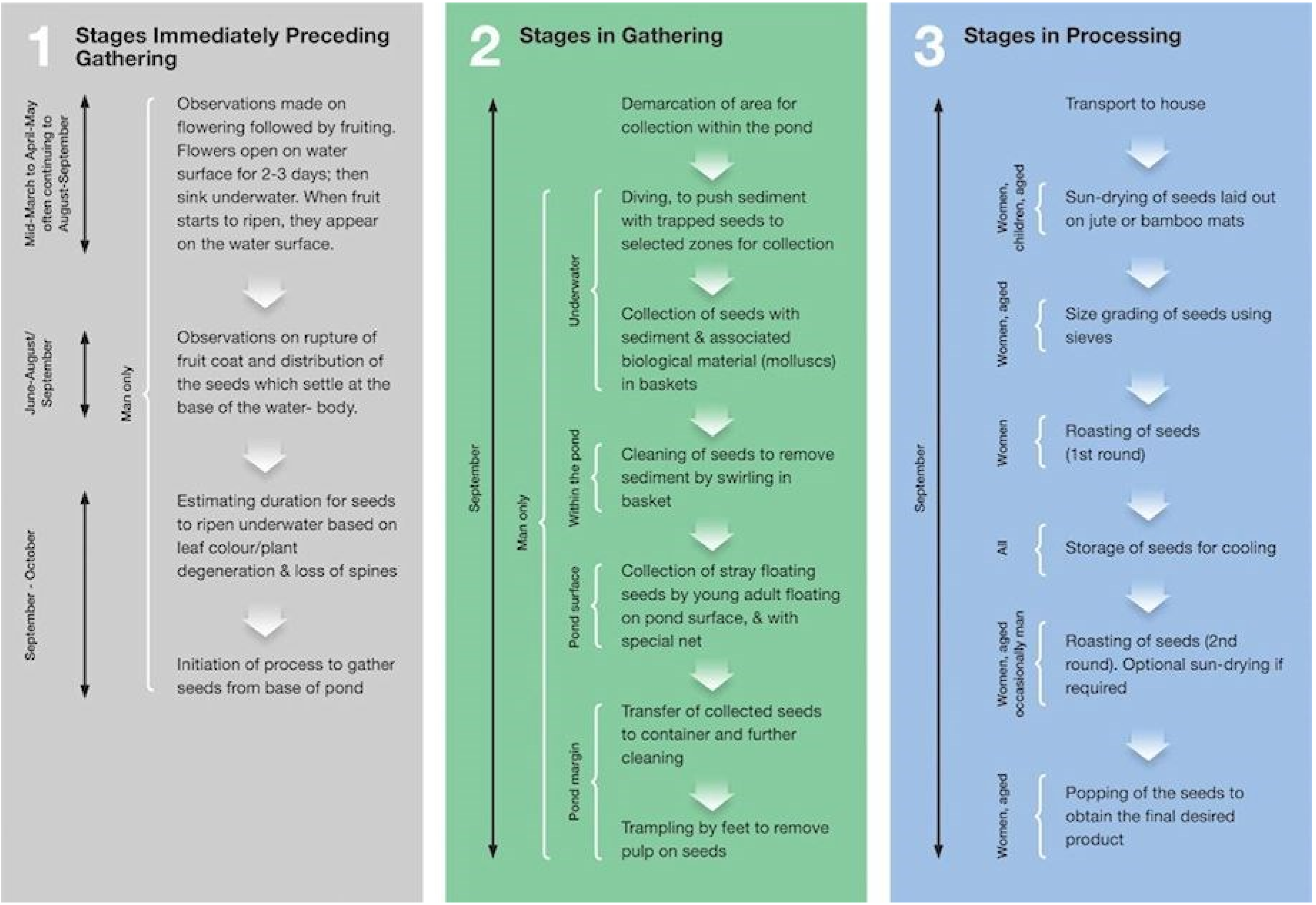

Figure 4: Flow charts highlighting the main events in the gathering and processing of *E. ferox* (locally called *Makhana*) based on our ethnographic observations in Madhubani District, Bihar and summarised from published literature (Jha *et al*. 1991; 2003; Mishra *et al*.2003; Mandal *et al*. 2010). (Image credit: authors)

5. Traditional Modes of Exploitation of *E. ferox* in India

Here, we draw on ethnographic analogies citing traditional methods of *E. ferox* exploitation in the water bodies of northern Bihar, India, where planned sequential procedures and decision-making strategies are employed by local communities in collecting and processing *E. ferox* nuts (Jha *et al*. 1991; 2003; Jha and Barat 2003; Ahmad and Singh 2003; Goswami 2003; Khan and Halim 2003; Mishra *et al*. 2003; Singh 2003; Jain *et al*. 2010; Jain *et al*. 2011; Mandal *et al*. 2010; Singh and Singh 2011). The procedures adopted in Bihar imply an excellent knowledge of the environment and seasonality in relation to the plants' life cycle (Jha *et al*. 1991) (Figure 4). Important to note here is the fact that the prickles/spines on mature fruits make them very difficult to harvest with bare hands. Once the mature fruits burst, the seeds float near the leaves and then sink to the base of the pond, from where they are collected. Thus, a structured sequential process has been devised for gathering and processing the nuts, which has been discussed in the literature (Jha *et al*. 1991; 2003; Ahmad and Singh 2003; Mishra *et al*. 2003; Singh 2003; Mandal *et al*. 2010) and documented as part of this study (see Figures 5–8).

Based on these sources of information, we note that gathering is carried out by adult males assisted by a few adolescent boys, with a division of activities that is related to age and/or experience. The process can be summarised as follows: 1) the equipment required (bamboo collection baskets of various types) is organised; 2) bamboo poles fixed to the base of the pond serve as guides to demarcate spaces selected for underwater gathering of the nuts and are shifted as collection proceeds across the water body; 3) adults repeatedly dive underwater to collect nuts that have sunk to the pond bed, at the base of the plant; 4) the nuts are scooped into bamboo baskets (sieves); 5) in larger ponds the nuts are scooped into a large cane basket and given a preliminary cleaning underwater by repeated rotation; 6) an adolescent (inexperienced in diving) floats on the water surface with the aid of pitchers or jerry cans and employs a sieve to collect stray nuts that float to the surface; 7) the nuts brought to the shore are cleaned by trampling to remove roots, plant matter and associated molluscs (Jha *et al*. 1991; 2003; Ahmad and Singh 2003; Mishra *et al*. 2003; Singh 2003; Mandal *et al*. 2010). Children actively participate in gathering molluscs, crabs and other plants that are associated with the *E. ferox* roots and are washed up on the shore during the gathering and cleaning procedure.

Figure 5: Procedures involved in the collection of *E. ferox* nuts, Madhubani District, Bihar, India; (A) General view of men of the fishing community involved in the gathering of *E. ferox (Makhana)* nuts; note one type of collecting basket in the background; (B) Close-up of *E. ferox*, showing the flower and characteristic leaves; (C) View of a diver manipulating a bamboo pole that aids in demarcating areas selected for underwater gathering of *E. ferox* nuts; (D) Diver surfacing after gathering *E. ferox* nuts using a special type of basket (*Gaanja*), with an aluminum pot also used for collection; (E) Adolescent boy collecting stray nuts that rise to the water surface from the pond bed during collection; (F) Divers (underwater) manipulating a large basket (*Auka*) in which nuts are collected. Note the two hands at the edge of the basket. (Image credit: authors)

Figure 6: Procedures involved in the collection of *E. ferox* nuts, Madhubani District, Bihar, India: (A) Diver with the basket that is rotated within water to cleanse the nuts; (B) Divers bring the basket to the shore to complete the process of cleansing the nuts; (C) Close-up of the collected nuts; (D) View of the *E. ferox* nuts with associated molluscs; (E) Trampling helps remove the pulp; F) A mound of nuts piled up near the water body ready for transport to the village. (Image credit: authors)

Figure 7: Procedures involved in processing of *E. ferox* nuts, Madhubani District, Bihar, India: (A) *E. ferox* nuts are spread out to dry in the sun in the village; (B) The nuts are sorted into differing size ranges using sieves of different dimensions; (C) The nuts are roasted and stirred using bamboo sticks; (D) Popping of the *E. ferox* nuts immediately after roasting; note the wooden anvil and hammer; (E) View of the popped *E. ferox* nuts ready to be eaten. (Image credit: authors)

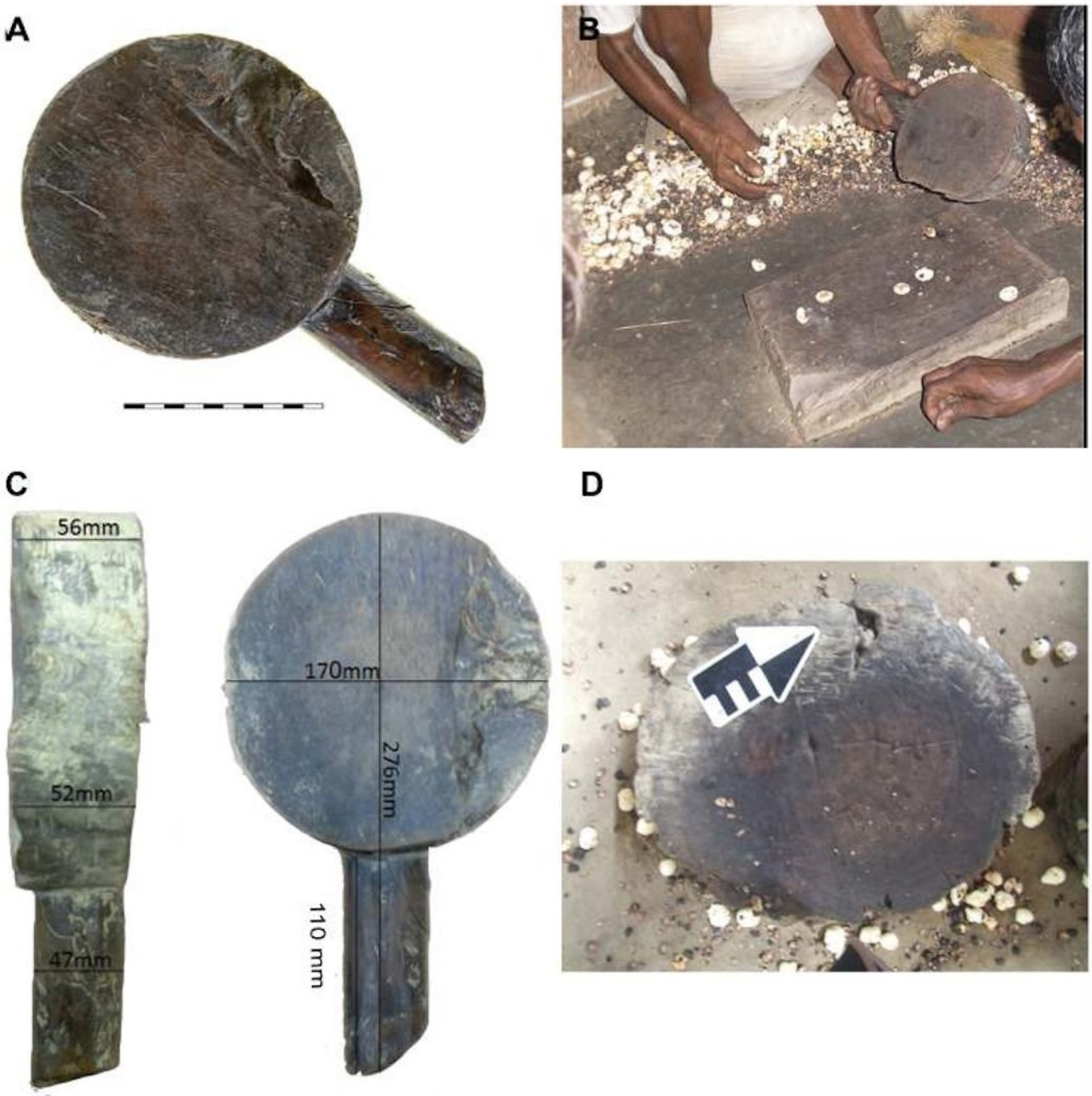

Figure 8: Hammer and anvil used for popping the dried and roasted *E. ferox* nuts in traditional practices in Madhubani District, Bihar, India: (A) General view of a wooden hammer (*Thaapi*) (photograph: Gabi Laron); (B) A wooden anvil (*Aphara*); (C) Measurements of a typical hammer; (D) Close-up of an anvil used for popping *E. ferox* nuts. (Image credit: authors)

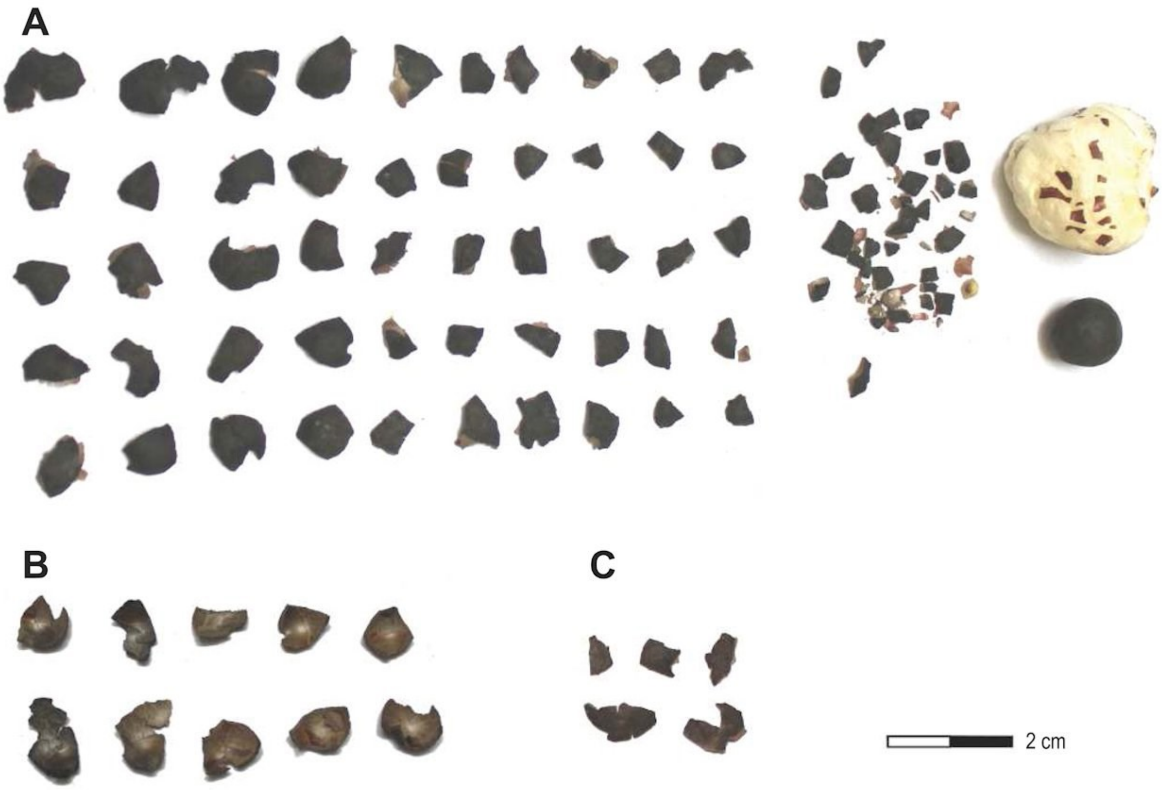

Figure 9: Debris of *E. ferox* nuts after popping: (A) A handful of nuts (eight in number) generally popped together (N=50 fragments varying from 1mm to 1cm, the rest being <1mm). At the top right of the image, note a complete roasted nut of the same size group (diameter=11.49mm) as well as the final popped *Makhana*; (B) Close-up of nut fragments showing inner concave side; (C) One roasted *Makhana* nut (N=5 fragments) after popping. (Image credit: authors)

Processing the nuts in the village comprises size sorting the nuts using a set of sieves, several stages of sun-drying and roasting on a wood fire and lastly popping, which results in the final nutritious product (Jha*et al*. 1991; 2003; Figures 7–9). The procedure of popping *E. ferox* seeds is widely used in Bihar and involves drying followed by at least two cycles of roasting the nuts. The nuts are then placed on a wooden anvil (around 60–70cm in diameter) and struck with a wooden mallet-like hammer (around 17–27cm in diameter) (Figures 7–8). These tools are purpose-built and are carved from the heartwood of *Dalbergia sisoo, Acacia lenticularis* and *Shorea robusta* (Jha *et al*. 2003) (Figures 7–8). Popping is a process whereby superheated vapour is created within the conditioned nut by heating the moisture contained within, following which the pressure is suddenly released, resulting in expansion of the volume of the kernel. Popping the *E. ferox* seeds by traditional methods increases the concentration of micronutrients per unit weight.

A distinct gender-based division of labour is observed. Activities within the pond/lake are male dominated, while those involving drying, cleaning, roasting and popping the seeds are largely the preserve of women, aided by children and elderly men.

It has been mentioned that the prickles/spines on the outer surface of mature fruits makes them difficult to harvest with bare hands, a problem resolved in the study region by collection after the fruits burst and sink to the bed of the pond. In Bangladesh, however, this species is harvested using boats and long-handled curved knives in order to cut the pedicle underwater (Khan and Halim 2003) and the pulpy aril and seeds are eaten, while the endosperm of the seeds is consumed raw or roasted (Khan and Halim 2003). In parts of north-east India, such as Assam, the edible seeds are eaten raw or in rare cases processed further (Goswami 2003, 34). In Manipur, the leaf petioles and seeds are eaten raw or boiled (Singh 2003, 10–11). Elsewhere in this state, the tender leaves, seed aril and fruit skin are also consumed after removal of the prickles by fire or otherwise, as is the mature leaf petiole after removal of the spines (Singh 2003, 11). It is also noted that the seeds are eaten raw after roasting in the sand and dehusking (as quoted in Singh 2003, 11). In several regions here, ripe seeds may also be eaten raw (Jain *et al*. 2010, 64; Jain *et al*. 2011) or used in a range of traditional food preparations for dietary or medicinal purposes. Others (Singh and Singh2011) note that the immature fruits are consumed after boiling while the ripe ones are eaten fresh. In all cases, attention is paid to seasonality in harvesting parts of the plant (Jain *et al*. 2010, 66).

6. Significance in Terms of *E. ferox* Exploitation at GBY

The Indian record of *E. ferox* seed consumption indicates that there are several ways to harvest and process *E. ferox* nuts. Clearly, the major difficulty to be overcome is the presence of prickles/spines that make processing the fruit difficult. Further difficulties involve collection of seeds after the fruit bursts. The Bihar method described here overcomes both of these problems through adoption of underwater collection procedures. Key points emerging from investigation of traditional methods from Bihar in the context of the*E. ferox* remains from GBY are summarised as follows: a) gathering of *E. ferox* seeds takes place after they ripen and sink to the bed of the water body; b) gathering by diving is a necessity, as the plants grow in still waters and seeds are not washed to the edges of the water body; c) the work necessitates observation of the lifecycle of the plant and of the prime time for gathering seeds; d) drying and popping seeds was done at a distance from the water body, where fire and dry land facilitated later stages of processing; e) roasting and popping are both procedures requiring the technology of fire and that of anvils and hammers; and f) a well-established division of labour was associated with each stage of gathering and processing.

Different methods of *E. ferox* consumption are cited here, showing that the seeds are a highly valuable component in the diet of wetland communities. It is clear from literature and our own data that common processing methods of *E. ferox* seeds in India are those that include the use of fire. Clearly, the prickly nature of the plant parts is an important trait that local communities have to consider and overcome. We believe that the traditional ethnobotanical procedures involved in the gathering and multistage processing of *E. ferox* in Bihar are instructive parallels for the interpretation of the GBY archaeological data. Thus, the archaeological record of GBY, which includes the use of fire and the presence of pitted stones, anvils and hammerstones in association with *E. ferox* seeds, strongly supports the use of analogies with traditional modes of gathering and processing, such as that practiced by communities in Bihar. Studies of the GBY archaeological record provides information on the co-occurrence of a range of finds that may be compared with the ethnographic data. 1) In each of the archaeologically rich horizons there were spatial concentrations of burned flint microartefacts. Analysis of these concentrations suggests the presence of phantom hearths, the earliest evidence for the control and continual use of fire in western Eurasia (Alperson-Afil and Goren-Inbar 2010). High-resolution data from excavations enables estimation of the size of these hearths, which were around 0.49m long and 0.35m wide (Alperson-Afil and Goren-Inbar 2010, 74, table 4.1). 2) Pitted stones and hammerstones, as well as the newly identified thin basalt anvils, were also found in each of these horizons (Figure 10). 3) In all archaeological horizons, remains of *T. natans* and *E. ferox* were discovered as well. The pristine taphonomic context of the archaeological horizons at GBY, along with the significant patterns of association noted between various find categories discussed above, provide a background for our discussions of the spatial patterning of past activities. Spatial analysis of these associations and analyses of Layer II-6 Levels 2 and 6 provide further insight into the proximity of hearths and pitted stones (on both blanks and blocks) (Table 1; Alperson-Afil and Goren-Inbar 2010, 91, figs 4.8, 4.9; Alperson-Afil *et al*. 2009, 1678, fig. 2). This correlation of nuts, phantom hearths and pitted stones at GBY leads us to suggest that some key aspects of the methods of collecting and processing noted in Bihar, which includes roasting and subsequent popping of the seeds, may be of greater relevance for the GBY data than those described from elsewhere in India. Greater precision in spatial associations between the nuts and other features in the vicinity of the paleo-lake is not possible owing to the light weight of the seeds. However, common aquatic taxa in the Upper Jordan Valley (Lake Hula), the Acheulian site of GBY and Bihar (India) (Table 2) reflect the extent of ecological similarity, despite their great biogeographical distance. The habitat and surrounding environment of paleo-Lake Hula was a rich and diverse Mediterranean one, as evidenced by the identification of an array of 60 edible taxa recorded at GBY (Melamed 2003, table 3), as well as a wealth of fish, crustaceans, birds and mammals.

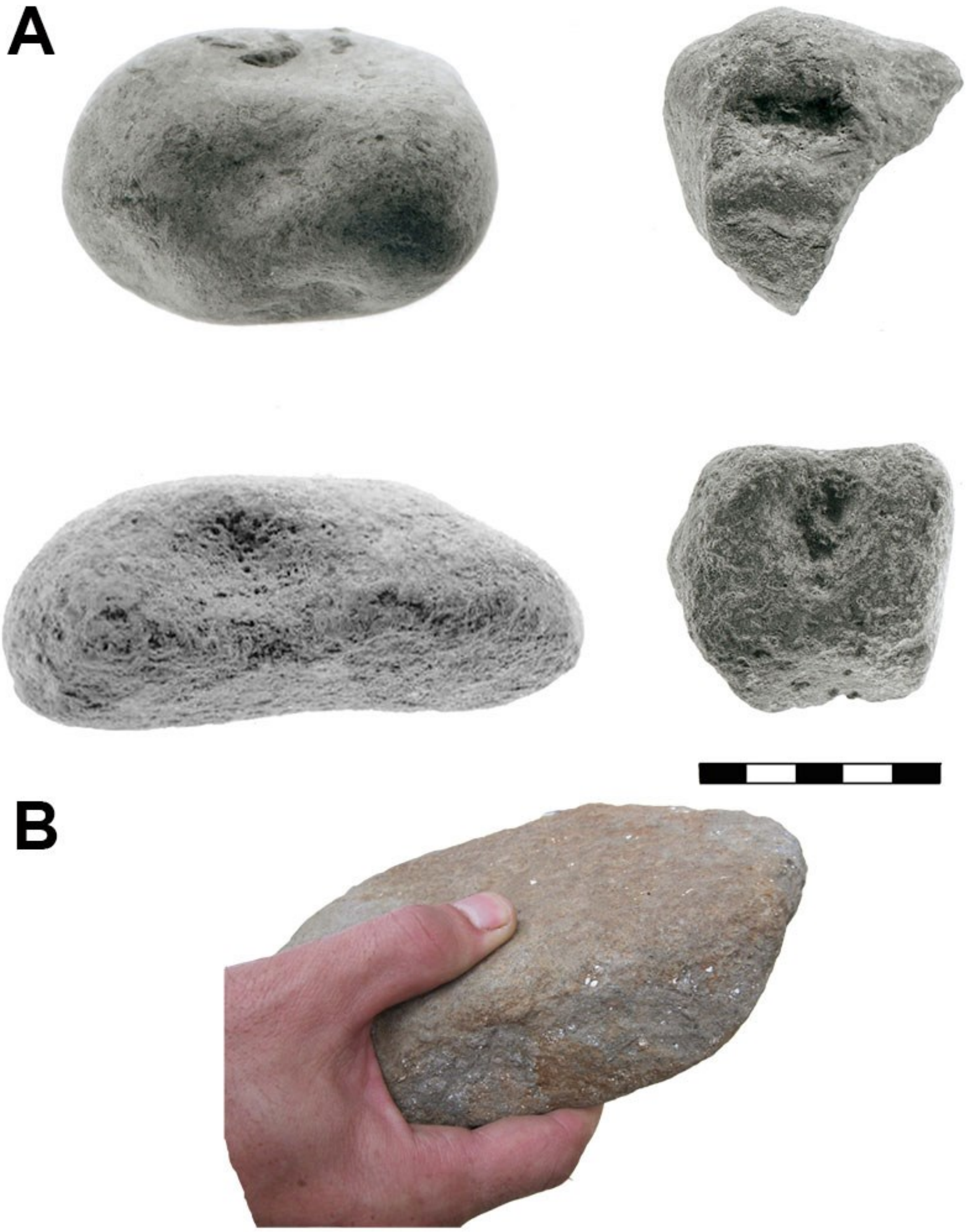

Figure 10: Anvils at the site of Gesher Benot Ya'aqov: A) Pitted anvils; B) Thin anvil. (Image credit: authors)

E. ferox grows in water bodies with water depths ranging from around 0.3m to 1.5m, up to a maximum of around 2.5m (Jha *et al*. 1991; Mishra *et al*. 2003; Mandal *et al*. 2010) or up to around 3.5m as noted in the study region. Although Acheulian hominins may have consumed seeds raw, this would have entailed considerable effort in harsh conditions owing to the prickly nature of the plants. With the technology enabling them to process nuts using fire, anvils and percussive tools, hominins could avoid the difficulties posed by exploitation of raw seeds.

The fluctuating water level of paleo-Lake Hula would have been an obstacle to adopting simpler methods for gathering nuts, in view of the plant's life cycle and the water depths and geochemistry required for its growth and survival. A desiccation scenario of fluctuating lake levels would have resulted in the death of plants, unable to regenerate as germination occurs under water. Exposure to atmospheric conditions would have resulted in the complete decomposition of the macrobotanical remains found at the site. The entire issue of organic preservation is based on anaerobic conditions (and hence inappropriate conditions for bacteria responsible for the decomposition of organic material). Irrespective of the depth of the water, hominins would have had to collect nuts from beneath the lake surface, entailing some amount of time spent under water.

It is important to note that we do not suggest that Acheulian hominins followed modes of collecting or processing that were identical to those practiced today, particularly in the case of elements dictated by modern economic conditions (use of bamboo poles to demarcate underwater areas for collecting nuts, sieves for sorting nuts for sale or even gender-based division of labour).

Such cognitive procedural abilities of planning and performance in aquatic habitats, particularly when combined with exploitation of fish (Zohar and Biton 2011) have not previously been reported for Acheulian hominins. Ethnographic analogies demonstrate that exploitation of *E. ferox* nuts is performed by communities of fishermen in water bodies that are also used for fishing (Jha *et al*. 1991). The most abundant fish species currently exploited in habitats associated with *E. ferox* include three families of air-breathing fish: Cyprinidae (carps), Clariidae (catfish) and Bagridae (catfish) (Table 2). At GBY, remains of Cyprinidae and Clariidae were recovered, predominantly Cyprinidae (mainly the large *Barbus* sp. and *Barbus longiceps*). Interestingly, the cyprinids remains were recovered in association with living floors excavated in Area B (Table 2) (Alperson-Afil *et al*. 2009; Zohar and Biton 2011). The archaeological association between *E. ferox* nuts, large quantities of cyprinid remains and other cultural activities documented at GBY presents novel evidence for intensive exploitation of the aquatic fauna and flora of paleo-Lake Hula.

Table 2: Common aquatic taxa from the Upper Jordan Valley (Lake Hula) (Danin 2004), the Acheulian site of GBY and Bihar (India) (Melamed 2003; Melamed *et al*. 2011). Data on fish from Goren and Ortal 1999; Zohar and Biton 2011; Montana *et al*. 2011. In Bihar, 35 species have a high commercial value, among which Cyprinidae and Clariidae predominate, as well as Balitoridae. The richness of native fish species here is very high (>260 species), thus differing from that of Lake Hula, similarities being at the family level (Cyprinidae predominate in both Bihar and GBY)
* = endemic species of fish

Group	Family	Lake Hula	GBY	Bihar
Aquatic flora	Ceratophyllaceae	*Ceratophyllum demersum* L.	*Ceratophyllum demersum* Salisb.	*Ceratophyllum demersum* Salisb.
Aquatic flora	Nymphaeaceae	*Euryale ferox* Salisb.	*Euryale ferox*	*Euryale ferox*
Aquatic flora	Nymphaeaceae		*Nuphar luteum*	
Aquatic flora	Salviniaceae		*Salvinia natans*	
Aquatic flora	Lemnaceae	*Lemna minor* L.		*Lemna minor*
Aquatic flora	Potamogetonaceae	*Potamogeton berchtoldii* Fieber		*Potamogeton berchtoldii* Fieber
Aquatic flora	Potamogetonaceae	*Potamogeton pectinatus* L.	*Potamogeton pectinatus* L.	*P. pectinatus* L.
Aquatic flora	Potamogetonaceae	*Potamogeton nodosus* Poir.		*P. nodosus* Poir.
Aquatic flora	Potamogetonaceae	*Potamogeton lucens* L.		*P. lucens* L.
Aquatic flora	Potamogetonaceae	*Potamogeton perfoliatus* L.		*P. perfoliatus* L.
Aquatic flora	Lythraceae	*Trapa natans* L.	*Trapa natans* L.	*Trapa natans* L.
Aquatic flora	Lentibulariaceae	*Utricularia australis* R.Br.		*Utricularia australis* R.Br.

Aquatic flora	Droseraceae		*Aldrovanda vesiculosa* L.	
Aquatic flora	Lentibulariaceae	*Utricularia gibba* L.		*Utricularia gibba*L.
		S=11 species	**S=7 species**	**S=11 species**
Osteichthyes	Cyprinidae	*Acanthobrama lissneri* (Tortonese 1952)	*Acanthobrama lissneri* (Tortonese 1952)	Cyprinids - 19 species
Osteichthyes	Cyprinidae	*Carasobarbus canis* (Valenciennes 1842)	*Carasobarbus canis* (Valenciennes1842)	
Osteichthyes	Cyprinidae	*Barbus longiceps* (Valenciennes 1842)	*Barbus longiceps*(Valenciennes,1842)	
Osteichthyes	Cyprinidae	*Capoeta damascina* (Valenciennes 1842)	*Capoeta damascina*(Valenciennes1842)	
Osteichthyes	Cyprinidae	*Garra rufa* (Heckel 1843)	*Garra rufa* (Heckel 1843)	
Osteichthyes	Cyprinidae	*Hemigrammocapoeta nana*(Heckel 1843)	*Hemigrammocapoeta nana*(Heckel 1843)	
Osteichthyes	Cyprinidae	*Mirogrex hulensis* (Goren *et al*. 1973)	*Mirogrex hulensis* (Goren *et al*. 1973)	
Osteichthyes	Cyprinidae	*Pseudophoxinus kervillei* (Pellegrin 1911)	*Pseudophoxinus kervillei* (Pellegrin 1911)	
Osteichthyes	Balitoridae	*Nemacheilus jordanicus* (Banarescu and Nalbant 1966)		*Nemacheilus* sp.
Osteichthyes	Balitoridae	*Nemacheilus panthera* (Heckel 1843)		

Osteichthyes	Balitoridae	Nun galilaeus* (Günter 1864)		
Osteichthyes	Clariidae	*Clarias gariepinus* (Burchell 1822)	*Clarias gariepinus* (Burchell 1822)	*Clarias* sp.
Osteichthyes	Cyprinodontidae	*Aphanius mento* (Heckel 1843)		
Osteichthyes	Cichlidae	*Oreochromis aureus* (Stiendachner 1864)	*Oreochromis aureus* (Stiendachner 1864)	
Osteichthyes	Cichlidae	*Sarotherodon galilaeus* (Artedi 1757)	*Sarotherodon galilaeus* (Artedi 1757)	
Osteichthyes	Cichlidae	*Tilapia zillii* (Gervais 1848)	*Tilapia zillii* (Gervais 1848)	
Osteichthyes	Cichlidae	*Tristramella simonis intermedia** (Steinitz and Ben-Tuvia 1960)	*Tristramella simonis intermedia** (Steinitz and Ben-Tuvia 1960)	
S= number of species		**S=17 species**	**S=13 species**	**S=260 species**

7. Discussion

The advanced and sophisticated cognitive abilities described above are supported by a series of additional observations drawn from various multidisciplinary studies of the GBY Acheulian record. These include aspects of planning and communication as derived from stone tool production sequences (Sharon *et al*.2011), spatial cognition of the landscape and intra-site spatial organisation (Goren-Inbar and Sharon 2006; Rabinovich *et al*. 2006; Rabinovich *et al*. 2008), procedural cognition, technical and procedural know-how and specialisation (Madsen and Goren-Inbar 2004; Alperson-Afil *et al*. 2009; Goren-Inbar 2011; Goren-Inbar *et al*. 2011; Rabinovich and Biton 2011), as well as social cognition (Goren-Inbar *et al*. 2002b; Goren-Inbar2011). These cognitive abilities are expressed in the multiphase process of realisation of the plan for achieving a particular goal. This is seen especially in the *chaîne opératoire* of basalt bifaces (handaxes and cleavers), documenting cognitive abilities in the structure of the long-term processes involved in biface manufacture.

In addition to the above cultural observations based on lithic assemblages and their reduction sequences, there is also evidence derived from the faunal record at the site. This is characterised by both richness and diversity of species, contributing substantially to the reconstruction of hominin knowledge of the environment in exploitation of both terrestrial wildlife (Rabinovich *et al*. 2012; Rabinovich and Biton 2011), such as modern-like processing of *Dama* sp. (Rabinovich *et al*. 2008), and aquatic resources such as turtles (Hartman 2004) and fish (Alperson-Afil *et al*. 2009; Zohar and Biton 2011).

Table 3: Edible species reported from GBY, including details of parts that can be consumed

Species	GBY remnant	Edible organs
Ceratophyllum demersum L.	nutlet	leaf
Euryale ferox Salisb.	seed coat	seed
Nuphar lutea (L.) Sm.	seed coat	leaf, petiole, rhizome
Lemna minor L.	–	whole plant
Potamogeton pectinatus L.	nutlet	leaf and stem
Trapa natans L.	nut shells	seed, root
Utricularia australis R. Br.	–	leaf, root

Palaeobotanical evidence contributes to our understanding of the multiple facets of the environmental knowledge of Acheulian hominins and their ability to structure modes of exploitation of diverse resources. At GBY, this exploitation of multiple resources includes that of seven fruit-bearing species with edible nuts belonging to both extant Mediterranean vegetation and locally extinct species

(Goren-Inbar *et al*. 2002a; Melamed 2003; Melamed *et al*. 2011). Two of the locally extinct species (in the Mediterranean biome) are edible aquatic nuts that flourished in paleo-Lake Hula and were found in quantities at the site: *E. ferox* and *T. natans* (Goren-Inbar *et al*. 2000; Goren-Inbar *et al*. 2002a; Rabinovich *et al*. 2012) (Table 3). The pitted stones and anvils mentioned above support the view that these remains were components of the paleo-diet (Goren-Inbar *et al*. 2002a). These were found in close spatial proximity with burned flint microartefacts, the latter indicating the location of Acheulian hearths (Goren-Inbar *et al*. 2002a; Goren-Inbar *et al*. 2004). Evidence of fire is seen throughout the sequence of Acheulian occupation at GBY (around 50,000 years at the site; Sharon *et al*. 2011) and attests to use and control of this component of culture. Continual fire making (Goren-Inbar *et al*. 2004) and the transmission of particular modes of technological tool production indicate evolved communication within the group, interpreted as language (Alperson-Afil and Goren-Inbar2010; Sharon *et al*. 2011). Clearly, long-term memory was already a component of the evolutionary realm of GBY hominins. The exploitation of *E. ferox* at GBY, supplemented by data from ethnographic parallels, indicates that Acheulian hominins implemented complex strategies to extract maximum nutritive value from plant species, despite the opportunity of consuming them fresh. It also suggests delayed gratification implied by the time gap between appearance and collecting of the nuts. We do not claim that Acheulian hominin cognitive abilities were similar to those of modern humans, but do suggest that some aspects of complex cognition possibly overlapped in these hominins.

Ethnographic analogies, when considered with archaeological evidence of nuts, pitted anvils and charred organic material, among other features, point to the possibility of a complex sequence of exploitation of an aquatic nut that included gathering by diving, underwater processing, drying, roasting and possibly popping. This process adds to a plethora of evidence of Acheulian hominin activities and diverse associated cognitive abilities, all of which emerge from the analyses of early Middle Pleistocene Acheulian finds from the Levantine Corridor.

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