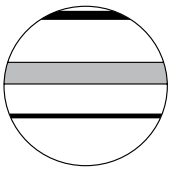
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Research paper

The Holocene
2018, Vol. 28(12) 1992–2005
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The Muknal cave near Tulum, Mexico: An early-Holocene funeral site on the Yucatán peninsula

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Abstract

Here, we report on an incomplete human skeleton, soot patches related to anthropogenic fireplaces, and cut marks on the mandible of an extinct peccary, from the submerged Muknal cave southwest of Tulum on the Mexican Yucatán peninsula. The human individual, here named 'Muknal Grandfather', was identified as a male based on cranial parameters. The age at the time of death was estimated to be between 40 and 45 years. We propose that the human bones have been brought to the cave during the latest Pleistocene or early Holocene, but not later than 8600 $_{14}$C yr BP (ca. 9600 cal BP), as a secondary burial of a partial skeleton. The peccary mandible was placed close to the burial site, possibly as part of the same ritual. The Muknal cave therefore served as a place for funeral rituals.

Keywords

burial, charcoal, cut marks, human settlement, Pleistocene/Holocene, soot patches, southern Mexico, Tayassuidae, Yucatán peninsula

Received 10 April 2018; revised manuscript accepted 30 July 2018

Introduction

Ongoing investigations on the Yucatán peninsula reveal one of the largest assemblages of late Pleistocene to early Holocene human skeletons in the Americas. Nine almost complete (>80%) human skeletons have been identified to date in the submerged caves in the Tulum area of Quintana Roo in southern Mexico (Chatters et al., 2014; González González et al., 2008a, 2013; Stinnesbeck et al., 2017c), some in association with hearths (Hering et al., 2018) and other archeological evidence such as anthropogenic cut marks on Pleistocene mammal bones (González González et al., 2008a, 2008b, 2013).

A diverse faunal assemblage was also discovered, including peccaries (*Muknalia minima*), tapirs (*Tapirus* sp.), camels (*Hemiauchenia* sp.), ground sloths (*Nothrotheriops shastensis, Xibalbaonyx oviceps, Nohochichak xibalbakah*), proboscideans (*Cuvieronius hyodon*), giant armadillos (*Glyptotherium* sp.), and horses (*Equus* sp.) of late Pleistocene and early Holocene ages (e.g. peccaries and tapirs; Chatters et al., 2014; González González et al., 2008b; McDonald et al., 2017; Stinnesbeck et al., 2017a, 2017b, 2017c).

Here, we report on new anthropogenic and paleontological evidence from the cave system located southwest of Tulum. These findings inside the submerged Muknal cave allow for a glimpse into the life and death of the early settlers of the Yucatán peninsula and add new evidence to the importance of the Tulum system of submerged caves as a potential place of ritual importance for these people.

The Karst System in the Tulum area

The Yucatán peninsula is characterized by limestone bedrock with a submerged karst system of >7000 km of caves, of which about 1000 km are currently explored (Bauer-Gottwein et al., 2011; Quintana Roo Speleological Society (QRSS), 2018). During the Late Glacial Maximum (LGM) of the Wisconsin Glacial, from 25,000 to 18,000 BP, sea level was about 120 m below present sea

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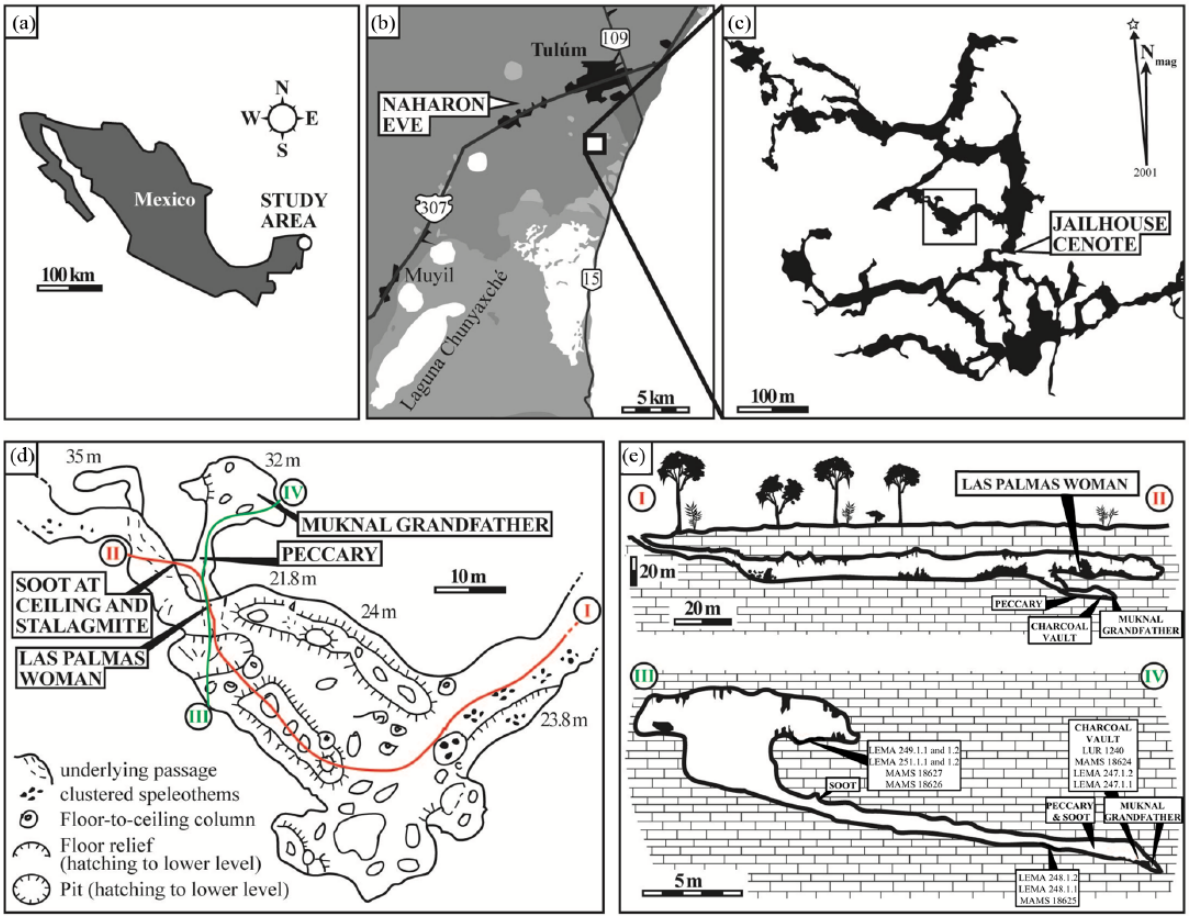


Figure 1. Study area near Tulum on the Yucatán peninsula of southeast Mexico (a and b) and location of the Muknal cave within the Remote Muknal Siphon area of the extended and complex Ox Bel Ha cave system (c). The box in the upper right figure is detailed in (d) and illustrates the cave near the Las Palmas and Muknal anthropological sites. Access is via Jailhouse cenote (c). (e) Cross sections through the Muknal cave. For position of sections I-II and III-IV, see (d). The deepest part of the cave is 34 m below sea level and was measured at the Muknal human site.

levels (bpsl) and large parts of this enormous cave system were exposed and accessible (Blanchon and Shaw, 1995; Moseley et al., 2015). The cave system was flooded during sea-level rise across the Pleistocene–Holocene transition from 12,000 to 8000 BP (Moseley et al., 2015; Smart et al., 2006), preserving paleontological and archeological evidence inside the caves.

The Muknal cave forms part of the Naranjal subsystem within the Ox Bel Ha system of connected caves and sinkholes, locally called *cenotes*, and it is located southwest of Tulum (Figure 1). Ox Bel Ha ranks among the most extended cave systems in the area, and globally, with 270 km of explored length and >140 cenotes proven to conform the system (QRSS, 2018). Name and connections of the cave system are presently as confusing as the multiple connections between the subsystems; here we only refer to the Naranjal subsystem known by local cave divers as the Muknal remote siphon (Figure 1). It is connected to the Jailhouse cenote, also called Las Palmas (QRSS, 2018), which is the entrance to both the Muknal and Las Palmas submerged caves from which anthropological sites are documented here (Figure 1).

Pre-ceramic evidence from the Naranjal system

Three pre-ceramic human skeletons have been reported from the Naranjal subsystem and are described briefly in González González et al. (2008b, 2013).

The 'Naharon Eve', a woman aged 18–20 years, was discovered mainly articulated, indicating an in situ decay in a dry cave. The skeleton was located at 23 m water depth and 368 m from the nearest entrance, Jailhouse cenote (González González et al., 2008a, 2008b).

The 'Las Palmas Lady', a female between 44 and 50 years old, was found at about 2 km distance south of the 'Naharon Eve' in the same cave system (Figure 1b). This site is located within the Muknal remote siphon area, at 24 m water depth and 59 m distance from the nearest entrance, the Jailhouse cenote (Figure 1c). The skeleton was documented as articulated, with arms and legs flexed and adducted to the body. This position of the body likely represents an intentional deposition, a crouch funeral with the corpse probably bundled with skins or strings (González González et al., 2013). This funeral ritual must then have taken place prior to cave flooding, which is consistent with ^{14}C ages measurements assigning both skeletons to the late Pleistocene–early Holocene transition, with 11,570 ± 65 ^{14}C BP (13,454 ± 117 cal BP) for the 'Naharon Eve' and 8050 ± 130 ^{14}C BP (8937 ± 203 cal BP) for the 'Las Palmas Lady' (González González et al., 2013). However, radiocarbon dating of human and animal bones from the submerged caves of Quintana Roo is a controversial issue (Taylor, 2009) due to long-term post-depositional dissolution of bones in the water-filled caves. These processes modified not only cortex and spongiosa of the bone tissue but also led to an almost complete degradation of collagen (Chatters et al., 2014; González González et al., 2013; Stinnesbeck et al., 2017c; Taylor, 2009).

After the discovery of the 'Naharon Eve' and the 'Las Palmas Lady', a third skeleton was found at only 60 m distance from the Las Palmas site and thus also within the Muknal remote siphon, at a depth of 34 m (Figure 1d and e). Access to this new site is also via Jailhouse cenote, passing the finding place of the 'Las Palmas Lady' (Figure 1d). The human skeleton was briefly documented by González González et al. (2013) and was referred to by these authors as the 'Muknal Grandfather'. Water temperature at the

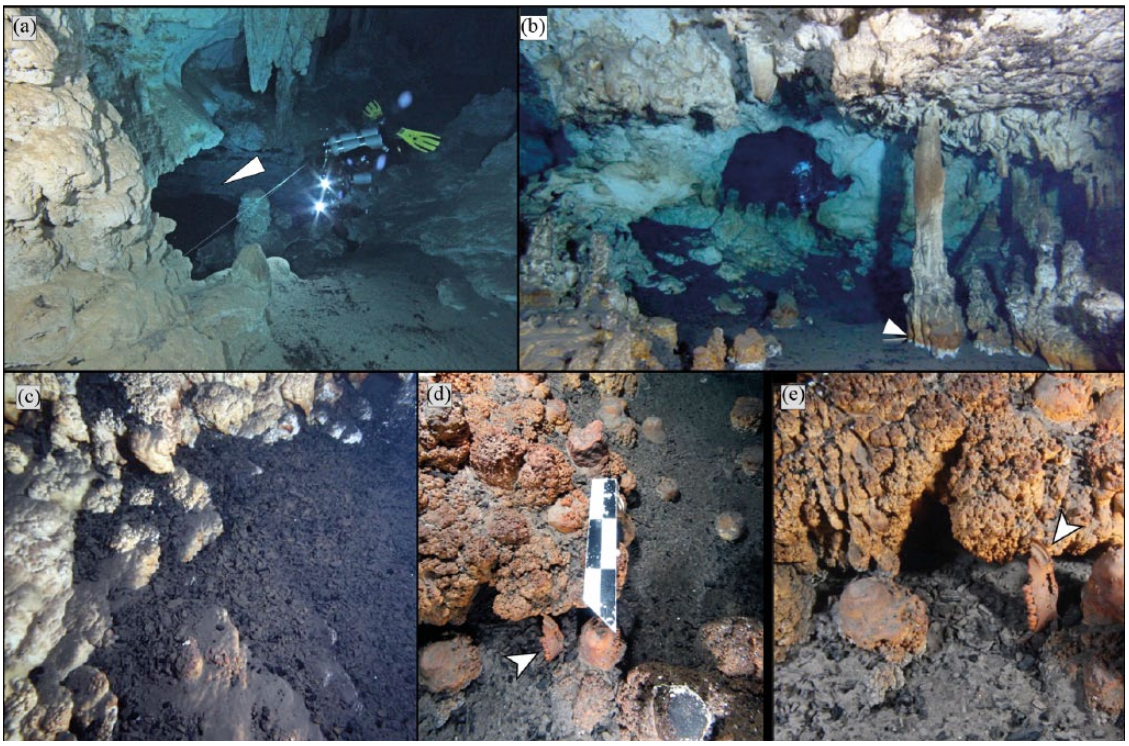


Figure 2. (a-e) Underwater photographs from the Muknal cave; for approximate location, see Figure 1. (a) Details of the internal pit at 25 m water depth, leading to the Muknal anthropological site. The arrow in (a) points toward the deepening tunnel. (b) From about 29 m water depth and illustrates the entrance to the tunnel deepening to the north and leading to the Muknal human site. Note the ancient watermark level, here pointed out by the white arrow. (c) Ash and charcoal coverage within the 'Charcoal Vault' chamber, at 34 m depth. (d) and (e) show the original upright position of the peccary mandibular ramus inside the cave.

site is about 27°C. The halocline was detected at around 16 m depth.

Location of the Muknal site and access

The partial skeleton of the 'Muknal Grandfather' was discovered by one of us (JAO) in 2012 (Figure 1). It can only be accessed from Jailhouse cenote (Figure 1c), which is located at about 210 m to the east of the finding site documented here. Inside the cave a wide east-west trending tunnel connects the cenote with the White River cave located to the northwest (Figure 1d). At about half way distance, an internal pit at about 25 m water depth marks the entrance into a 30-m-long tunnel trending to the north and deepening from 25 to about 35 m maximum water depth (Figures 1 and 2a and b). This tunnel, only 0.5–1.5 m high (Figures 1e and 2a), has abundant speleothems and represents a restrictive (bottleneck) situation even for experienced cave divers. A peccary mandible was found on the western side of the tunnel at 13 m distance from the internal sinkhole, while the 'Muknal Grandfather' was discovered at the end of the tunnel in a 3 m × 5 m wide dead-end chamber (Figures 1d and e and 2d and e). The site, also known as the 'Charcoal Vault' (Figure 2b and c) by the local cave diving community, was measured to 28–34 m water depth and corresponds to the deepest part of the Muknal cave.

Materials and methods

Diving campaigns into the cave system were initiated in 2004. Subsequent visits to the site were performed from 2006 to 2014. The 'Muknal Grandfather' and peccary mandible were discovered and collected in 2012. Both the Muknal human and the peccary mandible were found in the saltwater unit of the submerged Muknal cave. For collection methodologies and equipment used during the dives, see González González et al. (2008b).

Photographs were made with an Olympus E 620 SLR camera with a Zuiko digital lens, 14–42 mm, 1:3.5–5.8. The peccary mandibular ramus has been described in detail and assigned to an extinct genus and species of peccary, *Muknalia minima*, by Stinnesbeck et al. (2017a). The peccary mandible was scanned with an Artec three-dimensional (3D) scanner. A colored 3D print is housed in the State Museum of Natural History in Karlsruhe, Germany.

The human skeletal material with the registration number PQR2011-PALMAS-H-2 and the peccary mandible PQR2011-PALMAS-V-1 are housed in the Laboratorio Arqueológico of the Dirección del Registro Público de Monumentos y Zonas Arqueológicos E Históricos (INAH) Tulum and Mexico City. All necessary permits were obtained from the Consejo de Arqueología (INAH) No. C.A.401-36/0960.

Osteological analysis

Morphometric analysis of the skull and mandible of the 'Muknal Grandfather' is based on a set of linear measurements of anatomical landmark points in the skull (Howells, 1973; Hubbe et al., 2011; Jantz and Owsley, 2001; Owsley and Jantz, 1999). Characters that are missing due to insufficient preservation were estimated by average geometric values of the sample (Hubbe et al., 2011) for a 3D reconstruction of the cranium. Osteological methods related to age and sexual interpretation of the Muknal individual are based on standard anthropological manuals (Buikstra and Ubelaker, 1994; Comas, 1966; Terrazas Mata and Benavente Sanvicente, 2006; White and Folkens, 2000).

Microscopical analysis

The surface modifications on the peccary mandibular ramus were analyzed and photographed with a Keyence digital microscope VHX-5000. Cut marks on the peccary mandible were examined

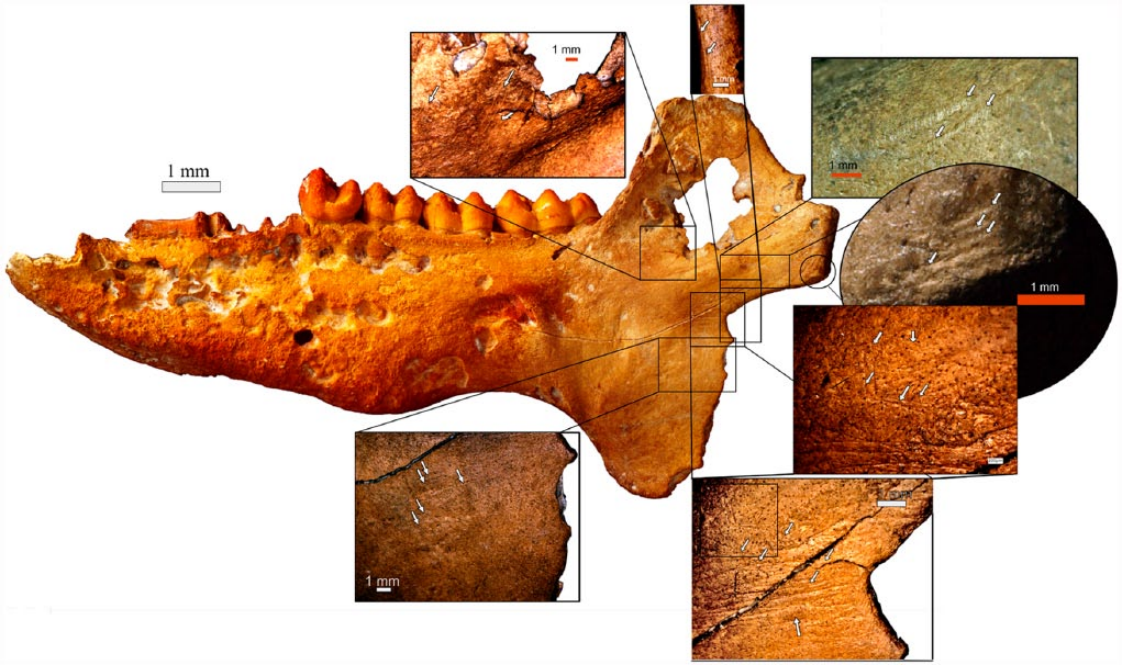


Figure 3. *Muknalia minima* (PQR2011-PALMAS-V-1): left mandibular ramus with details of cut marks (white arrows), in lateral view.

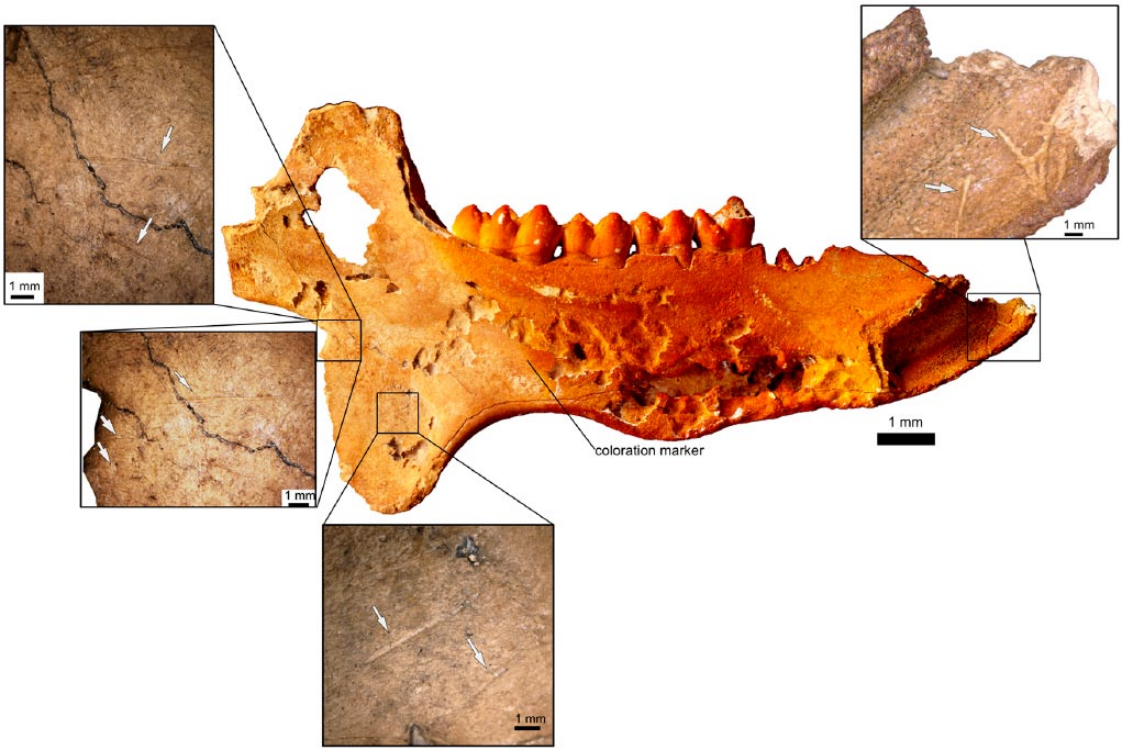


Figure 4. *Muknalia minima* (PQR2011-PALMAS-V-1) left mandibular ramus of peccary with details of cut and scratch marks in medial view.

under optical magnification (15×–100×) and were then mapped and numbered consecutively (Figure 3; Supplementary 1, available online).

All modifications were examined under magnifications of 5×–50× and 15×–200× using a VH-Z20R/W lens. Additional photographs were taken with a resolution of 3200 × 2400 pixels (Figures 3 and 4). A high-resolution 3D model of each mark was created by the scan software of the Keyence VHX-5000, thus accurately representing the micromorphology of these modifications (Bello et al., 2009; Courtenay et al., 2017). Relief and depth of the cross-sections of the marks were measured perpendicular to the longitudinal axis of the modification and interpreted according to the attributes developed by Bello and Soligo (2008), Domínguez-Rodrigo et al. (2009), and Bello et al. (2011). They include cut mark length and depth, opening angle of the mark, the shoulder height index, and floor radius. The following abbreviations are used slightly modified after Bello et al. (2011) and Waltenberger and Schutkowski (2017):

Cut mark depth (CMD): The deepest point of the cut mark floor measured perpendicularly from the connection line of both shoulder margins.

Table 1. ^{14}C Radiocarbon dating of charcoal and soot associated with the 'Muknal Grandfather' underwater cave system.

	Sample depth (m)	Material	Labcode	^{14}C years BP	cal yr BP (1σ)	Mean (cal yr BP)
Las Palmas site	24	Charcoal	LEMA 249.1.2	8.737 ± 30	9.623–9.765	9.705 ± 62
Las Palmas site	24	Charcoal	LEMA 249.1.1	8.836 ± 30	9.780–10.119	9.957 ± 139
Las Palmas site	24	Charcoal	LEMA 251.1.1.	8.854 ± 55	9.820–10.153	9.965 ± 144
Las Palmas site	24	Charcoal	LEMA 251.1.2	8.824 ± 30	9.769–10.114	9.934 ± 138
Las Palmas site	24	Charcoal	MAMS 18627	8.963 ± 35	9.982–10.196	10.089 ± 107
Las Palmas site	24	Charcoal	MAMS 18626	8.908 ± 34	9.959–10.146	10.053 ± 93
Muknal Tunnel	27	Soot	MAMS 30421	8.605 ± 34	9.583–9.530	9.564 ± 33
Peccary site	28	Soot	MAMS 30420	8.749 ± 44	9.628–9.886	9.747 ± 109
Muknal Tunnel	28	Charcoal	LEMA 248.1.2	9.301 ± 50	10.422–10.575	10.495 ± 72
Muknal Tunnel	28	Charcoal	LEMA 248.1.1	9.375 ± 45	10.525–10.670	10.607 ± 57
Muknal Tunnel	30	Charcoal	MAMS 18625	9.430 ± 36	10.610–10.706	10.658 ± 48
'Charcoal Vault'	33	Charcoal	LUR 1240, UNAM	8.890 ± 100	9.797–10.139	9.968 ± 171
'Charcoal Vault'	33	Charcoal	MAMS 18624	9.589 ± 36	10.823–11.063	10.943 ± 120
'Charcoal Vault'	33	Charcoal	LEMA 247.1.2	9.588 ± 55	10.786–11.092	10.945 ± 132
'Charcoal Vault'	33	Charcoal	LEMA 247.1.1	9.646 ± 45	10.869–11.175	11.011 ± 133

For location of the samples within the cave, see Figure 1.

Shoulder height right side (SHR): Right side slope of the cut mark.

Shoulder height left side (SHL): Left side slope of the cut mark.

Maximum shoulder height (MSH): Height between the deepest point of the cut mark floor and the top level of the shoulder margin.

Cut mark width (CMV): The width between the top shoulder margins of the cut mark measured perpendicular to cut mark direction.

Cut mark length (CML): The maximum length of the cut mark measured at the cut mark floor.

Opening angle (OA): The angle between the two cut mark walls or slopes (Bello et al., 2009).

Floor radius (FR): The radius of a circle connects the transverse endpoints of the cut mark floor, where it is angled against the slopes. FR only applies to marks with a through-shaped cross-section.

Floor angles (FA): The angle between the slopes and the cut mark floor marks a trough-shaped cross-section, measured on the left (FAL) and right side (FAR) ignoring the actual orientation of the mark.

Radiocarbon dating

The charcoal and soot samples (Table 1) were radiocarbon dated at the Curt-Engelhorn-Center Archaeometry gGmbH (CEZA) at Mannheim, Germany, with a MICADAS (Mini Carbon Dating System) AMS system. Both charcoal and soot samples were prepared using a standard protocol including acid and base treatments to remove contaminants such as carbonate and humic acids (Lindauer et al., 2017). The BP Radiocarbon years were calibrated with OxCal version 4.2.4. The calibrated ages are given as weighted mean and 1-sigma standard deviations. No ^{14}C age could be obtained from the peccary mandibular ramus (Stinnesbeck et al., 2017). The sample treatment then included steps to remove the conservation chemicals using organic solvents, but no collagen was detected. Initial radiocarbon ages of the Muknal skeleton and of charcoal collected from the interior of the skull were published by González González et al. (2013) and were dated by the Laboratorio Universitario de Radiocarbono (LUR) del Laboratorio Nacional de Geoquímica y Mineralogía of the UNAM/CONACYT, México. Further charcoal samples were dated by the Laboratorio de Espectrometría de Masas con Aceleradores (LEMA) of the Instituto de Física of the UNAM. All radiocarbon dates were calibrated using Oxcal 4.2.4 with the IntCal13 dataset (Reimer et al., 2013).

Results

'Muknal Grandfather'

The bones of the 'Muknal Grandfather' (PQR2011-PALMAS-H-2) laid scattered but clustered, across an area of about 1 m^2 on a limestone rock shelf, about 0.5 m above the cave floor and thus above the charcoal layer (Figure 5). Only the right humerus and right tibia were leaning obliquely against the socket of the rock shelf (Figure 5). Bones lying on the rock shelf were mostly devoid of charcoal coverage but a few charcoal flakes were found inside the calvarium, although the bones do not show any signs that they were exposed to heat.

Bone preservation is good, but the long bones show erosion pits reaching into the spongiosa. These are due to chemical dissolution that also destroyed the collagen during the long exposure in the water. The bones do not show any rolling wear, transport fractures, or marks, suggesting that they were deposited on the shelf and may only have moved slightly during the flooding of the cave. The bone color is mostly pale yellow to light buff, but irregular black-colored patches are present on the external surface and likely result from temporary contact with local charcoal flakes.

Osteology of the 'Muknal Grandfather'. Skull (Figure 6a): Resulting from post-mortem fractures and superficial dissolution of the ethmoid and the internal portion of the orbits, only part of the greater wings and spines of the sphenoid are preserved. A post-mortem fracture is identified in the ventral portion of the malar. The zygomatic arches are fractured with sharp margins, suggesting that the fractures are recent. In ventral view, the entire caudal fourth of the maxilla adjacent to the sphenoid is lost, including the posterior alveolar region of the first molar of the right side and all teeth anterior to the third molar on the left side. The anterodorsal portion of the right maxilla is also missing, as well as the plate of the ethmoid, the infraorbital margin, and ventral margin of the maxilla. Almost the entire basicranium is lost. Only the posterior

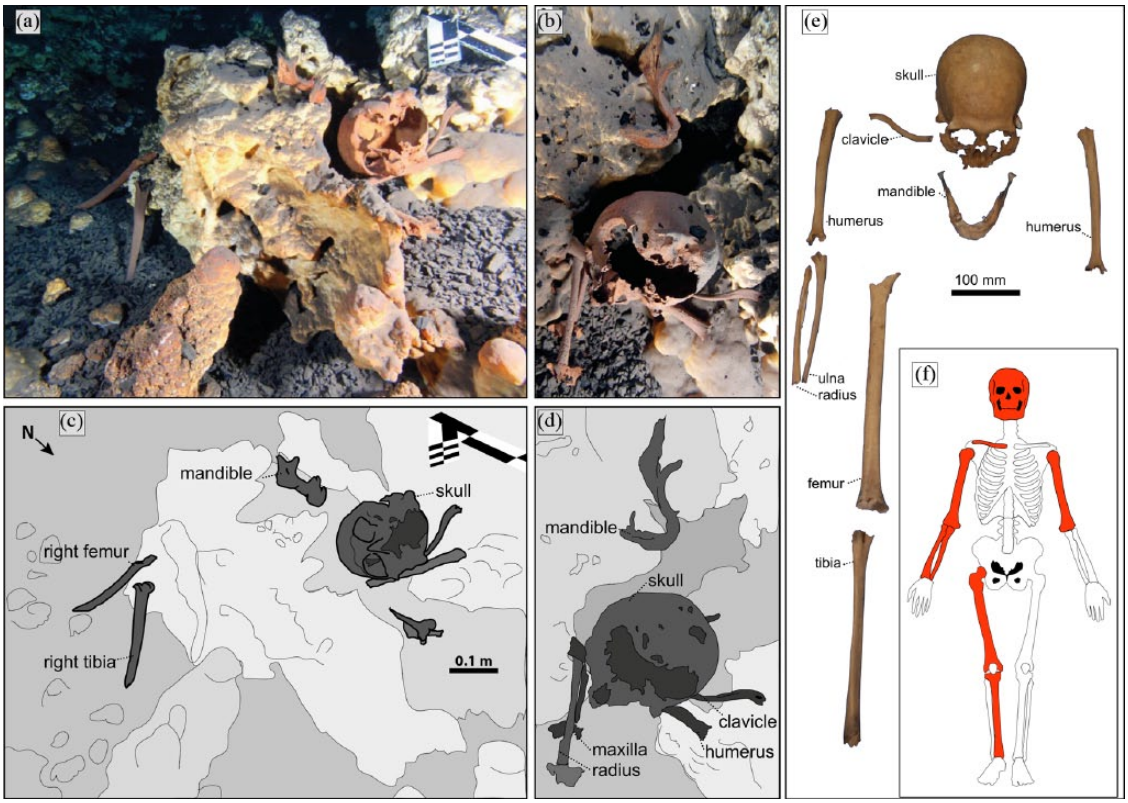


Figure 5. (a and b) Location and bone distribution of the 'Muknal Grandfather' at 34 m water depth in the 'Charcoal Vault' of the Muknal cave. (a) and (b) Underwater photographs of the skeleton in situ; (c) and (d)) interpretative line drawings of the different elements of the skeleton found in situ, (e) the Muknal skeleton, and (f) illustration of a human skeleton, the red colored bones are the equivalent that have been found at the Muknal anthropological side.

margin of the foramen magnum is preserved. Black rims on the break edges on the cranial base indicate that they are considerably older than the facial fractures. Most teeth (Figure 6b and c) must have been lost *ante mortem*, among them the right second incisor, the second right premolar, the left canine, the first left premolar, and first left molar. A possible left premolar and some badly preserved roots detached on the respective alveolar cavities of the maxilla were too abraded during life of the individual to allow a secure identification. The skull roof and the right orbit are complete, part of the left malar and the central portion of the maxilla are broken, but were reconstructed in the laboratory to their original anatomical position (see Figure 6).

The identification of the sex of the 'Muknal Grandfather' follows the method of Buikstra and Ubelaker (1994). The superciliar arches are medially prominent. They merge with the glabella forming a robust bulge reaching grade 4 in the scale of Buikstra and Ubelaker (1994). The nuchal crest reaches grade 3 in this scale. The mastoid process is medium-sized, anteriorly inclined, and identified as grade 3. The supraorbital margin is delicate, slightly rounded, and elevated to grade 4 (Buikstra and Ubelaker, 1994). The chin is deformed due to alveolar resorption caused by the loss of teeth. Still, a marked triangular chin of grades 3 to 4 is present. According to the Buikstra and Ubelaker (1994) scale of grades, the Muknal skeleton represents a male individual. Even though the individual has lost all molars during life, the eruption of the third mandibular and maxillary molars was completed. The few teeth that are preserved in the mandible show extreme abrasion (Figure 6b and c), reaching grade I of dental attrition (White and Folkens, 2000), whereas the maxillary tooth abrasion reaches grade H. This suggests that the age of the individual may range between 45 and 55 years considering the abrasion grade of the mandibular teeth and between 40 and 50 based on the abrasion grade of the maxillary teeth.

According to Lovejoy and Mendl (in White and Folkens, 2000), the fusion stage of the cranial sutures suggest an age of 48.5 (SD 10.5) for the first group of sutures and 56 (SD 8.5) for the second. However, these standard techniques are known to present a wide range of error and the Muknal individual shows little bone-tissue degeneration. The age at death may therefore have been lower than suggested by the index-based data above and may range between 40 and 45 years, as it is suggested by the analysis of the mandible.

Charcoal samples and soot patches on the cave ceiling

The Muknal anthropological site is characterized by extensive but patchy accumulations of charcoal and ash covering the cave floor of the north-south directed tunnel deepening from 25 to 35 m, and the 'Charcoal Vault' chamber at the dead end of this tunnel (Figure 2). The charcoal and ash coverage extends over an area of 60 m^2. It is 30 m long and 2 m wide and reaches a thickness of up to 1.0 m. Charcoal flakes and ashes accumulated in cave floor depressions and reached maximum thickness in the 'Charcoal Vault', where the bones of the 'Muknal Grandfather' were deposited.

Several charcoal samples were taken along the tunnel (see Figure 1 and Table 1 for exact location). A charcoal sample taken from below the Muknal skeleton was dated by the LUR lab of the UNAM to 8890 ± 100 ^{14}C yr BP, $\delta^{13}C$ –26.63, ±1σ (9968 ± 171 cal BP; UNAM-1240), while three samples analyzed by LEMA and MICADAS from charcoal collected in the charcoal vault, in a radius of 1–2 m (Figures 1e and 2c) to the skeleton resulted in ages between 9589 ± 36 and 9646 ± 45 BP (10,943–11,011 cal BP; Table 1). Further samples were taken from locations between the cave entrance at Jailhouse cenote and the 'Muknal Grandfather' (Figure 1 for locations and Table 1 for lab details and ages).

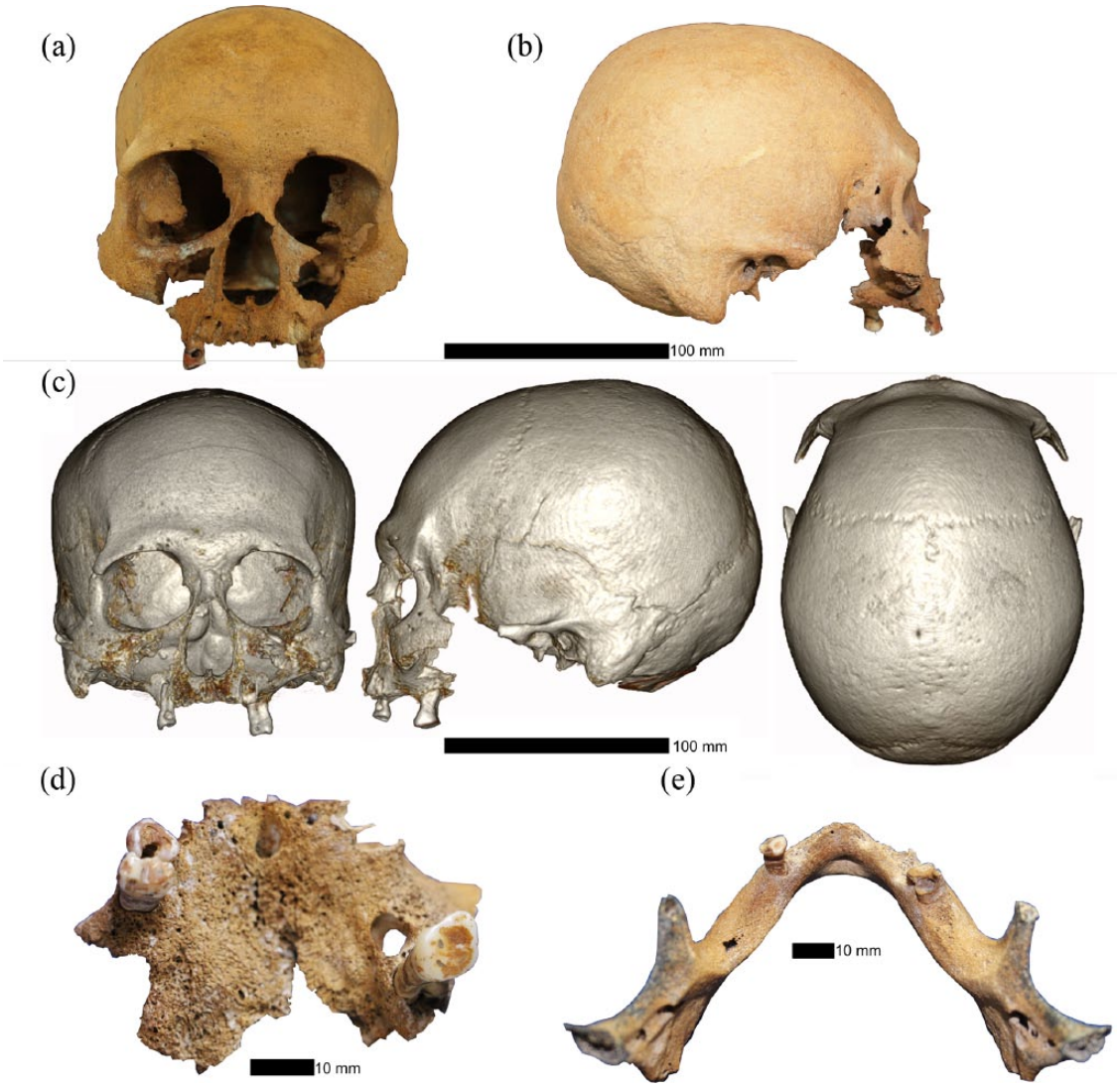


Figure 6. 'Muknal Grandfather' skull in (a) rostral view and (b) lateral view. (c) 'Muknal Grandfather' cranium 3D reconstruction in rostral, lateral, and dorsal view; (d) ventral view of the maxilla and (e) dorsal view of the mandible.

Several irregular patches of soot were detected on the ceiling of the north-south directing cave tunnel descending toward the 'Charcoal Vault' (Figures 1 and 7). We collected samples of this soot at about 13 m south of the partial human skeleton at 2.5 m above the peccary mandibular ramus (Figures 1 and 7a), and a second sample at about 6 m to the west (Figures 1 and 7b). The 'peccary site' sample was dated to 8605 ± 34 ^{14}C years BP (9583–9530 cal BP; MAMS 30421, 1σ) at CEZA, while the second sample, located 6 m to the west, was dated to 8749 ± 49 BP years (9886–9628 cal BP, MAMS 30420, 1σ).

Peccary mandibular ramus (PQR2011-PALMAS-V-1)

A left mandibular ramus of the peccary *Muknalia minima*, Stinnesbeck et al. (2017a), was discovered in the Muknal remote siphon in 2012 by JAO and EAN and collected in the same year. The mandibular ramus was found at about 197 m distance from the Jailhouse cenote entrance and <13 m south of the 'Muknal Grandfather' in the cave tunnel terminating in the 'Charcoal Vault' (Figure 1), at a water depth of 30 m. The mandibular ramus was found in a vertical position, with the rostral end up and the articular part sticking in a charcoal accumulation at about 1.0–1.5 m distance from four prominent stalagmites (Figure 1d and e). The mandibular ramus does not present evidence for carbonization by burning.

The red-brown color of the mandibular ramus is due to mineralization by Fe-hydroxides (Figures 3 and 4). The bone surface is perforated by numerous irregular dissolution pits resulting from long-lasting exposure to saltwater. These pits occur on the medial and lateral surface and reach to between 0.5 and 20 mm in diameter. The surface of the coronoid process exhibits a hole of 10 mm diameter. The rostral end of the mandibular ramus is strongly eroded and lacks the incisor part.

Manipulation of the peccary mandibular ramus PQR2011-PALMAS-V-1 by man prior to deposition is suggested by a total of 112 cut and scratch marks, approximately 87 on the lateral (Figure 8) and 25 on the medial face of the ramus (Figure 8; Supplementary, available online). The cut and scratch marks are of the same color as the bone, indicating that processes leading to the coloration of the mandibular ramus must have followed the cutting or scratching processes (Figures 3, 4, and 8). Recent marks would be distinguished by a lighter color of the bone. The marks are therefore regarded to be ancient, man-made, but cannot have been caused by recent vandalism of the site or inappropriate treatment. V-shaped microscopical grooves have been interpreted as cut marks, based on experimental archeology (Bello, 2011; Braun et al., 2016; Domínguez-Rodrigo et al., 2009), while trough-shaped marks (_/) are here regarded as scratch marks, produced by a blunt tool, but there presently is no positive evidence for this interpretation other than the horizontal floor.

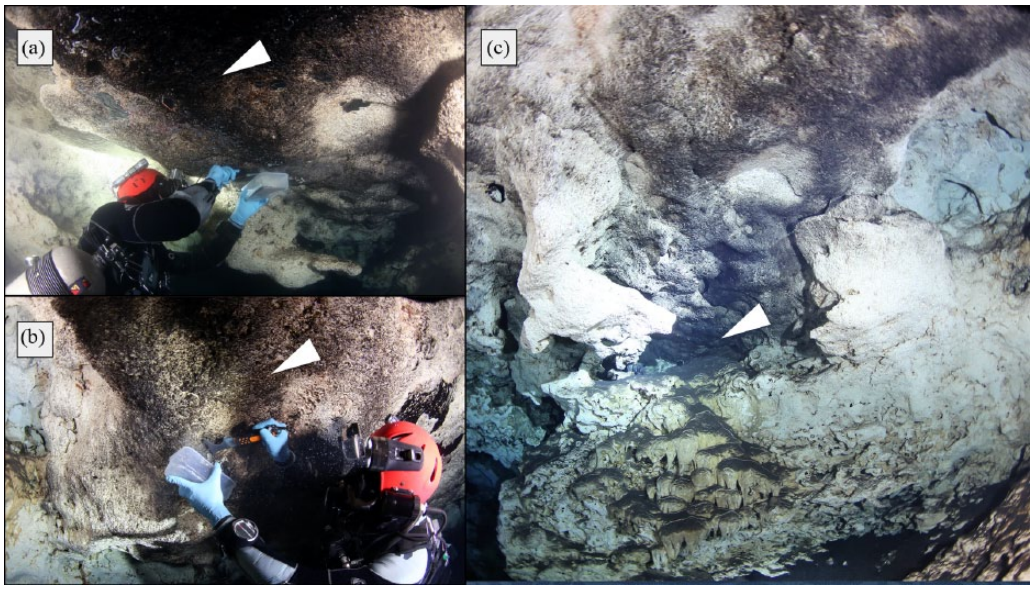


Figure 7. Photographs of soot patches on the cave ceiling leading to the Muknal anthropological site: (a, b) JAO during the sample taking, notice that the remaining area (c) is light colored.

The cut and scratch marks are accumulated in four areas on the lateral surface (Figure 8a–d) and three on the medial face (Figure 8a–c; for abbreviations see section 'Results').

Lateral face

Area A on the lateral side (Figure 8a–d): Two intersecting groups of cut marks run dorsal of the caudal limit of the masseteric fossa. The dorsal series of 26 marks is similar to the caudal series of 20 marks in running vertically and parallel to each other. The marks of the dorsal series (1–26) show an average length of 367 µm, of which 218 µm is the shortest and 516 µm the longest measured mark. The marks of the caudal series are slightly longer, with an average length of 529 µm. 394 µm represents the shortest and 656 µm the longest mark. The microtopography of individual marks shows an OA of 59.5°, an SHL of 61.57 µm, and an SHR of 72 µm in average. 34 µm is the shortest measured SHL, 101 µm the MSH on the left side, 49 µm the shortest SHR, and 131 µm the MSH on the right side. Two single marks are identified on the mandibular ramus situated rostroventrally to the group of aligned, almost parallel running marks. They are twice the length of the intersected cut marks and run rostroventrally to vertically to each other (Figure 8).

Area B: This area (Figure 8) presents the largest cut marks. The marks diverge fan-like from the caudal-most concavity of the mandibular ramus toward rostrally. Intervals between individual scratches range from 0.5 to 0.8 mm.

A total of 26 marks were counted in area B with an average length of 3.9 mm. 1.97 mm was the shortest and 6.21 mm the longest measured mark. 80% of all marks show a V-shaped cross-section, 20% show a trough-shaped cross-section. The average OA is 63°. The shortest measured SHL is 47 µm, and 41 µm is the shortest SHR. The MSH is 308 µm on the left and 226 µm on the right side.

A large scratch mark runs from the mandibular ramus across the dorsal half of the mandibular angle to rostrally, terminating on the mandibular body level with m3.

Area C: This area lies caudal to area B. A total of 12 marks are accumulated on the lateral surface of the mandibular angle (Figure 8). Area C is divided into two opposing clusters of marks: the first cluster is characterized by marks running diagonally from dorsally to caudoventrally, while the opposite cluster consists of diagonal marks running from caudally to rostroventrally. All marks run subparallel to each other at distances ranging between 0.23 and 0.32 mm and have an average length of 2.54 mm. The shortest mark detected in the rostral cluster of area C reaches a length of 1.28 mm. The longest mark, reaching a length of 6.32 mm, belongs to the caudal cluster. The microtopography of the marks shows a V-shaped cross-section with an OA of 35° to 46°, an average SHL of 346 µm and an average SHR of 266 µm. The lowest SH measured here is 344 µm on the left and 210 µm on the right side. The left MSH measures up to 348 µm, and the right MSH is 266 µm.

Area D: This area consists of three single marks and is located ventral to m2 on the lateral surface of the mandibular body (Figure 8). The marks run diagonally from dorsally to caudoventrally and are 2.73–3.8 mm long.

Medial face

A total of 27 marks were documented on the medial side of the mandibular ramus (Figure 8b). Area A: 23 marks are located on the ramus and angular process of PQR2011-PALMAS-V-1. The incisions on the median surface show a fan-like distribution, initiating near the caudal margin of the ramus and diverging rostrally with intervals of 350–550 µm between each other. The largest cluster is identified on the medial side of the mandibular ramus (Area A, medial side). These marks reach an average length of 2.63 mm, with 0.92 mm measured for the shortest and 6.56 mm for the longest mark. The OA measures 34° in average, with 84 µm as the shortest SHL and 80 µm as the shortest SHR. The MSH on the left side reaches 126 µm and the MSH on the right side 167 µm.

Area B: Two single marks are located on the mandibular angle running diagonally (Figure 8b) from caudoventrally to rostrodorsally. Area C: Two additional marks are located rostroventrally of the alveolus of the canine, diverging from each other from dorsally to ventrally.

Overall, 114 cut marks were measured, their cross-sections evaluated at approximately 400 µm distance between each other. On average, a cut mark is 2 mm long, 150 µm deep, and 35 µm wide, with OAs of 62°, SAs of 122° to 133°, and

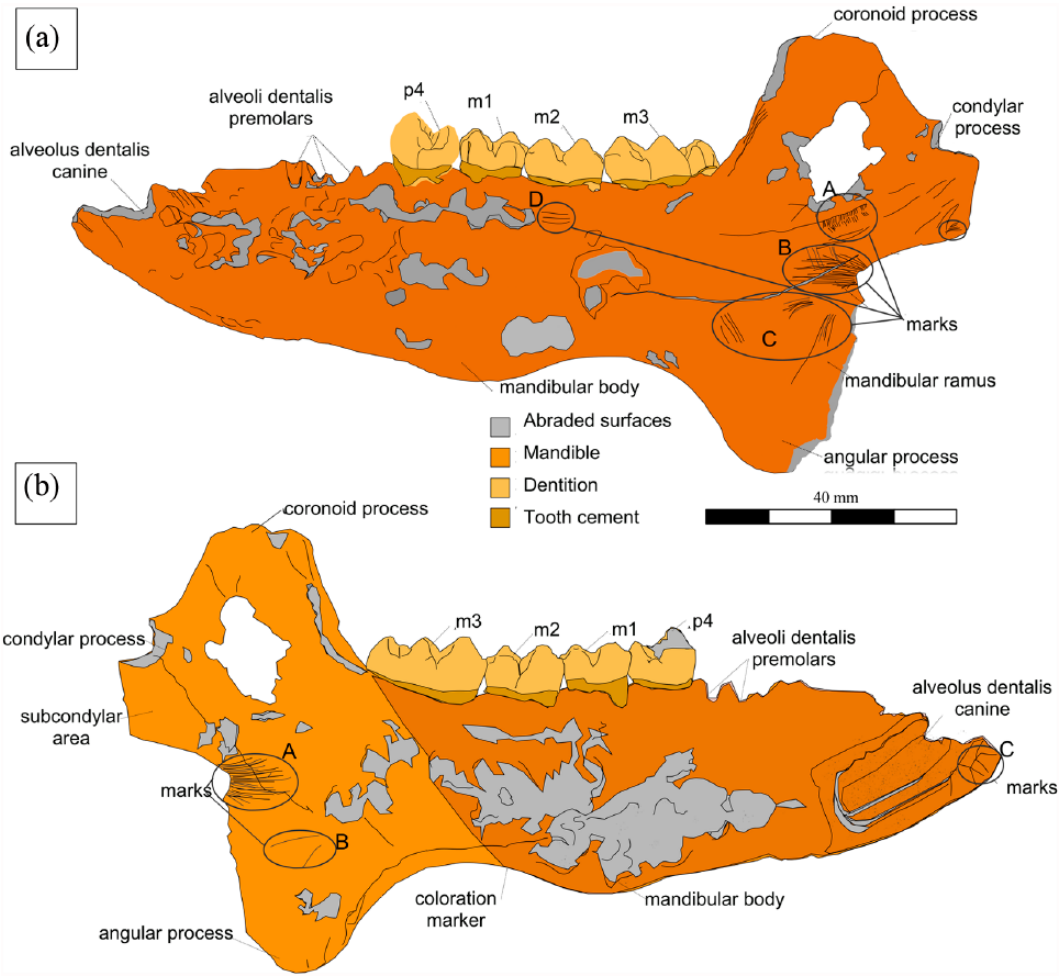


Figure 8. *Muknalia minima* (PQR2011-PALMAS-V-1), interpretative line drawing of the left mandibular ramus: (a) lateral view and (b) medial view.
Note that *several* sets of approximately parallel cut marks are identified in both views and are concentrated on the mandibular ramus and angular process (black lines).

22° for FAs. The average FR is 32 μm. These small values of the V-shaped mark indicate the sharpness of the cutting edge (Bello et al., 2011). The oblique cutting angles of the mark with respect to the bone surface result in a different height of the slope and suggest a usage of the tool to remove meat (Bello et al., 2011).

Discussion

The 'Muknal Grandfather'

Five out of nine preceramic human individuals reported to date (Chatters et al., 2014; González González et al., 2013, 2008b; Stinnesbeck et al., 2017) from the submerged cave system north and south of Tulum are virtually complete, with >80% of the respective skeletons present, and even including the preservation of tiny, delicate bones such as auditory ossicles and sesamoid bones (González González et al., 2008b, 2013; Stinnesbeck et al., 2017). The skeletons discovered in Naharon, Las Palmas, El Templo, Chan Hol I and II were close to be articulated. The overall preservation status of the human skeletons and their completeness suggests that these humans died or were placed in the caves while these were dry. Their arrival at the sites must thus have occurred prior to the early–middle Holocene sea-level rise resulting in flooding of the caves (González González et al., 2013; Stinnesbeck et al., 2017). The flooding of the cave systems was very slow, since in the Muknal cave of fossils remained at their original place, for example at the Las Palmas funeral site.

The 'Muknal Grandfather' does not belong to the group of virtually complete skeletons, because only the skull, mandible, clavicle, and a few long bones were present. Ribs, vertebrae, girdle bones, and small bones such as phalanges and tarsals are missing. All bones discovered by us laid clustered in a radius of about 1 m. When compared to other similarly old human skeletons found in the submerged cave system of the Tulum area, only two individuals from El Pit are comparably incomplete (González González et al., 2013). These skeletons were discovered on the debris mount of the El Pit sinkhole below the cenote opening (González González et al., 2013). In consequence, they may have fallen into the deep El Pit sinkhole and their corpses could have disintegrated while floating in the water, or bones could have been displaced gravitationally on the steep and rocky slopes of the debris mount.

Taphonomical circumstances indicate that this scenario does not hold true for the Muknal individual as is indicated by the following characteristics of preservation:

1. The site of the 'Muknal Grandfather' is located 210 m away from the nearest entrance, the Jailhouse cenote, and thus in a remote part of the cave. The latter is a complex system of tunnels, halls, and galleries with abundant speleothem development and rock falls (Figures 1 and 2), especially in the declining tunnel leading to the 'Charcoal Vault'. If the 'Muknal Grandfather' had fallen into Jailhouse cenote and died, the corpse would have disintegrated there. Even if there had been a water current

facilitating the transport of the corpse into the cave tunnel, it is physically impossible that this body would have made its way through the labyrinth of stalactites and stalagmites. It is further unlikely that it would have passed through the internal pit and sunk through the deepening tunnel ending in the 'Charcoal Vault' (Figure 1). In addition, in the case of drift and slow decay, the skull and extremities would have been among the first parts to disintegrate from the body and fall off (Sorg and Haglund, 2002). However, the skull and long bones are present at the Muknal site but not the torso (Figure 5).

2. The bone concentration, clustered on 1 m^2, precludes a long-distance water transport of a decomposed carcass, even if the bones discovered in the 'Charcoal Vault' are scattered. This scenario is supported by the complete absence of rolling traces or fractures caused by water transport through a rocky tunnel, as well as by the location of these bones 0.5 m above the cave floor on top of a rock shelf. In addition, the anthropological material comprises right side long bones and the skull. These bones must have been pre-selected prior to deposition in the cave.
3. Transport by predatory animals or scavenging could explain the presence of a partial skeleton in a cave, with bones scattered and many of them missing. However, none of the preserved bones shows bite marks. A strong argument against scavenging is the remote place of deposition. Predators, even jaguars and bears that are provided with an excellent night vision and known to live in shelters and cave entrances, are unlikely to penetrate a cave for hundreds of meters to hide prey.

With no plausible evidence for a natural transportation process of the 'Muknal Grandfather' to its final burial place, we here argue for handling of the bones by ancient settlers and hypothesize that these people transported and deposited selected bones for a final rest. Two potential scenarios could be put forward to explain the enigmatic taphonomy presented by the partial skeleton:

1. The 'Muknal Grandfather' died on the rock shelf of the cave. In this case, the selective removal of bones must have occurred when the body was largely decomposed. We exclude the option of a modern modification of the locality by unknown cave divers, because cranium and long bones are present at Muknal. In the nearby Chan Hol II site laymen cave divers stole the most interesting skeletal parts such as the cranium and all collectable large bones, but ignored numerous small bones and bone fragments including teeth and auditory ossicles (Stinnesbeck et al., 2017c). It appears similarly unlikely to us that ancient inhabitants would have selectively taken all small bones of the Muknal skeleton, but left the cranium and a few long bones in place.
2. The cranium, the right-side long bones, and the left humerus of the 'Muknal Grandfather' were brought to the cave post-mortem and placed there in a dead-end chamber on an elevated rock shelf. This specific presentation of the bones represents a secondary burial. Manipulation of bones and secondary burials are an ancient practice (Neves et al., 2002; Oliveira et al., 2012; Strauss, 2017; Strauss et al., 2015), also existing in the Maya tradition (*pumoc tradition*; Gómez Cobá, 2011) to present day (Fornaciari et al., 2010; Millaire, 2004; Schroeder, 2001; Strauss et al., 2015). In this scenario, the body of the 'Muknal Grandfather' was originally buried elsewhere on the surface of the Yucatán peninsula or in another part of the dry cave system of Tulum. Due to the lack of soil on the karst surface, the burial was superficial and decomposition rapid. Alternatively, the corpse could have been placed on a scaffold and exposed to surface decay, but this is also a hypothetical scenario. However, the corpse could have been accessible to scavengers at an early stage of decay. When the bones were clean, the remainders not scavenged by predators, or washed away by rain, were collected and brought into the cave for a secondary burial. Such a manipulation and secondary intentional placement of specific bones would best explain the location of bones on a rock shelf in a deep and remote site inside the cave, the exclusive presence of selective unarticulated bones (e.g. skull, mandible, long bones), and their clustered distribution. The long bones leaning to the shelf may have moved and fallen down the shelf during flooding of the cave. Due to the air-filled spongiosa, these bones were extremely light-weighted when dry and could have been lifted then, drifting over the edge of the shelf during flooding.

Soot patches and charcoal in the cave

Convincing evidence for anthropogenic fires comes from local soot patches found on the ceiling of the Muknal cave, including stalactites. These soot patches were identified at the uppermost end of the diagonal tunnel leading to the 'Muknal Grandfather' above the peccary mandible (Figures 1 and 7), and a few meters to the northwest, but not inside the 'Charcoal Vault'. These patches are well identified on the otherwise gray to white cave ceiling by their dark gray-black color (Figure 7). Tips of stalactites are coated by an evenly distributed dark stain from all directions. This is consistent with a staining from below and opposes coverage by flowing water containing soot particles. The presence of soot was discovered by JAO and two ^{14}C ages were determined: 8605 $\pm$ 34 ^{14}C years BP (9583–9530 cal BP MAMS 30421) and 8749 $\pm$ 49 BP (9886–9628 cal BP MAMS 30420). These ages are roughly consistent with the sea-level rise and flooding of the caves based on isotope analysis on speleothem and radiocarbon dating on hearths and fires (Hering et al., 2018; Khan et al., 2017; Moseley et al., 2015; Smart et al., 2006) and indicate one or several human visits to this part of the cave (Figure 9).

In order to reach the deep and most remote part of the lightless and dangerous Muknal cave, the people depositing the bones must have lit fires to artificially illuminate their path or used torches. While the soot at the ceiling thus provides evidence for these human-made illumination fires, the charcoal accumulations discovered by us variously on the cave floor is not considered here to be unequivocal prove for an anthropogenic origin (Scott and Damblon, 2010). Rather, the wide coverage of the area of 30 m $\times$ 2 m, the concentration of charcoal and ash in depressions of the floor, the absence of clearly defined hearths, and the accumulation of charcoal in an explicitly deep location suggest a natural origin of most of the Muknal charcoal and wash-in by the raising water. This is evidenced by the fact that the Muknal charcoal contains burned and unburned wood and unburned leafs (e.g. Fabaceae), grasses (Graminacea), seeds (Fabaceae, Apocynaceae, Sapotaceae), as well as unidentified fruits and root fragments, indicating that the area was already forested and exposed to wildfires around 9500 BP (10,943 cal BP). Charcoal accumulation is not restricted to the chamber containing the 'Muknal Grandfather', but is present inside the cave all the way between the Las Palmas and Muknal sites, with increasing quantities in the tunnel descending to the 'Charcoal Vault', the deepest part of the local cave system. This situation suggests charcoal and plant debris intake by massive rainfalls that likely alternated with dry seasons during which the wildfires may have broken out. Because this forest existed at a time, when the groundwater level was

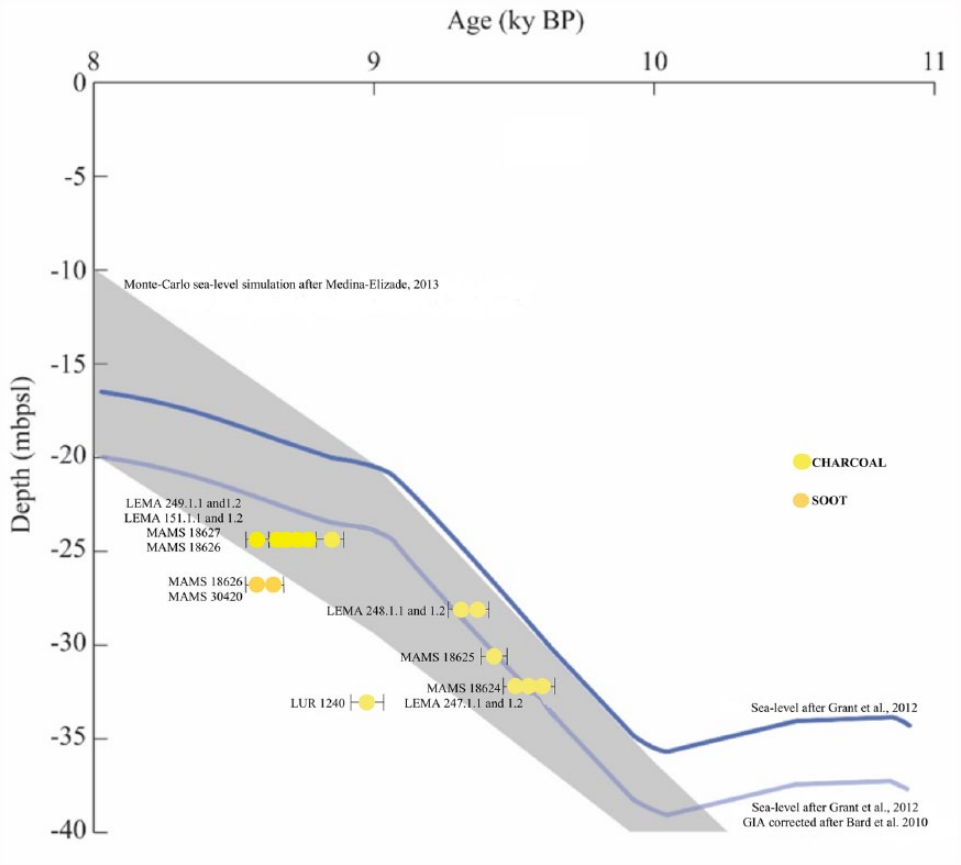


Figure 9. Muknal charcoal and soot data plotted on top of the Yucatán relative sea level curve.

some 30 m below today, such heavy seasonal rains must have soaked the limestone in a way that the development of a forest in the Yucatán peninsula was possible. Our initial evidence clearly favors such a scenario, but this needs to be substantiated by further investigations.

Small clusters of ash and charcoal that would provide unequivocal evidence for hearths, or black-stained patches interpreted as burned cave floor, are not identified to date in the Muknal cave, in contrast to the nearby Chan Hol cave, where an early Holocene use of the cave is evidenced by numerous hearths dating from 8110 $_{14}$C yr BP (9122–8999 cal BP) to 7177 $_{14}$C yr BP (8027–7951 cal yr BP; Hering et al., 2018). However, if the 'Charcoal Vault' was artificially illuminated by man during the secondary burial process, these fires did not leave soot at the cave ceiling, probably because the ceiling was higher than in the descending tunnel or because a different kind of burning material was used. If there were hearth fires in 'Charcoal Vault', their leftovers were mixed with charcoal, ash and plant debris washed in at a later stage, which is also suggested by the thick accumulation of charcoal.

In dry caves, cell wall reflectance analysis is frequently used for an evaluation of temperatures reached during burning, which occasionally allows for a distinction between wild- and anthropological fires (e.g. in metallurgical processes; McParland et al., 2009). Due to the underwater location, however, reflectance parameters are not preserved in the Muknal charcoal.

Peccary mandibular ramus

We hypothesize that the peccary mandible was deposited by man. This is indicated by the following lines of evidence:

1. The upright position of the mandibular ramus suggests placement on purpose in the dry cave and precludes an allochthonous deposition by water transport. Recent placement of the bone by cave divers is objected by the differential coloration observed in the mandibular ramus (Figures 3, 4, and 8). The caudal end of the bone that was stuck in the charcoal accumulation is brown-colored, while the rostral part that was exposed to saltwater is red-colored. This differential chemical coloration by Fe-hydroxides requires a long-term exposure to water for hundreds, if not thousands, of years. The maintained upright position over many thousands of years was possible only under extremely low energy water current conditions during flooding of the originally dry cave system.
2. The cut marks on the caudal edge of the mandibular ramus are straight, subparallel, with a symmetrical or asymmetrical V-shaped cross-section and extensive shoulder effects, suggesting the use of a simple flake as a tool (Domínguez-Rodrigo et al., 2009). Only 20% of all documented marks show a trough-shaped cross-section (_/), especially the ones on the rostral part of the ramus. Experimental studies now interpreted these types of marks with maximum depths > maximum width as modifications by scraping tools (Domínguez-Rodrigo et al., 2009; Domínguez-Rodrigo and Yravedra, 2009; Reynard, 2014). These marks are arranged in sets of parallel striations identified on both the lateral and medial surfaces of the mandible, and they were likely caused by a scraping tool to separate the soft tissue from the bone. Due to the upright position of the mandible on the cave floor, we speculate that the ramus was intentionally deposited there. Whether or not the peccary mandibular ramus was placed there in the context of the funeral of the 'Muknal Grandfather' cannot be said, because the soot remains above the mandibular ramus are slightly younger than the charcoal found in the deepest part of 'Charcoal Vault'. This means that the

'Charcoal Vault' may already have been flooded when people returned to the site where the *Muknalia* mandibular ramus was placed. Still, a depositional context between the peccary bone and the bones of 'Muknal Grandfather' cannot be positively precluded.

The concentration of cut marks on the mandibular ramus is consistent with the removal of the principal masticatory musculature and possibly the canine as well (Figure 8).

1. *Muknalia minima* (Stinnesbeck et al., 2017; UNAM PQR2011-PALMAS-V-1) represents an extinct new genus and species of peccary. This taxon from the Muknal cave formed part of the American mammal fauna that went extinct at, or near, the Pleistocene–Holocene boundary, during a short period of time between 11,400 and 10,800 BP (e.g. Barnosky et al., 2004; Haynes, 2013). Last appearance data (LADs) of other extinct Tayassuids from North America also date to this time interval (e.g. LAD of *Mylohyus* is 11,860 ± 40 BP and that of *Platygonus* is 11,060 ± 60 BP; Haynes, 2013, 2016). The peccary was intentionally placed by humans inside the cave before the flooding of the cave systems (>8000 BP), or even prior to the continent-wide megafauna extinction in the latest Pleistocene.

The Muknal burial under the aspect of early Holocene sea-level rise

The bones of the 'Muknal Grandfather' must have been actively deposited in the dry Muknal cave prior to the flooding of the 35 m deep dead-end chamber at about 9900 BP (Collins et al., 2015; Hering et al., 2018; Khan et al., 2017; Moseley et al., 2015; Smart et al., 2006). Ages determined for the soot patches on the cave ceiling of the tunnel leading to the 'Charcoal Vault' suggest the use of artificial illumination, but possibly not in the context the deposition event, but later. The absence of evident autochthonous charcoal concentrations such as unequivocal hearths at the burial site inside the 'Charcoal Vault', unlike in other caves in the region (Hering et al., 2018), may be a taphonomic artifact due to a wash-in of younger charcoal that mixed up with possible hearth or illumination charcoal. The random, extensive, and fan-shaped distribution of charcoal in the Muknal cave suggests such a later wash-in, probably by several flooding events. The bathymetric distribution of charcoal is correlated to the early Holocene rise of sea level and successive flooding of cave floors. This interpretation is suggested by a weak correlation between radiometric ^{14}C charcoal ages and their depth positions. Even though the charcoal ages range from 8890 to 9589 BP (9968 to 10,943 cal BP; Table 1), oldest ages were measured in the deepest sector of the cave (33–34 m), near the 'Muknal Grandfather', which may be a result of a mix-up of 'funeral charcoal' with early wild-fire charcoal. Successively younger ages are identified in lower bathymetric levels (Figure 9). ^{14}C ages measured from the 24–25 m level between Jailhouse cenote and Muknal, for example, near the 'Las Palmas Lady' by us and González González et al. (2008, 2013) cluster to about 8737 ± 30 BP to 8908 ± 34 BP (9000 to 10,100 cal BP). The ^{14}C ages presented here are therefore consistent with their bathymetric sequence and correlate well with ages postulated for the drowning of deep parts of the Yucatán cave system (Khan et al., 2017; Moseley et al., 2015; Smith et al., 2011) and established sea-level curves (Grant et al., 2012). Ancient watermark levels are identified in the cave (e.g. Figure 2b), suggesting that the flooding process was interrupted by temporary standstills, for example, at about 30 m water depth, which corresponds to the deposition time of most of the charcoal and plant debris. Our data show that a placement of the 'Muknal Grandfather' later than 8600 yr BP (ca. 9600 cal BP) was impossible. This age is also suggested by the soot discovered on the cave ceiling at 27–28 m depth (Figure 7).

The gradual rise of water level and flooding of the cave was a slow and low energy process. Otherwise, the human lower arm bones and the peccary mandible would not have maintained their upright position.

Significance of the Muknal burial site

The Muknal burial site adds new evidence to the interpretation of González González et al. (2008, 2013) that the Tulum caves and particularly the Ox Bel Ha system was an important burial and ritual site for the first settlers of the area. For instance, the unnaturally flexed legs of the nearly complete and mostly articulated 'Las Palmas Lady' and 'Naharon Eve' suggest intentional burial bundles, including wrapping of the corpses in leather, tissue, or vegetable cords (González González et al., 2008, 2013). The 'Las Palmas Lady' was discovered at 24 m water depth at only 58.6 m distance from the 'Muknal Grandfather' inside the same cave, but at a different depth level (Figure 1e), while the 'Naharon Eve' was found at 23 m depth at about 368 m to the north. The nearest sinkhole is the cenote Cristal. The Muknal anthropological site differs from the latter two in representing a potential secondary funeral, previously unknown from the early human settlers in this area of the Yucatán peninsula.

Conclusion

Human remains, faunal assemblages of Pleistocene age and anthropogenic fires dated to about the Pleistocene–Holocene transition, suggest that the Tulum cave system was an area of potential ritual significance for the early human settlers of the Yucatán peninsula.

Taphonomical evidence suggests that the cranium and several long bones of the 'Muknal Grandfather' were intentionally placed in a dead-end chamber of the Muknal cave by early settlers as a secondary burial. We suggest that the bones were not transported by water, cave divers, or animals. A modified mandibular ramus of the extinct peccary *Muknalia minima* was placed at only 13 m distance from the human burial. It exhibits post-mortem cut marks on its medial and lateral surface, indicating removal of the masticatory muscles with a sharp, unretouched tool. The most likely scenario would be that this peccary bone was placed there in the context of the burial. Based on this finding complex we propose that the Muknal cave was a funeral site during the late Pleistocene to early Holocene, in which important members of the community of early settlers of the Yucatán peninsula were laid to rest. Evidence for the early Holocene age of the Muknal burial site comes from soot on the cave ceiling dated to 8600 BP, indicating dry and accessible cave pathways to the 35 m depth level, and from the interpretation that the man-handled peccary mandibular ramus represents an element of the Pleistocene American fauna, which went extinct around the Pleistocene/Holocene boundary.

Acknowledgements

Identification and registration of submerged prehistoric caves in Quintana Roo, Mexico, was only possible due to the great support of cave divers of the region: Valentina Cucchiara, Mario Zavaleta r.i.p., Steve Gerrard, Kate Lewis, Vicente Fito, Pichicuas Martinez, Alejandro Elizondo, Vincenzo Viroli, and Jim Coke. Without their collaboration and dedicated participation in our work, this research would not have been possible. We also thank the QRSS team of underwater cave survey and cartography and the Instituto Nacional de Antropología e Historia (INAH) centro Quintana Roo that supported the project 'Estudios de los grupos humanos preceramicos de la costa oriental de Quintana Roo, México, a través

de los contextos actualmente inundados'. Dr Corina Solís Rosales from the UNAM and Fabio Hering kindly assisted us with the charcoal samples. *Dive-xtras* are acknowledged for their support with units of their diver propulsion vehicles, xscooters 'Piranhas' and 'Cudas 800', as well as the *Me dive center* and *Playa del Carmen diving center, Grupo Xcaret*, and the Rotzinger family. We are grateful to two anonymous reviewers and editor Professor Arlene Rosen for their useful comments and suggestions.

Funding

We greatly acknowledge financial support by the German Federal Ministry of Education and Research (BMBF projects 01DN119 and 01DN15030 to W.S.), German Exchange Service (DAAD Kurzreisestipendium für Doktoranden 91683941 to S.R.S.), and the German Research Foundation (DFG project STI 128/28 to W.S.).

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