



## OPEN ACCESS

## EDITED BY

Shinya Shoda,  
University of York, United Kingdom

## REVIEWED BY

Michael Spate,  
The University of Sydney, Australia  
Pavel Tarasov,  
Freie Universität Berlin, Germany

## \*CORRESPONDENCE

Traci N. Billings  
billings@shh.mpg.de

## SPECIALTY SECTION

This article was submitted to  
Paleoecology,  
a section of the journal  
Frontiers in Ecology and Evolution

RECEIVED 15 July 2022

ACCEPTED 26 August 2022

PUBLISHED 28 September 2022

## CITATION

Billings TN, Cerasetti B, Forni L,  
Arciero R, Dal Martello R, Carra M,  
Rouse LM, Boivin N and Spengler RN III  
(2022) Agriculture in the Karakum: An  
archaeobotanical analysis from  
Togolok 1, southern Turkmenistan (ca.  
2300–1700 B.C.).  
*Front. Ecol. Evol.* 10:995490.  
doi: 10.3389/fevo.2022.995490

## COPYRIGHT

© 2022 Billings, Cerasetti, Forni,  
Arciero, Dal Martello, Carra, Rouse,  
Boivin and Spengler. This is an  
open-access article distributed under  
the terms of the [Creative Commons  
Attribution License \(CC BY\)](https://creativecommons.org/licenses/by/4.0/). The use,  
distribution or reproduction in other  
forums is permitted, provided the  
original author(s) and the copyright  
owner(s) are credited and that the  
original publication in this journal is  
cited, in accordance with accepted  
academic practice. No use, distribution  
or reproduction is permitted which  
does not comply with these terms.

# Agriculture in the Karakum: An archaeobotanical analysis from Togolok 1, southern Turkmenistan (ca. 2300–1700 B.C.)

Traci N. Billings<sup>1,2\*</sup>, Barbara Cerasetti<sup>3,4</sup>, Luca Forni<sup>3,4</sup>,  
Roberto Arciero<sup>3,5</sup>, Rita Dal Martello<sup>1</sup>, Marialetizia Carra<sup>6</sup>,  
Lynne M. Rouse<sup>7,8</sup>, Nicole Boivin<sup>1,9,10,11</sup> and  
Robert N. Spengler III<sup>1</sup>

<sup>1</sup>Department of Archaeology, Max Planck Institute for Geoanthropology, Jena, Germany, <sup>2</sup>Institute for Prehistoric and Protohistoric Archaeology, Christian-Albrechts University of Kiel, Kiel, Germany, <sup>3</sup>ISMEO – The International Association for Mediterranean and Oriental Studies, Rome, Italy, <sup>4</sup>Department of History and Cultures, University of Bologna, Bologna, Italy, <sup>5</sup>Department of World Archaeology, Leiden University, Leiden, Netherlands, <sup>6</sup>ArcheoLaBio, Research Center for Bioarchaeology, Department of History and Cultures, University of Bologna, Bologna, Italy, <sup>7</sup>Eurasia Department, German Archaeological Institute (DAI), Berlin, Germany, <sup>8</sup>Department of Anthropology, Washington University in St. Louis, St. Louis, MO, United States, <sup>9</sup>School of Social Science, The University of Queensland, Brisbane, QLD, Australia, <sup>10</sup>Department of Anthropology and Archaeology, University of Calgary, Calgary, AB, Canada, <sup>11</sup>Department of Anthropology, National Museum of Natural History, Smithsonian Institution, Washington, DC, United States

Southern Central Asia witnessed widespread expansion in urbanism and exchange, between roughly 2200 and 1500 B.C., fostering a new cultural florescence, sometimes referred to as the Greater Khorasan Civilization. Decades of detailed archeological investigation have focused on the development of urban settlements, political systems, and inter-regional exchange within and across the broader region, but little is known about the agricultural systems that supported these cultural changes. In this paper, we present the archaeobotanical results of material recovered from Togolok 1, a proto-urban settlement along the Murghab River alluvial fan located in southeastern Turkmenistan. This macrobotanical assemblage dates to the late 3rd - early 2nd millennia B.C., a time associated with important cultural transformations in southern Central Asia. We demonstrate that people at the site were cultivating and consuming a diverse range of crops including, barley, wheat, legumes, grapes, and possibly plums and apples or pears. This, together with the associated material culture and zooarchaeological

evidence, suggest a regionally adapted mixed agropastoral economy. The findings at Togolok 1 contribute to the ongoing discussion of dietary choices, human/landscape interactions, and the adaptation of crops to diverse ecosystems in prehistoric Central Asia.

#### KEYWORDS

palaeoeconomy, archaeobotany (palaeoethnobotany), Murghab, Central Asia, Bronze Age

## Introduction

The oldest evidence for agriculture in the piedmont of the Kopet Dag foothills in Turkmenistan comes from the Neolithic settlement of Djeitun, dated to approximately 6000 B.C. (Harris, 1997, 2010). Recovered remains of sheep (*Ovis* sp.) and goat (*Capra* sp.), as well as charred chaff and/or grains from six-row barley (*Hordeum vulgare*), einkorn (*Triticum monococcum*), and possibly emmer (*Triticum dicoccum*) and free-threshing wheat (*Triticum aestivum/durum*) suggest Djeitun's inhabitants practiced a mixed subsistence economy (Masson, 1961; Kasparov, 1992; Legge, 1992; Harris et al., 1993; Harris, 2010). Further evidence of cereal processing at the site included, sickle blades, stone mortars, pestles, and grindstones (Korobkova, 1981; Harris et al., 1993). The early presence of einkorn and six-row barley at Djeitun provides support for the eastward movement of these crops from Southwest Asia (Jones et al., 2011; Stevens et al., 2016). Between the mid-fourth and third millennia B.C., the piedmont plain north of the Kopet Dag experienced settlement expansion. The period was also marked by greater interactions between the populations of the piedmont and areas such as Shahr-i Sokhta in Iran, Mundigak in Afghanistan, and the Zeravshan River in Uzbekistan, which has been demonstrated by material finds (Salvatori, 2008a). During the fourth through third millennium B.C., proto-urban settlements were first constructed along the inner river delta of the Tedjen (the Geoksyur Oasis sites), and by the mid-third millennium B.C. in the previously under-exploited Murghab River alluvial fan (Masimov, 1981; Kohl, 1984; Gubaev et al., 1998; Salvatori et al., 2008; Bonora and Vidale, 2013; Lyonnet and Dubova, 2021; cf., Salvatori, 2007, 2008b regarding archaeology visibility). In addition to the increase in urbanism, there is evidence for significant inter-regional trade and wider connectivity between regions, including the Indus Valley, Iranian Plateau, Persian Gulf, and Mesopotamia (Sarianidi, 1986, 1998, 2005; Hiebert and Lamberg-Karlovsky, 1992; Salvatori, 2000; Winkelmann, 2000; Possehl, 2002; Tosi and Lamberg-Karlovsky, 2003; Kohl, 2007; Salvatori et al., 2008; Frachetti, 2012; Lombard, 2021; Lyonnet and Dubova, 2021). Possehl (2002, 2007) calls this connectivity the Middle Asian Interaction Sphere (MAIS). The movement of goods during this

period is supported by a broad geographic range of 'exotic items' such as, ivory objects, etched carnelian beads, faience, chlorite products, figurines, pottery, seals from the Indus Valley and Iranian Plateau, and possibly metal ore (Sarianidi, 2001, 2007; Salvatori et al., 2008; Kaniuth, 2010; Frenez, 2018; Garner, 2021; Lyonnet and Dubova, 2021). These ancient exchange networks undoubtedly contributed to what would become the Silk Road three millennia later.

Building from this widespread expansion of urbanism and trade was the development of a cultural phenomenon (with distinct architecture and material culture) broadly centered in the region between northern Afghanistan, southern Uzbekistan, western Tajikistan, and the Murghab River alluvial fan of southeastern Turkmenistan; although, its geographical boundaries are not sharply defined (ca. 2250–1700 B.C.; Lyonnet and Dubova, 2021). This cultural phenomenon has sometimes been referred to as the Bactria-Margiana Archeological Complex (BMAC; Sarianidi, 1974), or, alternatively, the Oxus Civilization (Francfort, 1984), and more recently, the Greater Khorasan Civilization (GKC; Biscione and Vahdati, 2021). Most archeologists agree that the GKC began to "decline"<sup>1</sup> between 1700–1500 B.C.; although, this shift may have begun earlier in the Murghab. Starting in the Late Bronze Age (ca. 1900 B.C.), the north-eastern part of the Murghab alluvial fan experienced a decentralization of its settlements (Salvatori, 2008b; Salvatori et al., 2008), likely due to the gradual aridification of the surrounding environment (i.e., the limited availability of water and encroaching aeolian sands; Cremaschi, 1998; Cattani et al., 2008; Cerasetti, 2008, 2012; Markofsky, 2014; Markofsky et al., 2017; Rouse and Cerasetti, 2017). Populations continued to shift southward upriver through time (Salvatori, 2008b; Salvatori et al., 2008; Cerasetti and Tosi, 2010).

Significant research concerning the architecture, climate, settlement patterns, hydrological systems, material culture, and population dynamics in the Murghab River region have been conducted (e.g., Masson and Sarianidi, 1972; Masimov, 1981; Sarianidi, 1986, 1990a,b, 1993; Lyapin, 1991; Hiebert, 1994,

<sup>1</sup> For a more detailed discussion of these transitions among different regions within the proposed GKC geographic range, see Luneau (2018, 2021).

1998; Cremaschi, 1998; Gubaev et al., 1998; Rossi Osmida, 2002; 2005, 2007; Cattani and Salvatori, 2008; Salvatori et al., 2008; Rossi Osmida, 2011; Cerasetti et al., 2014; Lyapin, 2014; Rouse and Cerasetti, 2014, 2017; Forni, 2017). Yet, there have been relatively few studies focused on what the economy looked like in these proto-urban settlements (c.f., Miller, 1993, 1999; Moore et al., 1994; Sataev, 2021). Recent archaeobotanical studies from settlement sites, such as Adjı Kui 1 (Spengler et al., 2018) and Gonur depe (Sataev and Sataeva, 2014), and mobile-pastoral sites, such as Ojakly and Chopantam (Spengler et al., 2014), are adding to what we know about past economic systems, foodways, and land use in the Murghab. Here, we present the archaeobotanical results from the 2014 field season at the Bronze Age site of Togolok 1 to explore subsistence practices during the transition between the third and second millennia B.C.

## Environmental setting

Togolok 1 (38°06'54.8" N, 61°59'50.8" E) is a proto-urban settlement, located along one of the main channels of the Murghab River in southeastern Turkmenistan (Figure 1), dated to the Middle to Late Bronze Age (3rd - 2nd millennia B.C.). The Murghab River flows from the Paropamisus Mountains north into the depression of the Turan Plain, where it spreads out into several channels creating an endorheic delta (or alluvial fan), which ultimately dissipates in the sands of the Karakum Desert (Babaev, 1994; Cremaschi, 1998; Marcolongo and Mozzi, 1998). The alluvial fan, while largely stable, has undergone a few changes over the millennia, including, a general westward shift because of underlying geomorphology and a retraction of its northern reaches possibly due to changes in water availability since the end of the third millennium B.C. (Cremaschi, 1998; Marcolongo and Mozzi, 1998; Markofsky et al., 2017). Shifts in water availability have stemmed from climatic and hydrological conditions, as well as anthropogenic pressures in more recent times (Cremaschi, 1998; Marcolongo and Mozzi, 1998; Markofsky et al., 2017).

Although some aspects of Holocene climate change in Central Asia remain unclear, general aridification and its variation through time has been considerably researched (Staubwasser et al., 2003; Staubwasser and Weiss, 2006; Chen et al., 2008; Luneau, 2018; Fouache et al., 2021). Pollen data recovered from lake cores in the eastern Pamirs [e.g., Lake Karakul, Tajikistan (Heinecke et al., 2017) and Lake Issyk-Kul, Kyrgyzstan (Ricketts et al., 2001)], as well as the northwestern Himalayas (e.g., lake Tso Moriri; Leipe et al., 2014) mark an environmental shift beginning after 5000 B.C. to more arid conditions across the broad region. This perceived shift may have been connected to changes in the influence of the monsoonal front (Leipe et al., 2014). Whereas Chen et al. (2008)'s compilation of available records from Central Asia suggests that a period of increasing aridity began after

2000 B.C. In the Murghab, this aridification may be partially responsible for the retraction of the terminal reaches of its alluvial fan, evident by the late Middle to Late Bronze Age (i.e., approximately 1900 B.C.; Cremaschi, 1998; Markofsky et al., 2017), which corresponded with a transformation of the settlement system in this area (Salvatori, 2008b). Similar population displacements or reorganizations, also attributed to hydro-environmental changes, are attested in other Central Asian alluvial fan regions, including on the Balkh and Zeravshan rivers (Fouache et al., 2012, 2021). Fouache et al. (2021, p. 82) suggest two major factors impacted settlement patterns in southern Central Asia, both of which are related to the availability of water, and include: a change to a river's course or a decline in its flow. Evidence for this in the Murghab is demonstrated by spatial distribution of settlement sites near paleochannels through time (Salvatori et al., 2008; Cerasetti and Tosi, 2010; Rouse and Cerasetti, 2017); although, it should be noted that Salvatori (2008b) has also emphasized the importance of considering the influence of socio-political factors when it comes to the settlement system(s) in the region.

Markofsky et al. (2017) highlight the dynamic nature of the liminal spaces found where floodplain transitions to desert in Central Asian inland deltaic environments and how this interplay shapes the way people use and interact with them (e.g., irrigation, crop production, and other resource use). Human (e.g., land use) and environmental (e.g., geology, hydrology, and vegetation) factors at the local level can influence broader ecological conditions, and vice versa (e.g., a change in spring rains in the mountains can greatly affect the availability of water) (Markofsky et al., 2017). They posit that understanding this "socio-ecological balance" allows for a clearer understanding of changes in human-environment relationships through time in the region (Markofsky et al., 2017, p. 2). Previous interpretations of prehistoric human occupation in the Murghab have often focused on the alluvial fan as an enclosed space. The "oasis" model suggests that settlements, like Togolok 1, were located in micro-oases along water channels within a largely desert landscape (e.g., Kohl, 1984; Sarianidi, 1990c; Hiebert, 1994). While an alternative model proposes that there was widespread occupation and possibly also cultivation of the Murghab floodplain (Cattani et al., 2008; Cattani and Salvatori, 2008; Cerasetti et al., 2014). Evidence underpinning the latter, includes the broad distribution of pottery found during surface surveys in the areas between the so-called "oases" (Cattani and Salvatori, 2008; Markofsky et al., 2017). Further evidence for this model is offered in Cremaschi (1998), where he describes looted burials (dating to mid-3rd to early 2nd millennia B.C.) from the cemetery near Gonur South. Specifically, he mentions burial 116, because a firepit with Late Bronze Age material was found on top of its looter shaft. This was important because the burials had been dug into alluvial soil and the only aeolian sand present in them was within the intrusions caused by the looters. This allowed Cremaschi (1998) to posit

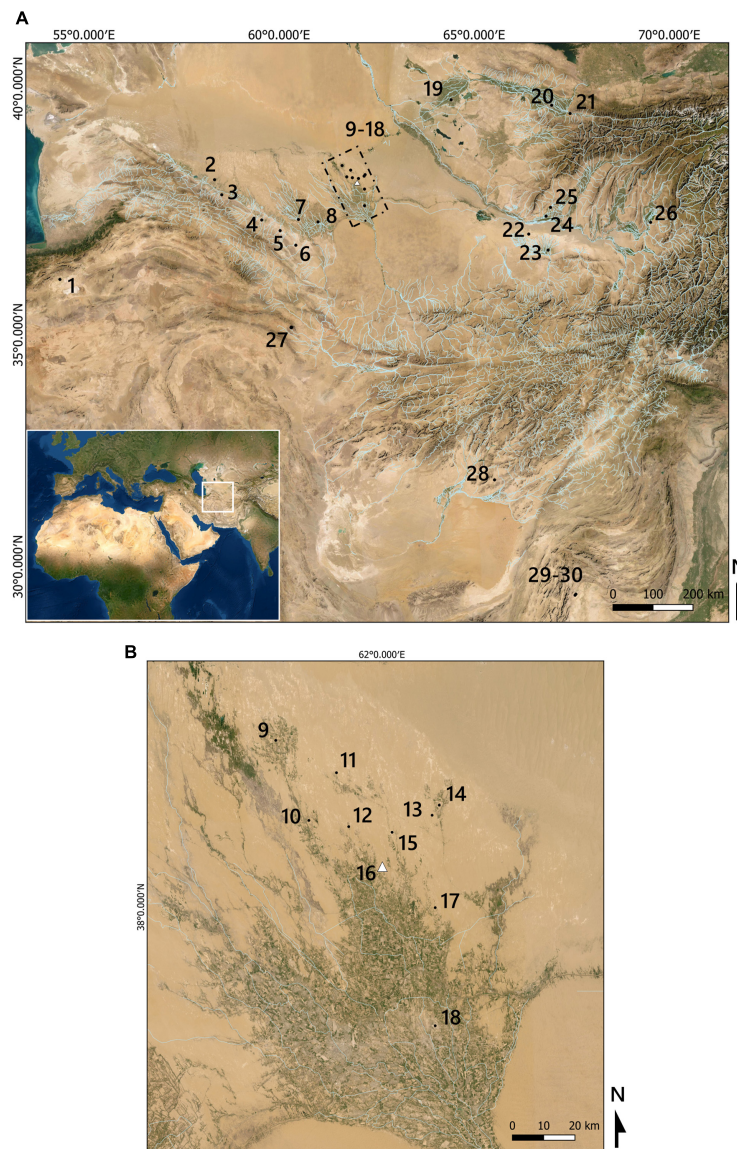


FIGURE 1

(A) Map of southern Central Asia and surrounding areas with key ancient cities/areas: 1-Hissar, 2-Djeitun, 3-Anau, 4-Namagza-depe, 5-Ulug-depe, 6-Altyn-depe, 7-Tedjen Alluvial Fan, 8-Geoksyur Oasis, 9–18-Murghab Alluvial Fan, 19-Bukhara, 20-Samarkand, 21-Sarazm, 22-Dashly, 23-Balkh, 24-Sapalli-tepe, 25-Djarkutan, 26-Shortugai, 27-Shahr-i Sokhta, 28-Mundigak, 29–30-Mehrgarh and Nausharo; (B) Close up of Murghab Alluvial Fan highlighting important sites: 9-Kelleli sites, 10-Taip sites, 11-Egri Bogaz sites, 12-Adji Kui sites, 13-Ojakly, 14-Auchin sites, 15-Gonur depe, 16-Togolok 1, 17-Chopantam, and 18-Merv. Map created with QGIS using Esri World Imagery Basemap, Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community; and river dataset source: 2005@Savitsky Ivan (taken from [https://www.caee.utexas.edu/prof/mckinney/Central\\_Asia\\_Data/index.htm](https://www.caee.utexas.edu/prof/mckinney/Central_Asia_Data/index.htm)) (07.03.2022).

that the encroachment by aeolian sands must have occurred after the initial Mid-Bronze Age burial and before the fire associated with the Late Bronze Age (i.e., suggesting later aeolian sand encroachment). Support for more nuanced interpretations situated within local contexts has characterized recent research (e.g., Cleuziou et al., 1998; Markofsky and Bevan, 2012; Cerasetti et al., 2014; Wilkinson, 2014; Markofsky et al., 2017; Rouse and Cerasetti, 2017). Markofsky et al. (2017) advocate for more critical interpretations concerning environmental and

human relationships and suggest that there is great variation not only within the interaction between encroaching aeolian sands, alluvial depositional processes, and other ecological factors, but also in human response or adaptations to environmental conditions at the local level of these inland deltas.

There is a general precipitation gradient in broader Turkmenistan, which suggests that precipitation declines with distance from the mountains in the southwest. Didovets et al. (2021) reported a mean average annual precipitation of 308 mm

between 2000 and 2013 for the Murghab alluvial fan. Their measuring station in Taghtabazar, however, is located further south, a distance of more than 200 km from the Togolok area. Given Togolok's location, a more reasonable estimation of modern mean average annual precipitation may be less than 100–130 mm (Babaev, 1994; Harris, 2010). This estimate is further supported by Orlovsky's (1994) assignment of a mean average annual precipitation of 110–150 mm to the lowland Karakum region, which encompasses the Murghab. Furthermore, the mean average annual precipitation for all of Turkmenistan is usually below 150 mm (Chemonics International Inc., 2001). Most of this precipitation falls between January and April, and it is typically drier and hotter from June through September. Mean average annual temperatures are usually around 16.5°C but can reach up to 48°C (Babaev, 1994). This modern climate data has been used in the region as a loose estimate of what happened in the past (e.g., Cerasetti et al., in press a).

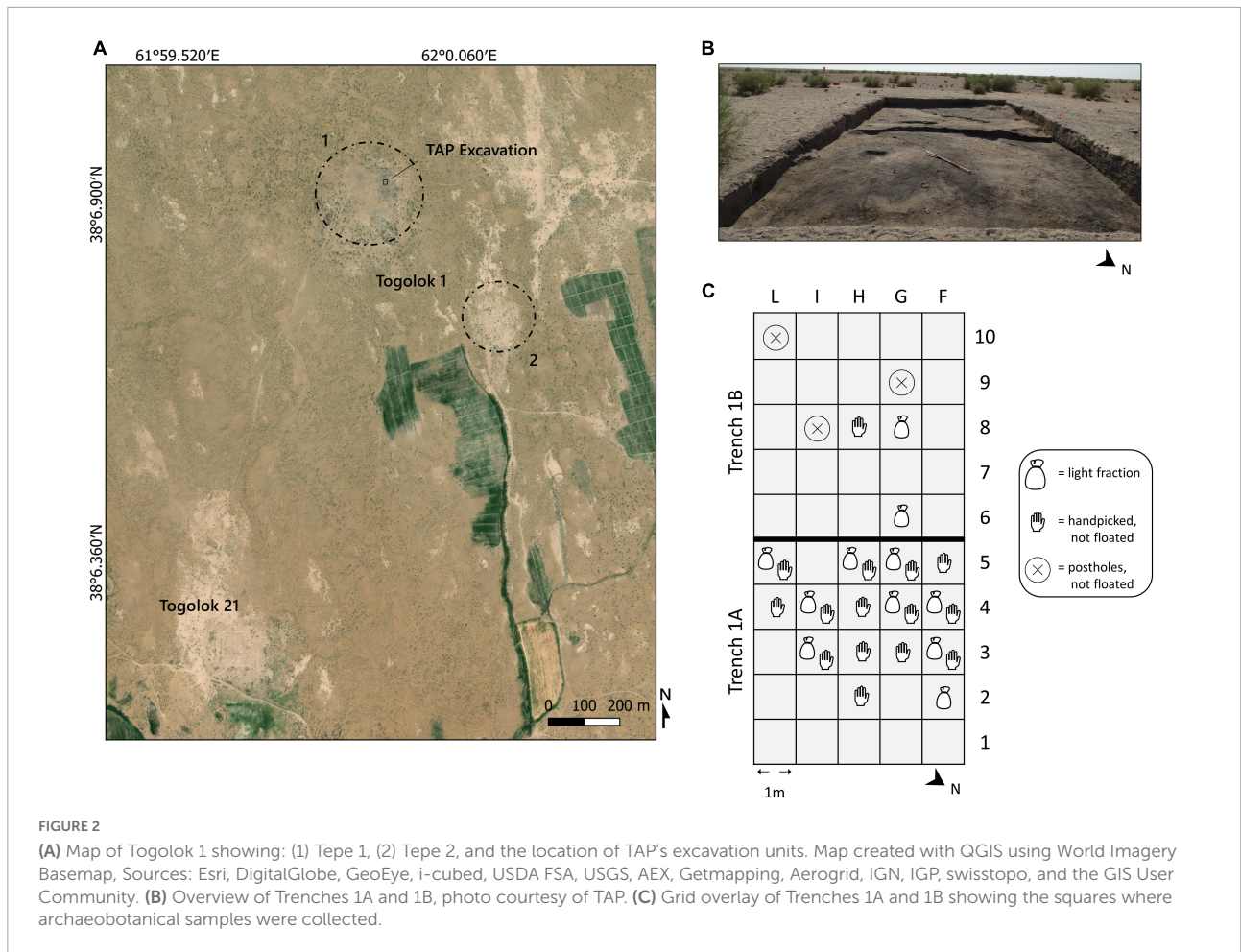
While the Murghab River alluvial fan is located within a xerophytic shrubland (Dinerstein et al., 2017), microenvironments consisting of reedy marshes and tugai forest persist along the edges of the natural river channels and other modern waterways (Suslov, 1961; Hiebert, 1994). Tugai forest vegetation includes genre such as Euphrates poplar (*Populus pruinose*), Russian olive (*Elaeagnus angustifolia*), and *Salix* and *Tamarix* (Walter and Box, 1983, 95–97; Hiebert, 1994; Ministry of Nature Protection, 2002). The desert vegetation is often dominated by *Artemisia* and halophytic species (*Salsola* and *Anabasis*). Other common genre found in the region include *Allium*, *Alhagi*, *Astragalus*, *Carex*, *Ephedra*, *Ferula*, *Halothamus*, *Haloxylon*, *Stipagrostis*, and *Tulipa* (Hiebert, 1994; Harris, 2010; Spengler et al., 2014). Desert soil in the region consists of two types: clay/loam and loess/gravel (Babaev, 1994). The clay and loam desert soil includes 'takyr,' which are clay surfaces, often found in interdune regions or depressions, that have a hard, cracked crust appearance (Babaev, 1994; Maman et al., 2011; Markofsky et al., 2017). Their high clay content contributes to poor drainage and makes takyr's natural water traps (Maman et al., 2011; Markofsky et al., 2017). Sierozems, highly fertile soils, often form on loess desert soils. Both sierozems and loess soils are high in carbonates (which can help regulate the pH and promotes soil fertility) and have low rates of salination (Babaev, 1994). Salination is a major cause of desertification in modern Central Asia (Severskiy, 2004).

## Archeological context

Togolok 1 is part of the broader archeological landscape of the Murghab Alluvial Fan, where about 2,000 archeological sites have been identified (Figure 1B; Masimov, 1981; Gubaev et al., 1998; Cerasetti, 2004, 2008; Salvatori et al., 2008; Cerasetti et al., 2014). The name 'Togolok,' Turkmen for 'mound,' is

used as a general designation for a cluster of archeological sites (>30) in the region (Cerasetti et al., in press a,b; Sarianidi, 1990c). Togolok 1 consists of two mounds (Sarianidi, 1986, 1990a; Hiebert, 1994): Tepe 1 (9 ha, 4 m high) and Tepe 2 (2.30 ha, 2 m high) (Figure 2), making it larger than other sites in the local vicinity. Tepe 2, a fortified structure comparable to but smaller than Togolok 21, was fully excavated in the late 1980's by Sarianidi (1986, 1990a,b). Tepe 2 and Togolok 21 were interpreted as monumental temple complexes (Sarianidi, 1986, 1990a,b). Material finds like those found at Dashly, Sapallitepe, and Djarkutan were uncovered at both sites (P'yankova, 1989; Hiebert, 1994). A deep test pit (~3.5 m) was also dug into the southeastern portion of Tepe 1 to investigate its stratigraphy (Sarianidi, 1986). Additionally, Togolok 1 was part of the broader program of surface surveys conducted by The Archeological Map of the Murghab Delta (AMMD) project (Gubaev et al., 1998; Salvatori et al., 2008). During these investigations, fortifications, including walls, round towers, gates, and a walled citadel, as well as ceramic production quarters were uncovered (Gubaev et al., 1998; Salvatori and Gundogdiyev, 2005; Salvatori et al., 2008). The site location, the division/organization of space within and outside the tepe, and analysis of pottery were used to suggest a possible administrative role for Togolok 1 (Salvatori and Gundogdiyev, 2005). This evidence allowed archaeologists to identify Togolok's archeological complex as one of the largest BMAC (i.e., GKC) proto-urban sites in the entire region [with respect to Smith's (2017) archeological urban attributes list; Salvatori, 2004, 2008a,b]. In 2005, one small-scale test trench (10 × 10 m) was excavated in Tepe 1, in an effort, to identify a site that was long lived (i.e., ideally incorporating the entire Bronze Age sequence) to allow archeologists to better understand the chronology in the Murghab (Salvatori and Gundogdiyev, 2005). This sub-surface test was positioned west of Sarianidi's pit in the southeast area of the tepe. Beyond these initial test trenches, Tepe 1 has not been extensively excavated.

More recently, the TAP – Togolok Archeological Project, directed by B. Cerasetti, has completed a series of small-scale test excavations on Tepe 1 during the field seasons of 2014, 2015, and 2018 (Cerasetti et al. in press a, 2019, in press b). These investigations were composed of a series of trenches (Trench 1A: 5 × 5 m; Trench 1B: 5 × 5 m; Trench 1C: 2 × 6 m) dug near the center of the mound. In Trench 1A, the excavators found dark deposits that contained carbonized seeds, dung, wood charcoal, faunal skeletal material, remnants of wattle and daub, and several postholes together with artificial platforms (which may suggest the presence of a temporary structure). Based on these findings, the context was interpreted as a possible animal enclosure (Cerasetti et al., in press b). Fireplaces, storage pits, artificial platforms, and a few artifacts (e.g., a terracotta figurine, spindle whorls, stone instruments, etc.) were mainly unearthed from the adjacent Trench 1B, that has been interpreted as a domestic context (Cerasetti et al., in press b). Trench 1C,



dug into the western area of the initial excavation (Trench 1A), has been interpreted as a refuse deposit. Composed of alternating sediment layers and widespread charcoal, this trench contained several artifacts (e.g., a flint arrow point, pottery disks, spindle whorls, zoomorphic and anthropomorphic figurines, etc.), carbonized seeds, faunal skeletal material, and evidence for artificial platforms and a fireplace (Cerasetti et al., in press a).

## Materials and methods

### Sampling and flotation

The archaeobotanical assemblage from the 2014 field season was collected from Trenches 1A and 1B (Figure 2). Soil samples were selected from stratigraphic units with the greatest likelihood of recovery of botanical remains (e.g., dark organic layers) and processed using the bucket flotation technique (Watson, 1976; Fritz, 2005; Pearsall, 2015) on site by the TAP team. To separate archaeobotanical material for analysis, each sediment sample was weighed in grams and then poured into a bucket with clean water. This mixture was then stirred, which

resulted in lighter organic material floating to the top and heavier material remaining on the bottom. After the mixture was sufficiently agitated, the organic material that floated to the surface was poured through 1.00 and 0.355 mm geological sieves consecutively. This process was repeated several times, adding more water as needed, until no more organic material floated. The material that had been collected in the sieves was then allowed to dry in the shade and packaged for analysis as light fraction. The material that remained on the bottom of the bucket was discarded (i.e., no heavy fraction was collected). In addition to the flotation samples, handpicked samples were also taken by excavators when they found particularly rich deposits of carbonized seeds during excavation. These samples were sent to the lab in labeled film cannisters.

### Archaeobotanical analysis

Initial analysis of the archaeobotanical assemblage was conducted by M. Carra at Bologna University (Cerasetti et al., in press b). M. Carra completed the analysis of 15 samples in this preliminary study. In 2019, these and the remaining

unprocessed samples were sent to T. Billings to be analyzed under the supervision of R. Spengler at the Max Planck Institute for Geoanthropology (formally Max Planck Institute for the Science of Human History) Paleoethnobotany Laboratory.

To sort the light fraction, the samples were systematically separated using a series of sieves (2.0, 1.4, 1.0, and 0.5 mm). Hand-picked samples were also separated using 2.0 mm and 0.50 mm sieves. The assemblage also contained samples of posthole fill that had not been floated. To allow for the broadest survey of the material, these were included in the analysis and were separated following the same method as light fraction. All identifiable plant remains were then carefully divided into categories (e.g., seeds, other plant parts, wood, dung, uncarbonized material, ceramic, and bones) and identified using a Leica Light Microscope. Identifications were made using comparative material and flora guides for the region [e.g., Flora of Turkmenia (Fedtschenko et al., 1932), Digital Atlas of Economic Plants in Archeology (Neef et al., 2012), Manual of Vascular Plants of Turkmenistan (Nikitin and Geldykhonov, 1988)]. For sieve sizes over 2.0 mm all carbonized seeds and other plant material, including rachises, culm nodes, and *Alhagi* sp. leaves, were separated and counted. For sieve sizes under 2.0 mm, all carbonized seeds were collected. *Alhagi* sp. leaves were collected from material above 1.4 mm, while rachis and Cerealia were collected from material above 1.0 mm. Material from the 0.5 mm sieve was scanned for botanical remains but in general, broken unidentifiable material was not collected. The length, width, and thickness of intact barley, wheat, and lentils were measured using a Keyence digital microscope and recorded for morphometric comparison. Samples from the initial analysis by M. Carra were re-analyzed to uniform nomenclature and included in this study. The archaeobotanical assemblage was cataloged and repackaged for long term storage. A digital archive containing at least one representative photo of each species from this assemblage will be made available as part of the Fruits of Eurasia: Dispersal and Domestication (FEDD) project<sup>2</sup>.

Counts were performed using the following system: one whole specimen equals one individual count, two half specimens of the same species equal one individual count, four fragments of the same species equal one individual count. These numbers were rounded up to nearest whole number for minimum number of individual (MNI) counts. The assemblage was examined to assess if this method of counting would be appropriate for each category. All domesticated grains and pulses, as well as wild seeds were counted in this way. Each rachis internode was counted as an individual. The cerealia were highly fragmented and was instead counted as individual fragments and not included in total counts. Unidentifiable fragments were also treated in this manner. The final table of absolute species counts was separated into three sub-tables

based on sample recovery type (LF- light fraction, NP- posthole fill, HP- handpicked). Ubiquity and abundance measurements were not calculated for the assemblage because of complications with cross comparison and subsequent small sample sizes. Given the exploratory nature of this initial archaeobotanical study, however, the presence/absence of plant species offers a wealth of information concerning plant use and environment.

## Radiocarbon dating

To temporally place the excavation at Togolok 1, charred grains of barley, wheat, and peas, corresponding to targeted stratigraphic layers in Trenches 1A and 1B, were sent for Accelerator Mass Spectrometry (AMS) dating (Figure 3). The seeds chosen were domesticated crops and thus provide direct evidence for the timing of their use. Together these 12 AMS dates (Figure 3) situate the broader archeological context of the excavation within the transition from the 3rd to the 2nd millennium B.C. More specifically, two barley grains taken from Trench 1A, SU# 127, SQ G2 and SU#127, SQ F4 provided dates for the 2014 field season botanical assemblage analyzed here (Figure 3). In addition to these two samples, one broomcorn millet (*Panicum miliaceum*) grain also recovered from Trench 1A, SU# 127, SQ G2 was sent for AMS dating (Figure 3).

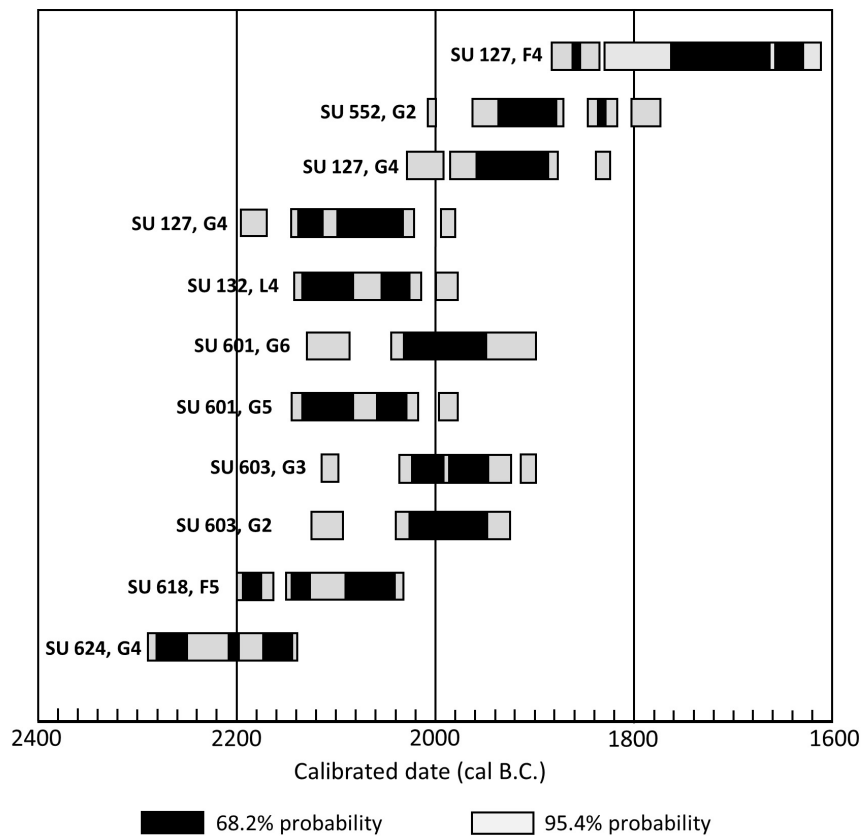
## Results

A total of 24,333 carbonized botanical remains (including seeds, floral and vegetative remains, nutshell, grain parts, and unidentifiable fragments) were recovered from 52 samples. The absolute counts of the major food crops and other species of interest are presented in Table 1. A complete table of absolute counts for all species can be found in Supplementary Table 1.

Major food crops found in this assemblage include domesticated grains (e.g., *Hordeum vulgare*, free-threshing wheat, most likely *Triticum aestivum*, and *Panicum miliaceum*) and legumes (e.g., *Pisum sativum*, *Lens culinaris*, *Vicia faba*, *V. sativa*, *V. ervilia*, and *Lathyrus sativus*). Evidence for fruits and nuts were also uncovered, including *Vitis vinifera*, *Crataegus* sp., *Prunus* sp., *Pyrus/Malus*, and nutshell. Several wild seeds were identified in the assemblage, such as wild grasses, pulses, sedges, knotweed, etc. (Supplementary Table 1). Additionally, unidentified charred remains, such as floral buds and a tuber were recovered.

Dung was well represented in 28 of the samples. Wood (fragments >2.00 mm) was slightly less frequent, occurring in 19 samples. In general, where dung was more abundant, there was less wood recovered and vice versa; although, there were exceptions (see SU123, FS#47). In addition to botanical remains and dung pellets, metal slag, terrestrial gastropod shells, fecal material (likely from a rodent), small fragments of ceramics, and

<sup>2</sup> <https://robertnspengler.com/fruits-of-eurasia-domestication-and-dispersal-fedd/>



C-14 Lab Sample Code	Material (charred seeds)	Context (Trench, SU#, Square)	C-14 yr B.P. (uncalibrated)	cal B.C. (Cerasetti et al. forthcoming a & b)	cal B.C. (calibrated using IntCal20)
CEDAD	<i>Hordeum vulgare</i>	1A, 127, F4	3420 ± 45	1880-1620'	1881-1612
OxA 38830	<i>Hordeum vulgare</i>	1B, 552, G2	3554 ± 21	1961-1873 (82.8%)°	2008-1776
SUERC 95396	<i>Hordeum vulgare</i>	1A, 127, G4	3581 ± 27	1986-1879 (80.3%)''	2026-1826
OS-164835	<i>Panicum milliaceum</i>	1A, 127, G4	3700 ± 25*	-	2197-1983
OxA 39550	<i>Hordeum vulgare</i>	1A, 132, L4	3681 ± 20	-	2141-1978
SUERC 95400	<i>Hordeum vulgare</i>	1C, 601, G6	3633 ± 27	-	2130-1900
OxA 38831	<i>Pisum sativum</i>	1C, 601, G5	3686 ± 20	-	2141-1980
OxA 38832	<i>Hordeum vulgare</i>	1C, 603, G3	3624 ± 20	2035-1919°	2113-1900
OxA 38833	<i>Pisum sativum</i>	1C, 603, G2	3631 ± 20	2038-1928 (92.5%)°	2124-1927
OxA 38835	<i>Triticum sp.</i>	1C, 618, F5	3722 ± 20	2104-2036 (51.2%)°	2200-2035
OxA 38334	<i>Hordeum vulgare</i>	1C, 624, G4	3784 ± 20	2287-2190 (65.3%)°	2288-2141

FIGURE 3

Accelerator mass spectrometry (AMS) radiocarbon dates from Togolok 1 (Cerasetti et al., in press a, in press b). Specific context from given as (trench, stratigraphic unit [SU], square). Graph adapted from OxCal v4.4.4 (Bronk Ramsey, 2009) with corresponding dates in last column of table. All dates were calibrated with 95.4% probability unless otherwise noted using IntCal20 (Reimer et al., 2020). Symbol key: 'Dates calibrated with OxCal 3.10 (Bronk Ramsey, 1995, 2001), IntCal13 (Reimer et al., 2013). °Dates calibrated with OxCal 4.3.2, Bronk Ramsey (2009), IntCal13 (Reimer et al., 2020). ''Dates calibrated with OxCal 4.4.2 (Bronk Ramsey, 2009), IntCal20 (Reimer et al., 2013). \*Newly reported date from this publication. Codes for labs: CEDAD- CEntro di Fisica applicata, DAtazione e Diagnostica, University of Salento, Italy; SUERC- Scottish Universities Environmental Research Centre Radiocarbon Lab, University of Glasgow, United Kingdom; OS, National Ocean Science AMS Lab, Woods Hole, United States; OxA, Oxford Radiocarbon Accelerator Unit, University of Oxford, United Kingdom.



**TABLE 1** Summary of total counts for the assemblage separated by sample collection type (LF, light fraction; NF, not floated, fill from postholes; HP, not floated, handpicked).

	LF	NF- Fill of Postholes	HP- Not floated
<b>Total No. of Samples:</b>	<b>20</b>	<b>7</b>	<b>25</b>
<b>Domesticated grains</b>			
<i>Hordeum vulgare</i>	688	1	1468
<i>Hordeum vulgare</i> var. <i>vulgare</i>	98	–	239
<i>Hordeum vulgare</i> var. <i>nudum</i>	53	–	197
<i>Triticum aestivum</i> (Free-threshing)	96	–	485
<i>Panicum miliaceum</i>	12	–	3
<b>Grain parts</b>			
Wheat Rachis (hexaploid)	393	–	13
Barley Rachis	3722	6	23
Cerealia	2351	117	220
Culm Node	42	–	55
<b>Legumes</b>			
<i>Pisum sativum</i>	78	–	615
<i>Vicia</i> cf. <i>sativa</i>	50	–	81
<i>Pisum sativum</i> / <i>Vicia sativa</i>	14	–	1015
cf. <i>Vicia ervilia</i>	–	–	6
<i>Vicia faba</i>	–	–	36
<i>Lens culinaris</i>	227	1	1439
<i>Lathyrus sativus</i>	29	–	325
cf. <i>Cicer arietinum</i>	–	–	5
Other legumes	101	3	233
<b>Fruits and nuts</b>			
cf. <i>Crataegus</i> sp.	1	–	–
<i>Malus</i> / <i>Pyrus</i>	4	–	5
<i>Prunus</i> cf. <i>insititia</i>	3	–	20
<i>Vitis vinifera</i>	1	–	7
Nutshell fragments	16	1	3
Nut meat	3	–	10
<b>Other</b>			
<i>Allium</i> sp.	–	–	1
<b>Wild grasses</b>			
cf. <i>Avena</i>	–	–	3
<i>Lolium</i> sp.	–	–	1
Panicoid	4	–	–
Poaceae	78	–	–
Poaceae Small Type	139	–	2
Pooid	85	–	5
<i>Aegilops</i> sp.	25	–	4
<i>Aegilops</i> sp. spikelet base	146	–	16
<i>Stipa</i> Type	21	–	–
<b>Weedy Taxa</b>			
<i>Chenopodium</i> spp.	99	–	1
<i>Sasola Kali</i>	34	1	1
Other Amaranthaceae	231	4	1
Asteraceae Floral Bud	111	–	87
Asteraceae (from Floral Bud)	336	–	39

(Continued)

**TABLE 1** (Continued)

	LF	NF- Fill of Postholes	HP- Not floated
<b>Total No. of Samples:</b>	<b>20</b>	<b>7</b>	<b>25</b>
Asteraceae Type B	403	–	20
<i>Xanthium</i> sp.	1	–	8
<i>Euclidium syriacum</i> capsule	126	1	15
<i>Convolvulus</i> sp.	156	–	159
<i>Carex</i> sp.	127	–	–
<i>Cyperus</i> sp.	5	–	–
Other Cyperaceae	404	3	24
<i>Alhagi</i> sp.	333	2	231
<i>Alhagi</i> sp. small + large pods	91	1	255
<i>Medicago/Melilotus</i> sp.	113	–	10
<i>Trigonella</i> sp.	234	1	14
Polygonaceae	306	1	–
<i>Rumex</i> sp.	27	–	–
<i>Polygonum</i> spp.	120	–	–
<i>Potentilla/Fragaria</i>	22	–	15
<i>Galium</i> sp.	670	2	1332
<i>Veronica</i> sp.	1	–	–
<i>Hyoscyamus</i> cf. <i>niger</i>	12	–	–
Solanaceae	42	–	6
<i>Thymelaea</i> sp.	17	–	–
Other Herbaceous plants	166	1	56
Unidentified Seeds	548	4	112
Unidentifiable Seed Fragments	1682	80	281
<b>Total macro-remains*</b>	<b>6707</b>	<b>27</b>	<b>8610</b>

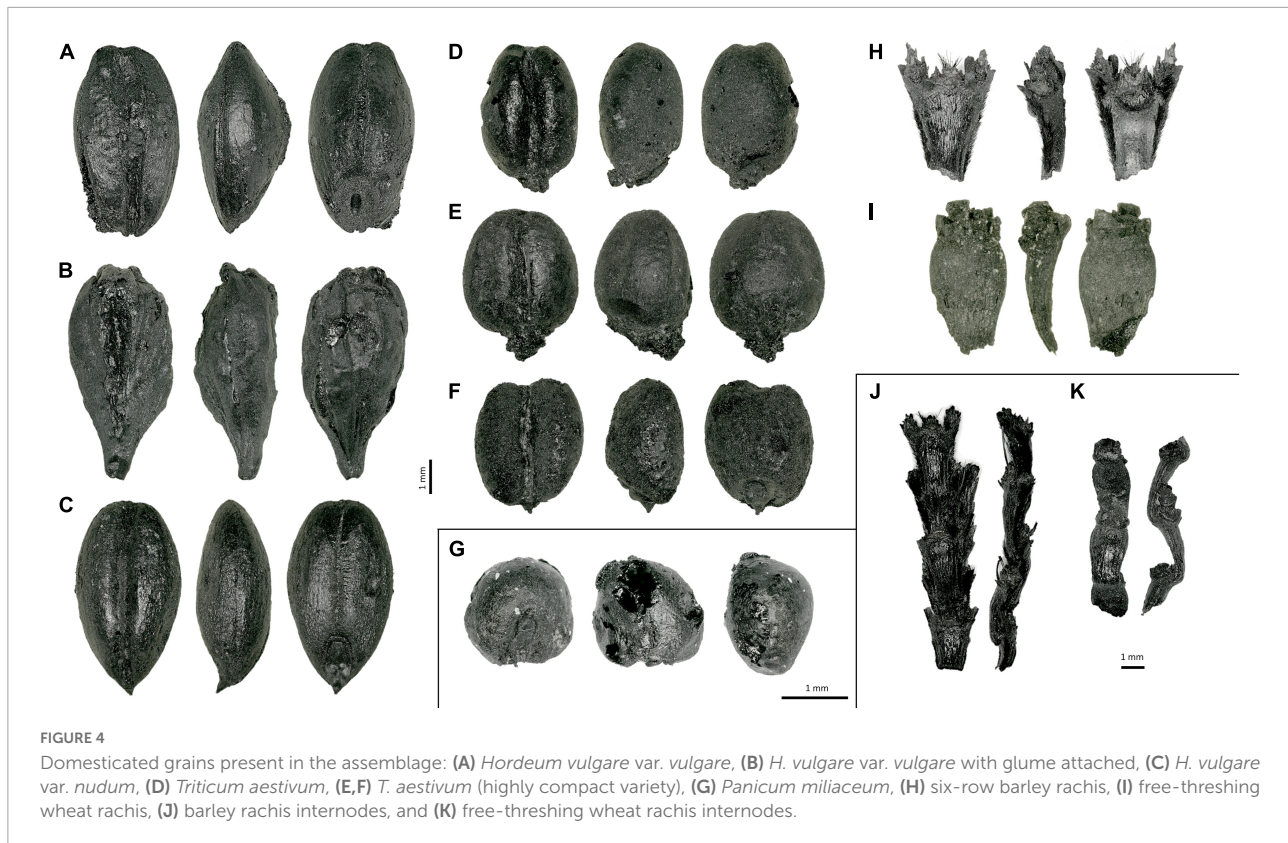
\*Excluding grain parts and unidentifiable seed fragments.

fauna skeletal material have been found. Most of the skeletal material is burnt, small, and highly fragmented; however, there were a few exceptions (e.g., intact small bone from SU119, FS#91, and three fish vertebrae from (SU109, FS#92). Only small and light-weight skeletal material was recovered, as larger and heavier bones were removed with the heavy fraction.

## Discussion

### Domesticated grains

*Hordeum vulgare* (barley) is the most common domesticated crop present in the assemblage. Both naked and hulled varieties of barley were recovered (hulled, indeterminate, and naked barley  $n = 2,744$ ; **Table 1**), as well as barley rachises ( $n = 3,751$ ; **Figure 4**). There was considerable variation in shape and size of the grains, some grains were very plump and spherical (e.g., see **Supplementary Table 2** and **Supplementary Figure 1**). In addition, several grains appeared puffed or distorted. For these reasons, only clear examples of hulled or naked barley were placed in these categories. The morphology of the

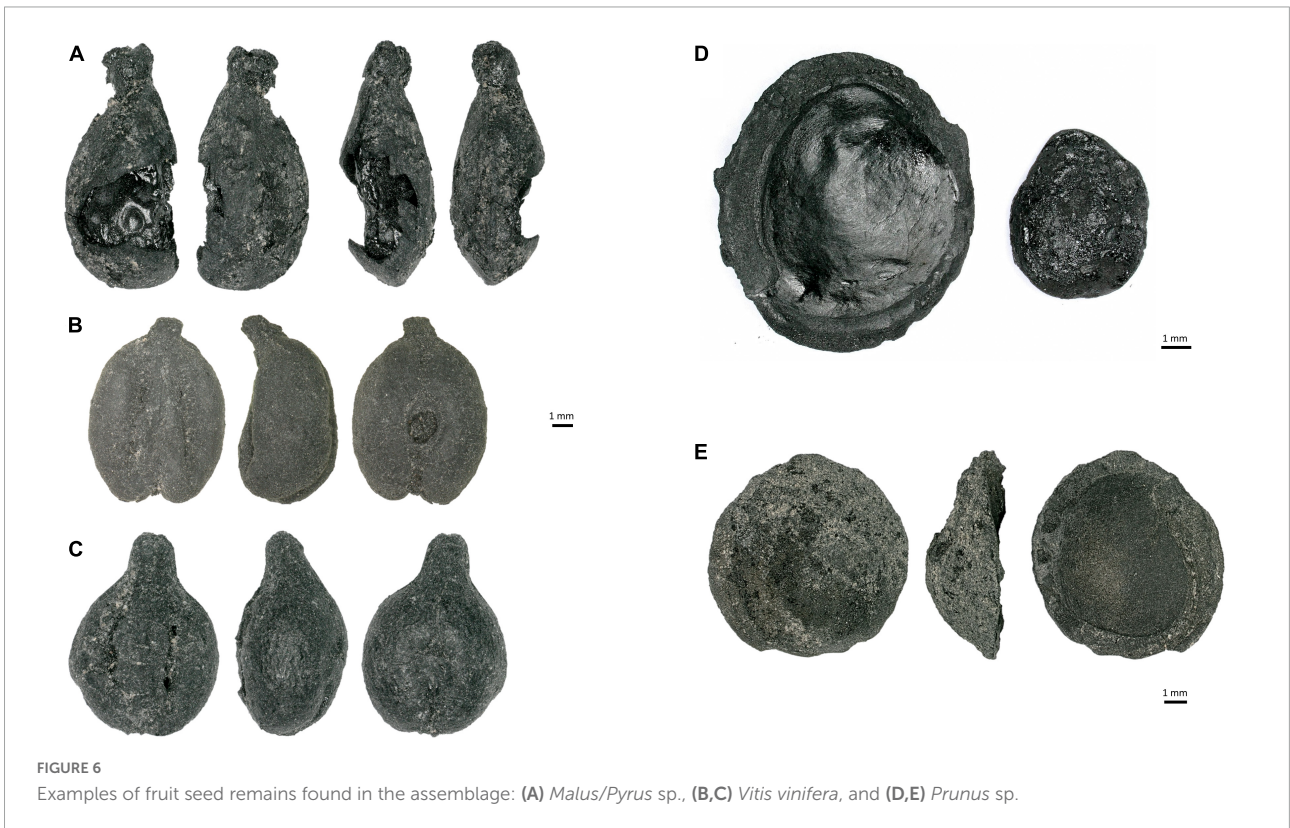
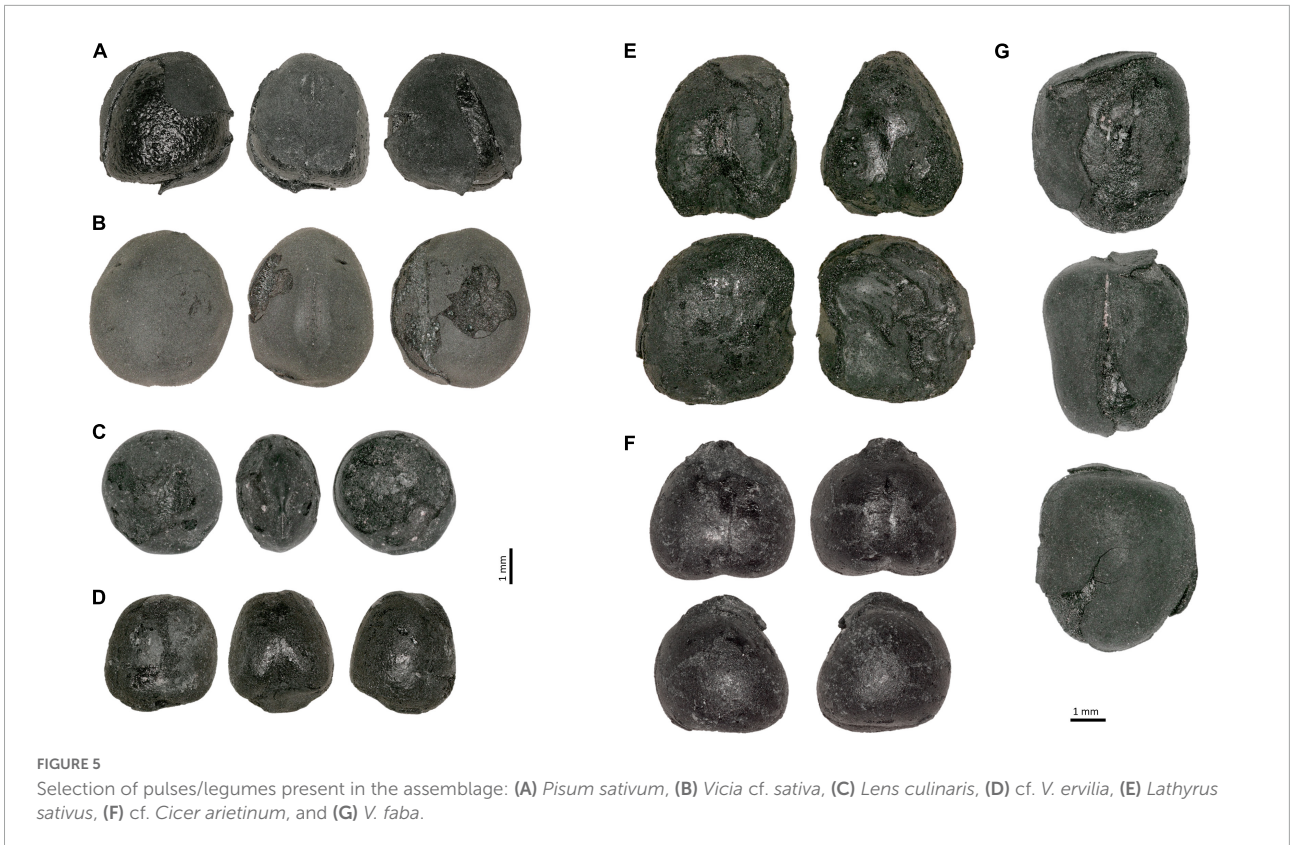


recovered rachises allowed for the identification of six-row barley. Interestingly, three *Hordeum vulgare* rachises show evidence of fungus growth or barley smut as reported earlier on specimens from Ojakly by Spengler et al. (2014). Barley is relatively more drought and saline/alkaline tolerant than other cereals (Zohary et al., 2012; Riehl, 2019), which may account for its prevalence in the assemblage.

*Triticum aestivum* (free-threshing wheat;  $n = 581$ ) and several well-preserved hexaploid wheat rachises ( $n = 406$ ) represent the second most common cereal crop recovered (Figure 4). These wheat grains also express considerable morphological variation (Supplementary Table 2 and Supplementary Figure 1). No attempt was made to systematically categorize specific varieties; however, a few examples of highly compact wheat have also been found (Figure 4). This wheat is plump and spherical in form. In publications with similar specimens, this wheat has been referred to as *T. aestivum* spp. *sphaerococcum*, *T. compactum*, or compact/highly compact wheat and has been found throughout Central Asia [e.g., Kazakhstan- Begash (Frachetti et al., 2010; Spengler, 2013), Tabas (Spengler, 2013); Kyrgyzstan- Aigyrzhal-2 (Matuzeviciute et al., 2017); Turkmenistan- Anau South (Miller, 1999, 2003), Chopantam (Spengler et al., 2014), Gonur North (Moore et al., 1994; Miller, 1999), Ojakly (Spengler et al., 2014)] and at Indus/Harappan-type sites in Pakistan [e.g., Mehrgarh (Costantini, 1984; Tengberg, 1999)] and

Afghanistan, [e.g., Shortugai (Willcox, 1991; Spengler and Willcox, 2013)]. It has been suggested that *T. aestivum* spp. *sphaerococcum* is relatively drought tolerant (e.g., Percival, 1921; Ellerton, 1939; Singh, 1946). If the compact wheat variety at Togolok 1 represents the same variety then it may have shared similar characteristics. Interestingly, this wheat variety was not identified at Adji Kui 1 (Spengler et al., 2018). The plump and spherical nature of both barley and wheat grains in the assemblage, however, raises questions about the effect of local growing conditions (e.g., aridity, access to water) on the morphology of grain seeds. A consideration already highlighted by Miller (1999) and further built upon by others (e.g., Spengler, 2015; Matuzeviciute et al., 2021).

High-yielding free-threshing bread wheats are in general easier to process than glume wheats. Wheat typically needs more water than other cereals, however, the relative amount depends heavily on the variety. Considering the crop requirements of wheat and barley and the seasonal climate in the Murghab, they may have been planted together in early Fall and harvested in late Spring. Examples of *Aegilops* sp. spikelet bases ( $n = 162$ ) and seeds ( $n = 29$ ; Figure 4) were identified. *Aegilops* is a wild ancestor of hexaploid bread wheat (Zohary et al., 2012, p. 24). Togolok 1 is located within the natural distribution of *Aegilops tauschii* (Zohary et al., 2012, see map page 46). This plant likely grew as a weed around the site in the wheat and barley fields, and subsequently was collected during cereal harvests. A possibility



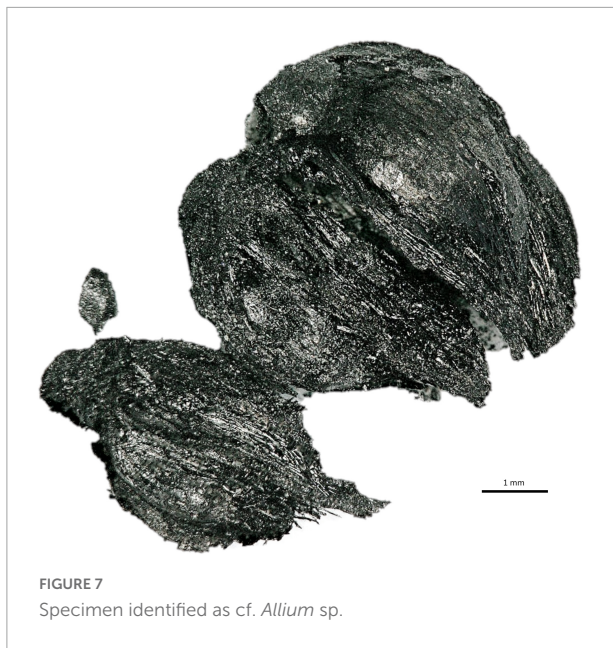


FIGURE 7  
Specimen identified as cf. *Allium* sp.

which is supported by the intermediate flowering times reported for its species across its range (Kihara et al., 1965; Matsuoka et al., 2008).

*Panicum miliaceum* (broomcorn millet;  $n = 15$ ; Figure 4), while present, was not abundant in the assemblage. When millet was identified in a sample, only one or two grains were recovered, apart from SU#108, SQ H3, which had four millet grains. Support for our identification of these specimens as millet comes from the  $\delta^{13}\text{C}$  isotope value of  $-10.69$  per mil, reported in Figure 3, which falls within the  $\text{C}_4$  plant range. The millet grains from this assemblage are quite large (e.g.,  $1.54 \times 1.61 \times 1.08$  mm, height  $\times$  width  $\times$  thickness), comparable to known modern cultivated varieties, suggesting they are not a wild relative. Miller et al. (2016) identified millet as a fast-growing, low-investment crop, with minimal water requirements used to mitigate risk. These qualities may have made it an attractive low-risk option for Togolok 1's population, given the ecological conditions in the Murghab. The small amount of recovered millet, however, makes it difficult to clarify its role in the economy.

## Legumes

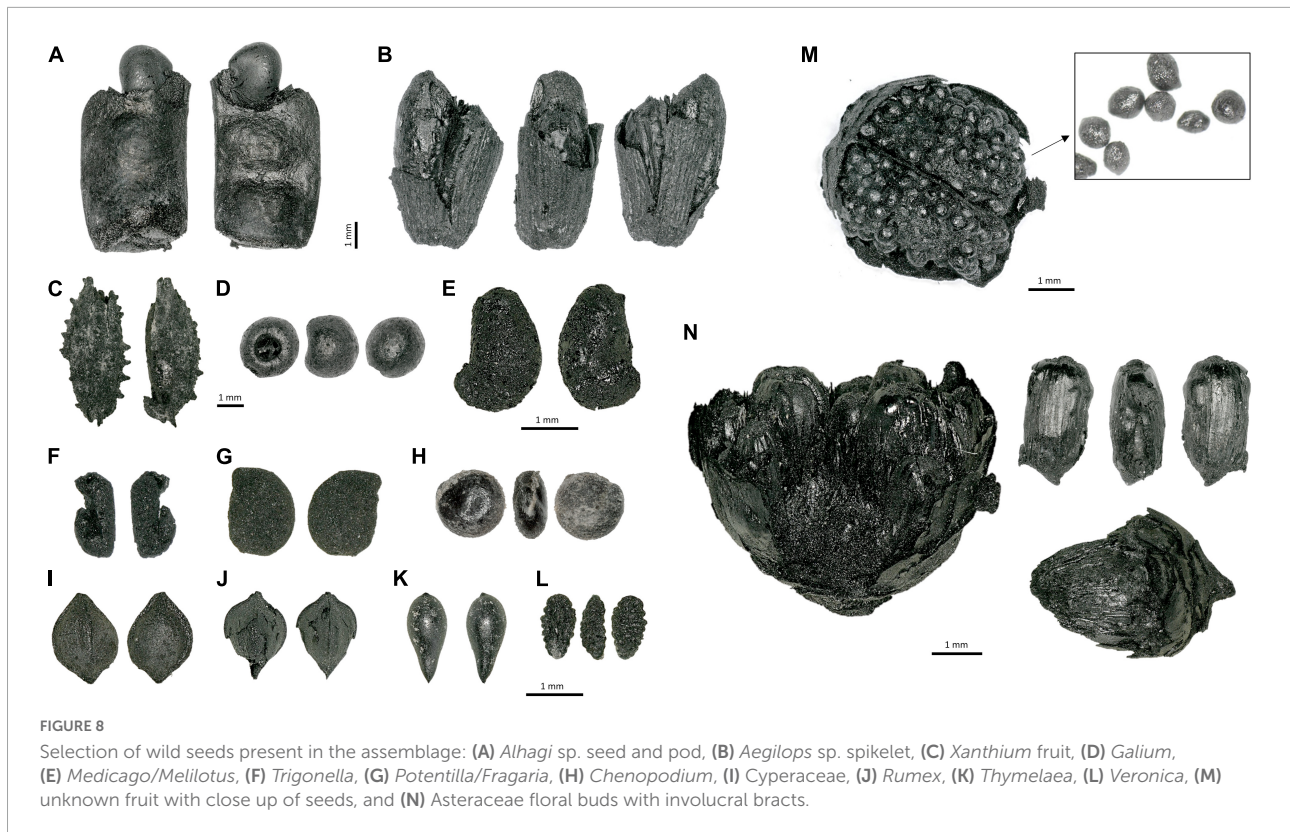
Large numbers of *Pisum sativum* (common peas;  $n = 693$ ), *Lens culinaris* (lentils;  $n = 1,667$ ), and *Lathyrus sativus* (grass peas;  $n = 354$ ) were recovered from the samples (Figure 5 and Table 1). In much smaller numbers, *Vicia* cf. *sativa* (common vetch;  $n = 131$ ), *V. faba* (fava beans;  $n = 36$ ), cf. *V. ervilia* (bitter vetch;  $n = 6$ ), and cf. *Cicer arietinum* (chickpeas;  $n = 5$ ) have also been identified (Figure 5 and Table 1). It was often difficult to differentiate between

common peas and vetch because many of their seed coats have not survived and/or their shape was distorted leading to them appearing morphologically similar. Common peas and vetch were positively identified only if they had general morphological integrity and their hilum was intact. If both criteria were not met, specimens matching general morphology of the two were placed in a *Pisum sativum/Vicia* cf. *sativa* category ( $n = 1,029$ ).

The Turkmen piedmont is within the natural distribution of the wild progenitor of lentils, *Lens culinaris* ssp. *orientalis* (Zohary et al., 2012, pp. 78–79), the average size of the lentils in our assemblage ( $3.60 \times 3.62 \times 2.09$  mm, diameter 1  $\times$  diameter 2  $\times$  thickness; Supplementary Table 2 and Supplementary Figure 1) suggest domesticated forms. Lentils are more drought tolerant than other legumes and are often grown in semi-arid environments. They generally require a minimum of 250 mm of annual precipitation (Cash et al., 2001; Pavék and McGee, 2016), and are also relatively tolerant of saline and alkaline soils (Muehlbauer et al., 2002; Pavék and McGee, 2016). Common vetch has also been shown to be relatively drought tolerant (see study by Tenopala et al., 2012). Grass peas, likewise, are able to grow in arid conditions with poor soil (Zohary et al., 2012) and are sometimes considered a survival food. Although, grass peas contain toxins, and require further processing (i.e., boiling) before consumption. These arid-land-adapted characteristics may account for the abundance of these species in the assemblage.

Whereas water requirements of over 355 mm of annual precipitation (Tulbek et al., 2017) suggest some form of irrigation was probably necessary for the cultivation of common peas at Togolok 1. Although, it should be noted that no definitively identified irrigation systems have been uncovered at Togolok 1 to date (Cerasetti et al., in press a). This, however, does not mean that the natural water courses were not managed. A few terracotta pipes have been identified at Gonur North (Sarianidi and Dubova, 2012), Togolok 1, and Togolok 21 (Hiebert, 1994). It has been suggested that these pipes (created by a series of interconnected terracotta conical tubes) were used to fill the pools found at the palace-temple complex and also as part of the drainage system of the palace at Gonur North (Sarianidi and Puschnigg, 2002; Sarianidi and Dubova, 2012). No water basins or artificial canal like those found at Gonur (Sataev, 2008; Sarianidi and Dubova, 2012), however, have been uncovered at Togolok 1 (Cerasetti et al., in press a).

Legumes are rich in protein and soluble fiber (Edde, 2022). Their ability to fix nitrogen and solubilize phosphates allows for an increase in overall soil nutrient levels and thus are valuable parts of multi-cropping systems (Singh et al., 1997; Edde, 2022). Spengler et al. (2014) has suggested that legumes need not have been grown in large, irrigated fields but instead could have been grown in small, hand watered, non-irrigated garden plots. The tentative nature and low numbers of fava beans, bitter vetch, and chickpeas complicate interpretations of their use. Ongoing



archaeobotanical studies at the site will hopefully clarify their role in the future.

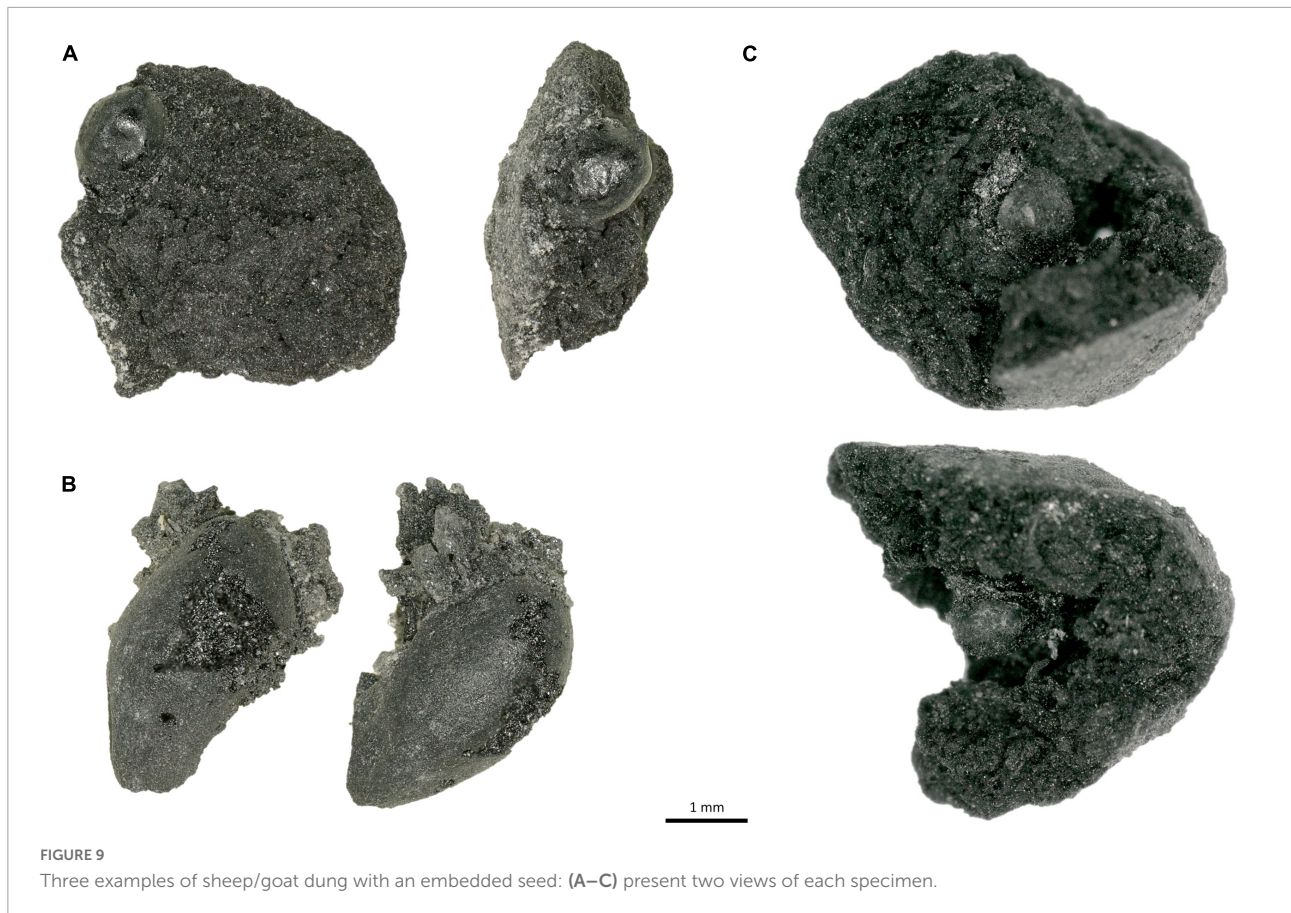
## Fruits and nuts

The several large *Prunus* pits (i.e., whole, half, or large fragments;  $n = 23$ ; **Figure 6**), from Togolok 1, appear to be from a wild relative of the plum, as their morphology suggests that they are too small and round to be apricots. Similar pits have been found at Adji Kui 1 (Spengler et al., 2018). Wild plum relatives are native to the region (e.g., greengages in Iran). The shape of the pits suggests these specimens may be related to *Prunus insititia*. The nutshell fragments ( $n = 20$ ) found in the assemblage can be divided into two categories: those that likely represent fragments of the *Prunus* pits and those that are unidentified, and relatively thinner than the other category. A small number of *Vitis vinifera* (grape;  $n = 8$ ) pips have been identified in the assemblage (**Figure 6**). Interestingly, we also found one example of a raisin. The considerable variation in grape pips among cultivars and distortion often caused by charring complicates criteria for identifying domestication (Miller, 2008; Uchescu et al., 2016). While wild grapes grow along rivers in the western piedmont of Turkmenistan, as well as in the valleys of the Kopet Dag (Harris et al., 1993; Zohary et al., 2012), the Murghab lies outside of their proposed natural

range. Nine cf. *Malus/Pyrus* (apple or pear; **Figure 6**) seeds were also recovered. It is not possible to definitively identify them to species based on charred archaeobotanical material alone. Sataev and Sataeva (2014) have reported apple remains from the nearby contemporaneous site of Gonur depe. Wild apples, pears, plums, hackberries, and nut trees grow in the woodlands of the Kopet Dag valleys (Harris et al., 1993). Thus, the specimens from Togolok 1, could have been cultivated, foraged, or acquired through trade.

One segmented bulb from cf. *Allium* (garlic) was tentatively identified (**Figure 7**). The recovery of *Allium* species in the archaeobotanical record is rare, especially in charred form, likely due to the ways the bulbs could become incorporated into the archeological record, ultimately, leading to biases in preservation. *Allium* bulbs are high in moisture, which contributes to rapid degradation after they have been discarded (Kubiak-Martens, 2002). In addition, charring usually destroys the fragile plant tissue or only leaves amorphous residue behind complicating morphological identification (Sarpaki, 2021), as a result, *Allium* species are usually found only in desiccated form (e.g., the onion and garlic bulbs presented in van der Veen, 2007).

Leeks and onions are either grown from seeds or bulbs, and most garlic varieties are grown through vegetative propagation which has led to several sterile cultivars, making the identification of its wild progenitor difficult



(Zohary et al., 2012). *A. longicuspis* has been posited as a potential ancestor of many of the current cultivars given its morphological and molecular similarity (Stearn, 1978), although the matter remains unresolved. Sarpaki (2021, p. 432) suggests that Central Asia, eastern Turkey, and Iran represent “the main center of garlic diversity” because geographically they encompass the natural range of *A. longicuspis*, as well as several other species including *A. tuncelianum*, *A. macrochaetum*, and *A. truncatum* (Ipek et al., 2008; Zohary et al., 2012).

## Seeds of wild herbaceous plants, wood charcoal, and dung

Seeds from several wild plant species have been recovered from the samples (Figure 8 and Supplementary Table 1). The most abundant species include two different varieties of *Alhagi* sp. (camel thorn), *Galium*, Convolvulaceae, and small wild Fabaceae (including *Trigonella*). A floral bud, from the Asteraceae family was also prevalent in the assemblage. Some scholars have suggested that large amounts of wild seeds may correspond to dung being burned as fuel (Miller and Smart, 1984; Miller, 1996, 2013; Spengler, 2018). Dung is a major source of fuel in Central Asia and other arid environments where

wood is scarce. However, large amounts of seeds could end up in the fire for a variety of reasons (e.g., cereal processing or burning brush; Miller and Smart, 1984; Miller, 1996; van der Veen, 2007). Dung is prevalent in the assemblage from Togolok 1, although wood charcoal is also present. The morphology of most of the dung pellets suggest they belong to either sheep or goat. Twenty-nine examples of seeds, including both domesticated and wild seeds, were found embedded inside dung pieces (e.g., Figure 9). Miller (1993) also reported seeds from wild (i.e., *Rumex* and cf. *Alhagi*) and possible domesticated (i.e., *Triticum* sp.) plants embedded in dung recovered at Gonur North. The wild seeds embedded in the dung may suggest that animals were pastured in non-agricultural fields for at least some of the time. The domesticated grains found in the dung may also suggest that the animals were being foddered with straw or crop chaff or allowed to pasture in fallow agricultural fields. Modern experimental studies focused on the survival of seeds after undergoing digestion have demonstrated that certain plant species do remain intact. They found, however, that this varies by animal species and individual (Atkeson et al., 1934; Harmon and Keim, 1934; Burton and Andrews, 1948; Takabayashi et al., 1979; Miller and Smart, 1984; Gardener et al., 1993; Anderson and Ertug-Yaras, 1996; Valamoti and Charles, 2005; Valamoti, 2013). Wild seeds tend to survive more because



they often have a harder seed coat (e.g., *Convolvulus arvensis* and *Amaranthus lividus*), but these studies have also found intact wheat and barley.

Wild seeds can also offer clues to the paleoenvironment or past land use. Camel thorn is an arid-adapted plant that grows in saline soil and disturbed areas, such as channel margins, making it a good indication of desert edges or semi-arid regions (Harris et al., 1993). Other species in the assemblage are common in arid grasslands or semi-dry (but not desert) areas. In addition to botanical remains, subsistence information may be gleaned from the faunal material uncovered in the samples. Three fish vertebrae were uncovered in the assemblage (Figure 10). Fish vertebrae, identified as Nemacheilidae *Paracobitis* sp., were also found at Adji Kui 1 (Spengler et al., 2018). Understanding how fish from small streams may have played a role in subsistence of the local community holds potential for future study.

## Integrating archaeobotanical and zooarchaeological evidence

Fish vertebrae found in the assemblage point to other potential food sources. Previously reported zooarchaeological evidence from Togolok 1 suggests that domesticated animals

included sheep, goats, cattle, pigs, and a dog (Cerasetti et al., in press a,b). Cattle and pig are suggestive of a sedentary context. This preliminary analysis also suggests that people, to a lesser extent, made use of wild resources (e.g., gazelles, foxes, and leprids; Cerasetti et al., in press a). Together, the archaeobotanical and zooarchaeological evidence provide a more holistic understanding of the food economy of the local population at Togolok 1 and suggest a mixed agropastoral system. Similar floral and faunal remains have been found at Gonur North and Adji Kui 1, which may suggest that people practiced similar economic strategies at these three proto-urbansites. Togolok's mixed agropastoral system also offers an association between the vast GKC sites and the pastoral settlements in the broader region (Luneau, 2017; Rouse, 2020; Cerasetti, 2021; Cerasetti et al., in press a).

## Wider regional context

The assemblage from Togolok 1 is comparable to other contemporaneous sites in the Murghab River alluvial fan and southern Central Asia more broadly. Both naked and hulled barley (especially the six-row variety), as well as, free-threshing wheat, and broomcorn millet have been uncovered from previously reported 2nd millennium B.C. contexts in the

Murghab (Table 2). Six-row barley has been described from 2nd millennium B.C. contexts at Anau South, Djarkutan, and Shortugai. This variety of barley appears to have a long history in Turkmenistan given its presence at Djeitun (Harris et al., 1993; Harris, 2010). Free-threshing wheat has also been recovered from Anau South, Djarkutan, and Shortugai. Conversely, free-threshing wheat has not been found at the later 2nd -1st millennia B.C. site of Takhirbai-depe (Nesbitt, 1994) which may be suggestive of deteriorating environmental conditions in the Murghab region at that time although socio-cultural influence should not be discounted. The absence of bread wheat, however, could also be a product of the small sampling size.

The direct AMS date on millet from Togolok 1 (2197–1983 cal B.C.; calibrated to 95.4% probability using OxCal 4.4 IntCal 20; Figure 3) is comparable to the oldest date for millet in the region, from Adji Kui 1, 3708 ± 45 uncal yr BP [2276–1956 cal B.C. calibrated to 95.4% probability using OxCal 4.4 IntCal 20 (Bronk Ramsey, 2009; Cerasetti et al., 2018; Spengler et al., 2018; Reimer et al., 2020)]. Broomcorn millet was also recovered from Gonur North, Shortughai, Ojakly, and the Chopantam sites. A few grains of either *Panicum* or

*Setaria* sp. were identified at Djarkutan, but cultivation could not be confirmed (Miller, 1999). The limited samples taken from Takhirbai-depe (Nesbitt, 1994) produced one millet grain. In addition to macroremains, impressions found inside vessels at Gonur South and Togolok 21 were tentatively identified as broomcorn millet by Bakels (2003; cf. Meyer-Melikyan, 1998; Meyer-Melikyan and Avetov, 1998). Nesbitt and Summers (1988) have demonstrated the widespread presence of millet in the surrounding regions during the Iron Age, yet we know relatively little about millet consumption in the Murghab between its initial appearance and later periods. Legumes are well represented among the sites in the Murghab, with settlement sites showing the greatest diversity in legume taxa.

Grapes were found at both Togolok 1 and Gonur North in the Murghab, as well as from 2nd millennium B.C. contexts at Anau South, Djarkutan, and Shortughai. Grape pips have also been recovered from earlier Iranian sites, [e.g., Hissar (4th millennium B.C. levels; Miller, 1991) and Shahr-i Sokhta (3rd millennium B.C.; Costantini, 1977; Miller, 1991)], as well as Indus sites [e.g., Mehrgarh and Nausharo (3200–1500 B.C.; Costantini, 1984, 1990; Bates, 2019; cf. discussion in

TABLE 2 Presence/absence of key economic species from second millennium B.C. contexts at archaeological sites in Turkmenistan, Uzbekistan, and northern Afghanistan.

Plant identification	Murghab Region, Turkmenistan					Turkmenistan	Afghanistan	Uzbekistan
	Togolok 1	Gonur	Adji Kui 1	Ojakly	Chopantam	Anau South	Shortughai	Djarkutan
<i>Hordeum vulgare</i> var. <i>vulgare</i> (hulled barley)	x	x	x	x	x	x	x	
<i>Hordeum vulgare</i> var. <i>nudum</i> (naked barley)	x	x	x	x	x	x		x
<i>Triticum aestivum/turigidum</i>	x	x	x	x	x	x	x	x
<i>Triticum aestivum</i> cf. <i>sphaerococcum</i> (highly compact wheat)	x	x		x	x	x		
<i>Triticum</i> cf. <i>dicoccum</i>		x						
<i>Triticum monococcum</i>		x						
<i>Panicum</i>	x	x	x	x	x		x	?
<i>Cicer arietinum</i>	x	x	x					
<i>Lens</i>	x	x	x		x			x
<i>Pisum</i>	x	x	x		x	x	x	
<i>Lathyrus sativus</i>	x	x	x		x			
<i>Vicia faba</i>	x		x					
<i>Vicia ervilia</i>	x		x					
<i>Vitis</i>	x	x				x	x	x
cf. <i>Malus</i>	x	x						
cf. <i>Prunus</i>	x	x	x					
<i>Crataegus</i>	x		x					
<i>Pistacia vera</i>							x	x
<i>Lallemantia</i> (oil crop)			x					
<i>Linum</i> (cf. flax seed)					x		x	

References reporting macrobotanical remains: Gonur North (Miller, 1993, 1999; Moore et al., 1994; Sataev and Sataeva, 2014), Adji Kui 1 (Spengler et al., 2018), Ojakly and Chopantam (Spengler et al., 2014), Anau South and Djarkutan (Miller, 1999), Shortughai (Willcox, 1991).



Bates, 2022)]. Less common species for 2nd millennium B.C. contexts, include chickpea, fava bean, bitter vetch, apple or pear, hawthorn, pistachio, and flax seed. Whereas emmer and einkorn and the oil seed crop *Lallemantia*, have only been found at Gonur North and Adjı Kui 1, respectively.

The Togolok 1 assemblage most closely aligns with Gonur North and Adjı Kui 1. This is expected as all three sites are settlements situated within the Murghab River alluvial fan. Interestingly, Togolok 1 also shares several key economic species with the mobile-pastoral site of Chopantam (Cattani, 2008a; Rouse and Cerasetti, 2018). Conversely, the mobile-pastoral site of Ojakly (Rouse and Cerasetti, 2014, 2018), located to the north-east of Gonur North in open pasturelands, is the most unlike the Togolok 1 assemblage. This difference may be related to biases in preservation caused by wind ablation at the Ojakly site. Building on previous research concerning the interaction between settled and mobile populations in the area (Hiebert and Moore, 2004; Cattani, 2008a,b; Cerasetti et al., 2018, 2019, in press a,b), we hope that ongoing research will provide a clearer picture of these economic relationships in the future.

## Conclusion

Domesticated grains (i.e., hulled/naked barley, free-threshing wheat, and millet), various legumes, and fruits, as well as several wild species of herbaceous plants have been identified in the 2014 archaeobotanical assemblage from Togolok 1. Crop processing on site is evidenced by the numerous remains of barley and wheat rachises, and culm nodes (i.e., straw). Millet, a low-investment, fast growing, drought-resistant crop, may have been adopted to mitigate risks associated with the shifting aridity at the beginning of the 2nd millennium B.C. Millet may also have been used for smaller scale production by pastoralists (Spengler et al., 2018). Given the small numbers of millet grains recovered, its precise role in the economy remains to be clarified. While most of the legumes present in the assemblage can grow in arid environments, these crops, along with peas and free-threshing wheat generally require more water than the Murghab's modern estimated annual precipitation of 100–130 mm. There may have been more available water in the past in the Murghab (Cremaschi, 1998); however, the region would have still been relatively semi-arid/arid (Cerasetti et al., in press a). As discussed in the environmental section above, crop production depended heavily on local contexts. The different growth seasons and water/nutrient requirements of these plants would have required careful planning concerning the timing and location of crop planting, as well as some form of management of local water resources. Whether this took the form of irrigation networks, remains to be determined, but is likely. It is possible that the inhabitants of Togolok 1 took advantage of secondary river channels to cultivate fields, similar to those found at the latter site of Takhirbai-depe, as

suggested by Cerasetti et al. (in press a; Cattani and Salvatori, 2008). If legumes were irrigated in large fields, they may have been part of a crop-rotation system, which allowed farmers to promote soil health. Alternatively, if legumes were grown in garden plots, they could have been watered by hand. A combination of both strategies, of course, would also have been possible. More work at the site is necessary to elucidate the answers to these questions. While we focused on agriculture at Togolok 1, increasing evidence suggests that the inhabitants made use of sheep, goats, pigs, cattle, and to a lesser extent wild animals. A mixed agropastoral economy and the diversification of plant use may have been in response to changing ecological conditions during the late 3rd-early 2nd millennia B.C. on an already dynamic landscape. This system would allow Togolok 1's inhabitants to engage with available ecotones between the desert and the alluvial fan. They may also have made use of the mountain foothills through trade.

This initial study, while limited in overall context, allows us to delve deeper into understanding the economies of these proto-urban settlements during a time of important cultural transformation (2200–1500 B.C.). Ongoing investigations at Togolok 1 by the TAP team will clarify more about the dietary choices, the unique human/landscape interactions, and the potential adoption of crop species in local contexts.

## Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author/s.

## Author contributions

TB, RS, and BC conceived and designed the study. BC, LF, RA, and LR contributed to initial investigation and collected and processed the samples. TB, RDM, and MC sorted and identified the botanical remains. RS supervised the sorting and identification of botanical remains. TB analyzed the material, created the tables and figures, and wrote initial draft. RS, BC, NB, and RDM offered guidance in overall process. All authors contributed to the revisions process and approved the submitted version of the manuscript.

## Funding

The excavation at Togolok 1 was funded by the Italian Ministry for Foreign Affairs and International Cooperation, ISMEO – The International Association for Mediterranean and

Oriental Studies, Rome, and the University of Naples “L’Orientale.” Funding for the archaeobotanical analyses was provided by the Max Planck Institute for the Science of Human History (MPI-SHH). Eleven AMS dates were funded through the Fruits of Eurasia: Domestication and Dispersal (FEDD) project (European Research Council Starting Grant [851102]). Funding for one AMS date was provided by the Volkswagen and Mellon Foundations, Fellowship for Research in the Humanities for research in Germany, Grant 2015–2016 (PI RS).

## Acknowledgments

This work was made possible by the support of our colleagues at the National Department for the Protection, Research and Restoration of Monuments of Ashgabat, the Ancient Merv National Historical Park of Bayram-ali, and the Museum of History and Cultures of Mary of the Ministry of Culture of Turkmenistan. We would also like to extend a special thank to the MPI-SHH Paleoethnobotanical Laboratory Technicians and FEDD team for their support through this process.

## References

- Anderson, S., and Ertug-Yaras, F. (1996). Fuel fodder and faeces: An ethnographic and botanical study of dung fuel use in Central Anatolia. *Environ. Archaeol.* 1, 99–109. doi: 10.1179/env.1996.1.1.99
- Atkeson, F. W., Hulbert, H. W., and Warren, T. R. (1934). Effect of bovine digestion and of manure storage on the viability of weed seeds. *J. Am. Soc. Agron.* 26, 390–397. doi: 10.2134/agronj1934.0002196200260005006x
- Babaev, A. G. (1994). “Landscapes of Turkmenistan,” in *Biogeography and ecology of Turkmenistan, monographiae biologicae*, Vol. 72, eds V. Fet and K. I. Atamuradov (Dordrecht: Springer), 5–22. doi: 10.1007/978-94-011-1116-4\_2
- Bakels, C. C. (2003). The contents of ceramic vessels in the Bactria-Margiana archaeological complex, Turkmenistan. *Electron. J. Vedic Stud.* 9, 49–52.
- Bates, J. (2019). The published archaeobotanical data from the Indus civilisation, South Asia, c. 3200–1500BC. *J. Open Archaeol. Data* 7:5. doi: 10.5334/joad.57
- Bates, J. (2022). *Vitis* sp., Vitaceae and viticulture in the Indus civilization, South Asia ca. 3200–1500 BC: A critical review. *Veg. Hist. Archaeobot.* 31, 205–220. doi: 10.1007/s00334-021-00842-1
- Biscione, R., and Vahdati, A. A. (2021). “The BMAC presence in eastern Iran: State of affairs in December 2018–towards the Greater Khorasan civilization?,” in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 527–550. doi: 10.4324/9781315193359-23
- Bonora, G. L., and Vidale, M. (2013). “The middle chalcolithic in southern Turkmenistan and the archaeological record of Ilygnyly-Depe,” in *Ancient Iran and its neighbours: Local development and long-range interaction in the fourth millennium BC*, ed. C. A. Petrie (Oxford: Oxbow Books), 140–165. doi: 10.2307/j.ctv1hdn46.13
- Bronk Ramsey, C. (1995). Radiocarbon calibration and analysis of stratigraphy: The OxCal program. *Radiocarbon* 37, 425–430. doi: 10.1017/S0033822200030903
- Bronk Ramsey, C. (2001). Development of the radiocarbon program OxCal. *Radiocarbon* 43, 355–363. doi: 10.1017/S0033822200038212
- Bronk Ramsey, C. (2009). Bayesian analysis of radiocarbon dates. *Radiocarbon* 51, 337–360. doi: 10.1017/S0033822200033865
- Burton, G. W., and Andrews, J. S. (1948). Recovery and viability of certain southern grasses and lespedeza passed through the bovine digestive tract. *J. Agric. Res.* 76, 95–103.
- Cash, D., Lockerman, R., Bowman, H., and Welty, L. (2001). *Growing lentils in Montana*. Bozeman, MT: Montana State University Extension Service.
- Cattani, M. (2008a). “Excavations at sites no. 1211 and no. 1219 (Final Bronze Age),” in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 119–132.
- Cattani, M. (2008b). “The final phase of the Bronze Age and the ‘Andronovo Question’ in Margiana,” in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 133–151.
- Cattani, M., Cerasetti, B., Salvatori, S., and Tosi, M. (2008). “The Murghab Delta in Central Asia 1990–2001: The GIS from research resource to a reasoning tool for the study of settlement change in long-term fluctuations,” in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 39–45.
- Cattani, M., and Salvatori, S. (2008). “Transects and other techniques for systematic sampling,” in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 3–30.
- Cerasetti, B. (2004). Reasoning with GIS: Tracing the silk road and the defensive systems of the Murghab Delta (Turkmenistan). *Silk Road* 2, 39–42.
- Cerasetti, B. (2008). “A GIS for the archaeology of the Murghab Delta,” in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 31–39.
- Cerasetti, B. (2012). “Remote sensing and survey of the Murghab Alluvial Fan, southern Turkmenistan: The coexistence of nomadic herders and sedentary farmers in the late Bronze Age and early Iron Age,” in *Mega-cities & mega-sites, the*

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher’s note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

## Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fevo.2022.995490/full#supplementary-material>

archaeology of consumption & disposal landscape, transport & communication, vol. 1. *Proceedings of the 7th international congress on the archaeology of the ancient near east held at the British Museum and UCL, London, 12-16 April 2010*, eds R. Matthew and J. Curtis (Wiesbaden: Harrassowitz Verlag), 539–558.

Cerasetti, B. (2021). “Who interacted with whom? Redefining the interaction between BMAC people and mobile pastoralists in Bronze Age southern Turkmenistan,” in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 487–495. doi: 10.4324/9781315193359-20

Cerasetti, B., Arciero, R., Billings, T. N., Cattani, M., D'Ippolito, L., Forni, L., et al. (in press a). “The rise and decline of the desert cities: The last stages of the BMAC at Togolok 1 (Southern Turkmenistan),” in *Cultures in contact Central Asia as focus of trade, cultural exchange and knowledge transmission*, eds C. Baumer, M. Novák, and S. Rutishauser (Wiesbaden: Schriften zur Vorderasiatischen Archäologie, Harrassowitz-Verlag).

Cerasetti, B., Arciero, R., Carra, M., Forni, L., Rouse, L. M., Billings, T. N., et al. (in press b). “Interactions between sedentary and mobile peoples in the Bronze Age of Southern Central Asia: Excavations at Togolok 1 in the Murghab region,” in *Farmers, traders and herders: The Bronze Age in Central Asia and Khorasan (3rd - 2nd Millennium BCE). Proceedings of the conference held in Berlin 2015*, eds N. Boroffka, S. Pollock, E. Luneau, and M. Teufer (Berlin: Deutsches Archäologisches Institut, Eurasien-Abteilung/Dietrich Reimer Verlag).

Cerasetti, B., Arciero, R., Carra, M., Curci, A., De Grossi Mazzorin, J., Forni, L., et al. (2019). “Bronze and Iron Age urbanisation in Turkmenistan preliminary results from the excavation of Togolok 1 on the Murghab alluvial fan,” in *Urban cultures of Central Asia from the Bronze Age to the Karakhanids learnings and conclusions from new archaeological investigations and discoveries. Proceedings of the first international congress on Central Asian archaeology held at the University of Bern, 4–6 February 2016*, eds C. Baumer and M. Novak (Wiesbaden: Harrassowitz Verlag), 63–72. doi: 10.2307/j.ctvnrnfq57.8

Cerasetti, B., Codini, G. B., and Rouse, L. M. (2014). “Walking in the Murghab Alluvial Fan (Southern Turkmenistan): An integrated approach between old and new interpretations about the interaction between settled and nomadic people,” in *“My life is like the summer rose” Maurizio Tosi e l'Archeologia come modo di vivere: Papers in honour of Maurizio Tosi for his 70th birthday British archaeological reports international series*, eds C. C. Lamberg-Karlovsky, B. Genito, and B. Cerasetti (Oxford: BAR Publishing), 105–114.

Cerasetti, B., Rouse, L. M., and de Nigris, I. (2018). “The influence of Bronze Age sedentary-mobile interactions on the Iron Age: Mobile pastoral occupation sites in the Murghab Alluvial Fan, Turkmenistan,” in *A millennium of history. The Iron Age in Southern Central Asia (2nd and 1st Millennia BC). Proceedings of the conference held in Berlin (June 23-25, 2014). Dedicated to the memory of Viktor Ivanovich Sarianidi. Archäologie in Iran und Turan 17*, eds J. Lhuillier and N. Boroffka (Berlin: Mémoires de la Délégation Archéologique Française en Afghanistan XXXV), 17–30.

Cerasetti, B., and Tosi, M. (2010). “Once upon a time... a brief reflection on the history of the archaeological map of the Murghab Delta (AMMD) project in relation to the fundamental role of V.I. Sarianidi,” in *On the track of uncovering a civilization: A volume in honor of the 80th-anniversary of victor Sarianidi*, eds P. M. Kozhin, M. F. Kosarev, and N. A. Dubova (Sankt-Petersburg: Transactions of the Margiana Archaeological Expedition), 86–103.

Chemonics International Inc. (2001). *Biodiversity assessment for Turkmenistan. Biodiversity & sustainable forestry IQC (BIOFOR)*. Almaty: USAID Central Asian Republics Mission.

Chen, F., Yu, Z., Yang, M., Ito, E., Wang, S., Madsen, D. B., et al. (2008). Holocene moisture evolution in arid Central Asia and its out-of-phase relationship with Asian monsoon history. *Quat. Sci. Rev.* 27, 351–364. doi: 10.1016/j.quascirev.2007.10.017

Cleuziou, S., Gaibov, V., and Annaev, T. (1998). “Off-site archaeological transects in N. Margiana,” in *The archaeological map of the Murghab Delta: Preliminary reports 1990-1995*, eds A. Gubaev, G. Koshelenko, and M. Tosi (Rome: Istituto Italiano per L'Africa e L'Oriente), 27–34.

Costantini, L. (1977). “Le piante [The plants],” in *La città bruciata del deserto salato [The burnt city in the salt desert]*, ed. G. Tucci (Venice-Mestre: Erizzo), 159–171.

Costantini, L. (1984). “The beginning of agriculture in the Kachi Plain: The evidence of Mehrghar,” in *South Asian archaeology*, ed. B. B. Allchin (Cambridge: Cambridge University Press), 29–33.

Costantini, L. (1990). “Harappan agriculture in Pakistan: The evidence from Nausharo,” in *South Asian archaeology 1987*, ed. M. Taddei (Rome: Istituto Italiano per il Medio es Estremo Oriente), 321–332.

Cremaschi, M. (1998). “Palaeohydrography and Middle Holocene desertification in the northern fringe of the Murghab Delta,” in *The archaeological map of the Murghab Delta, preliminary reports 1990-1995*, eds A. Gubaev, G. A. Koshelenko, and M. Tosi (Rome: Istituto Italiano per L'Africa e L'Oriente), 15–25.

Didovets, I., Lobanova, A., Krysanova, V., Menz, C., Babagalieva, Z., Nurbatsina, A., et al. (2021). Central Asian rivers under climate change: Impacts assessment in eight representative catchments. *J. Hydrol. Reg. Stud.* 34:100779. doi: 10.1016/j.ejrh.2021.100779

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N. D., Wikramanayake, E., et al. (2017). An ecoregion-based approach to protecting half the terrestrial realm. *Bioscience* 67, 534–545. doi: 10.1093/biosci/bix014

Edde, P. A. (2022). *Field crop arthropod pests of economic importance*. San Diego, CA: Academic Press. doi: 10.1016/B978-0-12-818621-3.00002-1

Ellerton, S. (1939). The origin and geographical distribution of *Triticum sphaerococcum* perc. and its cytogenetical behaviour in crosses with *T. vulgare* VILL. *J. Genet.* 38, 307–324. doi: 10.1007/BF02982176

Fedtschenko, B. A., Popov, M. G., and Shishkin, B. K. (1932). *Flora Turkmenii*. Leningrad: An SSSR.

Forni, L. (2017). Bronze Age terracotta anthropomorphic and zoomorphic figurines from the Murghab Region (Turkmenistan): New evidence and interpretations. *Ocnus Quad. Scuola Specializzazione Beni Archeol.* 25, 9–18.

Fouache, E., Besenval, R., Cosandey, C., Coussot, C., Ghilardi, M., Huot, S., et al. (2012). Palaeo-channels of the Balkh River (Northern Afghanistan) and human occupation since the Bronze Age. *J. Archaeol. Sci.* 39, 3415–3427. doi: 10.1016/j.jas.2012.05.030

Fouache, E., Cez, L., Andrieu-Ponel, V., and Rante, R. (2021). “Environmental changes in Bactria and Sogdiana (Central Asia, Afghanistan, and Uzbekistan) from the Neolithic to the Late Bronze Age. Interaction with human occupation,” in *The world of the Oxus civilisation*, eds B. Lyonnet and N. A. Dubov (London: Routledge), 82–109. doi: 10.4324/9781315193359-5

Frachetti, M. D. (2012). Multi-regional emergence of mobile pastoralism and non-uniform institutional complexity across Eurasia. *Curr. Anthropol.* 53, 2–38. doi: 10.1086/663692

Frachetti, M. D., Spengler, R. N., Fritz, G. J., and Mar'yashev, A. N. (2010). Earliest direct evidence for broomcorn millet and wheat in the Central Eurasian steppe region. *Antiquity* 84, 993–1010. doi: 10.1017/S0003598X0006703X

Francfort, H. P. (1984). “The early periods of Shortughai (Harappan) and the western Bactrian culture of Dashly,” in *South Asian archaeology 1981*, ed. B. Allchin (Cambridge: Cambridge University Press), 170–175.

Frenez, D. (2018). Manufacturing and trade of Asian elephant ivory in Bronze Age Middle Asia: Evidence from Gonur Depe (Margiana, Turkmenistan). *Archaeol. Res. Asia* 15, 13–33. doi: 10.1016/j.ara.2017.08.002

Fritz, G. J. (2005). “Paleoethnobotanical methods and applications,” in *Handbook of archaeological methods*, eds D. G. Manschner and C. Chippindale (Walnut Creek, CA: Altimira Press), 771–832.

Gardener, C. J., McIvor, J. G., and Jansen, A. (1993). Passage of legume and grass seeds through the digestive tract of cattle and their survival in faeces. *J. Appl. Ecol.* 30, 63–74. doi: 10.2307/2404271

Garner, J. (2021). “Metal sources (tin and copper) and the BMAC,” in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 799–826. doi: 10.4324/9781315193359-33

Gubaev, A., Koshelenko, G., and Tosi, M. (1998). *The archaeological map of the Murghab Delta: Preliminary reports 1990-1995*. Rome: Istituto Italiano per L'Africa e L'Oriente.

Harmon, G. W., and Keim, F. D. (1934). The percentage and viability of weed seeds recovered in the feces of farm animals and their longevity when buried in manure. *Agron. J.* 26, 762–767. doi: 10.2134/agronj1934.00021962002600090010x

Harris, D. (1997). Jeitun and the transition to agriculture in Central Asia. *Archaeol. Int.* 1, 28–31. doi: 10.5334/ai.0109

Harris, D. R. (2010). *Origins of agriculture in Western Central Asia: An environmental-archaeological study*. Philadelphia, PA: University of Pennsylvania Museum of Archaeology and Anthropology.

Harris, D. R., Masson, V. M., Berezkin, Y. E., Charles, M. P., Gosden, C., Hillman, G. C., et al. (1993). Investigating early agriculture in Central Asia: New research at Jeitun, Turkmenistan. *Antiquity* 67, 324–338. doi: 10.1017/S0003598X00045385

Heinecke, L., Mischke, S., Adler, K., Barth, A., Biskaborn, B. K., Plessen, B., et al. (2017). Climatic and limnological changes at Lake Karakul (Tajikistan) during the last ~29 cal ka. *J. Paleolimnol.* 58, 317–334. doi: 10.1007/s10933-017-980-0

Hiebert, F. T. (1994). *Origins of the Bronze Age Oasis civilization in Central Asia*. Cambridge, MA: Harvard University.

Hiebert, F. T., and Lamberg-Karlovsky, C. C. (1992). Central Asia and the Indo-Iranian Borderlands. *Iran* 30, 1–15. doi: 10.2307/4299865

- Hiebert, F. T., and Moore, K. M. (2004). "A small steppe site near Gonur," in *U istokob zivilisazii: Sbornik statej k 75-letiju Viktora Ivanovicha Sarianidi [At the origins of civilization: Collection of articles dedicated to the 75<sup>th</sup> anniversary o Viktor Ivanovich Sarianidi]*, ed. M. F. Kosarev (Moskva: Staryj sad), 294–302.
- Ipek, M., Ipek, A., and Simon, P. W. (2008). Genetic characterization of *Allium tuncelianum*: An endemic edible *Allium* species with garlic odor. *Sci. Hortic.* 115, 409–415. doi: 10.1016/j.scienta.2007.11.002
- Jones, M., Hunt, H., Lightfoot, E., Lister, D., Liu, X., and Motuzaite-Matuzevičiute, G. (2011). Food globalization in prehistory. *World Archaeol.* 43, 665–675. doi: 10.1080/00438243.2011.624764
- Kaniuth, K. (2010). Long distance imports in the Bronze Age of Southern Central Asia: Recent finds and their implications for chronology and trade. *Archäol. Mitt. Iran Turan* 42, 3–22.
- Kasparov, A. K. (1992). "Bone collection at the Jeitun settlement," in *New research at the Jeitun settlement (preliminary reports on the work of the Soviet-British expedition)*, ed. V. M. Masson (Ashkabad: Academy of Sciences of Turkmenistan), 50–76.
- Kihara, H., Yamashita, K., and Takaka, M. (1965). "Morphological, physiological, genetical and cytological studies in *Aegilops* and *Triticum* collected from Pakistan, Afghanistan, and Iran," in *Results of the Kyoto University scientific expedition to the Karakoram and Hindukush, 1955*, ed. K. Yamashita (Kyoto: Kyoto University), 1–118.
- Kohl, P. L. (1984). *Central Asia: Palaeolithic beginnings to the Iron Age*. Paris: Editions Recherche sur les civilisations.
- Kohl, P. L. (2007). *The making of Bronze Age Eurasia*. Cambridge: Cambridge University Press. doi: 10.1017/CBO9780511618468
- Korobkova, G. F. (1981). "Ancient reaping tools and their productivity in the light of experimental tracewear analysis," in *The Bronze Age civilization of Central Asia*, ed. P. L. Kohl (New York, NY: ME Sharpe), 325–349. doi: 10.2753/AAE1061-1959190304325
- Kubiak-Martens, L. (2002). New evidence for the use of root foods in pre-agrarian subsistence recovered from the late Mesolithic site at Halsskov, Denmark. *Veg. Hist. Archaeobot.* 11, 23–32. doi: 10.1007/s003340200003
- Legge, A. J. (1992). "The exploitation of sheep and goat at Jeitun," in *New research at the Jeitun settlement (preliminary reports on the work of the Soviet-British expedition)*, ed. V. M. Masson (Ashkabad: Academy of Sciences of Turkmenistan), 77–83.
- Leipe, C., Demske, D., Tarasov, P. E., and HIMPAC Project Members (2014). A Holocene pollen record from the northwestern Himalayan lake Tso Moriri: Implications for palaeoclimatic and archaeological research. *Quat. Int.* 348, 93–112.
- Lombard, P. (2021). "The Oxus civilization/BMAC and its interaction with the Arabian Gulf. A review of the evidences," in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 607–634. doi: 10.4324/9781315193359-26
- Luneau, E. (2017). "Transfers and interactions between north and south in Central Asia during the Bronze Age," in *Interaction in the Himalayas and Central Asia: Processes of transfer, translation and transformation in art, archaeology, religion and polity*, eds E. Allinger, F. Grenet, C. Jahoda, M. K. Lang, and A. Vergati (Vienna: Verlag der Österreichischen Akademie der Wissenschaften), 13–27. doi: 10.2307/j.ctt1pv891n.5
- Luneau, E. (2018). "Climate change and the rise and fall of the Oxus civilization in Southern Central Asia," in *Socio-environmental dynamics along the historical silk road*, eds L. E. Yang, H. R. Bork, X. Fang, and S. Mischke (Cham: Springer), 275–299. doi: 10.1007/978-3-030-00728-7\_14
- Luneau, E. (2021). "The end of the Oxus civilization," in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 496–524. doi: 10.4324/9781315193359-21
- Lyapin, A. A. (1991). Paleogeographic features of the Murgab and Tedzhen deltas (Eneolithic period, Stone Age). *Probl. Desert Dev.* 2, 63–70.
- Lyapin, A. A. (2014). "Kistorii oroshenija v del'te Murgaba [On the history of irrigation in the delta of the Murghab River]," in *Trudy margianskoj arkeologičeskoj ekspeditsii 5 [Transactions of margiana archaeological expedition]*, Vol. 5, ed. V. I. Sarianidi (Moscow: Staryj Sad), 60–91.
- Lyonnet, B., and Dubova, N. A. (2021). *The world of the Oxus civilization*. London: Routledge. doi: 10.4324/9781315193359
- Maman, S., Orlovsky, L., Blumberg, D. G., Berliner, P., and Mamedov, B. (2011). A landcover change study of takyr surfaces in Turkmenistan. *J. Arid Environ.* 75, 842–850. doi: 10.1016/j.jaridenv.2011.04.002
- Marcolongo, B., and Mozzi, P. (1998). "Outline of recent geological history of the Kopet- Dag mountains and the southern Kara-Kum," in *The archaeological map of the Murghab Delta: Preliminary reports 1990-1995*, eds A. Gubaev, G. Koshelenko, and M. Tosi (Rome: Istituto Italiano per L'Africa e L'Oriente), 1–14.
- Markofsky, S. (2014). When survey goes east: Field survey methodologies and analytical frameworks in a Central Asian context. *J. Archaeol. Method Theory* 21, 697–723. doi: 10.1007/s10816-013-9172-9
- Markofsky, S., and Bevan, A. (2012). Directional analysis of surface artefact distributions: A case study from the Murghab Delta, Turkmenistan. *J. Archaeol. Sci.* 39, 428–439. doi: 10.1016/j.jas.2011.09.031
- Markofsky, S., Ninfo, A., Balbo, A., Conesa, F. C., and Madella, M. (2017). An investigation of local scale human/landscape dynamics in the endorheic alluvial fan of the Murghab River, Turkmenistan. *Quat. Int.* 437, 1–19. doi: 10.1016/j.quaint.2016.01.006
- Masimov, I. S. (1981). The study of Bronze Age sites in the lower Murghab. *Sov. Anthropol. Archeol.* 19, 194–220. doi: 10.2753/AAE1061-1959190304194
- Masson, V. M. (1961). The first farmers in Turkmenia. *Antiquity* 35, 203–213. doi: 10.1017/S0003598X0003619X
- Masson, V. M., and Sarianidi, V. I. (1972). *Central Asia: Turkmenia before the Achaemenids*. New York, NY: Praeger Publishers.
- Matsuoka, Y., Takumi, S., and Kawahara, T. (2008). Flowering time diversification and dispersal in Central Eurasian wild wheat *Aegilops tauschii* Coss.: Genealogical and ecological framework. *PLoS One* 3:e3138. doi: 10.1371/journal.pone.0003138
- Matuzevičiute, G. M., Mir-Makhamad, B., and Spengler, R. N. (2021). Interpreting diachronic size variation in prehistoric Central Asian cereal grains. *Front. Ecol. Evol.* 9:633634. doi: 10.3389/fevo.2021.633634
- Matuzevičiute, G. M., Preece, R. C., Wang, S., Colominas, L., Ohnuma, K., Kume, S., et al. (2017). Ecology and subsistence at the Mesolithic and Bronze Age site of Aigyrzal-2, Naryn valley, Kyrgyzstan. *Quat. Int.* 437, 35–49. doi: 10.1016/j.quaint.2015.06.065
- Meyer-Melikyan, N. R. (1998). "Analysis of floral remains Togolok 21," in *Margiana and Protozoroastrism*, ed. V. I. Sarianidi (Athens: Kapon Editions), 178–179.
- Meyer-Melikyan, N. R., and Avetov, N. A. (1998). "Analysis of floral remains in the ceramic vessel from the Gonur Termenos," in *Margiana and Protozoroastrism*, ed. V. I. Sarianidi (Athens: Kapon Editions), 176–177.
- Miller, N. F. (1991). "The near east," in *Progress in old world palaeoethnobotany*, eds W. van Zeist, K. Wasylikowa, and K. E. Behre (Rotterdam: A. A. Balkema), 133–160.
- Miller, N. F. (1993). Preliminary archaeobotanical results from the 1989 excavation at the Central Asian site of Gonur Depe, Turkmenistan. *Inf. Bull. Int. Assoc. Study Cult. Cent. Asia* 19, 149–163.
- Miller, N. F. (1996). Seed eaters of the ancient near east: Human or herbivore? *Curr. Anthropol.* 37, 521–528. doi: 10.1086/204514
- Miller, N. F. (1999). Agricultural development in western Central Asia in the Chalcolithic and Bronze Ages. *Veg. Hist. Archaeobot.* 8, 13–19. doi: 10.1007/BF02042837
- Miller, N. F. (2003). "The use of plants at Anau North," in *A Central Asian village at the dawn of civilization, excavations at Anau, Turkmenistan*, ed. F. T. Hiebert (Philadelphia, PA: University of Pennsylvania Museum of Archaeology and Anthropology), 126–138.
- Miller, N. F. (2008). Sweeter than wine? The use of the grape in early western Asia. *Antiquity* 82, 937–946. doi: 10.1017/S0003598X00097696
- Miller, N. F. (2013). Agropastoralism and archaeobiology: Connecting plants, animals, and people in west and Central Asia. *Environ. Archaeol.* 18, 247–256. doi: 10.1179/1749631413Y.0000000003
- Miller, N. F., and Smart, T. L. (1984). Intentional burning of dung as fuel: A mechanism for the incorporation of charred seeds into the archaeological record. *J. Ethnobiol.* 4, 15–28.
- Miller, N. F., Spengler, R. N., and Frachetti, M. (2016). Millet cultivation across Eurasia: Origins, spread, and the influence of seasonal climate. *Holocene* 26, 1566–1575. doi: 10.1177/09596836166641742
- Ministry of Nature Protection (2002). *Country study on the status of biodiversity of Turkmenistan*. Ashgabat: Ministry of Nature Protection.
- Moore, K. M., Miller, N. F., Hiebert, F. T., and Meadow, R. H. (1994). Research on agriculture and herding in the early oasis settlements of the Oxus civilization. *Gloucester* 68:418. doi: 10.1017/S0003598X00046767
- Muehlbauer, F. J., Summerfield, R. J., Kaiser, W. J., Clement, S. L., Boerboom, C. M., Welsh-Maddux, M. M., et al. (2002). *Principles and practice of lentil production*. Pullman, WA: USDA-Agricultural Research Service.

- Neef, R., Cappers, R. T. J., and Bekker, R. M. (2012). *Digital atlas of economic plants in archaeology*, Vol. 17. Groningen: Barkhuis & Groningen University Library. doi: 10.2307/j.ctt20p56d7
- Nesbitt, M. (1994). Archaeobotanical research in the Merv Oasis. The international Merv project: Preliminary report on the second season. *Iran* 32, 71–73. doi: 10.2307/4299905
- Nesbitt, M., and Summers, G. D. (1988). Some recent discoveries of Millet (*Panicum Miliaceum* L. and *Setaria italica* (L.) P. Beauv.) at Excavations in Turkey and Iran. *Anatol. Stud.* 38, 85–97. doi: 10.2307/3642844
- Nikitin, V. G., and Geldykhonov, A. M. (1988). *Manual of vascular plants of Turkmenistan*. Leningrad: Science Publishers.
- Orlovsky, N. S. (1994). "Climate of turkmenistan," in *Biogeography and ecology of turkmenistan, monographiae biologicae* 72, eds V. Fet and K. I. Atamuradov (Dordrecht: Springer), 23–48.
- Pavek, P. L. S., and McGee, R. (2016). *Plant guide for lentil (Lens culinaris Medik.)*. Pullman, WA: USDA-Natural Resources Conservation Service, Pullman Plant Materials Center.
- Pearsall, D. M. (2015). *Paleoethnobotany: A handbook of procedures*, 3rd Edn. Walnut Creek, CA: Left Coast Press.
- Percival, J. (1921). *The wheat plant: A monograph*. London: Duckworth and Company.
- Possehl, G. L. (2002). *The Indus civilization: A contemporary perspective*. Walnut Creek, CA: Rowman Altamira.
- Possehl, G. L. (2007). The middle Asian interaction sphere. *Expedition* 49, 40–42.
- P'yankova, L. T. (1989). Pottery complexes of Bronze Age Margiana (Gonur and Togolok 21). *Inf. Bull. Int. Assoc. Study Cult. Cent. Asia* 16, 27–54.
- Reimer, P. J., Austin, W. E. N., Bard, E., Bayliss, A., Blackwell, P. G., Ramsey, C. B., et al. (2020). The IntCal20 Northern Hemisphere radiocarbon age calibration curve (0–55 cal kBP). *Radiocarbon* 62, 725–757. doi: 10.1017/RDC.2020.41
- Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B., et al. (2013). IntCal13 and Marine13 radiocarbon age calibration curves 0–50,000 years cal BP. *Radiocarbon* 55, 1869–1887. doi: 10.2458/azu\_js\_rc.55.16947
- Ricketts, R. D., Johnson, T. C., Brown, E. T., Rasmussen, K. A., and Romanovsky, V. V. (2001). The Holocene paleolimnology of Lake Issyk-Kul, Kyrgyzstan: Trace element and stable isotope composition of ostracodes. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 176, 207–227. doi: 10.1016/S0031-0182(01)00339-X
- Riehl, S. (2019). "Barley in archaeology and early history," in *Oxford research encyclopedia of environmental science*, ed. H. H. Shugart (Oxford: Oxford University Press). doi: 10.1093/acrefore/9780199389414.013.219
- Rossi Osmida, G. (2002). *Margiana. Gonur-Depe Necropolis: 10 years of excavations by Ligabue Study and research centre*. Trebaseleghe: IL Punto.
- Rossi Osmida, G. (2011). *Adji Kui Oasis: La cittadella della stauette [The citadel of the figurines]*. Padova: IL Punto.
- Rouse, L. M. (2020). Silent partners: Archaeological insights on mobility, interaction, and civilization in Central Asia's past. *Cent. Asian Surv.* 39, 398–419. doi: 10.1080/02634937.2020.1769024
- Rouse, L. M., and Cerasetti, B. (2014). Ojaky: A late Bronze Age mobile pastoralist site in the Murghab Region, Turkmenistan. *J. Field Archaeol.* 39, 32–50. doi: 10.1179/0093469013Z.000000000073
- Rouse, L. M., and Cerasetti, B. (2017). Micro-dynamics and macro-patterns: Exploring new archaeological data for the late Holocene human-water relationship in the Murghab alluvial fan, Turkmenistan. *Quat. Int.* 437, 20–34. doi: 10.1016/j.quaint.2015.12.021
- Rouse, L. M., and Cerasetti, B. (2018). Mixing metaphors: Sedentary-mobile interactions and local-global connections in prehistoric Turkmenistan. *Antiquity* 92, 674–689. doi: 10.15184/aqy.2018.88
- Salvatori, S. (2000). Bactria and Margiana seals: A new assessment of their chronological position and a typological survey. *East West* 50, 97–145.
- Salvatori, S. (2004). "Mappa Archeologica del Murghab: Distribuzione insediamentale dal Bronzo Medio al periodo Sasanide. Elementi per lo studio della formazione delle società complesse [Archaeological map of Murghab: Settlement distribution from the Middle Bronze Age to the Sasanian period. Elements for the study of the formation of complex societies]," in *Scritti di archeologia in onore di Gustavo Traversari [Writings on archaeology in honor of Gustavo Traversari]*. *Archeologica* 141, ed. M. Fano Santi (Rome: Giorgio Bretschneider Editore), 751–772.
- Salvatori, S. (2007). About recent excavations at a Bronze Age site in Margiana (Turkmenistan). *Riv. Archeol.* 31, 11–28.
- Salvatori, S. (2008a). "Cultural variability in the Bronze Age Oxus civilisation and its relations with the surrounding regions of Central Asia and Iran," in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 75–98. doi: 10.30861/9781407302935
- Salvatori, S. (2008b). "The Margiana settlement pattern from the Middle Bronze Age to the Parthian-Sasanian: A contribution to the study of complexity," in *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and Methodological Proposals for a redefinition of the research strategies*, eds S. Salvatori, M. Tosi, and B. Cerasetti (Oxford: Archaeopress), 57–74. doi: 10.30861/9781407302935
- Salvatori, S., and Gundogdiyev, O. (2005). Preliminary report on the first campaign: September 21<sup>st</sup>-October 9<sup>th</sup> 2005, internal Turkmen-Italian joint archaeological expedition to the Murghab Delta report. Unpublished. Rome: The Italian Ministry of Foreign Affairs and International Cooperation (MAECI).
- Salvatori, S., Tosi, M., and Cerasetti, B. (2008). *The Bronze Age and early Iron Age in the Margiana Lowlands: Facts and methodological proposals for the redefinition of the research strategies*. Oxford: Archaeopress. doi: 10.30861/9781407302935
- Sarianidi, V., and Puschnigg, G. (2002). The fortification and palace of Northern Gonur. *Iran* 40, 75–87. doi: 10.2307/4300619
- Sarianidi, V. I. (1974). Baktrija v epokhu bronzy [Bactria in the Bronze Age]. *Sov. Arkheol.* 4, 49–71.
- Sarianidi, V. I. (1986). Le complexe culturel de Togolok 21 en Margiane [The religious complex of Togolok 21 in Margiana]. *Arts Asiatiq.* 41, 5–21. doi: 10.3406/arasi.1986.1195
- Sarianidi, V. I. (1990a). Sel'skiy khram Togolok-1 v Margiane [The village temple of Togolok 1 in Margiana]. *Bull. Ancient Hist.* 193, 161–167.
- Sarianidi, V. I. (1990b). Togolok 21, an Indo-Iranian temple in the Karakum. *Bull. Asia Inst.* 4, 159–165.
- Sarianidi, V. I. (1990c). *Drevnosti Strani Margush [Antiquities of the country Margush]*. Ashkhabad: Ylym.
- Sarianidi, V. I. (1993). Excavations at Southern Gonur. *Iran J. Br. Inst. Persian Stud.* 31, 25–37. doi: 10.2307/4299885
- Sarianidi, V. I. (1998). *Myths of ancient Bactria and Margiana on its seals and amulets*. Moscow: Pentagaphic.
- Sarianidi, V. I. (2001). *Necropolis of Gonur and Iranian paganism*. Moscow: World Media.
- Sarianidi, V. I. (2005). *Gonurdepe: City of kings and Gods*. Ashgabat: Miras.
- Sarianidi, V. I. (2007). *Necropolis of Gonur*. Athens: Kapon Editions.
- Sarianidi, V. I., and Dubova, N. A. (2012). Goňurdepe suw üpjüçiligi we onuň dolandyrylyşy [Water supply and its management in Gonur Depe]. *Türkmenistanda Ylym Tehnika* 2, 115–121.
- Sarpaki, A. (2021). The archaeology of garlic (*Allium sativum*): The find at Akrotiri, Thera, Greece. *Doc. Praehist.* 48, 432–445. doi: 10.4312/dp.48.20
- Sataev, R. (2008). "Raskopki drevnego irrigatsionnogo kanala [Excavations of the ancient irrigation canal]" in *Trudy Margianskoj Arheologicheskoy Ekspeditsii 2 [Transactions of Margiana archaeological expedition, Vol. 2, ed. V. I. Sarianidi (Moscow: Staryj Sad)*, 65–66.
- Sataev, R. (2021). "Animal exploitation at Gonur Depe," in *The world of the Oxus civilization*, eds B. Lyonnet and N. A. Dubova (London: Routledge), 438–456. doi: 10.4324/9781315193359-18
- Sataev, R., and Sataeva, L. (2014). "Results of archaeozoological and archaeobotanical research at the Bronze Age Gonur Depe site (Turkmenistan)," in *Proceedings of the 8th international congress on the archaeology of the ancient near east (ICAANE)*, Vol. 8, eds P. Bielinski, M. Gawlikowski, R. Kolinski, D. Lawecka, A. Soltysiak, and Z. Wagnanska (Wiesbaden: Harrassowitz Verlag), 367–370.
- Severskiy, I. V. (2004). Water-related problems of Central Asia: Some results of the (GIWA) international water assessment program. *AMBIO* 33, 52–62. doi: 10.1579/0044-7447-33.1.52
- Singh, B. B., Chambliss, O. L., and Sharma, B. (1997). "Recent advances in cowpea breeding," in *Advances in cowpea research*, eds B. B. Singh, D. R. Mohan Raj, K. E. Dashiell, and L. E. N. Jackai (Ibadan: International Institute of Tropical Agriculture [IITA]), 30–49.
- Singh, R. (1946). *Triticum sphaerococcum* Perc. (Indian dwarf wheat). *Indian J. Genet. Plant Breed.* 6, 34–37.

- Smith, M. (2017). "How can archaeologists identify early cities? Definitions, types, and attributes," in *Eurasia at the dawn of history: Urbanization and social change*, eds M. Fernández-Götz and D. Krause (Cambridge: Cambridge University Press), 153–168. doi: 10.1017/9781316550328.010
- Spengler, R. N. III (2013). *Botanical resource use in the Bronze and Iron Age of the Central Eurasian mountain/steppe interface: Decision making in multi-resource pastoral economies*. Ph.D. thesis. St. Louis, MO: Washington University.
- Spengler, R. N. III, De Nigris, I., Cerasetti, B., Carra, M., and Rouse, L. M. (2018). The breadth of dietary economy in Bronze Age Central Asia: Case study from Adji Kui 1 in the Murghab Region of Turkmenistan. *J. Archaeol. Sci. Rep.* 22, 372–381. doi: 10.1016/j.jasrep.2016.03.029
- Spengler, R. N. (2015). Agriculture in the Central Asian Bronze Age. *J. World Prehist.* 28, 215–253. doi: 10.1007/s10963-015-9087-3
- Spengler, R. N. (2018). Dung burning in the archaeobotanical record of West Asia: Where are we now? *Veg. Hist. Archaeobot.* 28, 215–227. doi: 10.1007/s00334-018-0669-8
- Spengler, R. N., Cerasetti, B., Tengberg, M., Cattani, M., and Rouse, L. M. (2014). Agriculturalists and pastoralists: Bronze Age economy of the Murghab Alluvial Fan, southern Central Asia. *Veg. Hist. Archaeobot.* 23, 805–820. doi: 10.1007/s00334-014-0448-0
- Spengler, R. N., and Willcox, G. (2013). Archaeobotanical results from Sarazm, Tajikistan, an early Bronze Age settlement on the edge: Agriculture and exchange. *Environ. Archaeol.* 18, 211–221. doi: 10.1179/1749631413Y.0000000008
- Staubwasser, M., Sirocko, F., Grootes, P. M., and Segl, M. (2003). Climate change at the 4.2 ka BP termination of the Indus valley civilization and Holocene South Asian monsoon variability. *Geophys. Res. Lett.* 30:1425. doi: 10.1029/2002GL016822
- Staubwasser, M., and Weiss, H. (2006). Holocene climate and cultural evolution in late prehistoric–early historic West Asia. *Quat. Res.* 66, 372–387. doi: 10.1016/j.yqres.2006.09.001
- Stearn, W. T. (1978). European species of *Allium* and allied genera of Alliaceae: A synonymic enumeration. *Ann. Mus. Goulandris* 4, 83–198.
- Stevens, C. J., Murphy, C., Roberts, R., Lucas, L., Silva, F., and Fuller, D. Q. (2016). Between China and South Asia: A Middle Asian corridor of crop dispersal and agricultural innovation in the Bronze Age. *Holocene* 26, 1541–1555. doi: 10.1177/0959683616650268
- Suslov, S. P. (1961). *Physical geography of Asiatic Russia*. London: W.H. Freeman and Company.
- Takabayashi, M., Kubota, T., and Abe, H. (1979). Dissemination of weed seeds through cow feces. *Jpn. Agr. Res. Q.* 13, 204–207. doi: 10.4035/jsfwr.1979.78
- Tengberg, M. (1999). Crop husbandry at Miri Qalat Makran, SW Pakistan (4000–2000 B.C.). *Veg. Hist. Archaeobot.* 8, 3–12. doi: 10.1007/BF02042836
- Tenopala, J., González, F. J., and de la Barrera, E. (2012). Physiological responses of the green manure, *Vicia sativa*, to drought. *Bot. Sci.* 90, 305–311. doi: 10.17129/botsci.392
- Tosi, M., and Lamberg-Karlovsky, C. C. (2003). "Pathways across Eurasia," in *Art of the first cities: The third millennium BC from the Mediterranean to the Indus*, eds P. Matthiae and C. Lamberg-Karlovsky (New York, NY: Metropolitan Museum of Art), 347–376.
- Tulbek, M. C., Lam, R. S. H., Wang, Y. C., Asavajaru, P., and Lam, A. (2017). "Chapter 9—Pea: A sustainable vegetable protein crop," in *Sustainable protein sources*, eds S. R. Nadathur, J. P. D. Wanasundara, and L. Scanlin (San Diego, CA: Academic Press), 145–164. doi: 10.1016/B978-0-12-802778-3.00009-3
- Ucchesu, M., Orrù, M., Grillo, O., Venora, G., Paglietti, G., Ardu, A., et al. (2016). Predictive method for correct identification of archaeological charred grape seeds: Support for advances in knowledge of grape domestication process. *PLoS One* 11:e0149814. doi: 10.1371/journal.pone.0149814
- Valamoti, S. M. (2013). Towards a distinction between digested and undigested glume bases in the archaeobotanical record from Neolithic northern Greece: A preliminary experimental investigation. *Environ. Archaeol.* 18, 31–42. doi: 10.1179/1461410313Z.00000000021
- Valamoti, S. M., and Charles, M. (2005). Distinguishing food from fodder through the study of charred plant remains: An experimental approach to dung-derived chaff. *Veg. Hist. Archaeobot.* 14, 528–533. doi: 10.1007/s00334-005-0090-y
- van der Veen, M. (2007). Formation processes of desiccated and carbonized plant remains—the identification of routine practice. *J. Archaeol. Sci.* 34, 968–990. doi: 10.1016/j.jas.2006.09.007
- Walter, H., and Box, E. O. (1983). "Middle Asian deserts," in *Ecosystems of the world, Vol. 5: Temperate deserts and semi-deserts*, ed. N. E. West (Amsterdam: Elsevier), 79–104.
- Watson, P. J. (1976). In pursuit of prehistoric subsistence: A comparative account of some contemporary flotation techniques. *MidCont. J. Archaeol.* 1, 77–100.
- Wilkinson, T. J. (2014). "A perspective on the 'continuous landscape' of the Murghab Region," in *My life is like the summer rose. Maurizio Tosi E L'Archeologia Come Modo Di Vivere: Papers in honour of Maurizio Tosi for his 70th birthday*, eds B. Cerasetti, K. Lamberg-Karlovsky, and B. Genito (Oxford: Archaeo press), 751–757.
- Willcox, G. (1991). "Carbonized plant remains from Shortughai, Afghanistan," in *New light on early farming: Recent developments in palaeoethnobotany*, ed. J. M. Renfrew (Edinburgh: Edinburgh University Press), 139–153.
- Winckelmann, S. (2000). Intercultural relations between Iran, the Murghabo-Bactrian archaeological complex (BMAC), Northwest India and Failaka in the field of seals. *East West* 50, 43–95.
- Zohary, D., Hopf, M., and Weiss, E. (2012). *Domestication of plants in the old world: The origin and spread of domesticated plants in Southwest Asia, Europe, and the Mediterranean basin*. Oxford: Oxford University Press. doi: 10.1093/acprof:osobl/9780199549061.001.0001