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## Prehistoric and historic exploitation of marine mammals in the Black Sea

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### ABSTRACT

The recent exploitation of marine species is relatively well documented and understood in terms of impacts on species abundance, distribution, and resource use. In contrast, ancient exploitation of marine mammals remains poorly documented; in part, because a detailed meta-analysis of their presence in the zooarchaeological record is lacking. This is true in the Black Sea, where cetaceans are reported in the zooarchaeological record but have not yet been studied comprehensively. Here, we synthesize all available published and unpublished zooarchaeological data from 27 sites around the Black Sea, dating from the Mesolithic and Neolithic periods (6500–6000 BCE) to the Medieval period (641–1475 CE), to document the extent and nature of the exploitation of the Black Sea cetacean species. The results suggest that cetacean exploitation was practised continuously in the Black Sea over a period of 8500 years from the Neolithic through to the Medieval period. This suggests a much longer history of marine mammal exploitation in the Black Sea than previously understood, pushing back the timeline of human impacts on the Black Sea marine fauna.

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### Author contributions

M.A., E.G., C.C., M.T.O. and P.G. conceived and designed the study; P.G., E.G., and C.C. provided data; M.A., M.T.O., and P.G. analysed the data; S.T., E.G., C.C. and Y. v.d.H. provided specialist knowledge and helped with analysis; M.A., M.T.O., and P.G. drafted an early version of the manuscript; all authors provided editorial inputs and approved the final version of the manuscript.

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### 1. Introduction

Humans have a long, interconnected history with marine and coastal ecosystems and species. Today, many of these ecosystems and species are threatened by the legacy of (over)exploitation and ecosystem degradation (Luypaert et al., 2020; Worm and Lotze, 2021). While overexploitation has traditionally been attributed to human activities within the past few centuries, a growing body of research emphasizes the importance of understanding the role of (pre)historic impacts on marine species and ecosystems to evaluate their current conservation status and how they have been shaped by cumulative impacts over long time-scales (Andrews et al., 2021; Atmore et al., 2021; Keighley et al., 2019).

Understanding the exploitation of marine mammals has

important economic, cultural, ethical, and conservation implications. From a modern-day conservation perspective, human impacts on marine mammals are wide-ranging and include bycatch, hunting, habitat degradation, ocean noise, ship collisions, and bioaccumulation of contaminants (Avila et al., 2018; Birkun, 2002; Harris and Weisler, 2018; Jefferson, 2019; Nabi et al., 2018). Marine mammals are not only key species in terms of public perception, but also play key roles in marine ecosystems, and are often viewed as sentinels for the ecosystem (Marx, 2016; Maxwell et al., 2013; Riisager-Simonsen et al., 2020). Thus, it is important to understand how marine mammal species and populations have been impacted by anthropogenic factors. Archaeo-historical analysis can offer longer chronological perspectives not available in ecological analyses. With the potential to avoid short-term bias including shifting baseline syndrome, as recent ecological assessments are representative of anthropogenically transformed/degraded ecosystems rather than a “natural” baseline (Pauly, 1995; Soga and Gaston, 2018; see Atmore et al., 2021 for a discussion of “natural baselines”). These present-day short-term baselines can result in a misinterpretation of changes over time, leaving researchers ill-equipped to understand the dynamics of changing ecosystems, their current state, and to provide recommendations for their management (Orton, 2016). Socio-historically, understanding human exploitation patterns and resource use is important in shaping our perception of past societies. For instance, food procurement and subsistence strategies have long been important areas of archaeological research as they represent the interface of a society's social structure, economy, technology, relationship with the environment, early globalization, and illuminate human-environmental relations (Holly, 2019; Twiss, 2007). Subsistence practices reflect rational social-economic choices both allowed and restricted by the environment, technology, and cultural considerations as well as the interactions between these factors (Raczek, 2003). Thus, examination of exploitation patterns is important to understand not only the diet and resource use of the people involved but also to provide insights into economic choices made by past human groups. As such, zooarchaeological assemblages have the potential to reveal critical information to aid in the reconstruction of palaeoenvironments, subsistence, and human-environmental interactions.

The Black Sea has a unique history of human cultural development and faunal history. The Black Sea itself has evolved over millions of years as a series of large lakes and seas with varying salinities, water levels, and connections with/isolation from the Mediterranean and Caspian Seas (Bănăduc et al., 2016). During periods of low eustatic sea levels in the Late Pleistocene (e.g., between 25,000 and 12,000 years ago), the Black Sea was a freshwater or brackish lake (1–10% salinity) isolated from the global ocean system (Badertscher et al., 2011; Özdoğan, 2011). The sea's modern status—connected to the global ocean system via the Bosphorus, the Sea of Marmara, and the Dardanelles Strait—occurred in the Holocene 9000 to 7500 years ago (Peev et al., 2020; Aksu and Hiscott, 2022). The Holocene connection to the Mediterranean Sea is important in the context of cetacean exploitation as this is when cetacean species (in concert with other marine species) are thought to have migrated to the Black Sea (Fontaine et al., 2014; Moura et al., 2013). In contrast, the first evidence of modern humans in the region dates to more than 40,000 years ago (Hajdinjak et al., 2021).

Three species of cetaceans are currently found in the Black Sea: the harbour porpoise (*Phocoena*), the bottlenose dolphin (*Tursiops truncatus*), and the common dolphin (*Delphinus delphis*). In addition, a pinniped—the Mediterranean monk seal (*Monachus*)—was present in the Black Sea until around the year 1997 when it went regionally extinct (Karamanlidis et al., 2016; Kırac, 2011), with a few individuals still present in the Sea of Marmara (Dede et al., 2016; Inanmaz et al., 2014). All modern-day marine mammal

species are represented by relatively isolated populations, proposed to be endemic subspecies (Fontaine, 2016; Kleinenberg, 1956; Tomilin, 1967; Viaud-Martinez et al., 2008; Viaud-Martínez et al., 2007) and have been labelled as vulnerable or endangered by the International Union for Conservation of Nature (IUCN) following decades of habitat degradation, bycatch, and intentional killings (Birkun et al., 2014).

Studies of prehistoric aquatic resource exploitation in the Black Sea region have typically focused on fish, freshwater habitats, and the importance of shore-zone marine fish in relation to artisanal and commercial harvest, with little emphasis on broader marine ecosystems or marine mammals (Braund, 2015; Ivanova, 2012). Thus, while there are a large number of archaeological sites surrounding the Black Sea and a very long history of human occupation, it is unclear to what extent Black Sea cetaceans have been impacted by human activities from their arrival during the Holocene to the modern period (Ivanova, 2012).

This review aims to synthesize and analyze all available zooarchaeological reports of cetacean remains from sites in the Black Sea to document their spatiotemporal occurrence and hence obtain an understanding of the extent and nature of prehistoric and historic exploitation. We are specifically interested in documenting cetacean exploitation and the broad regional patterns of this exploitation. We acknowledge that there are many cultural groups that have made up the Black Sea region and do not expect these groups to have similar diets or subsistence strategies. Rather, we are interested in the general patterns of cetacean presence in zooarchaeological records over time, and contrasting this with the presence of other fauna; primarily domestic and wild vertebrates (mammals, fish, birds and reptiles). We include zooarchaeological data from 27 sites ranging from the Mesolithic to the Medieval period from which the number of identifiable specimens (NISP) for all species reported was gathered into a meta-database in English. We use the Mediterranean as a comparative region as it has historically been considered in tandem with the Black Sea, its ecological importance in regards to the Black Sea, and due to the presence of Greek and Roman colonies starting in the Archaic period. Further, the NISP data was examined throughout time to identify differences in exploitation based on the time period. When combined with contextual data and the presence of other faunal groups, trends in cetacean exploitation can be ascertained.

## 2. Methods

### 2.1. Data

Zooarchaeological data from the Black Sea region was gathered—regardless of marine mammal presence—based on all available publications and reports. Additionally, previously unreported zooarchaeological data was provided by authors PG, EG, and CC (Table 1). The data represents 27 sites in the Black Sea region dating from the Mesolithic and Neolithic periods (7000–6000 BCE) through to the Medieval period (641–1475 CE), for which quantitative data on the faunal assemblages are available (Fig. 1). Most sites are on the northern coast of the Black Sea and the southern coast of the Sea of Azov in modern-day Ukraine. Sites, for which only the presence of species was detected, were not included in the analysis but mentioned in the overall characteristics of time periods and are reported in Table S2. The paucity of data along the southern coast of the Black Sea (Northern Anatolia) was unexpected due to the number of described archaeological sites (Bilde et al., 2007; Burney, 1956), however, there were no available zooarchaeological reports for the region. There is a similar lack of sites along the south-eastern coast of the Black Sea (modern-day Georgia and Turkey), another major historical ground for cetacean hunting

**Table 1**

Site name, time period, date of occupation, and citation.

Site Name	Modern Location	Subsistence Type	Culture/State	Period	Date	Publication
Beikush	Ukraine; coastal lagoon	Agriculture and fisheries	Greek	Archaic	6th c BCE	Zhuravliov and Iyevlev (2020)
Berezan	Ukraine; small island in the sea near an estuary	Agriculture, fisheries, and trade	Greek	Archaic Hellenistic All Horizons	6th c BCE 300 BCE 7th c BCE – 3rd c CE	Zhuravliov and Iyevlev (2020) Yanish and Kasparov (2015) Ivanova (1994)
Chersonesos	Ukraine; maritime coast; a major urban site	Agriculture, fisheries, and trade	Greek, Byzantine	Hellenistic Roman  Medieval  All Horizons	2nd c BCE 5th c CE  11–13th c CE  Tajkova and Klochko (2013)	Fišaková (2009), dated by Ushakov (2010) Gol'din et al. (2012), Gol'din et al. (2013a), Gol'din et al. (2013b), <b>this study</b> <b>This study</b>
Chortuvate	Ukraine; a steppe site near an estuary	Agriculture, fisheries, and trade	Greek	Archaic	6th c BCE	Zhuravliov and Iyevlev (2020)
Durankulak	Bulgaria; coastal lagoon	Agriculture and fisheries	Varna	Chalcolithic  Chalcolithic Bronze Age  Chalcolithic Chalcolithic	4500–4100 BCE 4200–4100 1300–1800 BCE  Spassov and Iliev (2002) Heinrich (1994)	Manhart (1998)
Fikirtepe	Turkey along the Bosphorus Strait	Agriculture and fisheries	Fikirtepe	Neolithic	6400–5800 BCE	Çakırlar (2013; In Press a, In Press b), Boessneck and Von den Driesch (1979)
Generalske West Gleiki 2	Ukraine; steppe, not far from the marine coast; a rural settlement Ukraine, maritime coastal site	Agriculture and fisheries Agriculture, fisheries, possibly trade	Bosporus Kamianka	Hellenistic Bronze Age	4th – 3rd c BCE 2000–1800 BCE	Danovsky and Maslennikov (2006), Kasparov (2010) Liashenko (2006), <b>this study</b>
Kepoi	Ukraine; maritime coast; urban site	Agriculture, fisheries, trade	Bosporus	Roman	1st – 4th c CE	Zalkin (1960)
Kytaion	Ukraine; maritime coast; urban site	Agriculture, fisheries, trade	Bosporus	Classical  Hellenistic Roman	5th – 3rd c CE  2nd – 1st c BCE 1st – 2nd c CE 3rd – 6th c CE	Molev (2015)
Laspi 7	Ukraine; maritime coastal site	Hunter-gatherer		Mesolithic	ca. 6000 BCE	Gorobets et al. (2013)
Matviivka 1	Ukraine along a riverbank by the mouth of the river		Catacomb	Bronze Age	1700 BCE	Zhuravliov and Sycheva (1989), Dated by Nikitin (1989)
Myrmekion	Ukraine; maritime coast; urban site	Agriculture, fisheries, trade	Bosporus	Hellenistic  Roman	4th – 2nd c BCE  Chalcolithic	Zalkin (1960)  Dobrovol'skaya (2013)
Myskhako	Russia, maritime coastal site	Agriculture and fisheries	Darkveti-Meshoko and Bosporus	Hellenistic	1st C CE	Bibikova (1958)
Olbia	Ukraine; an estuarine coast near the sea; a major urban site	Agriculture, fisheries, trade	Greek	Hellenistic  Roman  All Horizons	300 - 48 BCE 50 - 250 C E 4th -6th c CE  Zhiteneva (1967) Voinstvensky (1958)	Bibikova (1958) Ivanova (1994)
Panticapaeum	Ukraine; maritime coast; a major urban site	Agriculture, fisheries, trade	Bosporus	Hellenistic Roman	200 BCE 1st – 4th c CE	Lebedev and Lapin (1954) Zalkin (1960)
Pendik	Turkey along the Bosphorus	Agriculture and fisheries	Fikirtepe	Neolithic		Çakırlar (2013), <b>this study</b>
Phanagoria	Russia; maritime coast; a major urban site	Agriculture, fisheries, trade	Bosporus	Archaic  Classical Hellenistic  Roman  Medieval	6th – 5th c BCE 4th c BCE 3rd – 1st c BCE 1st – 4th c CE 3rd – 4th c CE 4th – 6th c CE 8th - 9th c CE	Dobrovol'skaya (2009) Dobrovol'skaya and Zavoikin (2016) Dobrovol'skaya (2013) Zalkin (1960), Dobrovol'skaya (2009) Dobrovol'skaya and Zavoikin (2016), Yurtseva (2016) Dobrovol'skaya (2009) Dobrovol'skaya and Zavoikin (2016), Yurtseva (2016) (2016)
Semenovka	Ukraine, maritime coastal rural site	Agriculture, fisheries	Bosporus	Roman	3rd c CE	Zalkin (1960)

(continued on next page)

Table 1 (continued)

Site Name	Modern Location	Subsistence Type	Culture/State	Period	Date	Publication
Sirenevaya Bukhta	Ukraine, maritime coastal rural site	Agriculture, fisheries	Bosporus	Roman	2nd – 7th c CE	Kasparov and Kovalchuk (2016)
Sozopol	Bulgaria, maritime coastal site	Agriculture, fisheries	Varna	Chalcolithic	4900–3900 BCE 4000–2800 BCE 2800–2400 BCE	Spassov and Iliev (1994)
Techirghiol	Romania; lacustrine coastal site	Agriculture, fisheries	Hamangia	Neolithic	5500–5000 BCE	Haimovici and Bălăşescu (2006)
Theodosia	Ukraine; maritime coast; urban site	Agriculture, fisheries, and trade	Bosporus	Roman	1st–4th c CE	Zalkin (1960)
Tyirtake	Ukraine; maritime coast; urban site	Agriculture, fisheries, and trade	Bosporus	Roman	1st – 4th c CE	Zalkin (1960)
Uch-Bash	Ukraine, a rural site at a riverbank near the river mouth	Agriculture, fisheries	Kyzyl-Koba	Bronze Age	850 - 750 BCE 750 - 650 BCE	Croiton (2012)
Yenikapi	Turkey; western shore of the Bosphorus Strait	Agriculture, fisheries	Fikirtepe	Neolithic	5800 BCE	Çakırlar (2013); this study
Zolote	Ukraine, maritime coastal rural site	Agriculture, fisheries	Bosporus	Roman	3rd c CE	Zalkin (1960)

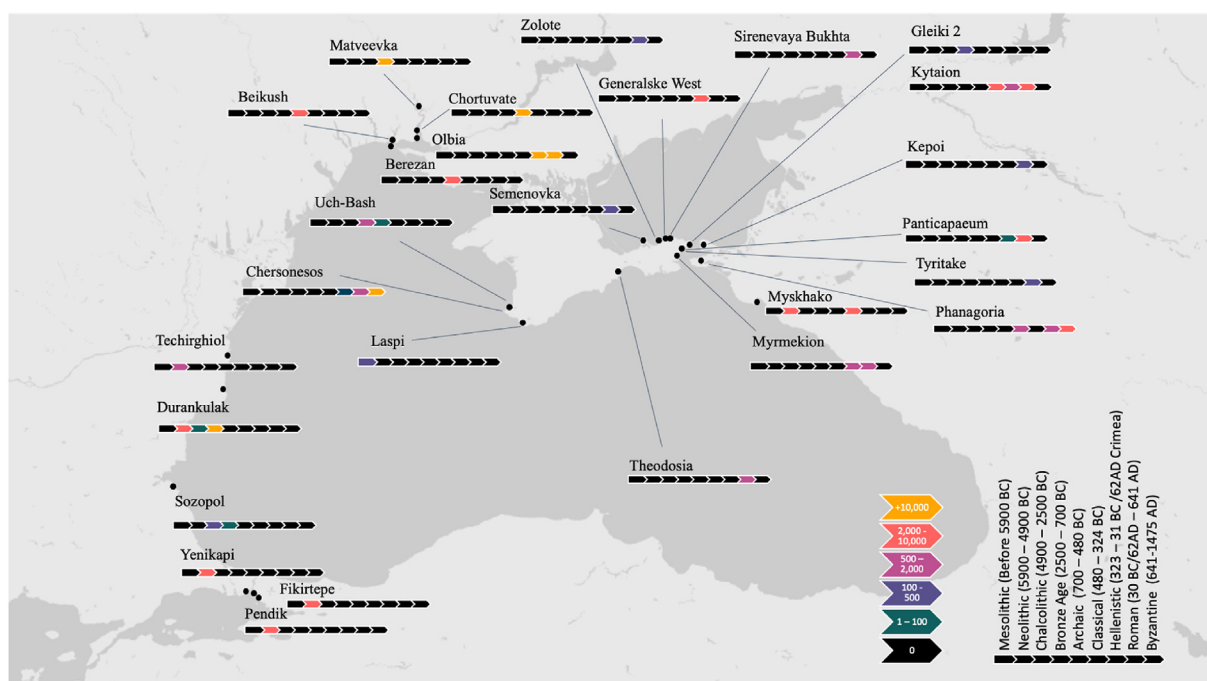


Fig. 1. Map of archaeological sites in the Black Sea region with indication of the combined mammal, fish, mollusc, reptile, and bird NISP recovered from each site (black to yellow scale) and time period (Mesolithic to Byzantine).

(Kleinenberg, 1956). This is likely due to acidic soil causing poor preservation of osseous material (Gol'din, 2022).

The NISP—defined as the aggregate total number of identified elements in a faunal assemblage—from all the faunal material was collected from the archaeological site reports. NISP can be biased by a number of factors, including animal size, anthropogenic modification, post-depositional fragmentation, analyst expertise, and access to a reference collection. As such, NISP is likely an ordinal measure of taxonomic abundance (Lyman, 2019). These counts can, at best, be used to rank abundance within assemblages, but do not provide a true ratio of abundance or reveal how relative abundance of species to each other, especially between sites limiting the ability to use NISP for statistical comparisons (Lyman, 2019; Lyman and Barker, 2008). Cetaceans are particularly prone to diagenesis as

their bones are quite porous and break down easily (Speller et al., 2016). Despite its limitations, NISP is a common way to describe and discuss fragmented faunal assemblages, and it is used here as it is the most reported measure of faunal assemblages in the published literature. The sites that did not report NISP either used another measurement of faunal assemblages, providing the percentage of the assemblage a species represented and classified much of the data in broad categories (i.e., “hunted animal”) or provided a list of species present without a numerical value indicating presence. Since these alternative ways of presenting the faunal data are not comparable to NISP data they could not be included in the analysis, but they can be found in Table S2, and the sites can be found in Table 1.



## 2.2. Analysis

After compiling the NISP data from all the sites, the species were categorized into broad groups according to their preferred habitat and ecology: cetaceans, terrestrial domesticated mammals, wild terrestrial mammals, fish, reptiles, molluscs, birds, crustaceans, and unidentified mammals (Table S2). NISP data was collected for the non-marine mammal species to contextualize the assemblages the cetaceans come from. The fish and bird categories were further subdivided by ecosystem: freshwater, marine, migrating, and unidentified for fish and domestic, terrestrial, freshwater, marine, other, and unidentified for birds (Table S2). The subdivisions were based on the IUCN classification of the species except in cases where there have been known historical changes (e.g., the sterlet, *Acipenser ruthenus*, has historically migrated between freshwater and marine ecosystems but is currently only found in freshwater).

The categories of species were subsequently examined by time period to examine trends in cetacean exploitation. When the dating for the site (or a specific stratigraphic layer at a site) placed it between two temporal categories, a single period was chosen based on the greatest overlap and the time period suggested by the excavators. Both the time period category assigned, and the site data are reported in Table 1.

## 3. Results

### 3.1. Summary of NISP data

Our synthesis of zooarchaeological data from the Black Sea region summed to a total of over 345,000 identified bone and shell fragments from 175 vertebrate species with a large spatiotemporal variation in NISP for the 27 sites (Fig. 1). Most sites were characterized by finds confined to a single or few time periods, whereas a few sites contained assemblages from multiple time periods (e.g., Chersonesos and Kytaion). The sites also varied greatly in the size of their assemblages, ranging from less than 50 fragments identified to very large assemblages with hundreds of thousands of fragments identified. While the number of remains recovered from a site does not correlate with the value of the samples or the site itself, it is important to note the discrepancies in NISP between the sites.

### 3.2. NISP by time period

The Mesolithic (ca. 6000 BCE) site of Laspi 7 does not have any marine mammal bones. There is a high percentage of NISP from bird species (68.2%), most of which were terrestrial (Fig. 2). The rest of the assemblage is composed of freshwater fish species and wild terrestrial mammals. While a large number of molluscs have been recovered from the site, they have not been counted (Telegin et al., 1975) This contrasts with the three Neolithic sites, Fikirtepe (7000–6000 BCE), Techirghiol (roughly contemporaneous to Laspi 7 but situated in the southern Black Sea where the Neolithic transition occurred earlier than in the northern Black Sea region), and Pendik. The majority of the assemblages of Fikirtepe and Techirghiol are terrestrial domestic mammals (71.6% and 62.5%, respectively), followed by unknown mammal (18.3% and 19%, respectively) with a smaller percentage of wild terrestrial mammals (3.9%, and 6.9%, respectively). Cetacean bones have been recovered from both Fikirtepe and Techirghiol, albeit in small numbers (nine bottlenose dolphin and eight harbour porpoise, respectively). The zooarchaeological assemblage at Pendik differs from the other Neolithic sites: while terrestrial domestic mammals still make up the largest proportion of the assemblage (53.1%), this is followed by molluscs (40%), and then wild terrestrial mammals (6.3%).

The Chalcolithic (4900–2500 BCE) sites are highly diverse in their faunal assemblages. The western coastal Durankulak assemblage is composed primarily of domesticated mammals (80.9%) with a smaller proportion of terrestrial wild mammals (16.9%). Marine mammals are only represented by a few fragments at Durankulak; however, this includes both cetaceans and monk seals ( $n = 8$ ; Manhart, 1998). This contrasts with Sozopol, which has a high percentage of wild terrestrial mammals (54.3%) and a smaller percentage of domesticated mammals (23.5%). Cetaceans make up 12.6% of the total assemblage at Sozopol with one stratum containing 217 identified cetacean fragments comprising 35.6% of the faunal remains from the layer with all three cetacean species represented. On the eastern coast, the faunal assemblage from the Chalcolithic site of Myskhako is divided between unidentified mammals (46.5%), followed by terrestrial domesticated mammals (29.8%), and molluscs (12.8%). Cetaceans make up 6.2% of the assemblage at Myskhako but unfortunately were only identified as “dolphins.” Within the Chalcolithic period, approximately half of the marine mammal bones are identified as “unidentifiable marine mammal.”

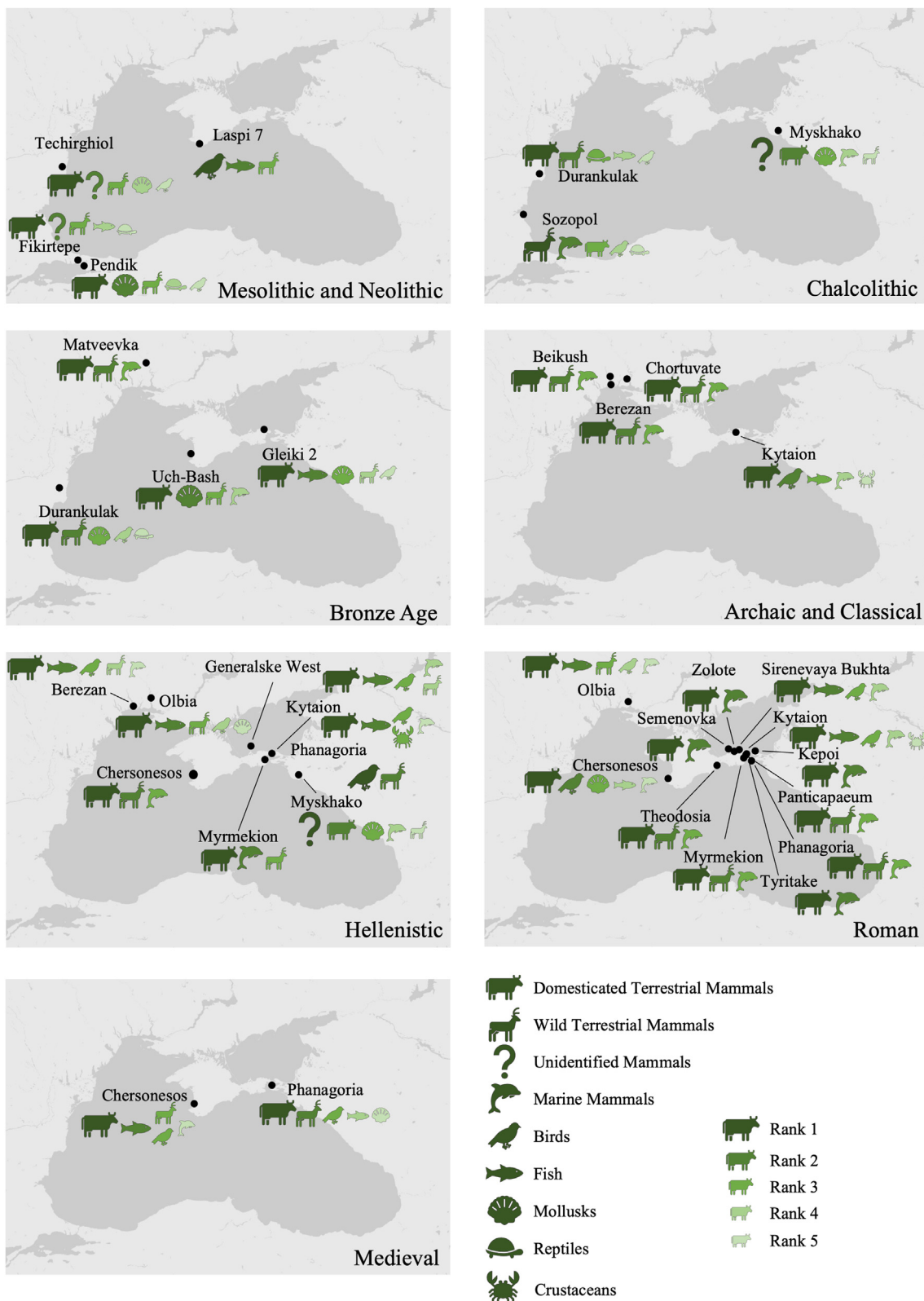
The Bronze Age (2900–700 BCE) sites of Matviivka, Gleiki 2, Uch-Bash, and Durankulak begin to show more homogenous faunal assemblages with all being represented by predominantly domestic mammals (99.7%, 47.4%, 71.9%, and 90.5%, respectively) followed by terrestrial wild mammals at Matviivka and Durankulak (0.3% and 7.4%, respectively), fish at Gleiki 2 (31.1%), and molluscs at Uch-Bash (10.9%). Cetaceans make up a very small percentage (less than 5%) of the faunal assemblages, though they are present at all four sites. Interestingly, in addition to the common dolphin, a fragmentary bone of a baleen whale (not native to the Black Sea) is reported from Bronze Age Durankulak.

The three Archaic (700–480 BCE) sites of Beikush, Chortuvate, and Berezan in the north-western Black Sea have very similar faunal assemblages; all three are almost exclusively composed of domestic terrestrial mammals (99.6%, 99.8%, and 99.5%, respectively) with a small percentage of wild terrestrial mammals (0.4%, 0.2%, and 0.5% respectively) and cetaceans (0.01%, 0.01%, and 0.02%, respectively) making up the remainder of the assemblage.

The Classical (480–324 BCE) site of Kytaion at the Kerch Strait (north-eastern Black Sea) differs geographically and temporally from the Archaic sites, and this is reflected in the faunal assemblage. While most of the assemblage is also domesticated mammals (92.7%), birds (3.7%) and fish (3.4%) make up most of the rest of the assemblage. Similar to the low frequencies at the Archaic sites, only three cetacean bones (0.14% of the assemblage) were identified from Kytaion, all identified as common dolphins.

The faunal assemblages from the Hellenistic period (323 BCE – 31 CE in the Balkans and 62 CE in Crimea) are more heterogeneous than those of the Archaic and Classical periods. Most of the sites, however, still have faunal assemblages dominated by terrestrial mammals. The exception is Phanagoria where only birds (52.0%) and wild terrestrial mammal species (47.2%) were identified. The faunal assemblage from Myskhako is also unusual; however, it is unclear what category is predominant as the largest portion of faunal remains (60.0%) is identified as “unidentified mammal.” Cetacean bones were identified at eight Hellenistic sites in north-western Crimea, seven of them together with bones of marine fish (Scheglov, 1978). Within the Hellenistic period, 68% of the cetacean bones are of “unidentified species.”

The faunal assemblages from the twelve Roman (31 CE in the Balkans/62 CE in Crimea – 641 CE) sites are relatively uniform in composition. With the exceptions of Sirenevaya Bukhta, which has a high proportion of fish (35.0%), and Chersonesos which has a high proportion of birds (10.4%), the sites’ assemblages are overwhelmingly domestic mammal based (around 90.0%). The rest of



**Fig. 2.** Composition of faunal assemblage by time period. The fauna is divided into eight categories: domesticated terrestrial mammals, wild terrestrial mammals, unidentified mammals, marine mammals, birds, fish, mollusks, reptiles, and crustaceans. The size and the colour of the icon correlate to the rank order of the species. Site reports where the analysis focused on a single species in a specialized faunal analysis (typically birds or fish) were excluded from the analysis. The rankings used in this figure can be found in [Table 2](#) and the supplementary material.

the assemblages are composed of fish, cetaceans, molluscs, crustaceans and terrestrial wild mammals. Two monk seal bones were recovered and identified from Roman period Olbia: providing the most recent evidence of the species in this study and the northernmost record of this species in the Black Sea. Two sites on the coast of the Sea of Azov, Zolote and Sirenevaya Bukhta, have larger proportions of cetaceans (5.9%, and 7.7%), all of which are identified as harbour porpoises.

The faunal assemblages of the two Medieval (641–1475 CE) sites, Chersonesos and Phanagoria, are predominantly domestic mammals (92% and 81.2%), although Phanagoria has a higher proportion of wild terrestrial mammals (15.7% versus 2.4% at Chersonesos). The only cetacean identified from this period, a single harbour porpoise bone, was recovered from Chersonesos.

Overall, the composition of the aquatic faunal assemblage appears to change over time, with diverse cetaceans and other species predominant in the Chalcolithic compared to freshwater species in the Mesolithic and mixed assemblages from the Neolithic (Fig. 2). A peak in cetaceans and other marine species is observed during the Roman period likely linked to an increase in site number and site, whereas the preceding and succeeding periods are dominated by terrestrial species. Interestingly, an increase in cetacean bones during the Chalcolithic appears to be driven by bottlenose dolphins and common dolphins, whereas the peak during the Roman period mainly owing to an increase in harbour porpoise and common dolphin finds (Fig. 3). By using an estimated frequency approach in Fig. 3., following Orton (2016), we were able to avoid the arbitrary temporal categories of pre-defined time periods and incorporate the specific dating information generated by archaeologists on a site-by-site basis.

There is a decrease in the variation of the faunal assemblages' categories starting in the Bronze Age and the Archaic and Classical periods. Prior to the Bronze Age, domestic terrestrial mammals, while still a large portion of the NISP at many sites, did not represent the majority of the entire assemblage. This changes in the Bronze Age with domestic terrestrial mammals becoming the dominant species at the sites such that, by the Archaic and Classical

periods, domestic terrestrial mammals are representative of greater than 90% of the NISP from the sites. This correlates with a decrease in frequencies from other categories, specifically wild terrestrial mammals. A decrease in non-domesticated terrestrial fauna is evident by the Hellenistic period.

### 3.3. Marine mammals at diachronic sites

There are only eight sites that have strata belonging to different time periods: Chersonesos, Myskhako, Kytaion, Phanagoria, Myrmekion, Durankulak, Uch-Bash, and Panticapaeum (Fig. 1). When comparing the marine mammal species and NISP over time, some noteworthy chronological patterns emerge. Primarily, the same species tend to be identified at the same site, the exception being Chersonesos where bottlenose dolphins were identified from the Roman layer, but not the previous Hellenistic nor the subsequent Byzantine. It is worth noting, however, that the Roman layer has the largest assemblage by NISP at the site by over 8-fold. Only one site, Myskhako, has two time periods divided by a large temporal gap (Chalcolithic and Hellenistic periods). Between these two periods, there is a decline in cetacean bones identified from the assemblages from 6.2% to 1.0%. For the sites with similarly dated strata (i.e., Hellenistic, Roman, Byzantine), the proportion of cetacean remains recovered is very similar and, in most cases, the difference in cetacean composition is less than 1%.

## 4. Discussion

### 4.1. Cetaceans are present throughout the Black Sea zooarchaeological record

Overall, cetacean bones are recovered from the majority of sites in the Black Sea, with 92% of the sites with zooarchaeological data having at least one cetacean bone identified (Tables 1 and 2). There are no cetacean bones recovered from the Mesolithic site of Laspi 7, but cetacean bones are recovered from the majority of the sites from subsequent periods (exceptions being: Neolithic Pendik as

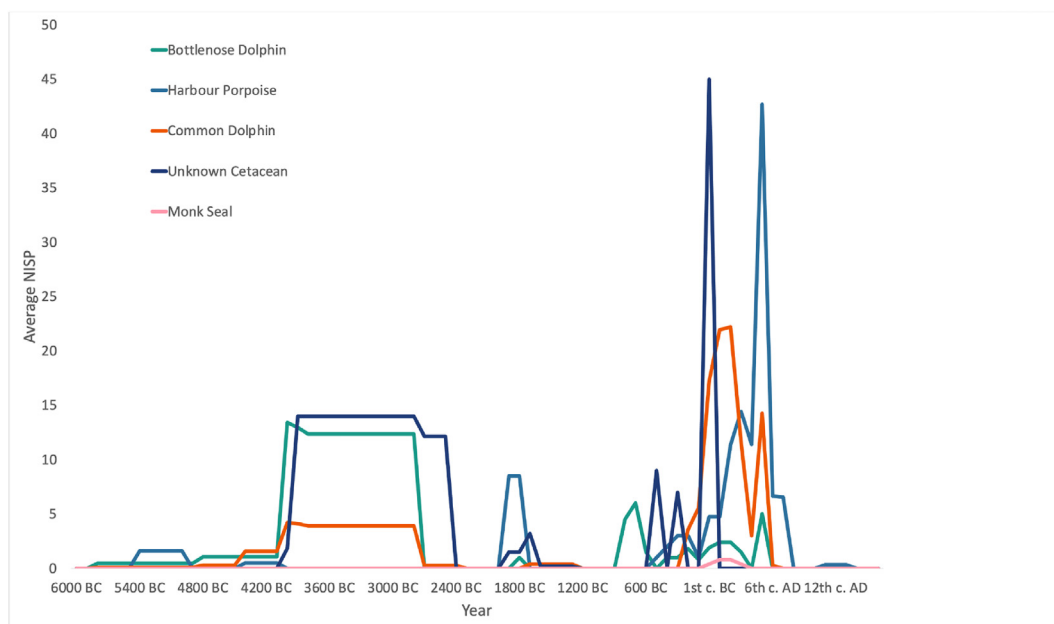


Fig. 3. Estimated frequency distribution of Black Sea marine mammal species through time. Prehistoric and historic frequency is estimated by NISP for marine mammal species recovered from Black Sea zooarchaeological sites from the Mesolithic to Medieval time periods. The NISP data was divided by the length of the date range for the site/layer and then grouped in 100-year increments to produce a distribution.



**Table 2**

Rank order of cetacean bones by site and time period including the percent of the assemblage, the number of cetacean bones recovered, the rank of cetacean bones, and the total number of ranked categories for the sites.

Site Name	Period	% of Assemblage	Rank of Cetacean Bones (Number of Ranks)
Beikush	Archaic	0.01% (n = 1)	3 (3)
Berezan	Archaic	0.02% (n = 8)	3 (3)
Chersonesos	Hellenistic	0.03% (n = 7)	5 (5)
	Hellenistic	1.8% (n = 1)	3 (3)
	Roman	2.0% (n = 23)	4 (6)
Chortuvate	Medieval	0.83% (n = 1)	5 (5)
	Archaic	0.01% (n = 1)	3 (3)
Durankulak	Chalcolithic	0.12% (n = 9)	7 (8)
	Bronze Age	0.03% (n = 3)	8 (10)
Fikirtepe	Neolithic	0.10% (n = 9)	7 (7)
Generalske West	Hellenistic	0.11% (n = 2)	4 (5)
Gleiki 2	Bronze Age	1.8% (n = 22)	6 (6)
Kepoi	Roman	0.29% (n = 1)	2 (2)
	Classical	0.14% (n = 3)	4 (5)
Kytaion	Hellenistic	0.24% (n = 4)	5 (5)
	Roman	0.09% (n = 3)	4 (5)
Laspi 7	Mesolithic	0	N/A
Matviivka 1	Bronze Age	0.02% (n = 3)	3 (3)
Myrmekion	Hellenistic	0.74% (n = 6)	2 (3)
	Roman	0.11% (n = 1)	3 (3)
Myskhako	Chalcolithic	6.2% (n = 182)	4 (7)
	Hellenistic	1.0% (n = 45)	7 (7)
Olbia	Hellenistic	0.03% (n = 11)	7 (7)
	Roman	0.05% (n = 51)	5 (7)
Panticapaeum	Roman	0.06% (n = 5)	3 (3)
Pendik	Neolithic	0	N/A
Phanagoria	Hellenistic	0	N/A
	Roman	0.95% (n = 4)	3 (3)
	Medieval	0	N/A
Semenovka	Roman	1.3% (n = 3)	2 (2)
Sirenevaya Bukhta	Roman	7.7% (n = 39)	4 (5)
Sozopol	Chalcolithic	24% (n = 220)	2 (6)
Techirghiol	Neolithic	0.56% (n = 8)	7 (8)
Theodosia	Roman	1.5% (n = 11)	3 (3)
Tyirtake	Roman	0.93% (n = 1)	2 (2)
Uch-Bash	Bronze Age	1.6% (n = 12)	4 (4)
Yenikapi	Neolithic	0.27% (n = 12)	5 (5)
Zolote	Roman	5.9% (n = 8)	2 (2)

well as Hellenistic and Mesolithic Phanagoria; [Table 3](#); Supplementary Material). Due to the omnipresence of cetacean bones throughout the zooarchaeological record, the quantity of bones becomes of interest.

Our study shows increases in cetacean bone recovery in two of the time periods: Chalcolithic and Roman ([Fig. 3](#)). The increase seen in the Chalcolithic is unprecedented in the region with no bones recovered in the Mesolithic and very few in the Neolithic. While a single site from the Mesolithic cannot represent the whole period, the zooarchaeological data fits with previous general descriptions of faunal assemblages from the period ([Telegin, 1982](#)), as well as paleontological data from seafloor sediment deposits ([V. Yanko-Hombach et al., 2014](#)). We propose that the observed increase in

cetacean bones in the Chalcolithic represents an increased familiarity with the new marine species colonizing the Black Sea region during the transitional period when the connection between the Mediterranean and the Black Sea was established ([Yanko-Hombach et al., 2014](#); [Williams et al., 2018](#)). The connection of the two bodies of water, although likely gradual, would have had a tremendous impact on the Black Sea ecosystem, transforming it from a low-saline brackish lake inhabited by freshwater and relict species to a saline sea with an influx of Mediterranean marine species ([Ivanova et al., 2007](#); [Valentina Yanko-Hombach et al., 2014](#)). Modern genetic studies of Black Sea harbour porpoises indicate a large population increase (estimated to be 15-fold) ending in the Chalcolithic followed by a large population reduction in the 18th

**Table 3**

Percentage of archaeological sites by time period with cetacean bones recovered.

Period	Number of Sites	Number of Sites with Cetacean Remains	% of Sites with Cetacean Remains
Mesolithic	1	0	0%
Neolithic	3	2	67%
Chalcolithic	3	3	100%
Bronze Age	4	4	100%
Archaic	3	3	100%
Classical	1	1	100%
Hellenistic	8	7	88%
Roman	12	12	100%
Byzantine	2	1	50%
<b>Total</b>	<b>36</b>	<b>33</b>	<b>92%</b>

century (Fontaine et al., 2012) suggesting that cetaceans were becoming more abundant throughout the Chalcolithic period.

The increase of cetacean finds in the Roman period is evident from both an increase in the total number of cetacean bones recovered from the sites compared to other time periods, as well as an increase in the rank order with cetaceans becoming the second or third most numerous category found at the sites. The presence of cetacean bones at the Roman sites is interesting as the variance of zooarchaeological material is otherwise diminished during the Roman period. Dietary analyses of Roman colonies outside the Black Sea have noted differences in the pre-Roman and the Roman period diets (Luley, 2014) as well as homogeneity in the Roman diet in the Western Mediterranean based on stable isotope analysis and dental buccal-microwear analysis (Salazar-García et al., 2016). This makes the presence of cetaceans in the Black Sea interesting as the Roman period elsewhere seems to correlate with a more homogeneous diet.

As discussed above, the main incentive for cetacean hunting in the Black Sea may have been meeting the demands for blubber and oil, but also to provide meat for consumption, as suggested by cut marks on harbour porpoise skeletal elements recovered from kitchen middens at Black Sea archaeological sites (Gol'din et al., 2013a). The observed peak of cetacean finds in the Roman period coincides with a peak in tuna (*Thunnus thynnus*), anchovy (*Engraulis encrasicolus*), and thornback ray (*Raja clavata*) exploitation and a general increase in fishing effort during the Roman period to meet the demands of an increasing human population in the greater Mediterranean-Black Sea region (Bernal-Casasola et al., 2016; Corcoran, 1964). Black Sea cetaceans are generally small (1.5–3 m) and possible to catch with fishing equipment (including nets and tridents) and thus do not require the development of specialized cetacean hunting equipment.

It should be acknowledged that differences in sampling strategy, excavation techniques, analytical methods, and experience of the excavators and faunal analysts will impact what skeletal material is recovered, kept, and identified. Indeed, as previously mentioned, NISP data is not a perfect measure of a faunal assemblage and often overestimates the actual number of individuals especially when the bones are highly fragmented due to pre-depositional practices (i.e., butchery) and/or taphonomic processes. Secondly, the absence of zooarchaeological reports for the southern Black Sea region is unfortunate as both ancient sources and modern documents suggest that cetacean hunting was common practice (Strabo, 1917; Tonay and Öztürk, 2012; Xenophon of Athens, 1998). Importantly, the difficulty in reliably identifying some cetacean bones based on morphology alone has resulted in a relatively large proportion of unidentified cetacean bones in faunal assemblages. This calls for the application of non-traditional identification methodologies including biomolecular methods such as Sanger sequencing, shotgun sequencing, target capture sequencing, and collagen peptide fingerprinting (ZooMS; Biard et al., 2017). Beyond cetaceans, the discontinuity in excavation practices, especially regarding sieving can have a large impact on the composition of assemblages.

#### 4.2. The zooarchaeological record in context

Cetacean remains from archaeological contexts are historically understudied. Despite more recent attempts to remedy this (Álvarez-Fernández et al., 2014; Biard et al., 2017; Erlandson et al., 2020; Evans et al., 2016; Hennius et al., 2018; Monks et al., 2001; Rastogi et al., 2004; Rodrigues et al., 2018; van den Hurk et al., 2021, 2020; Wagner et al., 2020), the marine mammal assemblages of many regions and time periods remain unknown. This is also true for the Black Sea region where, although cetacean bones are found in zooarchaeological reports and papers, their importance is often

relegated to a list of species identified, occasionally including a brief description of the bones recovered. Our synthesis of zooarchaeological reports and papers from the Black Sea region document that cetacean bones are recovered from the majority of sites and from all of the time periods analysed.

The presence of cetaceans throughout the Black Sea zooarchaeological record is supported by ancient written sources. The Roman writer Galen suggests that cetacean meat was regularly salted and consumed, likely by common people in the Roman world (Marzano, 2013). The ancient Greco-Roman historian Oppian (2nd century AD) while writing about fishing states that Thracians and people from Byzantium hunt dolphins with tridents and line, a practice that he suggests is appealing (Hal. 5.521). Similarly, Xenophon and Strabo report hunting dolphins alongside tuna harvesting in the Black Sea during the Classic Greek and Hellenistic period (Strabo, 1917; Tonay and Öztürk, 2012; Xenophon of Athens, 1998), and Genoese and Ottoman documents describe deliberate catches of cetaceans in the Black Sea region (Dede et al., 2016; Kleinenberg, 1956; Vigne, 1871).

The presence of cetacean remains at archaeological sites in the Black Sea region is in stark contrast to the nearby and connected Mediterranean, where far fewer cetacean bones have been identified despite the presence of a wider variety of cetacean species, including larger baleen whales (Bernal-Casasola, 2010, 2018; Rodrigues et al., 2018). MacKinnon (2014) suggests that the Greeks and Romans did not typically hunt dolphins except for rare cases for medicinal purposes, but that they were hunted by Thracians (western Black Sea) and Byzantines. Greek colonies were present in the Black Sea since at least 700 BCE; however, north-eastern colonies became part of the Bosphorus Kingdom known for its syncretic culture, and during the Hellenistic period, the Pontus was influential in the region, before becoming under Roman rule by 62 AD.

It is unclear what factors are causing this discrepancy in cetacean zooarchaeological finds in the Mediterranean and the Black Sea regions. Cetaceans could be disproportionately represented in the zooarchaeological record due to regional differences in behaviour and distribution, making them easier to harvest in the Black Sea than in the Mediterranean. The Black Sea is generally shallower than the Mediterranean, it has an extensive shelf zone in the northern parts and an extremely shallow area in the Sea of Azov, and it is more productive in fish than the Mediterranean; a contrast that was significant before fish stock declines in the 20th century (Daskalov, 1999, 2002; Demirel et al., 2020). Cetaceans historically reached enormous abundance and density in the Black Sea, possibly up to a million animals in the early 1900s (Zemsky and Yablokov, 1974). These general factors themselves could well explain the accessibility of Black Sea cetaceans for hunting and bycatch in ancient times. Finally, discrepancies may arise from methodological constraints, including isostatic variation limiting the number of visible sites and limited morphologically diagnostic bone fragments from cetacean species (Bernal-Casasola et al., 2016; Biard et al., 2017; Bikoulis, 2015; Doonan, 2010; Papadopoulos and Rusillo, 2002; Peev et al., 2019).

Additionally, and perhaps more likely, the presence of cetacean bones could relate to environmental and socioeconomic factors driving differences in prehistoric natural resource utilization. While the Mediterranean region produced a large amount of olive oil, the Black Sea region did not and instead would have relied on oil imports from the Mediterranean (Marzano, 2013; Opař, 2010). There are records in the Byzantine period of cetaceans being hunted for their blubber to meet the oil demand for lighting (including lighthouses), as well as for skin processing, soap making, lubricants, and medicinal uses (Kleinenberg, 1956; Tonay and Öztürk, 2012; Xenophon of Athens, 1998). Indeed, the exploitation of cetaceans for oil has continued until recently in some coastal Black Sea

regions (Gol'din and Gol'din, 2004; Kleinenberg, 1956; Tonay and Öztürk, 2012). If oil was the driving factor in Black Sea cetacean exploitation, this practice would not be expected to expand to the Mediterranean as olive oil would have been abundant.

### 4.3. Were cetaceans scavenged, bycaught, or actively hunted?

Fishing technology in the Black Sea appears to have remained relatively stable in the Greek and Roman periods (from the Archaic period to the Medieval; Højte, 2005). A wide range of types of nets including gillnets and purse seining was available and commonly employed (Marzano, 2013; Bekker-Nielsen, 2005; Højte, 2005), which were used in cetacean hunting or bycatch. Net weights are commonly found at Greek and Roman sites throughout the Black Sea (Højte, 2005). In addition, fishing with a harpoon or trident likely occurred in shallow water such as lagoons throughout the Roman Mediterranean and Black Sea, and ancient sources suggest cetaceans were hunted in the Black Sea in this manner (Marzano, 2013). Indeed, harpoons and tridents are found in the Black Sea, albeit to a lesser extent than the more durable net weights (Højte, 2005; Bekker-Nielsen, 2005).

It could be suggested that some of the cetacean remains from zooarchaeological assemblages could originate from stranded animals found ashore. Active exploitation of fauna is typically demonstrated archaeologically via statistical comparison of elements present, but this is difficult with cetacean species as it is unclear what type of deposits would be expected for the systematic exploitation of whales (Bernal-Casasola, 2018). It is normally assumed that cetacean exploitation originated as opportunistic hunting or takes of stranded whales and subsequently developed

into actively targeted hunts with technological and social developments (Speller et al., 2016; van den Hurk et al., 2021). As discussed previously, by the Archaic period, fishing technology would have been developed enough for cetacean hunting to have occurred. Additionally, the species ratio of remains found by our zooarchaeological study is different from both the ratio of stranded cetaceans observed in nature where the harbour porpoise dominates on the Black Sea coast (Birkun and Krivokhizhin, 2011), as well as the present-day species distribution where the common dolphin and harbour porpoise each make up approximately 40% of the Black Sea cetacean population (ACCOBAMS, 2021, Fig. 4). This is not a perfect measure of exploitation and could indicate a change to the overall composition of the marine mammal fauna rather than the targeted hunting of species. Still, when considering the zooarchaeological, archaeological, and literary evidence, targeted exploitation is a likely cause of the cetacean remains recovered from the Black Sea.

The bottlenose dolphin remains are particularly abundant in the archaeological record in comparison with the relatively low abundance of this species in modern times (ACCOBAMS, 2021; Kleinenberg, 1956). They dominate the identified material among cetacean remains at the earliest sites, whereas there is a decrease in bottlenose dolphin remains recovered after the Bronze Age. Their presence in the Neolithic through to the Bronze Age is consistent with their modern distribution and can likely be linked to feeding on near-shore pelagic and benthic fish, most commonly found in the shelf zone (ACCOBAMS, 2021; Birkun, 2012; Gladilina et al., 2018; Sánchez-Cabanes et al., 2017) making them accessible to early hunters. Additionally, bottlenose dolphins are known to enter estuaries and coastal gulfs with occasional reports of them entering

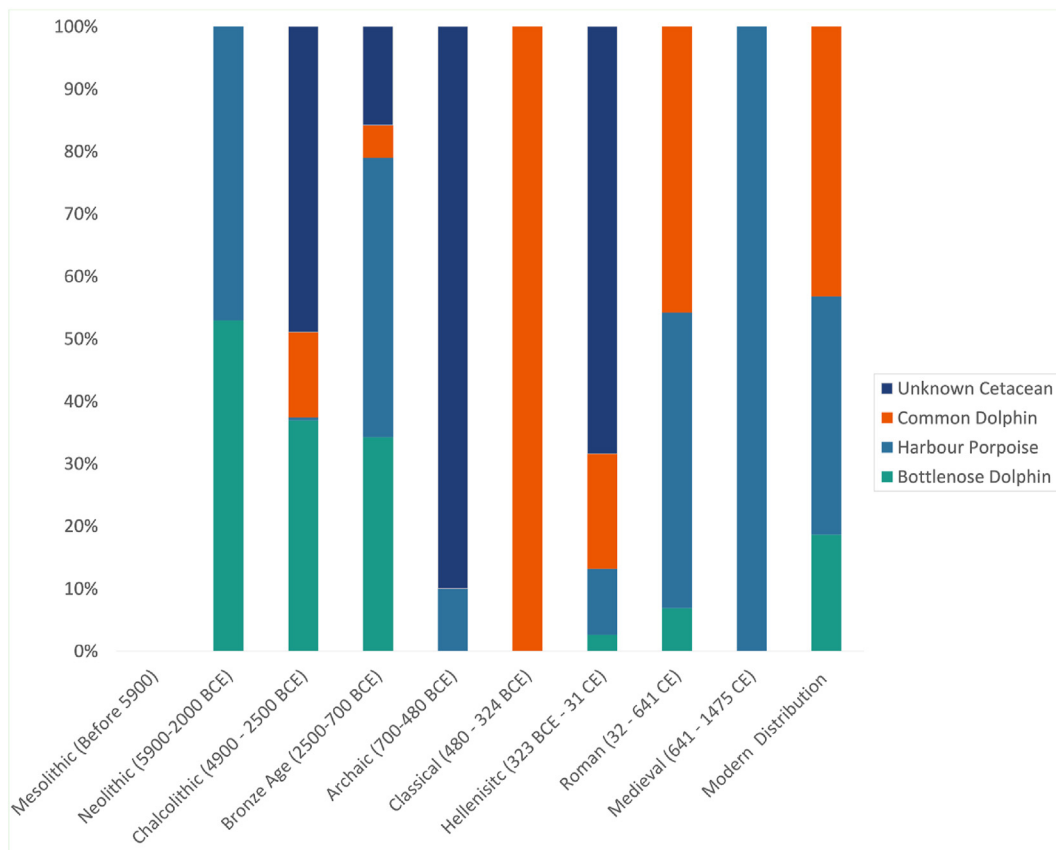


Fig. 4. NISP for marine mammal species recovered from Black Sea zooarchaeological sites from the Mesolithic to Medieval time periods, modern stranding data by species from (Birkun and Krivokhizhin, 2011), and modern species distribution by species (ACCOBAMS, 2021).

large rivers including the Danube and Dnieper (Birkun et al., 2014). This would make them relatively easily available with minimal seafaring technology.

The common dolphin appears less frequently than the other species in the zooarchaeological record, except in the Classical period from which only one site with three identified bones makes up the marine mammal assemblage. Common dolphins are typically located across the Black Sea pelagic area (Birkun, 2002; Birkun et al., 2014). Their modern range does not include the Azov Sea and they typically avoid the Kerch Strait and low salinity waters (ACCOBAMS, 2021; Birkun, 2002; Birkun et al., 2014). Importantly, while Black Sea common dolphins do move inshore seasonally following the migrations of small pelagic fish (sprat, *Sprattus*, and anchovy, *Engraulis encrasicolus*; Birkun, 2002), they appear to prefer deeper water than the other cetacean species and are often found in the open sea (ACCOBAMS, 2021; Birkun et al., 2014; Sánchez-Cabanes et al., 2017) suggesting that they may have been more difficult to hunt, rarely bycaught, and/or stranded less frequently.

Contemporary populations of the harbour porpoise can be found throughout the Black Sea, where they reach their greatest density at the continental shelf and the shelf slopes and are seasonally common in the Sea of Azov, Kerch Strait, Sea of Marmara, and the Bosphorus as they migrate leaving the Azov Sea in the winter and returning in the spring (ACCOBAMS, 2021; Vishnyakova and Gol'din, 2015). Interestingly, Black Sea harbour porpoise populations do not avoid areas of low salinity and have been reported in shallow, brackish, bays and lagoons (Birkun, 2002). Given the coastal distribution and high contemporary bycatch rate observed in modern populations, the limited presence of harbour porpoise remains in the faunal record is unexpected, though this could reflect the small body size limiting identification of the osseous remains.

## 5. Conclusions and perspectives

Our understanding of (pre)historic cetacean exploitation is far from complete. While the presence of the three cetacean species can be confirmed at archaeological sites, the purpose and extent of exploitation are unknown. By combining NISP data from archaeological sites around the Black Sea, we were able to elucidate broad trends in cetacean exploitation over a period of approximately 8500 years, covering the entire known period of cetacean presence in the Black Sea.

The increase of cetaceans and other marine species in the Chalcolithic zooarchaeological record seems to reflect the natural historical pattern of colonization of the Black Sea by marine fauna of Mediterranean origin which is suggested to have reached its present-day condition by 5600 B P (Marret et al., 2009). The peak in cetacean finds during the Roman period is interesting to consider as this is not present in other regions in the Roman empire, making the Black Sea an anomaly. There are several interconnected reasons that could lead to a peak in cetacean exploitation in the Roman period of the Black Sea, including human population growth leading to higher levels of exploitation, and reliance on marine mammals to supplement oil imports from the Mediterranean.

Cetacean bones are found throughout the Black Sea zooarchaeological assemblages and were recovered from most sites and all time periods (except the Mesolithic). This contrasts with the nearby Mediterranean where there is less zooarchaeological evidence for the exploitation of marine mammals. Thus, while it is clear that Roman marine resource utilization was highly organized throughout the Mediterranean-Black Sea region and we present clear evidence of cetacean exploitation in the Black Sea, the scale of marine mammal exploitation by the Romans in the Mediterranean and North Atlantic remains uncertain (Rey-Iglesia et al., 2020;

Rodrigues et al., 2018; Speller et al., 2016; van den Hurk et al., 2020, 2021).

Ultimately, while cetaceans were exploited in the Black Sea, it is still unclear how this has influenced the abundance and distribution of contemporary populations. The zooarchaeological material reviewed here, however, provides novel insight into (pre)historical cetacean exploitation and a unique resource for future retrieval and analysis of ancient DNA, which may provide additional insights into the natural history of the Black Sea marine mammals.

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## Conflicting interests

The authors declare no conflicts of interest.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data is available in the supplementary material.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quascirev.2023.108210>.

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