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IsoArch.eu: an open-access and collaborative isotope database for bioarchaeological samples from the Graeco-Roman World and its margins

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Abstract

This paper describes IsoArch, a new web-based database of isotopic data for bioarchaeological samples from the Graeco-Roman World and its margins. IsoArch was designed as a cooperative platform for the dissemination of isotopic data and associated archaeological information. IsoArch follows the open access model and is freely accessible online (<http://www.isoarch.eu>). Created for paleodietary, paleomobility and paleoenvironmental reconstruction research purposes, IsoArch compiled to this day published isotopic data for human, animal, and plant remains, as well as organic residues, from nearly 300 sites. All data have been georeferenced allowing for their display on ancient world maps and placement into their contemporaneous geopolitical background. In this paper, several data-driven examples are shown to illustrate the research potential offered by IsoArch.

Keywords

1. Classical Antiquity, 2. Iron age, 3. Diet, 4. Mobility, 5. Paleoenvironments, 6. Georeferenced database, 7. Isotopic proxies

1. Introduction

37 Isotopic proxies are widely recognized as a powerful tool to improve knowledge of past human
38 and animal diet and mobility patterns, to ascertain ancient crop and animal management practices,
39 and to reconstruct paleoenvironments (Drucker *et al.* 2012; Knudson *et al.* 2012; Boogard *et al.* 2013;
40 Müldner 2013; Touzeau *et al.* 2013; Knipper *et al.* 2016; De Cupere *et al.* 2017). Within
41 archaeological studies isotopic data has allowed for a better understanding of the social structure,
42 political organisation, economy, technology, and environmental contexts of past human groups (*e.g.*
43 Prowse *et al.* 2004; Craig *et al.* 2009; Crowe *et al.* 2010; Pollard *et al.* 2011; Mays and Beavan 2012;
44 Salesse *et al.* 2013, 2014; Salesse 2015; Killgrove and Tykot 2017). The number of archaeological
45 publications containing isotopic data has surged during the past 20 years (Pestle *et al.* 2014; Szpak *et*
46 *al.* 2017). However, the number of isotope web databases remains surprisingly low. There are several
47 databases of radiocarbon data (*e.g.* RADON, Kneisel *et al.* 2013; CARD, Martindale *et al.* 2016),
48 databases of modern environmental samples (*e.g.* IsoMAP, Bowen *et al.* 2017; IRHUM, Willmes *et al.*
49 2014) or archaeological artefacts (*e.g.* OXALID, Stos-Gale and Gale 2009). However, only a few
50 databases have gathered bioarchaeological isotope data, and even less include data from human
51 remains (*e.g.* KIK-IRPA, van Strydonck and de Roock 2011; dIANA, Etu-Shivola *et al.* 2015; IsoMemo,
52 Fernandes *et al.* 2017).

53 With a particular interest in isotopic studies concerning the Greco-Roman world *sensu lato*, we
54 build IsoArch, a web isotope database covering a wide chronological range (12th c. BCE - 8th c. CE) for
55 bioarchaeological samples from European, Middle Eastern and North African contexts. IsoArch is also
56 a member of the IsoMemo initiative (Fernandes *et al.* 2017). The IsoMemo initiative follows a
57 collaborative model for data sharing and project building that brings together different isotope
58 databases within the research fields of ecology, environmental sciences, and archaeology.

59 IsoArch is the first and main isotope web database fully dedicated to the Greco-Roman world
60 and its margins. Furthermore, IsoArch offers unique features, such as data display on ancient world
61 maps, which are not available elsewhere and are of special research interest in the study of the focus
62 region and time period.

63

64 **2. Description of IsoArch**

65 IsoArch was designed as a web-based isotope database for bioarchaeological samples from Iron
66 Age, Classical Antiquity and Late Antiquity (i.e. 12th c. BCE to 8th c. CE). It is hosted on a server
67 relying entirely on open-source software solutions and implemented following a relational database
68 model. The database structure of IsoArch is divided according to four different types of
69 bioarchaeological samples: human, animal, plant, and organic residues. Isotopic ratios (δD , $\delta^{13}C$,
70 $\delta^{15}N$, $\delta^{18}O$, $\delta^{34}S$ and $^{87}Sr/^{86}Sr$) and associated quality control indicators are recorded following two
71 main divisions: organic or mineral fractions on different kinds of samples (*e.g.* bone, tooth, hair,

72 calculus, etc.). The isotopic data is supplemented by archaeological and chronological information
73 relative to the sample (*e.g.* identification number, date range, description of archaeological context,
74 etc.). The selection of data fields for supporting information depends on the type of sample. For
75 example, for human samples supporting information includes the description of sex, age at death,
76 stature, and type of burial. Full citation details are provided for collected published data. IsoArch
77 compiled to this day isotopic data for 4,000+ humans, 2,000+ animals, 100+ plants, and 10+ organic
78 residues from nearly 300 archaeological sites. Detailed information on database organisation and
79 web database architecture is provided in supplementary files 1 and 2.

80 IsoArch is a collaborative database accessible to both researchers and the non-academic
81 audience. Users can freely query the database and download the resulting output. Furthermore,
82 users can contribute to expand IsoArch by uploading complied or their own generated data. IsoArch
83 administrators check each new submission to ensure the maintenance of data consistency and
84 quality. Once newly submitted data is approved, it is then added to the database and made available
85 online. More information on database collaborative platform is given in supplementary file 3.

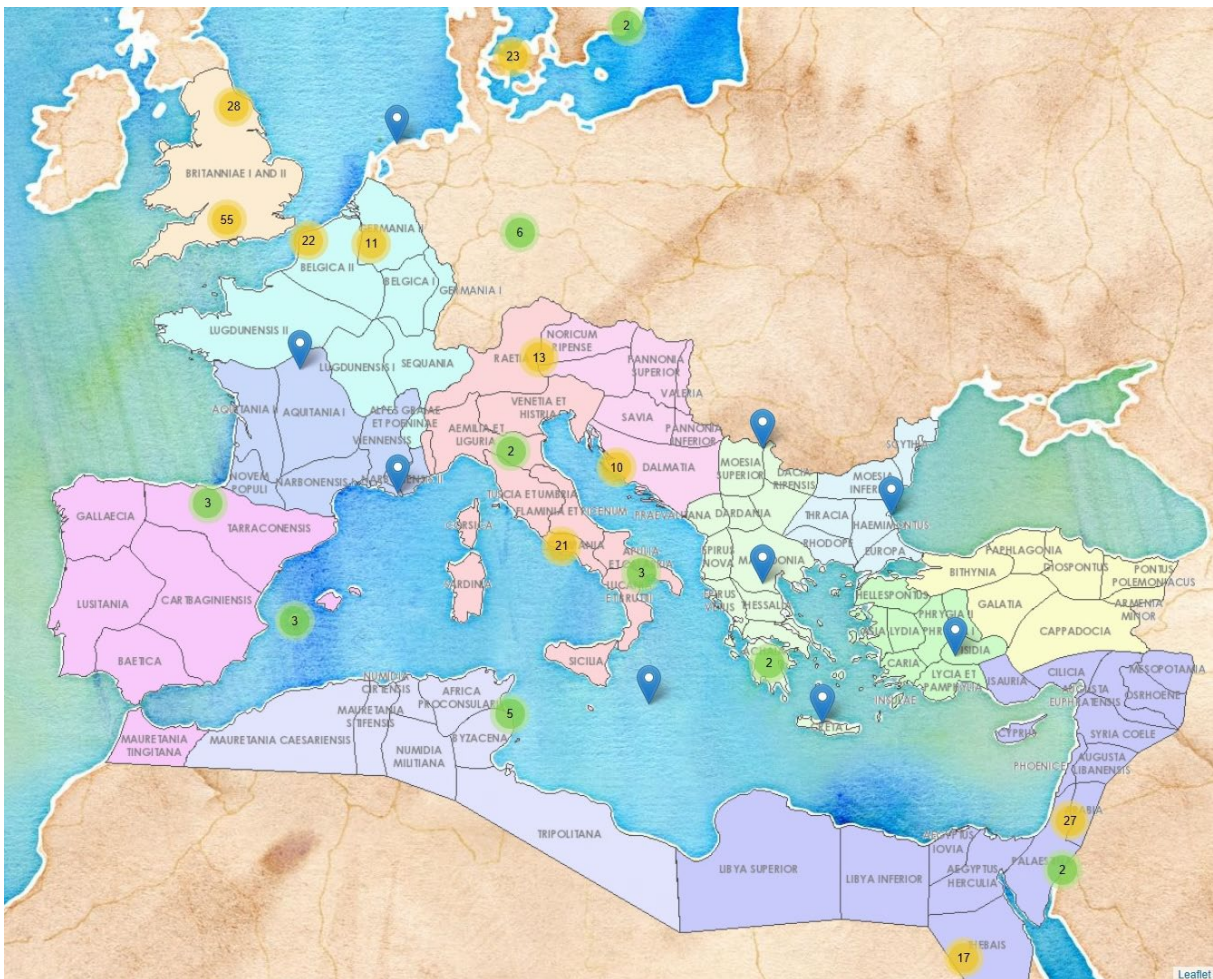
86 As a spatial database dedicated to the Graeco-Roman world and its margins (*i.e.* Europe, Near
87 and Middle East, and North Africa), all stored isotopic data is georeferenced. Using a web-mapping
88 capability, samples can be framed within the contemporary geopolitical context through their display
89 on ancient world maps. Available ancient world maps include those for the Persian, Alexander's,
90 Roman and Byzantine empires, plus for many other chrono-cultural entities. These maps serve as
91 backgrounds on which archaeological sites are projected (Figure 1). In addition, the projected maps
92 are interactive and can be used to explore the database with or without an initial query. Through the
93 selection of a site, users can have a summary of available data for that site (*e.g.* site name, number of
94 referenced individuals, population means for isotope values, and references). Detailed information
95 on web-mapping tool architecture is provided in supplementary file 4.

96 An open-access database policy is followed by IsoArch which means that data is made available
97 free of restrictions on both access and use. IsoArch is a public website, accessible at
98 <http://www.isoarch.eu>, with no login requirement for data visualisation. However, a login is required
99 for database querying and data downloading. The content of IsoArch is licensed under the Creative
100 Commons Attribution-NonCommercial-ShareAlike 4.0 International License (CC BY-NC-SA 4.0). Users
101 are free to copy and redistribute the data from IsoArch in any medium or format. They can also
102 modify and build upon available data but they must distribute their contributions under the same
103 license as the original. The licensor cannot revoke these freedoms as long as the license terms are
104 followed. Under the previous terms, users must give in their productions 1) appropriate credits (*i.e.*
105 this publication and "Salesse, K., Fernandes, R., de Rochefort X., Brůžek J., Castex D., Dufour É.,
106 (2017), www.isoarch.eu (v.1.0), accessed mm/dd/yyyy"), 2) provide a link to the license

107 (<https://creativecommons.org/licenses/by-nc-sa/4.0/>), and 3) indicate if any changes were made.
108 Material obtained from IsoArch cannot be used for commercial purposes.

109 The full advantages of the database are expected to arise from its collaborative approach.
110 IsoArch plans to become a new efficient tool at the service of the scientific community to provide an
111 overview of the state of paleodiet, paleomobility, and paleoenvironmental research in the ancient
112 Mediterranean. IsoArch is part of a broadly-based concept of data centralization that should elicit
113 new discussions and encourage stronger interdisciplinary collaboration. The online interface provides
114 easy access to a library of embedded data organized in multiple layers that facilitates the building of
115 local isotopic baselines plus regional and temporal comparisons of data. Finally, IsoArch will monitor
116 the release of publications pertaining to the Greco-Roman world and collect newly available isotopic
117 data.

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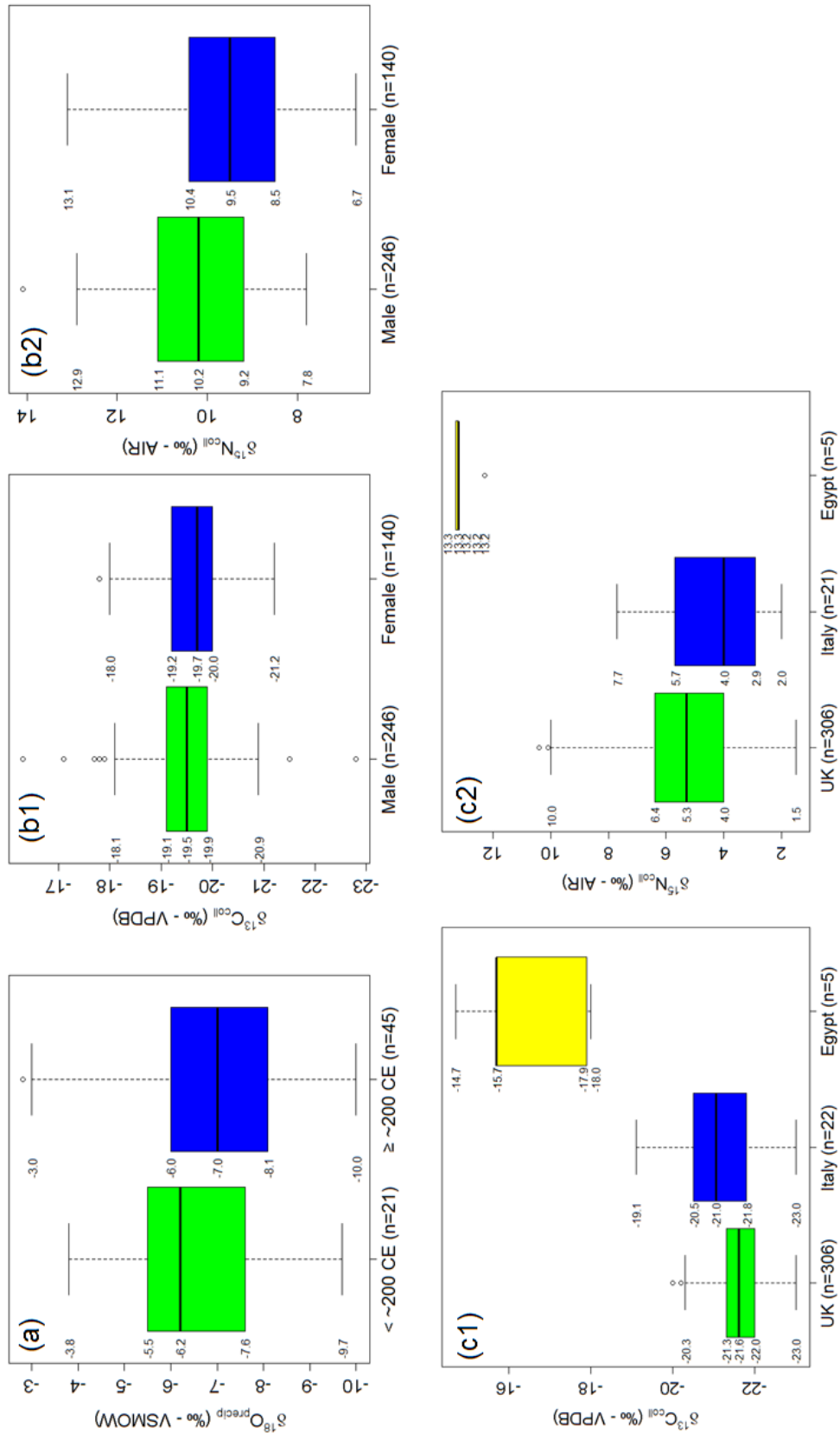
120 *Figure 1. Example of a map generated through IsoArch showing the distribution of Roman archaeological sites where*
121 *isotopic data from human and non-humans samples are available. The used map overlay is available from DARMC and*
122 *shows the Roman provinces between 303 and 324 CE.*

123

124 3. Research applications

125 Isotopic data, together with associated chronological and other supporting information,
126 collected at IsoArch allows for numerous research applications. These may include large scale
127 comparative studies of human diet or mobility following multiple selection criteria (*e.g.* chronology,
128 region, social variables). Whereas stored animal isotopic data can contribute to the reconstruction of
129 local environmental and human impact histories. For instance, herbivore collagen carbon or nitrogen
130 stable isotope values can be used as proxies to establish past vegetation types (C_3 or C_4), levels of
131 aridity, and forest density (Schwarcz *et al.* 1999; Kelly 2000; Bonafini *et al.* 2013). IsoArch can also be
132 used to identify data gaps for certain regions, time periods, or sample types. Concerning the latter,
133 there is presently a clear insufficiency of published plant isotopic data although this has a great
134 research potential. Carbon and nitrogen stable isotope data for cultivated plants can be used to
135 assess water availability and soil fertility which are also determined by human farming practices such
136 as irrigation and manuring (Aguilera *et al.* 2008; Szpak 2014; Styring *et al.* 2016). In addition, both
137 plant and animal isotopic data are required to define temporal and regional baselines for the
138 accurate quantification of human diets in isotope-based studies (Fernandes *et al.* 2015).

139 Within this section a few illustrative examples are given and briefly discussed to demonstrate
140 research uses for the data made available at IsoArch. Oxygen isotopes measured in human teeth
141 and bone chiefly reflect the isotopic composition of drinking water and have been frequently used in
142 Roman mobility studies (see Killgrove & Montgomery 2016 and references therein). A simple
143 temporal comparison was made of human oxygen isotopic data from the Italian peninsula. Selected
144 for comparison was tooth $\delta^{18}O$ data (a single tooth per individual, mostly third molars) from human
145 remains dating between 400 BCE and 400 CE. The selection was further limited to individuals for
146 which the difference between the upper and lower limit of the assigned chronological boundaries
147 was lower than 200 years. The individuals were grouped into two broad chronological groups ($< \sim 200$
148 CE and $\geq \sim 200$ CE) using as criterion the median of the chronological boundaries assigned to each
149 individual. Different types or reported measurements and units of reported $\delta^{18}O$ tooth data ($\delta^{18}O$
150 carbonate or phosphate relative to VPDB or VSMOW standards) were subjected to necessary
151 calculations to report these as $\delta^{18}O$ precipitation values relative to the VSMOW standard (Chenery *et*
152 *al.* 2012). Boxplots for selected human data $\delta^{18}O_{\text{precip}}$ are shown in Figure 2a.



153

154 Figure 2. a) Comparison of $\delta^{18}O_{precip}$ values calculated from tooth $\delta^{18}O$ data for Roman individuals from the Italian peninsula.

155 b) Comparison of Romano-British male and female human bone collagen $\delta^{13}C_{coll}$ (b1) and $\delta^{15}N_{coll}$ (b2) values.

156 c) Comparison of Roman British, Italian, and Egyptian herbivore bone collagen $\delta^{13}C_{coll}$ (c1) and $\delta^{15}N_{coll}$ (c2) values. Box edges represent 25th

157 and 75th percentiles (inter quartile range or IQR) while the horizontal line is the 50th percentile (median). Whiskers are the

158 minimum and maximum values that do not exceed a distance of 1.5 times the IQR. Beyond this distance single points

159 represent outliers.

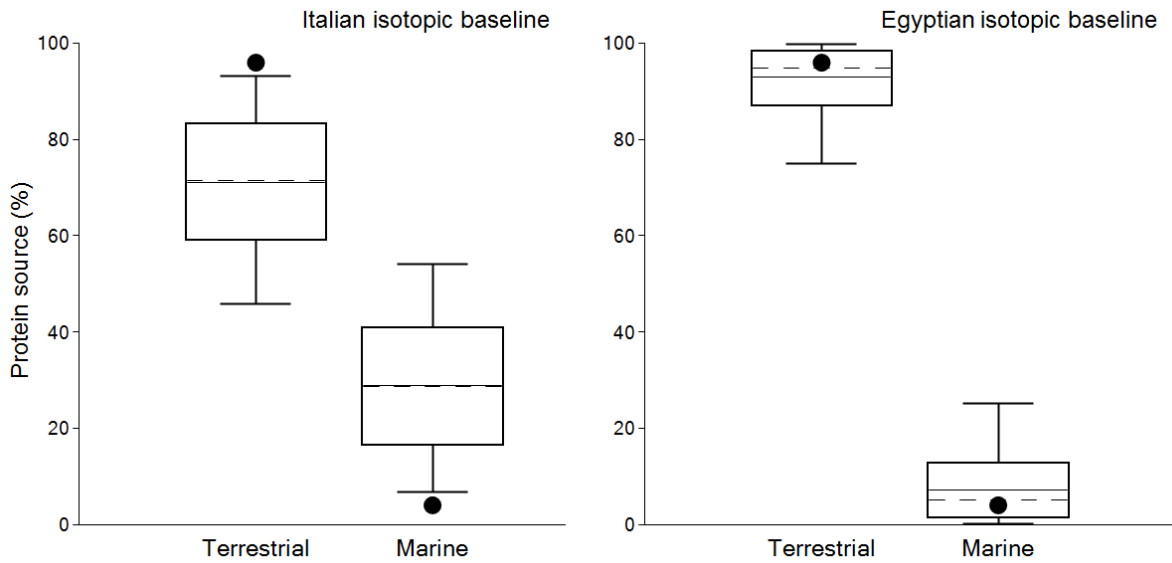
160 The inter quartile ranges of $\delta^{18}\text{O}_{\text{precip}}$ values shown in Figure 2a for the younger and older
161 chronological groups are contained within modern day ranges of $\delta^{18}\text{O}_{\text{precip}}$ values observed for the
162 Italian peninsula (Lightfoot & O'Connell 2016). However, both chronological groups show a wide
163 range of $\delta^{18}\text{O}_{\text{precip}}$ values, larger for the younger group, which is indicative of a high degree of
164 mobility. The $\delta^{18}\text{O}_{\text{precip}}$ mean for the younger group (mean $\delta^{18}\text{O}_{\text{precip}} = -6.8 \pm 1.7\text{‰}$) is slightly smaller
165 than that of the older group (mean $\delta^{18}\text{O}_{\text{precip}} = -6.3 \pm 1.6\text{‰}$) but the difference is not statistically
166 significant (Welch two sample t-test: $t = 1.1863$, $df = 41.56$, $p\text{-value} = 0.2422$). The chronology of the
167 individuals from the younger group roughly coincides with a broadly warmer period (from ca. 250 to
168 400 CE) for which higher $\delta^{18}\text{O}_{\text{precip}}$ values are observed relative to the previous centuries (McCormick
169 *et al.* 2012). Since the opposite trend is observed for $\delta^{18}\text{O}_{\text{precip}}$ values in Figure 2a, it suggests a larger
170 degree of mobility during the second half of the Imperial period which would possibly include a
171 larger proportion of individuals from northern regions. It would be interesting to place this within the
172 context of the 3rd century crisis and a possibly greater connectivity with the northern regions of the
173 Roman Empire. Nonetheless, some interpretative caution is necessary since the isotopic dataset is
174 limited, both in total numbers and spatial representatively, and the chronological resolution is poor.

175 Human bone collagen $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ signals are proxies for dietary sources of protein
176 (Fernandes 2016). A comparison of these isotopic signals is shown in Figure 2b for Romano-British
177 adult male and female individuals. The difference between male (mean $\delta^{13}\text{C}_{\text{coll}} = -19.5 \pm 0.7\text{‰}$) and
178 female (mean $\delta^{13}\text{C}_{\text{coll}} = -19.6 \pm 0.6\text{‰}$) mean $\delta^{13}\text{C}_{\text{coll}}$ values is small and not statistically significant
179 (Welch two sample t-test: $t = 1.6429$, $df = 319.89$, $p\text{-value} = 0.1014$). There is a larger difference
180 between male (mean $\delta^{15}\text{N}_{\text{coll}} = 10.4 \pm 1.2\text{‰}$) and female (mean $\delta^{15}\text{N}_{\text{coll}} = 9.5 \pm 1.3\text{‰}$) mean $\delta^{15}\text{N}_{\text{coll}}$
181 values that is statistically significant (Welch two sample t-test: $t = 4.785$, $df = 269.89$, $p\text{-value} =$
182 $2.818\text{e-}06$). The difference in $\delta^{15}\text{N}_{\text{coll}}$ values is likely due to a higher consumption by men of terrestrial
183 domesticated animal protein having $\delta^{15}\text{N}$ values higher than plant protein. Differentiated
184 consumption of marine fish protein, having elevated $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values compared to terrestrial
185 protein sources, is unlikely given the similarity in $\delta^{13}\text{C}_{\text{coll}}$ values for both genders. The energetic cost
186 of producing animal protein is greater than that of plant protein making access to animal protein
187 typically more limited. This could imply that men had a higher social status than women, although
188 other hypotheses for observed isotopic gender differences have also been previously put forward
189 (Craig *et al.* 2009). Furthermore, possible differences in social status were certainly not only gender-
190 based as females show a larger variability in $\delta^{15}\text{N}_{\text{coll}}$ values compared to men.

191 The impact of regional climatic and environmental variability in herbivore bone collagen
192 $\delta^{13}\text{C}_{\text{coll}}$ and $\delta^{15}\text{N}_{\text{coll}}$ signals is illustrated in Figure 2c through a comparison of Roman herbivore data
193 from the United Kingdom, Italy, and Egypt. There are large differences in the number of available
194 records for the three regions with Egypt represented by a single location (Kellis). However, large

195 isotopic differences can be observed between Egypt and European regions. Higher Egyptian
196 herbivore $\delta^{15}\text{N}_{\text{coll}}$ values reflect higher plant $\delta^{15}\text{N}$ values resulting from lower levels of precipitation in
197 Egypt compared to European regions (Schwarcz *et al.* 1999). The more arid environment of Egypt
198 also results in a larger abundance of C_4 plants which are better adapted than C_3 plants to such
199 environments and have more elevated $\delta^{13}\text{C}$ values (Tiezen 1991). There is a statistically significant
200 difference between the $\delta^{13}\text{C}_{\text{coll}}$ values of British and Italian samples (Welch two sample t-test: $t = -$
201 2.5301 , $df = 21.885$, $p\text{-value} = 0.01911$). Herbivores from Roman Italy have a larger mean $\delta^{13}\text{C}_{\text{coll}}$
202 value (mean $\delta^{13}\text{C}_{\text{coll}} = -21.1 \pm 1.0\text{‰}$), and also a larger amount of variability, compared to Romano-
203 British herbivores (mean $\delta^{13}\text{C}_{\text{coll}} = -21.6 \pm 0.5\text{‰}$). Plant $\delta^{13}\text{C}$ values decrease with higher mean annual
204 precipitation and higher forest density (canopy effect) (Aguilera *et al.* 2008; Bonafini *et al.* 2013).
205 Both of these parameters have, in general, higher values in Britain than in Italy. There was also a
206 statistically significant difference between $\delta^{15}\text{N}_{\text{coll}}$ values from British and Italian samples (Welch two
207 sample t-test: $t = 2.7093$, $df = 22.67$, $p\text{-value} = 0.01261$). Romano-British herbivores have a larger
208 mean $\delta^{15}\text{N}_{\text{coll}}$ value (mean $\delta^{15}\text{N}_{\text{coll}} = 5.3 \pm 1.7\text{‰}$) compared to herbivores from Roman Italy (mean
209 $\delta^{15}\text{N}_{\text{coll}} = 4.3 \pm 1.7\text{‰}$). This suggests that British soils accessible to local herbivores were more fertile
210 than Italian soils and that Italian herbivores did not have a significant access to manured fields
211 (Aguilera *et al.* 2008; Szpak 2014).

212 One of the significant repercussions of observed animal isotopic variability across different
213 regions is the need to establish a local and contemporary isotopic baseline when doing isotope-based
214 human diet reconstruction. This is illustrated through a simple example in which the diet of Roman
215 adult individuals from the Egyptian site of Kellis was quantitatively reconstructed from published
216 tooth (M3 molar) dentin isotopic data (mean $\delta^{13}\text{C}_{\text{coll}} = -18.8 \pm 0.3\text{‰}$ and mean $\delta^{15}\text{N}_{\text{coll}} = 17.7 \pm 1.0\text{‰}$)
217 using the Bayesian mixing model FRUITS (Dupras & Tocheri 2007; Fernandes *et al.* 2014). The
218 adopted modelling approach is essentially the same as employed for individuals from the Roman city
219 of Herculaneum (Italy) in which protein contributions (marine vs. terrestrial) were quantified
220 (Fernandes 2016). The accuracy of model estimates for the Herculaneum individuals was assessed by
221 comparing individual model estimates with observed human dietary radiocarbon reservoir effects
222 showing an excellent agreement. Two isotopic baselines were considered to estimate the group
223 protein contributions for the adults from Kellis. One relying on Italian herbivore isotopic data as
224 described in Fernandes (2016) and a second relying on Egyptian herbivore isotopic data as shown in
225 Figure 2c. For both baselines the same isotopic values of Mediterranean marine fish were taken as
226 reference. Model estimates are shown in Figure 3 and demonstrate the differences in protein
227 estimates generated under the two isotopic baselines. Also included in Figure 3 is the estimated
228 group protein contribution for adults from Herculaneum (filled circles). Estimates generated using an
229 Egyptian isotopic baseline result in similar group dietary estimates for Kellis and Herculaneum adults.



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Figure 3. Comparison of dietary protein Bayesian group estimates for adults from Kellis under two isotopic baselines (Italian and Egyptian). Filled circles represent estimated mean protein contribution for Herculanum group boxes represent a 68% credible interval while the whiskers represent a 95% credible interval. The horizontal continuous line indicates the average while the horizontal discontinuous line indicates the median.

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4. Conclusions and future developments

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The few research examples shown in this paper illustrated how data stored at IsoArch allows for multi-scale analysis and extensive studies on topics related to paleodiet, paleomobility and paleoenvironment. The task of defining contemporary and local baselines necessary for the study of subsistence strategies and mobility patterns of past humans and animals becomes greatly simplified. Database querying also highlights existing data gaps for certain sample types, time periods, and regions which motivate future isotopic research.

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IsoArch database will be expanded in the future by adding new data and entities (e.g. additional isotopic proxies, new archaeological parameters, etc.). This will follow from the feedback provided by the users of IsoArch. A forum addressed to researchers using the website is envisaged for discussions on IsoArch related topics. Tutorials, possibly in the form of a video, will be available on the website to describe to users how to use IsoArch. We also plan to implement free statistical tools online (e.g. Shiny, a web application framework for R) as well as implement the capability to export the ancient world maps generated on IsoArch. Automatic submission tools are planned to be developed so that batch data submissions might become easier. Moreover, user session will be expanded to allow members to operate IsoArch using their own unpublished works and make use of online tools (e.g. digital maps, datasets, baselines) without being compelled to share their data publicly.

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269

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