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# Animal proxies to characterize the strontium biosphere in the northeastern Nile Delta

Chris Stantis*[1], Geoff M. Nowell[2],
Silvia Prell[3], Holger Schutkowski[1]
[1] Faculty of Science and Technology,
Department of Archaeology and Anthropology, Bournemouth University,
Fern Barrow, Poole, Dorset BH12 5BB, United Kingdom
email: cstantis@bournemouth.ac.uk (corresponding author)
[2] Department of Earth Sciences, Durham University, Durham,
Lower Mountjoy, South Rd, Durham DH1 3LE, United Kingdom
[3] Austrian Academy of Sciences,
Vordere Zollamtsstrasse 3, 1030 Vienna, Austria

**Abstract**: *Strontium ($^{87}Sr/^{86}Sr$) isotope analysis is a potent tool for reconstructing the residential mobility of humans and animals in the past but is reliant on knowledge of strontium isotope variation within the expanded physical environment. This paper aims to contribute to the isoscape in the northeastern Nile Delta with faunal samples from the site of Tell el-Dab'a (Avaris), believed to be the capital of the so-called Hyksos kings.*

*Mapping the available $^{87}Sr/^{86}Sr$ ratios from Egypt and the Sudan highlights major research gaps outside the Nile region. The current corpus of knowledge also shows that the Nile River region yields a homogenous range of isotopic values (median and IQR 0.7076±0.0003). Strontium isotope ratios from human dental enamel, which record childhood residence, will provide evidence of non-locals from outside the Nile area with confidence but these values suggest that identifying movement along the Nile River in the past will be difficult without the use of supplementary evidence (e.g. oxygen stable isotope analysis).*

*We present $^{87}Sr/^{86}Sr$ ratios of archaeologically-derived faunal bone samples (n=6) from the site of Tell el-Dab'a (Avaris) in the northeastern Nile Delta. The $^{87}Sr/^{86}Sr$ ratios fit within the expectations of the wider Nile values (mean 0.70769±0.00003) and serve as the first archaeologically-derived values reported for this area of Egypt.*

**Key words**: paleomobility; migration; biosphere baseline; Egypt

## Introduction

The use of strontium isotope ($^{87}Sr/^{86}Sr$) analysis as a tool for identifying human and animal mobility and residence among past populations allows insight into large scale socio-political dynamics by revealing patterns on the level of the individual (e.g. Bastos et al. 2016; Knudson et al. 2014; Madgwick et al. 2019; Sołtysiak 2019). The

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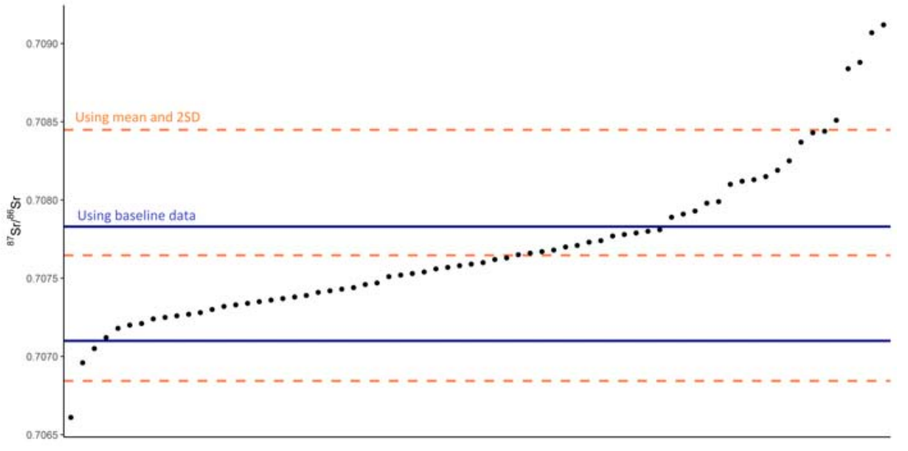


**Figure 1.** $^{87}Sr/^{86}Sr$ ratios of Tombos humans with mean $\pm$ 2SD as dashed lines and $^{87}Sr/^{86}Sr$ ratios of Tombos humans, with local biosphere range (as recommended by Schrader et al. 2019) as solid lines. Note the more restricted 'local' range compared to mean $\pm$ 2SD.

interpretation of movement using strontium isotope analysis rests upon the assumption that the $^{87}Sr/^{86}Sr$ ratios of an individual's body tissues will generally reflect the $^{87}Sr/^{86}Sr$ ratios of the underlying geology in which they lived when these tissues were forming (Bentley 2006; Montgomery et al. 2005). Strontium has an atomic radius similar to that of calcium (200pm and 180pm, respectively) and belongs to the same group of alkaline earth elements in the periodic table (Lewis & Evans 2003). As a result, strontium readily replaces calcium in minerals, including calcium carbonate in chalk, limestone, and marble, and calcium in the bones and teeth (Burton 2008). Erosion of the underlying geological formations is the major contributor to the $^{87}Sr/^{86}Sr$ ratios of the soil (Evans et al. 2009; Evans et al. 2010), even though recent research suggests that modern agricultural fertilising practices may have an impact as well (Thomsen & Andreasen 2019).

However, bioavailable strontium, or the strontium values obtained from plants and animals, is not a direct reflection of the underlying geological substrate due to factors such as differential erosion of geological formations and atmospheric contribution, and so bioavailable $^{87}Sr/^{86}Sr$ ratios as observed in plants and animals provide better ideas of local ratios than geological baselines. Additionally, unlike light stable isotopes (e.g., carbon, nitrogen, oxygen, sulfur), there is no appreciable fractionation across trophic levels or in metabolic processes, allowing direct comparison from the bioavailable strontium ratios (Lewis et al. 2017). Creating a local biosphere baseline is vital to confidently identifying non-locals in a cemetery assemblage. Beyond that, having a wider local isotope baseline, sometimes called an 'isoscape', allows strontium isotope analyses to go beyond a local/non-local dichotomy to address questions about the original residence of non-locals. Non-locals in an assemblage could be recognized as those individuals falling two standard deviations outside the population mean (Bentley et al. 2003; Bentley et al. 2004; Price et al. 2002; Stantis et al. 2016; Stantis et al. 2015). This method, however, may not be satisfactory as the mean might not represent the local biosphere and two standard deviations (estimated to cover 95% of a given dataset) might encompass non-local values as well as local individuals.

Multiple paleomobility studies conducted on the New Kingdom assemblage at Tombos (ancient Nubia) stand as excellent examples (Buzon & Simonetti 2013; Buzon et al. 2007; Schrader et al. 2019). Had these studies used the mean $\pm$ 2SD to identify non-locals in their assemblages with a wide range of $^{87}Sr/^{86}Sr$ ratios, the majority of the population would be classified as local (**Figure 1**, dashed lines). However, local biosphere data in the form of modern and ancient faunal samples, as well as soil, create a much tighter local range (**Figure 1**, solid lines), identifying a higher number of non-locals and lending support to the textual evidence of movement into Tombos during that time period (Smith & Buzon 2018).

As will become evident with the literature review, there is a gap in knowledge about the strontium values of the Nile Delta biosphere. The research we present here seeks to contribute to the isoscape of the northeastern Nile Delta with faunal samples from the site of Tell el-Dabʿa (Avaris).

## Background

To create a current map of the known Nilotic isoscape, we incorporate published studies from Egyptian and Sudanese contexts to investigate the utility of strontium isotope analyses in identifying migrants within this region (Buzon & Simonetti 2013; Buzon et al. 2016; Buzon et al. 2007; Schrader et al. 2019; Touzeau et al. 2013). These studies span from ca. 6950 BCE to 700 CE and incorporate modern faunal samples; given the broad timespan covered by these samples, it must be kept in mind that there may have been changes along the Nile River, and accordingly changes in isotopic values, due to shifts in contributions between the two main tributaries: the White Nile and the Blue Nile (Bentley 2006; Buzon & Simonetti 2013). No $^{87}Sr/^{86}Sr$ ratios from floral samples could be found in the literature. Krom et al. (2002) analysed $^{87}Sr/^{86}Sr$ ratios in soil sediments, but unfortunately did not provide raw data, only graphical representation and so cannot be commented on in-depth. The collated data of human and animal $^{87}Sr/^{86}Sr$ values are summarised in **Tables 1** and **2** along with approximate location coordinates, as derived from the original reference sources. The median and inter-quartile range (IQR) are presented rather than mean and standard deviation as the data are not normally distributed and possibly skewed by immigrants with ‘deviant’ values. **Figure 2** maps the median values for each site and highlights an important research gap for strontium data: there are no sites from the Western Desert, Eastern Desert, or Sinai Peninsula. Therefore, the potential utility for $^{87}Sr/^{86}Sr$ paleomobility analysis when the water source for drinking and irrigation is not the Nile River cannot be assessed.

**Table 1**. Summary data of human $^{87}Sr/^{86}Sr$ ratios (sites arranged in alphabetical order).

| Site | n | Median | IQR | Country | Latitude | Longitude |
|---|---|---|---|---|---|---|
| Abu Fatima[1] | 25 | 0.70749 | 0.00028 | Sudan | 19.6100 | 30.4167 |
| Amara West[2] | 24 | 0.70756 | 0.00021 | Sudan | 20.8148 | 30.5118 |
| Deir el-Medina[3] | 5 | 0.70775 | 0.00008 | Egypt | 25.7384 | 32.6014 |
| Elephantine[3] | 3 | 0.70777 | 0.00002 | Egypt | 24.0846 | 32.8832 |
| Hannek[1] | 4 | 0.70776 | 0.00066 | Sudan | 19.4200 | 30.2000 |
| Kerma[2] | 15 | 0.70736 | 0.00024 | Sudan | 19.6409 | 30.4172 |
| Khozam[3] | 6 | 0.70777 | 0.00002 | Egypt | 25.7925 | 32.7675 |
| Memphis[2] | 15 | 0.70764 | 0.00038 | Egypt | 29.7052 | 31.2243 |
| Sheikh Abd el-Qurna[2,3] | 29 | 0.70778 | 0.00024 | Egypt | 25.7383 | 32.6078 |
| Shellal[2] | 15 | 0.70764 | 0.00045 | Egypt | 24.0333 | 32.9000 |
| SJE[6] C-Group[2] | 15 | 0.70760 | 0.00031 | Sudan | 21.9955 | 31.3009 |
| SJE[6] Pharaonic[2] | 15 | 0.70751 | 0.00019 | Sudan | 21.9955 | 31.3009 |
| Tombos[2,4,5] | 115 | 0.70758 | 0.00037 | Sudan | 17.4200 | 30.2300 |

[1] Schrader et al. 2019 [2] Buzon & Simonetti 2013 [3] Touzeau et al. 2013
[4] Buzon et al. 2007 [5] Buzon et al. 2016 [6] Scandinavian Joint Expedition

**Table 2**. Summary data of animal $^{87}Sr/^{86}Sr$ ratios (sites arranged in alphabetical order).

| Site | n | Median | IQR | Country | Latitude | Longitude |
|---|---|---|---|---|---|---|
| Abu Fatima[1] | 1 | 0.70734 | | Sudan | 19.6100 | 30.4167 |
| Amara West[2] | 10 | 0.70715 | 0.00021 | Sudan | 20.8148 | 30.5118 |
| Askut[2] | 14 | 0.70724 | 0.00118 | Sudan | 27.1833 | 31.1667 |
| el-Kurru[2] | 3 | 0.70869 | 0.00194 | Sudan | 18.4100 | 31.7714 |
| Kawa[2] | 11 | 0.70910 | 0.00150 | Sudan | 19.1354 | 30.4991 |
| NDR[3] P37[2] | 3 | 0.70692 | 0.00039 | Sudan | 19.1354 | 30.4991 |
| SJE[4] C-Group[2] | 10 | 0.70762 | 0.00073 | Sudan | 21.9955 | 31.3009 |
| Tombos[2] | 14 | 0.70752 | 0.00029 | Sudan | 17.4200 | 30.2300 |

[1] Schrader et al. 2019 [2] Buzon & Simonetti 2013 [3] Northern Dongola Reach
[4] Scandinavian Joint Expedition

In total, 290 human samples from twelve sites throughout the Nile Valley in Egypt and the Sudan with $^{87}Sr/^{86}Sr$ values are available. Faunal samples (n=65) are from Buzon et al. (2007), Buzon and Simonetti (2013), and Schrader et al. (2019), who included modern and ancient animal enamel samples as a means of understanding the local baseline of their Sudanese archaeological sites. There is generally a narrower

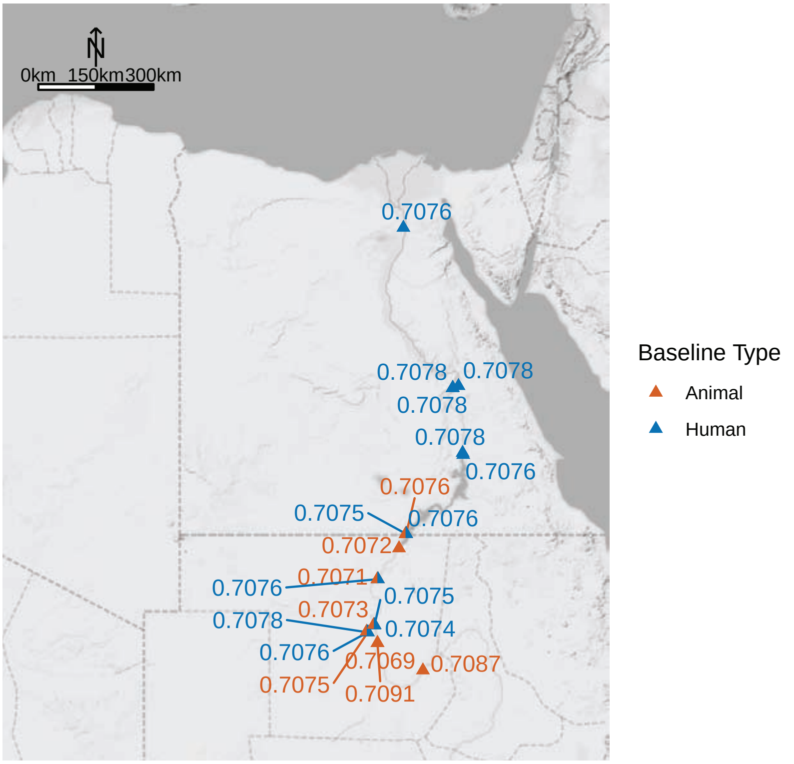


**Figure 2.** Median $^{87}Sr/^{86}Sr$ ratios across the Nile. Data from Buzon and Simonetti 2013; Buzon et al. 2013; Buzon et al. 2007; Schrader et al. 2019; Touzeau et al. 2013.

IQR in human values compared to faunal $^{87}Sr/^{86}Sr$ values when grouped by site. This could be because humans are omnivorous, eating foods from a variety of sources. Thus, each human likely reflects averaged values of several food sources, which creates an overall restricted group range compared to herbivorous domesticates often kept on controlled feeding regimes. The wide range of values in animals may also be a result of long distance trade, with animals from the sites of el-Kurru and Kawa displaying much higher $^{87}Sr/^{86}Sr$ ratio medians than all other subgroups in Egypt and the Sudan. Of course, another possibility is biased distribution due to small sample size in the region.

There are statistically significant differences in $^{87}Sr/^{86}Sr$ values between the human data when grouped by site, ($H(13)=38.053$, $p=0.0002$). In addition, the IQRs are remarkably small for all sites, ranging from 0.00002–0.00045. These IQRs would suggest that we could assert the provenience postulate: that between-source differences must exceed within-source differences in order for provenience estimation to be possible (Weigand et al. 1977). Unfortunately, the differences between sources are also very small, with an overall IQR for the Nile Valley at ±0.00034. To put these numbers into some perspective, a pan-Mesoamerican study (Price et al. 2008) found that Central America's $^{87}Sr/^{86}Sr$ variation between sites was generally c. ±0.001, five-fold the average variation between these Nile Valley sites; the researchers commented that ±0.001 was exceptionally low from their experience.

## The biosphere

The Nile is formed from the Blue Nile tributary running through modern-day Ethiopia and Sudan and the White Nile tributary, which, depending on the definition, either begins at Lake No in South Sudan or further north in the African Great Lakes Region (for a review, see Said 2017). With the Nile serving as the main source of drinking water through the Nile Valley, erosion of the northern heterogenous and complex geological formations combine to create low variability of biogenically available strontium. This lack of variation offers no surprise to geologists, as $^{87}Sr/^{86}Sr$ variation is largely dependent on the underlying geology of an area. The homogeneous Nile strontium ratios imply that, when studying Egyptian and Nubian archaeological assemblages, identifying individuals from outside the Nile catchment is feasible. Although animal values show a wide range, human medians and IQRs across the Nile largely display a restricted range, even with the inclusion of likely non-locals widening the IQRs (**Figure 3**). As such, differentiating between locals and non-locals originating from other sites along the Nile appears to be limited if using $^{87}Sr/^{86}Sr$ analysis alone.

## Isoscape of Tell el-Dab'a in the northeastern Nile Delta

With the perspective provided from past research, we hypothesize that biospheric strontium ratios of the northeastern Nile Delta will be similar to the overall Nile median from both animal and human values: 0.7076±0.0003. This study utilizes animal bone samples collected from the site of Tell el-Dab'a (Hutwaret/Avaris) to act as proxies for the local bioavailable strontium signature. The northeastern Nile Delta region is characterized by low plains of rich alluvial deposits with SW-NE belts of hills or *geziras* (Said 2017). Tell el-Dab'a sits on the now-defunct Pelusiac branch of the Nile. During the Second Intermediate Period (c. 1782–1570 BCE), several river channels formed a network around a *gezira*, which was formed by aeolian sands (also called turtle back), in Tell el-Dab'a (Dorner 1994; Tronchere et al. 2012).

The stratigraphic sequence at Tell el-Dab'a indicates occupation of this site extending over 500 years (Bietak 1996; Bietak 2010). Initially called Hutwaret, this settlement was founded in the 12$^{th}$ dynasty, possibly during the reign of Amenemhat I

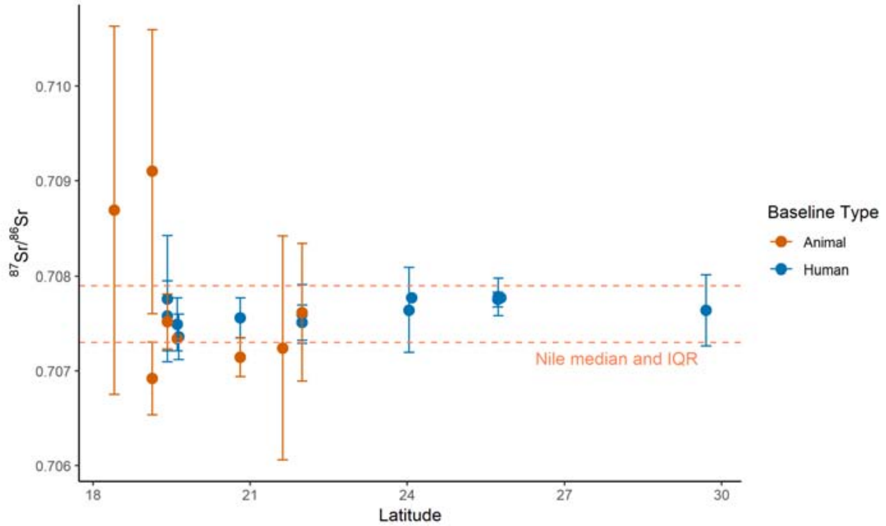


**Figure 3**. Median and IQR $^{87}Sr/^{86}Sr$ ratios of previous Egyptian/Sudanese research, graphed by latitude (N). Data from Buzon and Simonetti 2013; Buzon et al. 2013; Buzon et al. 2007; Schrader et al. 2019; Touzeau et al. 2013.

(c. 1996–1967 BCE), and expanded during the time of Amenemhat II (c. 1933–1899 BCE) (Czerny 2015; Forstner-Müller 2007). During the Middle Kingdom (2040-1782 BCE), Hutwaret was an administrative center and a harbor city that grew in power to finally become the capital of the regional Hyksos Kingdom around 1650 BCE. Then known as Avaris, various peoples and groups from both near and far negotiated their concepts of life, religion, technology, politics and power in this harbor hub. The city was later largely abandoned around 1550 BCE, evidently following the campaigns of the southern Theban Kingdom (17$^{th}$ Dynasty) in its pursuit to expel the Hyksos rulers and forge the New Kingdom (Bietak 2011; Bietak et al. 2016), although a palace complex in the northeastern part of the city (‘Ezbet Helmi) dating to the early 18$^{th}$ dynasty shows a certain continuity of site use (Bietak 2018).

## Materials

The animal bones (n=6) were sent from the Bavarian State Collection of Anthropology and Palaeoanatomy (SAPM) in Munich (Germany) and the Natural History Museum Vienna (Austria) to Bournemouth University (United Kingdom) for destructive analyses. The SAPM animal bones were originally sent to the institute by Angela von den Driesch, one of the zooarchaeologists examining the material from Tell el-Dab‘a (Boessneck & von den Driesch 1992) whose zooarchaeological reference collection formed part of the SAPM when it was founded in 2000 (Henriette Obermaier, SAPM, pers. comm.). However, the original context information beyond site provenance no longer exists. The samples from the Natural History Museum Vienna derive from a tomb in area A/II at Tell el-Dab'a that, according to its stratigraphy and the included grave goods (Bietak 1991:46-50), can be dated to stratum F (Middle Bronze Age II A-B), which is the period shortly before the rise of the Hyksos.

## Methods

Small pieces of animal bone (4–68mg) were separated from the larger pieces and sandblasted to remove surface contaminants. The three rodent samples appeared to have been treated with some sort of resinous material, so all samples were treated with acetone for 5 minutes before being rinsed three times with MilliQ water. Samples were purified using the ion exchange method presented by Deniel and Pin (2001). Strontium isotope ratios were measured using a ThermoFinnigan Multi-collector ICP Mass Spectrometer (MC-ICP-MS) at the Department of Earth Sciences, Durham University (United Kingdom). Reproducibility of the standard NBS987 during sample analysis was 0.710248±0.000010 (2SD, n=12). All NBS987 values have been normalized to the accepted value of 0.710240.

## Results and discussion

The six samples analyzed have a restricted $^{87}Sr/^{86}Sr$ range, 0.707658–0.707779 with a median value of 0.707707±0.000061 (**Table 3**). This range and mean follow the observed Nile values (**Figure 4**). Other regions might have experienced changes to the local environment from agricultural practices such as the use of lime (Thomsen & Andreasen 2019), but the arable Nile Delta region is not expected to have been altered significantly. As bone tissue has been shown to readily equilibrate with the surrounding burial environment (Budd et al. 2000), centuries of annual inundation with Nile water may have caused diagenetic alterations, causing the leaching of strontium from bone and the precipitation of strontium from the groundwater and soil. Further, biogenic and diagenetically-deposited apatite are structurally very similar and thus difficult to separate (Hoppe et al. 2003; Trickett et al. 2003). Comparing the relative concentration of strontium in associated tooth enamel has been used as a metric of whether bone $^{87}Sr/^{86}Sr$ values have been altered due to post-depositional diagenesis (Montgomery et al. 2007), but no animal tooth enamel from Tell el-Dab'a is currently available for destructive analyses. Because of the limited physical range from which these samples are derived, the six samples can stand as an initial local bioavailable signature of the biospheric range until a wider sampling strategy can be utilized in later studies to assess human mobility and migration to the site.

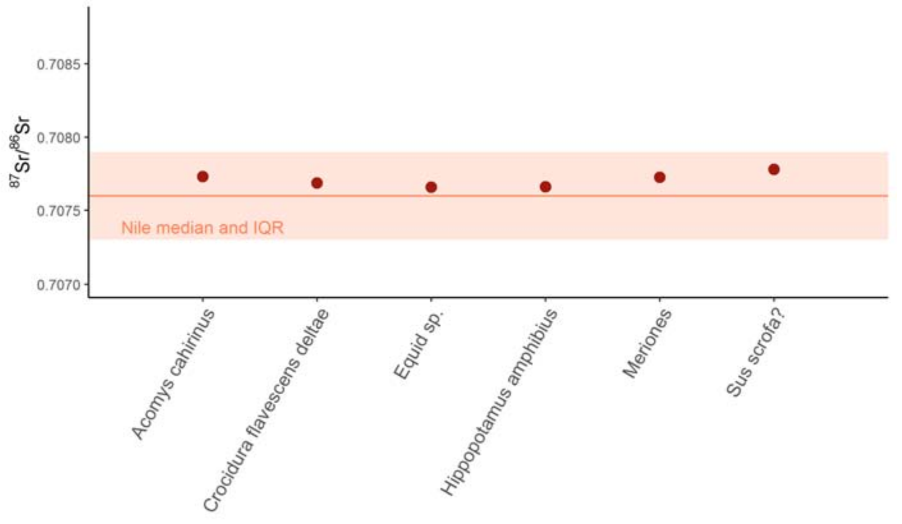


**Figure 4.** $^{87}Sr/^{86}Sr$ ratios of Tell el-Dab‘a animals in reference to Nile median and IQR.

## Conclusions

Overall, the whole of the Nile shows a median strontium isotope ratio value of 0.7076 with an IQR of 0.0003. This homogeneity will create challenges for determining movement up and down the Nile, but stands as a restricted range for identifying animals and humans in the past who originated from outside this area. Yet, this review highlights major gaps in research knowledge of the wider region, as no strontium ratios outside the Nile Valley in Egypt and the Sudan are currently available for comparison.

Faunal samples collected from the site of Tell el-Dab‘a display a narrow range of strontium ratios that fit within the wider Nile Valley. They will serve as a useful baseline of values for future research investigating human paleomobility for those buried at Tell el-Dab‘a and associated sites in the Nile Delta (Forstner-Müller 2010). Given that the restricted biogenic range of values along the Nile can be taken as established,

**Table 3.** $^{87}Sr/^{86}Sr$ results of faunal samples from Tell el-Dab‘a.

| Sample tag | Species | Common name | Bone type | $^{87}Sr/^{86}Sr$ | SE |
|---|---|---|---|---|---|
| T81/371 | *Acomys cahirinus* | Cairo spiny mouse | coxa | 0.707730 | 0.000004 |
| T81/9 | *Crocidura flavescens deltae* | African giant shrew | femur | 0.707688 | 0.000006 |
| T83/147 | *Meriones* sp. | Gerbil | femur | 0.707725 | 0.000006 |
| T83/1295 | *Hippopotamus amphibius* | Hippopotamus | mandible | 0.707660 | 0.000008 |
| T83/125 | *Equid* sp. | Equid | femur | 0.707658 | 0.000008 |
| A/II l/11 G.3/14 | *Sus scrofa* (?) | Pig | vertebra | 0.707779 | 0.000008 |

future research energy and time should be spent gathering baseline samples outside the Nile catchment rather than continuing to confirm the Nile Valley strontium range.

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