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Fish δ13C and δ15N results from two Bronze/Iron Age sites (Tell Tweini & Sidon) along the Levantine coast

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ABSTRACT

Stable isotope ratio measurements of fish remains from archaeological sites are relatively rare so here we report results of 201 fish remains from two Bronze and Iron Age sites along the Syrian (Tell Tweini) and Lebanese (Sidon) coast to document the inter- and intra-specific variation of the $\delta^{13}C$ and $\delta^{15}N$ isotope values. Due to poor preservation, successful isotopic results were only obtained from 42 specimens (21%). Our results were combined with previously published fish isotopic results from Sidon (n = 16) so that a total 58 specimens representing 16 different fish taxa are presented. A wide variation was observed between species that appears to be related to the ecology of the fish, in particular their salinity tolerance and feeding behaviour. The largest intra-specific variation was observed in mullets (Mugilidae) and seabreams (Sparidae) in both $\delta^{13}C$ and $\delta^{15}N$ values, and it appears, after comparison with published data from the Northern Aegean, some clustering occurs with location. However, the data clustering is not discrete enough to allow provenancing of fish remains from archaeological sites in this region. This large series of fish isotope values can also serve as an isotopic baseline for other studies, including the dietary reconstruction of Eastern Mediterranean human remains.

1. Introduction

Until recently, the importance of fishing in the eastern Mediterranean during prehistoric and, in particular, historic times was rather poorly documented, mainly as a result of the lack of sieving during excavation combined with the limited number of modern reference collections needed for the correct identification of fish bones (Van Neer et al., 2005; Bar-Yosef Mayer and Zohar, 2010). Although sieving is still not systematically practised on historic sites (i.e. from the Bronze Age onwards) in the region, some larger ichthyofaunas have been retrieved and published over the last decade, mainly from the Levantine coast (Fig. 1). This is the case in southern Turkey for 5th c. BC Kinet Höyük (Çakirlar et al., 2016), in Syria for Bronze and Iron Age Tell Tweini (Lernau, 2006Linseele et al., 2013Linseele et al., 2019), in Lebanon for the Bronze Age site Tell Fadous (Genz et al., 2009) and for Bronze and Iron Age Sidon (Van Neer, 2006; Chahoud, 2013, 2016/2017), in Israel for Iron Age Tel Dor (Raban-Gerstel et al., 2008), for Bronze and Iron Age Megiddo (Lernau, 2006), for Bronze and Iron Age City of David (Jerusalem) (Lernau et al., 2008), for (mainly) Iron Age Tel Beth-Shean (Lernau, 2009) and for Middle and Late Bronze Age Lachish (Lernau and Golani, 2004). These coastal sites are characterised by an exploitation focussing on inshore marine fish, including brackish water species when the sites are located along an estuary or lagoon. Freshwater fish are less abundant and, depending on the location of the site, can include carp fish (Cyprinidae family), cichlids (Cichlidae family, including tilapia) and catfish (Clariidae). The import of Egyptian freshwater species, in particular the Nile perch (*Lates niloticus*) is attested since the Early Bronze Age and becomes more important during the Middle Bronze Age (Van Neer et al., 2004).

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Fig. 1. Location of Tell Tweini, Sidon and the other Levantine sites mentioned in the text.

The relative contribution of fish to the overall human diet in the Eastern Mediterranean region (and elsewhere) is still poorly understood. This is due to the often incomplete recovery of the fish bones as a result of the aforementioned inadequate sampling techniques, and to the relatively poor preservation of fish bones compared to those of other vertebrates which makes it difficult to quantify the relative importance of aquatic and terrestrial resources (Szpak, 2011; Fuller et al., 2012). Although the meat yield per fish is low compared to that of a domestic animal (sheep, goat, pig, cattle) or a hunted medium-sized species (e.g., a gazelle), it is possible that fish were a regular food item. Judging from the large amount of fish bones on sites such as Sidon (Chahoud, 2016/2017), where systematic sieving has been carried out, and taking into account the preservation bias, fish may have been more often on the menu than meat from a domestic animal that may have been slaughtered less regularly, or that may have been purchased less frequently by consumers. Stable isotope ratio studies, in particular δ^{13}C, δ^{15}N, and δ^{34}S have the potential of contributing to the question what fish meant in terms of nutritional value compared to terrestrial animals and plant food (e.g. Szpak, 2011; Fuller et al., 2012; Nehlich, 2015; Robson et al., 2012, 2016).

However, unlike humans and terrestrial animals, fish have thus far received little attention during stable isotope ratio analysis work carried out on Mediterranean archaeological sites. Previous stable isotope work (δ^{13}C and δ^{15}N) on fish bone collagen in the region includes sporadic samples analysed from Upper Palaeolithic and Mesolithic deposits on the island of Favignana, Ègadi Islands, Sicily (Mannino et al., 2012; n = 3 fish), from Mesolithic layers at Uzzo Cave in Sicily (Francalacci, 1988; n = 1 fish), Early Bronze Age Cova des Riuets at Formentera, Spain (Garcia-Guixé et al., 2010; n = 5 fish), Middle Bronze Age and Late Roman/Byzantine contexts at Ya'amūn, Jordan (Sandias and Müldner, 2015; n = 5 fish), Roman period Leptiminus, Tunisia (Keenleyside et al., 2009; n = 2 fish), Roman period Velia, Italy (Craig et al., 2009; n = 4 fish), Roman period Isola Sacra, Italy (Prowse et al., 2004; n = 5 fish), and late medieval Gandía, Spain (Alexander et al., 2015; n = 5 fish). In addition, a previous isotopic study was conducted at the site of Sidon, Lebanon (Schutkowski and Ogden, 2012; n = 16 fish), but as we have resampled additional material from Sidon for this study, these results will be combined and discussed in more detail below. Finally, the only detailed archaeological study carried out thus far in the Mediterranean was on five Northern Aegean sites dating between the Mesolithic and classical times of which a total of 76 fish bone samples were analysed of specimens identified at the level of family (Vika and Theodoropoulou, 2012).

In addition to the aforementioned δ^{13}C and δ^{15}N work, δ^{18}O analysis has been carried out on molariform teeth of gilthead seabreams (*Sparus aurata*) from 12 coastal and inland sites in the southern Levant dating between the Pre-Pottery Neolithic and the Byzantine period (Sisma-Ventura et al., 2015, 2018). This study allowed the provenance of the sparids to be documented and showed that they came from other locations besides the expected coastal waters. Since the Late Bronze Age, it appears that they also came from hyper-saline lagoons indicating either that such habitats existed in the past near the Levantine coast or, alternatively, that some of the seabreams were an import from Egypt.

1.1. Stable isotope ratios in archaeological aquatic environments

While many complexities are associated with stable isotope ratio measurements in aquatic ecosystems (Schoeninger and DeNiro, 1984; Szpak et al., 2009, 2011), δ^{13}C and δ^{15}N results have the ability to distinguish between fish residing in different localities (Grupe et al., 2009; Fuller et al., 2012; Robson et al, 2016; Guiry, 2019). For example, a study of 18 taxa of archaeological fish remains from Belgium found that freshwater fish had a distinct range of δ^{13}C values (−28‰ to −21‰) compared to fish residing in brackish (−20‰ to −15‰) and marine (>−14‰) environments (Fuller et al., 2012). In marine environments, microalgae such as phytoplankton have higher δ^{13}C values compared to macroalgae such as kelps and seaweeds (France, 1995), and thus fish inhabiting ecosystems closer to shore and in benthic environments will have enriched carbon and nitrogen isotopic results in relation to fish from offshore and pelagic environments (Wainright et al., 1998; Fuller et al., 2012). Fish isotopic values are also influenced by latitude, with middle latitude species exhibiting higher δ^{15}N results in relation to species from higher latitudes (Newsome et al., 2010), and this can complicate the direct comparison of the same archaeological species from different locations. In addition, fish isotopic results from the same species can vary as a result of maturity and size of the individual (Häberle, 2016a, 2016b). Thus, where possible the reconstructed fish lengths of archaeological specimens should be reported and archaeologists are encouraged to implement sieving as a rule during excavation so that fish from all different size classes can be recovered and compared to gain a fuller understanding of aquatic resource subsistence practices in the past.

2. Material and methods

As mentioned above, the δ^{13}C and δ^{15}N stable isotope work in the Mediterranean has thus far mainly been carried out on a limited number of specimens of a small number of families. For the present study we had at our disposal the two extensive ichthyofaunal assemblages that were retrieved at Tell Tweini (Linseele et al., 2013; Linseele et al., 2019) and Sidon (Van Neer, 2006; Chahoud, 2016/2017) two historic sites along the Levantine coast. At both sites there is evidence for the exploitation of the local marine and freshwater habitats as well for the import of Nile fish. Fig. 2 shows the relative importance of the major fish groups at both sites. The proportions shown for Sidon are

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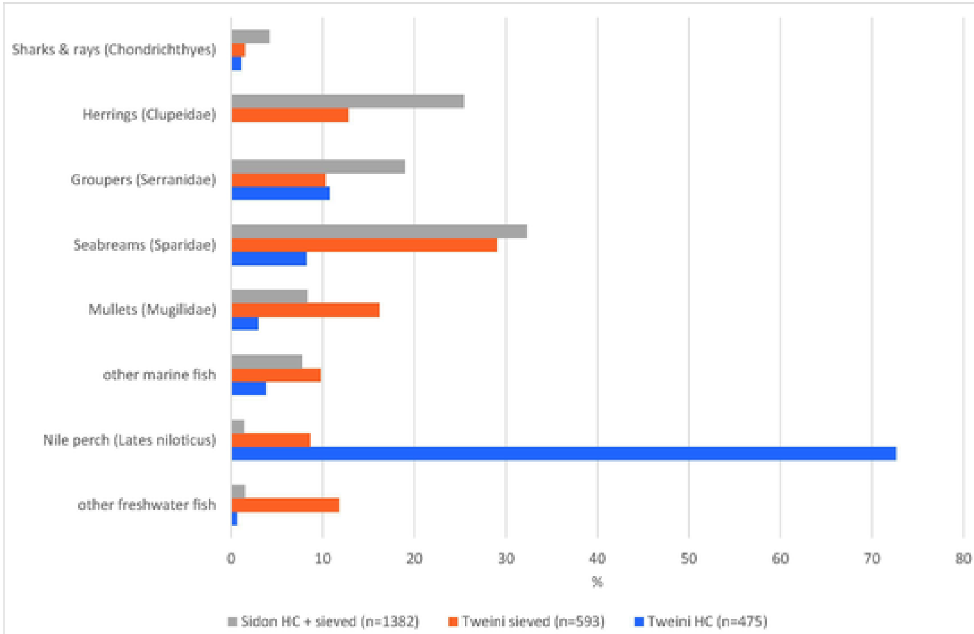

Fig. 2. Relative importance of the major fish groups identified at Tell Tweini and Sidon. HC = hand collected. The sieved and hand collected materials from Tell Tweini are shown separately as not all the sediment was sieved at Sidon.

based on material derived from Middle Bronze Age structures and a temple (Chahoud, 2016/2017, Table B.9) and there fish bones were almost entirely obtained through fine sieving at a 0.5 mm mesh and systematic floatation. The fish fauna from Tell Tweini (Linseele et al., 2013: 214, Table 2) does not include many Middle Bronze Age remains, most of the material dates to Late Bronze Age, to the Iron Age or is undated. The proportions shown in Fig. 2 for this site are those for all the periods together. At Tell Tweini fish was retrieved from most contexts by hand collecting in the trench whereas wet sieving was done on subsamples of soil using a 0.5 mm mesh. Sieved and hand-collected samples were kept separate during analysis which allows a better comparison with the ichthyofauna of Sidon. The hand-collected sample of Tell Tweini is clearly biased towards larger taxa and the high proportion of Nile perch is particularly striking. The sieved samples of Tell Tweini compare rather well with the assemblage from Sidon with the same major groups being well represented, also the smaller fish such as the herrings. It appears hence that during the Bronze Age and Iron Age similar taxa were exploited at coastal sites.

Table 1 lists the fish bone samples from Tell Tweini (n = 129) and Sidon (n = 72) that were selected for the $\delta^{13}C$ and $\delta^{15}N$ stable isotope ratio analyses carried out here, as well as the samples (n = 24) from Sidon that were provided by WVN for an earlier isotope study (Schutkowski and Ogden, 2012). Thanks to the sampling protocol that aimed at sampling as many taxa as possible, no less than 20 different fish families could be included in the analysis. Unlike studies carried out previously, we tried as much as possible to sample bones of fish that were identified beyond family level. Additionally, we also recorded the reconstructed fish lengths as it is known that due to dietary changes through their lives, isotopic signatures can change as fish grow (Häberle et al., 2016a, 2016b). Finally, in the results and discussion paragraphs below reference is often made to the geographical distribution or ecological preferences of fish species. Unless stated otherwise this information has been taken from Froese and Pauly (2018).

Fish bone specimens from Tell Tweini (n = 129) and Sidon (n = 72) were prepared for collagen extraction at the Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology in Leipzig, Germany, using the protocol outlined in Richards and Hedges (1999), with the addition of ultrafiltration prior to lyophilization as described in Brown et al. (1988), and the reader is directed to these articles for more details. However, given the poor quality collagen preservation from these specimens, in some cases a smaller sized cut off of ultrafilter was used (>10 kDa), instead of the normal (>30 kDa) to increase collagen yield for isotopic analysis. This was done when > 30 kDa fractions produced no yield, as all of the < 30 kDa fractions were saved for each specimen. Comparison of results with between gelatin samples ultrafiltered at 10 and 30 kDa is possible as past research has found no meaningful differences between these two collagen fractions (Beaumont et al., 2010). The purified collagen (~0.5 mg) was placed in tin capsules and combusted in duplicate (where possible) to CO_2 and N_2 in an automated carbon and nitrogen analyzer (Carlo Erba) coupled to a continuous-flow isotope ratio-monitoring mass spectrometry (PDZ Europa Geo 20/20). Samples were run using the IAEA N1, N2, CH6 and CH7 isotope standards as well as two internal standards (bovine liver and methionine). Errors were calculated using the average variation of the internal standards over at least one year of measurements and were less than 0.2‰ for both $\delta^{13}C$ and $\delta^{15}N$.

3. Results

Tables S1 through S3 provide the isotopic results, context information and reconstructed body lengths of the analysed fish. Of the 129 samples from Tell Tweini, representing 19 taxa, only 36 (28%) gave acceptable results and this reduced the number of taxa to 13. In the case of Sidon, 22 of the 96 samples (23%) produced acceptable results and these represent 9 taxa, 7 of which are also represented at Tell Tweini.

The samples from both Tell Tweini and Sidon were poorly preserved in terms of % collagen yield, with nearly all having values below 1%, but as the extracted collagen was ultrafiltered, this significantly contributed to the lower collagen yields (Guiry et al., 2016). This ultrafiltered collagen, while smaller in terms of % collagen yield, represents a more purified form of collagen fraction since contaminants (e.g. humic acids) and the degraded collagen fragments of these poorly preserved samples are discarded (Brown et al., 1988; Beaumont et al., 2010; Fuller et al., 2014, 2015). Therefore, despite the very low % yields, we believe that what was measured was the best preserved

Table 1
Overview of the fish bones from Tweini and Sidon processed during this study, as well as those from Sidon previously analysed by Schutkowski and Ogden (2012).

Fish Species	Tweini		Sidon		Sidon	
	This study		This study		Schutkowski and Ogden (2012)	
	N analysed	N successful	N analysed	N successful	N analysed	N successful
Lamnidae (mackerel sharks)						
Lamna nasus (porbeagle)	–	–	1	0	–	–
Carcharhinidae (requiem sharks)	3	2	–	–	–	–
Sphyrnidae						
Sphyrna sp. (hammerhead shark)	–	–	17	2	3	2
Hypotremata (rays and skates)						
Myliobatidae (eagle and manta rays)	3	0	–	–	–	–
Hypotremata indet.	3	2	–	–	–	–
Clupeidae (herrings, shads, sardines)	2	0	2	0	–	–
Belonidae (needlefishes)	1	1	–	–	–	–
Serranidae (groupers)	21	4	31	1	3	3
Moronidae (temperate basses)						
Dicentrarchus sp.	2	1	1	0	–	–
Carangidae (jacks and pompanos)						
Seriola dumerilii (greater amberjack)	–	–	7	0	3	3
Carangidae indet.	7	2	–	–	–	–
Sciaenidae (drums or croakers)						
Argyrosomus regius (meagre)	10	3	–	–	3	1
Sciaena umbra/Umbrina cirrosa (corb)	1	1	–	–	–	–
Sparidae (seabreams)						
Sparus aurata (gilthead seabream)	19	4	1	1	2	2
Dentex sp.	1	0	–	–	–	–
Diplodus sp.	5	1	–	–	–	–
Pagrus sp.	9	2	–	–	1	1
Sparus/Pagrus	5	3	–	–	–	–
Sparidae indet.	4	0	–	–	–	–
Scaridae (parrotfishes)						
Sparisoma cretense (parrotfish)	1	0	–	–	–	–
Scombridae						
Euthynnus alletteratus (little tunny)	–	–	1	0	–	–
Thunnus sp. (tuna)	–	–	2	0	3	0
Sphyraenidae						
Sphyraena sp. (barracudas)	1	0	–	–	–	–
Mugilidae (mullets)	14	4	–	–	3	2
Balistidae (triggerfishes)						
Balistes capriscus (grey triggerfish)	1	0	2	2	–	–
Anguillidae (freshwater eels)						
Anguilla anguilla (European eel)	1	1	–	–	–	–
Cyprinidae (carp fish)						
Barbus sp. (barbel)	1	0	–	–	–	–
Cyprinidae indet.	2	2	–	–	–	–
Clariidae (clariid catfish)	2	0	2	0	–	–
Latidae (Lates perches)						
Lates niloticus (Nile perch)	10	3	5	0	3	2
TOTAL	129	36 (28%)	72	6 (8.3%)	24	16 (67%)

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collagen fractions from these generally very poorly preserved fish bone specimens. In addition, we examined the %C and %N values of each sample and excluded specimens with values <13% for carbon and <4.8% for nitrogen based on the findings that Ambrose (Ambrose, 1990) provided for non-ultrafiltered collagen. Specifically, Ambrose (1990) noted that well preserved bones with % collagen yields below 2% had %C and %N values above 13% and 4.8%, respectively. Ambrose (1990) only rejected specimens as diagenetically altered that had %C values below 4.5% and %N values below 0.9%. While using these %C (>13%) and %N (>4.8%) values as criteria for well-preserved collagen potentially excludes specimens that may have produced acceptable isotopic results, there are no published acceptable ranges for %C and %N for ultrafiltered collagen. Finally, samples with atomic C:N outside the acceptable values of 2.9–3.6 were not considered in the results and discussion (DeNiro, 1985).

There is a marked difference in the success rate of the Sidon samples processed by us (8.3%) and those analysed by Schutkowski and Ogden (2012) (67%). Although it is not excluded that differences in their extraction protocol may have played a role, it is worth mentioning the fact that the fish bones we analysed came from different archaeological contexts. All the fish remains analysed by Schutkowski and Ogden (2012) were from bones that were buried as grave goods together with human interments, and this protected/sealed environment possibly decreased diagenetic destructive processes and increased collagen survival. Almost all of the fish remains that we analysed came from refuse layers, and these bones were likely subject to more intensive, harsh and destructive diagenetic processes. For example, subaerial weathering and decay under the influence of bacteria and fungi almost certainly had a greater impact on the lack of preservation and quality of the collagen recovered in these samples in contrast to Schutkowski and Ogden (2012).

All of the acceptable fish remains from the different time periods of Tell Tweini and Sidon are plotted in Fig. 3 and they show a wide range of δ^{13}C (−29.5‰ to −5.8‰) and δ^{15}N values (4.0‰ to 12.1‰) which is due to the fact that the species are derived from marine, brackish and freshwater habitats and feeding in various trophic levels (e.g. Grupe et al., 2009; Fuller et al., 2012).

The freshwater species that yielded acceptable isotopic results include European eel (*Anguilla anguilla*), cyprinids and Nile perch (*Lates niloticus*). The very low δ^{13}C value of the eel, only found at Tell Tweini, is completely in line with the freshwater habitat in which the species stays during most of its life. The cyprinids, only represented at Tell Tweini, and the Nile perch, from both Tell Tweini and Sidon, have δ^{13}C values that are comparable to those of the mullets (Mugilidae). Mullets are marine fish with a preference for estuarine environments and lagoons and some species can also stay seasonally in freshwater. The δ^{13}C values of the Nile perch (−14.6 ± 1.3‰), a species that was imported from Egypt (e.g., Linseele et al., 2013), indicate that these fish must have originated from the Nile delta. It makes sense in terms of travel distance that production of preserved fish meant for export took place here. The two cyprinid bones that yielded acceptable results are from rather large individuals with a standard length (SL) of 50–60 cm and 60–70 cm. Their δ^{13}C values are −15.1‰ and −16.5‰. The *Barbus* sp., the sole cyprinid from Tell Tweini that could be identified beyond family level, had a C:N that was too high, but its large size, more than 60 cm SL, is of relevance for the interpretation of the provenance of the cyprinids.

When looking at the freshwater fish distribution in the Levant, it appears that there are no such large cyprinids in the ichthyofaunal province to which Tweini belongs (Krupp, 1987). The only cyprinid reported from this province is *Capoeta damascina* that has a maximum standard length of 35 cm (Coad, 2010). *Barbus* does not live in the small coastal rivers of Lebanon and Syria, but *Barbus canis* and *Barbus longiceps* occur further south in the small coastal rivers of Israel (Krupp, 1987). A wide range of cyprinid taxa are known from the Orontes River that can attain the large sizes of the Tell Tweini specimens (Krupp, 1987). If it is assumed that the cyprinids were imported to the site from the Orontes River, then they must have come from waters close to or in the estuary where brackish conditions prevailed. Alternatively, the cyprinids may have come from the Nile delta, in which case they were probably *Barbus bynni* or *Labeo coubie*. These are the only species from the Egyptian Nile reported to attain sizes over 50 cm SL (Lévêque and Daget, 1984).

In terms of their δ^{13}C values the four mullets from Tell Tweini plot in a rather narrow range between −19.2‰ and −15.6‰ typical of brackish water fish. There is more variation in the δ^{15}N values (6.2‰ to 10.2‰), but this does not seem to be related to a size-dependent change in dietary uptake (cf. Häberle, 2016a, 2016b) as both the lower three values and the highest values are from fish that measured 40–50 cm SL. Such a relationship is also not shown by the two mullets from Sidon that have values far apart from each other and that are also outside the range observed for the Tell Tweini Mugilidae: δ^{13}C = −7.9‰; δ^{15}N = 4.0‰ for a fish of about 50 cm SL and δ^{13}C = −13.3‰; δ^{15}N = 11.5‰ for a somewhat smaller specimen of 35–40 cm SL.

Another fish taxon that falls in the δ^{13}C range corresponding to a brackish environment is the seabass, *Dicentrarchus* sp., only represented by one specimen from Tell Tweini (δ^{13}C = −15.7‰) that can either be a *Dicentrarchus punctatus* (spotted seabass) or a *Dicentrarchus labrax* (European seabass). Both species can be found in coastal waters, but they are especially common in estuaries and occur occasionally in rivers.

The remaining fish that were investigated have δ^{13}C values typical of marine environments. The best represented fish family are the Sparidae (seabreams) the identification of which was possible at different levels. The majority of the diagnostic elements that were chosen for isotopic analysis could be identified as *Sparus aurata*, the gilthead seabream. Other specimens were identifiable to genus level (genera *Diplodus* and *Pagrus*) whereas some of the analysed fish bones were la-

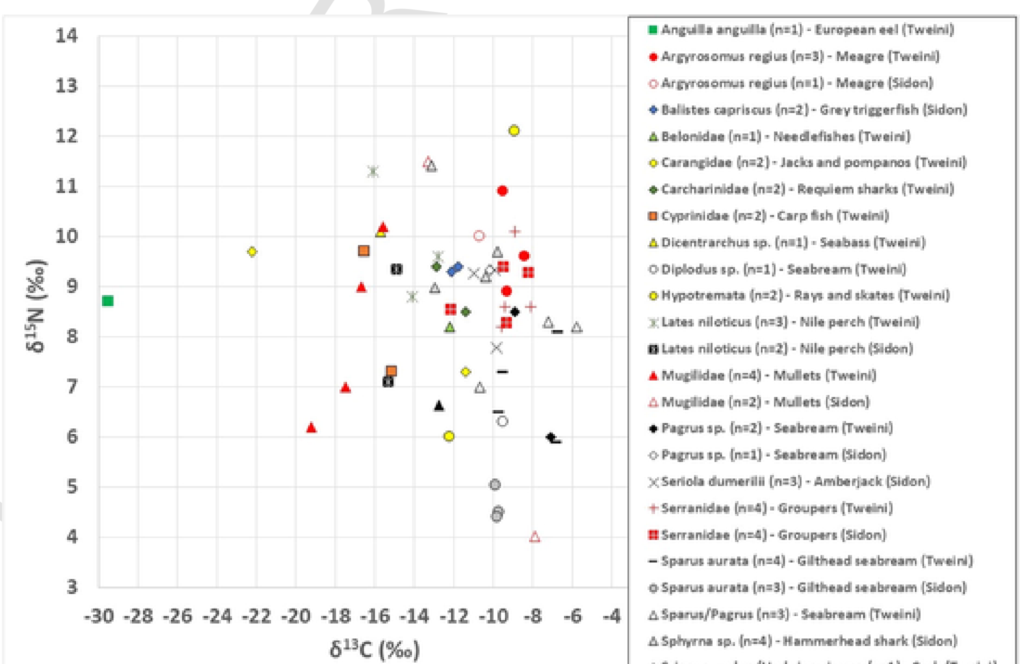

Fig. 3. δ^{13}C and δ^{15}N results from all of the fish taxa from Tell Tweini (n = 36) and Sidon (n = 22) that produced acceptable isotopic results.

belled as *Sparus/Pagrus* because no distinction was possible between *Sparus aurata* and one of the three *Pagrus* species living in the area. Despite the fact that the analysed bones are from at least three different taxa, it appears at Tell Tweini that the range of both isotope ratios is rather narrow for all sparids together: δ^{13}C (−10.7‰ to −5.8‰) and δ^{15}N values (5.9‰ to 8.5‰). There are a large number of sparid species along the Syrian coast, but most of the taxa represented in our assemblage feed typically on molluscs, crustaceans, worms and some of them also take fish (Bauchot and Hureau, 1986, 1990). This diet explains the relatively low δ^{15}N values compared to the groupers (Serranidae) and the meagre (*Argyrosomus regius*) that are higher trophic feeders with more fish in their diet. The values for the sparids from Sidon show that the sole *Pagrus* sp. (δ^{13}C = −10.2‰; δ^{15}N = 9.3‰) is close to the upper values of the sparids from Tell Tweini whereas all three *Sparus aurata* show remarkably low δ^{15}N values (4.4‰ to 5.0‰). The δ^{13}C values between −9.9‰ and −9.7‰ show the fish are from a marine environment.

The four groupers (Serranidae) from Tell Tweini that yielded acceptable results are of medium size (one of 30–40 cm SL, two of 40–50 cm SL and one of 50–60 cm SL). This means that these fish probably do not belong to one of the species of the genus *Serranus* that do not grow larger than 40 cm SL. The Serranidae with the acceptable results must either belong to *Mycteroperca rubra*, *Hyporthodus haifensis* or one of the four species of the genus *Epinephelus* that occur along the Syrian coast. All these Epinephelinae can attain sizes over 1 m. They feed mainly on cephalopods, crustaceans and fish; the larger individuals feed on a greater proportion of fishes. The carnivorous diet is reflected at Tell Tweini in the δ^{15}N values that range between 8.2‰ and 10.1‰. The four groupers from Sidon are also of medium size: apart from one specimen of 30–35 cm SL, they all are between 50 and 70 cm SL. Their isotope ratios are very comparable to those from Tell Tweini, i.e. δ^{13}C between −12.1‰ and −8.2‰; and δ^{15}N between 8.3‰ and 9.4‰.

The three meagre (*Argyrosomus regius*) from Tell Tweini are also relatively small specimens (reconstructed SL: one of 35–40 cm and two of 40–50 cm) taking into account that this species can attain sizes of over 1.5 m. Smaller individuals consume mainly crustaceans but when the fish reach sizes from 40 to 45 cm SL they shift their preference to fish (Valero-Rodriguez et al., 2015). This piscivorous diet is reflected in the δ^{15}N values of the Tweini meagre that range between 8.9‰ and 10.9‰. Although meagre are known to spend part of their lives in estuaries and that they in certain regions seasonally enter rivers during adulthood (Quéro and Vayne, 1997), this is not reflected in their δ^{13}C values that range between −9.5‰ to −8.4‰. The sole meagre with acceptable isotopic results from Sidon is from an individual that is much larger (80–100 cm SL) than those from Tell Tweini, but its signature is comparable (δ^{13}C = −10.7‰; δ^{15}N = 10.0‰) showing that it probably had a comparable habitat and diet.

The highest δ^{15}N value observed in all the analysed fish is 12.1‰ for an unidentified ray or skate (Hypotremata) from Tell Tweini that must have been piscivorous. Another shark or ray specimen, from the same site, has a very low δ^{15}N value (6.0‰) and may represent a species with a diet mainly composed of invertebrates such as molluscs. Among the (unsuccessful) fish samples analysed there were three remains of Myliobatidae (eagle and manta rays) that include species such as the eagle ray or the cow ray feeding to a large extent on molluscs and other invertebrates which could result in relatively low δ^{15}N values. Intermediate δ^{15}N values 8.5‰ and 9.4‰ were obtained for requiem sharks (Carcharinidae) from Tell Tweini. Four of the 20 analysed remains of hammerhead sharks (*Sphyrna* sp.), all from Sidon, yielded acceptable results; their δ^{13}C values range between −13.1‰ and −9.8‰; and the δ^{15}N values between 9.0‰ and 11.4‰.

Of the 7 analysed samples of Carangidae (family of the jacks and pompanos) from Tell Tweini, only two yielded acceptable results. Both specimens are of small size (20–30 cm SL) and both their δ^{13}C and δ^{15}N values differ significantly: one is heavily ^{13}C-depleted (−22.2‰) and has a relatively high δ^{15}N value (9.7‰), the other fish has a marine signature δ^{13}C (−11.4‰) and a lower δ^{15}N value (7.3‰). As these two specimens were only identifiable to family level and because there are 11 species in the region it is hard to explain the observed differences. The specimen with the more marine signature could be a juvenile of a larger species that did not yet have the carnivorous diet that is typical of the larger carangids. The specimen with the heavily ^{13}C-depleted value may have been residing in an estuarine environment and its high δ^{15}N value shows that this fish was already carnivorous despite its relatively small size. From Sidon, bones were available from 10 great amberjack (*Seriola dumerilii*) of which three yielded acceptable results. These fish are all of large size (between 90 and 120 cm SL) and their isotopic ratios range between −11.0‰ and −9.8 for δ^{13}C; and between 7.8‰ and 9.3‰ for δ^{15}N. This is a rather narrow range that falls close to the variation observed for the groupers and the meagres.

At Tell Tweini, two additional fish taxa occur, each represented by one specimen with acceptable results. These are a needle fish (Belonidae) of 60–70 cm SL (δ^{13}C = −12.2‰; δ^{15}N = 8.2‰) and a Sciaenidae (δ^{13}C = −12.8‰; δ^{15}N = 6.6‰) that is clearly no meagre but that should belong to a corb either *Sciaena umbra* or *Umbrina cirrosa* of 30–40 cm SL. All three needlefish species living in the area feed on small fish which explains why the δ^{15}N value (8.2‰) is close to the lower values observed for requiem sharks, groupers and meagre. *Umbrina cirrosa* (shi drum) feeds on bottom invertebrates whereas *Sciaena umbra* (brown meagre) feeds on small fish and crustaceans. Finally, at Sidon, two grey triggerfish (*Balistes capriscus*) occur with very similar values: −11.8‰ and −12.1‰ for δ^{13}C; and 9.3‰ and 9.4‰ for δ^{15}N.

4. Discussion

In the presentation of the results above, we concentrated mainly on the data from Tell Tweini as they are the most numerous in terms of sample size and species diversity. The data from Sidon deal with a smaller number of taxa, which are to a large extent in common with Tell Tweini, but these nevertheless provided a partial insight in the variation within species. The number of isotopic results per species, even if combining Tell Tweini and Sidon, is too low to allow for a diachronic analysis. In the paragraphs below we will compare our data with those obtained by Vika and Theodoropoulou (2012) on a number of sites in the northern Aegean (Greece) in an attempt to document the regional variation within taxa, and to see if isotopic signatures can be related to the fish ecology or to the fishing grounds from which they were taken.

The publication on this Greek material discusses the δ^{13}C and δ^{15}N data obtained on a total of 40 fish bone samples that yielded collagen of acceptable quality. The fish remains come from 5 sites in the northern Aegean ranging in time between the Mesolithic/Neolithic and the 5th c. BC. Except for a Neolithic inland site, located along a lake, the sites are insular or coastal. The fish taxa that were used by Vika and Theodoropoulou (2012) have been identified to family level only and include two freshwater families, namely the Cyprinidae (carp fish) and Siluridae which in Greece only comprises the European catfish *Silurus glanis*. The marine taxa are Mugilidae (mullets; MNI = 6), Serranidae (groupers; MNI = 4), Sparidae (seabreams; MNI = 14), Moronidae (temperate basses; MNI = 1), Sciaenidae (drums; MNI = 1), Scorpaenidae (scorpionfish; MNI = 2), Thunnidae (tunas; MNI = 5), and Scombridae (mackerels; MNI = 1). The material from Tell Tweini and Sidon did not include any scorpionfish or mackerels whereas the values obtained for tunas were not acceptable. On the other hand, several marine taxa analysed at Tell Tweini and Sidon are not represented in the dataset of the Greek sites. That is the case for the requiem sharks (Carcharhinidae), hammerhead sharks (*Sphyrna* sp.), needle fish (Belonidae), jacks and pompanos (Carangidae) including the greater am-

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berjack (*Seriola dumerilii*), and grey triggerfish (*Balistes capriscus*). The Levantine sites yielded moreover two freshwater species not present on the Greek sites, namely eel (*Anguilla anguilla*) and Nile perch (*Lates niloticus*). As a result, comparisons of Tell Tweini and Sidon with the Greek sites are restricted to the taxa that they have in common, i.e. the groupers, mullets, seabreams, temperate basses and drums.

The isotopic signatures of the groupers from Tell Tweini and Sidon are almost equal and their average $\delta^{15}N$ values are close to that of the Greek fish (Fig. 4). However, the Greek sites have on average more ^{13}C-depleted values. This low average $\delta^{13}C$ value for the Greek sites is to a large extent due to an aberrant individual ($\delta^{13}C = -19.2‰$; $\delta^{15}N = 8.9‰$) from the Mesolithic/Neolithic cave site of Cyclops at Youra which was omitted from the discussion in Vika and Theodoropoulou (2012). The specimen has a freshwater signature that is difficult to explain as groupers are rarely encountered in such a habitat. Given the old age of the cave deposits from which the bone was recovered, it is unlikely that the specimen would be from an imported Nile perch (as these species can have freshwater and/or brackish isotopic signatures), but given the similar skeletal morphology of groupers and Nile perch these species can sometimes be misidentified as one or the other. If this specimen is not retained, the average values for the Greek groupers ($\delta^{13}C = -13.8 \pm 1.0‰$; $\delta^{15}N = 8.4 \pm 1.2‰$) are closer to those from the Levantine coast. Overall it can be said that the groupers from the Aegean and the Levantine coast do not show a wide variation, despite the fact that in the region this family is composed of numerous species. The isotopic signatures suggest that they apparently occupy rather similar ecological niches.

The mullet family also consists of several species in the eastern Mediterranean and, contrary to the groupers, their ecology varies considerably (Ben-Tuvia, 1986). Thus far no detailed comparative osteomorphological analysis has been carried out on isolated bones of mullets allowing species identification of archaeological specimens. However, of the six species that live in the area nowadays, boxlip mullet (*Oedalechilus labeo*) can probably be excluded as being present at the sites as these fish do not grow larger than 25 cm total length, i.e. about 20 cm SL. The specimens from Tell Tweini and Sidon range in size between 30 and 50 cm SL with the exception of a single bone of a fish measuring 20–25 cm SL that was so small that another specimen (from the same context) had to be added to it in order to have sufficient bone mass for analysis. Unless several specimens have been used in the individual mullet samples of the Greek sites, it is probable that there as well, this smaller species was not included in the analysis. The five remaining species living in Greek, Syrian and Lebanese waters today are the golden grey mullet (*Chelon auratus*), the thicklip grey mullet (*Chelon labrosus*), the thinlip grey mullet (*Chelon ramada*), the leaping mullet (*Chelon saliens*) and the flathead grey mullet (*Mugil cephalus*).

With the Greek mullets included in the graph (Fig. 5), there is a total of 12 data points and these seem to form different isotopic clusters with low and high $\delta^{15}N$ values. The most distinct group is formed by three of the mullets from Greece (two from Mesolithic/Neolithic Youra and one from Late Bronze Age to 5th c. BC Karabournaki) and one of the two fish from Sidon (EBA). The $\delta^{13}C$ values vary between −10.9‰ and −7.3‰ whereas the $\delta^{15}N$ values range between 3.6‰ and 4.3‰. Average values are $\delta^{13}C = -8.9 \pm 1.6‰$; $\delta^{15}N = 4.0 \pm 0.3‰$. Another group is made up of the three other specimens from Greece (one from Youra and two from Bronze and Iron Age Toumba) and the second specimen from Sidon have higher $\delta^{15}N$ values ranging between 7.1‰ and 10.8‰ and their $\delta^{13}C$ values are between −13.3‰ and −11.5‰. Average values are $\delta^{13}C = -12.2 \pm 1.4‰$; $\delta^{15}N = 9.4 \pm 2.1‰$. Finally, all the specimens from Tell Tweini, seem to form a group of fish typical of brackish water with $\delta^{13}C$ values varying between −19.2‰ and −15.6‰ and $\delta^{15}N$ values ranging between 6.2‰ and 10.2‰. Average values are $\delta^{13}C = -17.3 \pm 1.5‰$; $\delta^{15}N = 8.1 \pm 1.8‰$. The wide range in $\delta^{13}C$ values is likely mainly related to the salinity of the waters in which the mullets stayed during their lives (Grupe et al., 2009; Fuller et al., 2012), although it is not possible to link the observed values to a particular species. The five species mentioned above are coastal fish and they can all enter brackish lagoons and estuaries, some of them are said to be rarely found in freshwater (*Chelon auratus*), others frequently enter freshwater (*Chelon labrosus* and *Mugil cephalus*). The latter species is reputed to occur sometimes far upriver.

The large variation in the $\delta^{15}N$ values of the mullets is more difficult to explain at first sight as all species are traditionally classified as

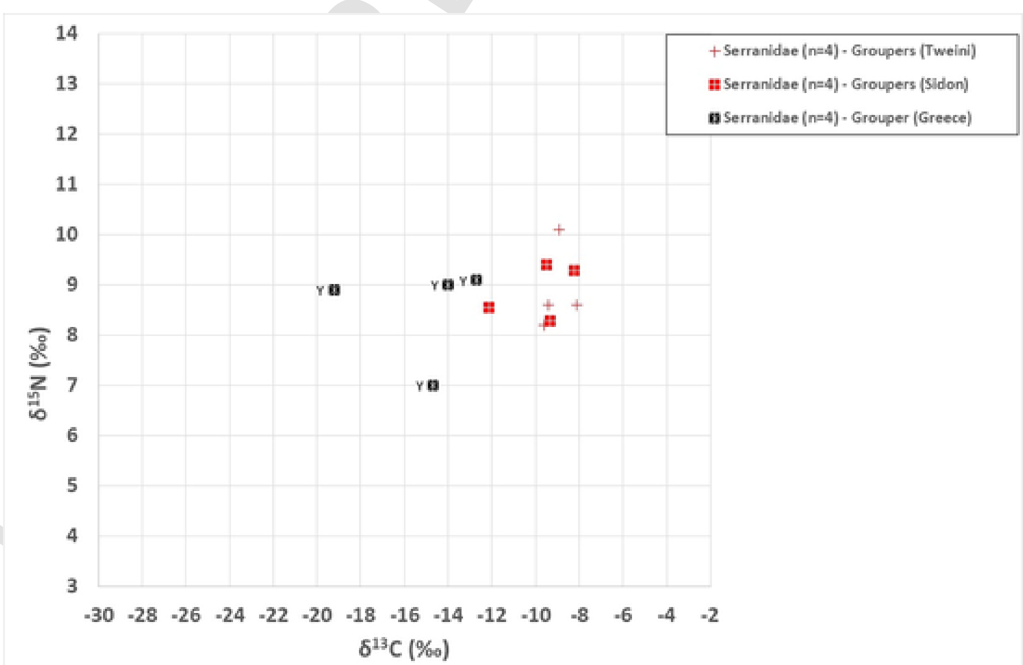

Fig. 4. $\delta^{13}C$ and $\delta^{15}N$ results of the groupers (Serranidae) from Tell Tweini (n = 4), Sidon (n = 4) and Greek sites (n = 4) that produced acceptable isotopic results. All the Greek specimens come from Youra and the Greek results are from Vika and Theodoropoulou (2012).

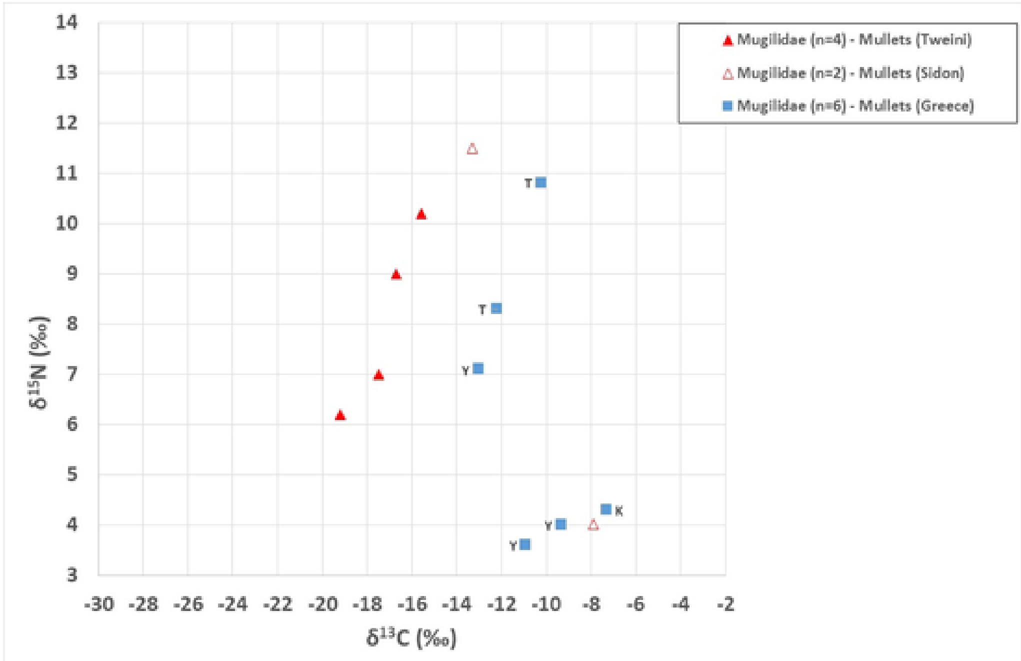

Fig. 5. $\delta^{13}C$ and $\delta^{15}N$ results of the mullets (Mugilidae) from Tell Tweini (n = 4), Sidon (n = 2) and Greek sites (n = 6) that produced acceptable isotopic results. The individual sites from Greece are indicated, K = Karabournaki; T = Toumba; Y = Youra and the Greek results are from Vika and Theodoropoulou (2012).

filter feeders that live on small benthic or planktonic organisms and detritus (Ben-Tuvia, 1986). However, some mullets occasionally take insects or small invertebrates. The mullets from Tell Tweini and Sidon do not show an increase in $\delta^{15}N$ values with increasing size (see above), a phenomenon that cannot be verified in the Greek specimens for which no reconstructed lengths were provided. Stable isotope ratio analysis carried out on modern mullets (*Chelon ramada* and *Chelon aurata*) has shown that the traditional view of mullets being primary consumers, needs to be adjusted (Lebreton et al., 2011). It appears that seasonally, during colonisation of lagoons, they can shift to a dietary behaviour that is mainly based on animal prey, particularly meiofauna, which can position them on a higher level in the food chain. Thus, this may be a reason for the large variation of the $\delta^{15}N$ values found here.

For the seabream family (Sparidae) the stable isotope ratios are available for 14 fish from Greek sites and 14 fish from the Levantine coast, meaning that of all families considered here, this is the largest dataset at our disposal. Twenty-three species live in Greek waters nowadays and along the Levantine coast 24 species have been recorded (22 of which are in common with Greece). These fish belong to 11 genera. The fish remains analysed from Greece were only identified to family level, whereas in the case of Tell Tweini and Sidon an effort has been made to select diagnostic bones. The gilthead seabream (*Sparus aurata*), a species that is very frequently found in archaeological sites along the Mediterranean (Van Neer et al., 2004) is represented by 8 bones whereas three skeletal elements could be identified as belonging to the genus *Pagrus*. Of the latter genus three species are known from Levantine waters, i.e. the red porgy (*Pagrus pagrus*), the bluespotted seabream (*Pagrus caeruleostictus*) and the redbanded seabream (*Sparus auriga*). In Greek waters only the two former species occur. A single bone from Tell Tweini could be identified as *Diplodus*, a genus that consists of five species in the eastern Mediterranean. At Tell Tweini there are also three sparid bones that were identified as *Sparus/Pagrus*.

When the isotopic values of the Greek sites are plotted against those of Tell Tweini and Sidon, it is striking that they show a wider range in both $\delta^{13}C$ and $\delta^{15}N$ values (Fig. 6): the $\delta^{13}C$ values vary between −19.6‰ and −7.6‰ whereas the $\delta^{15}N$ values range between 5.8‰ and 11.6‰. Average values are $\delta^{13}C = -12.9 \pm 3.7$‰; $\delta^{15}N = 9.1 \pm 1.8$‰. Vika and Theodoropoulou (2012) mention that the values from Karabournaki cluster but that is also the case for Youra and even the values for Archontiko and Toumba seem to form distinct isotopic groups according to our plots (Fig. 6). The Toumba sparids fall within the range of the Levantine fish with their clear marine signal, whereas all the others have more ^{13}C-depleted values. The Greek specimens with more ^{13}C-depleted values must have been taken from a brackish environment (Grupe et al., 2009; Fuller et al., 2012). Observations on the ecology and behaviour of the sparids living in the region show that juveniles of many of these species can occur in estuaries, but it is *Sparus aurata* that is said to be the most euryhaline species that can live permanently in brackish waters (Quéro and Vayne, 1997). As the sparid remains from the Greek sites are not identified beyond family level, it cannot be verified if they belong to gilthead seabream and if a similar explanation would hold. There is also a large overall variation in $\delta^{15}N$ values albeit that this is much less the case when the values are considered by region or site (in the case of Greece). From the Levantine material it was clear that there was no growth-related trend in the $\delta^{15}N$ values, but this cannot be verified for the Greek samples as the reconstructed fish lengths are unknown. As the signatures cluster by site, it is likely however that the ecology of the fishing grounds where the sparids came from plays a role.

Based on geographical distribution of this species, the Moronidae specimen from Toumba must belong to *Dicentrarchus* which is the sole genus of that family living in Greek waters and, as in the case of the Syrian seabass, it may have been either *Dicentrarchus labrax* or *D. punctatus*. As mentioned above, both are coastal species that often occur in estuaries and sometimes in rivers. Judging from the $\delta^{13}C$ values, the specimen from Toumba ($\delta^{13}C = -11.6$‰; $\delta^{15}N = 10.4$‰) passed its life mainly in coastal waters whereas the seabass from Tell Tweini ($\delta^{13}C = -15.7$‰; $\delta^{15}N = 10.1$‰) has a brackish water signature. The $\delta^{15}N$ values of both fish are comparable which is in line with their diet that is composed mainly of shrimps, mollusks and also fish (Fig. 7).

At Toumba a single bone of the Sciaenidae family was analysed ($\delta^{13}C = -10.1$‰; $\delta^{15}N = 12.1$‰). Although again no precise identification is provided, it is likely that the specimen is from a meagre (*Argyrosomus regius*) which is a very common species in Mediterranean ar-

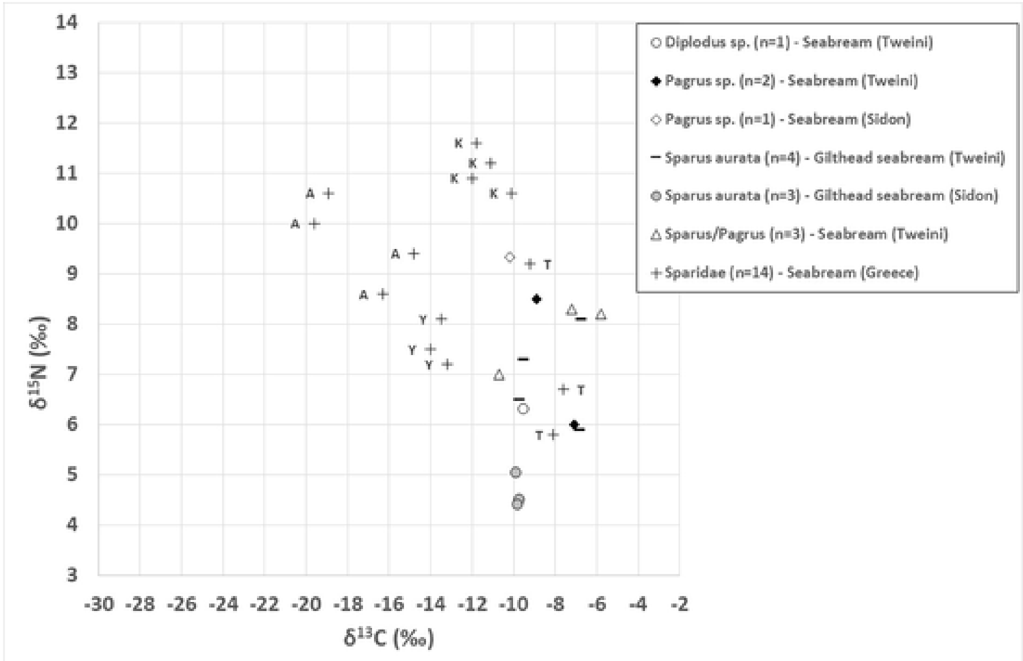

Fig. 6. $\delta^{13}C$ and $\delta^{15}N$ results of the seabreams (Sparidae) from Tell Tweini (n = 10), Sidon (n = 4) and Greek sites (n = 14) that produced acceptable isotopic results. The individual sites from Greece are indicated, A = Archontiko; K = Karabournaki; T = Toumba; Y = Youra and the Greek results are from Vika and Theodoropoulou (2012).

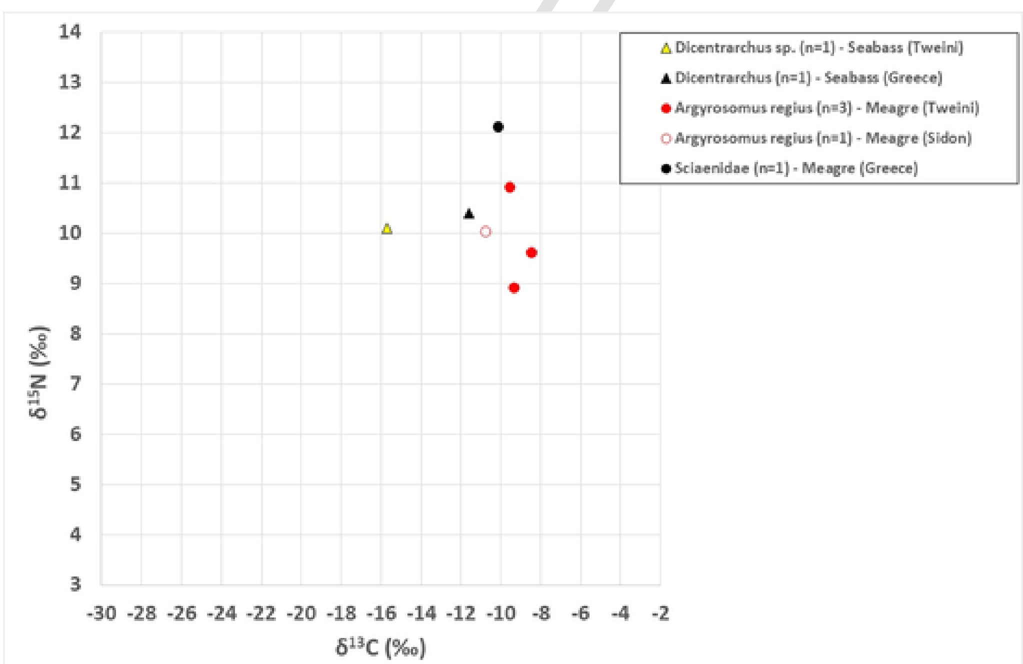

Fig. 7. $\delta^{13}C$ and $\delta^{15}N$ results of the seabass (*Dicentrarchus* sp.) from Tell Tweini (n = 1) and Toumba (n = 1), and of the Sciaenidae from Tell Tweini (n = 3), Sidon (n = 1) and Toumba (n = 1) that produced acceptable isotopic results. The Greek results are from Vika and Theodoropoulou (2012).

chaeofaunas. It was an important food resource and because of its large size (up to over a meter in length) its bones preserve well and are more easily recovered than those of the two other, smaller sciaenid species (*Sciaena umbra* and *Umbrina cirrosa*) occurring in the Eastern Mediterranean. The Toumba sciaenid has a somewhat more elevated $\delta^{15}N$ value than the Levantine meagres but its $\delta^{13}C$ value is in the same range (Fig. 7).

The isotopic results presented here provide important new information on the ecology and dietary patterns of archaeological fish species from the Eastern Mediterranean. However, in addition to this environmental information, these results can serve as a valuable isotopic baseline for human dietary studies in the region. In particular, these results illustrate some cautions that need to be considered in palaeodietary reconstructions. For instance, for archaeological sites where fish species from brackish and/or freshwater environments were exploited, a switch in dietary emphasis from marine to brackish and/or freshwater resources has the potential to be misinterpreted as a change in overall fish consumption. Thus, the entire range of fish isotopic results from an archaeological site should be investigated and considered for more detailed human dietary reconstructions in the Mediterranean region.

5. Conclusion

Of the 201 fish bones analysed by us from Tell Tweini and Sidon plus the 24 analysed from Sidon by Schutkowski and Ogden (2012), 58 or 29% produced acceptable results which covered 16 different fish taxa of the 29 that were sampled in total. These successful samples represent the major fish species that are traditionally found on Levantine sites and that, because of their abundance and high meat yield, were also the most important food providers for humans among the fish. Except for the groupers, the marine fish from the Levantine sites show a wide variation in both δ^{13}C and δ^{15}N values that are related to differences in ecology, in particular salinity tolerance and feeding strategies. Contrary to what was concluded by Vika and Theodoropoulou (2012: 1625) that there would be no clustering with locality and species, we see that for some taxa, such as the Sparidae, a certain clustering appears with site, even in the Greek samples. However, at the moment this data clustering is not discrete enough to allow for provenancing of fish remains from archaeological sites in the region. Thus, additional large-scale isotopic research projects concentrated on archaeological fish remains are needed from other locations in the Mediterranean.

In particular, future work should try and document the isotopic values of taxa that were not successfully analysed here, and that in some cases are not frequently found on archaeological sites as a result of inadequate sampling strategies. For example, small fish taxa, in particular pelagic species of the Clupeidae family (herrings, shads, sardines) that occur in large schools, may have been a regular human food resource in the past. Their remains are often missed during excavation and they may have less preservation chances, which explains why so few samples are available for analysis. For the present study each of the two clupeid samples from both Levantine sites did not yield collagen for analysis. As a result, this dataset presented here does not include any primary consumers, except maybe for some of the mullets. What is also missing are data on the tunas that normally should be high in the food chain. Thus, it is clear that for a more comprehensive estimation of human fish consumption in the past in this region, it will be necessary to have additional large scale studies of archaeological fish remains from the Mediterranean as there is likely important geographical variation in the isotope ratios between and within species.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2019.102066.

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