Journal of Archaeological Science 64 (2015) 46–53

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Oxygen isotope composition of Sparidae (sea bream) tooth enamel from well-dated archaeological sites as an environmental proxy in the East Mediterranean: A case study from Tel Dor, Israel

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ARTICLE INFO

Article history:
Received 28 December 2014
Received in revised form
7 August 2015
Accepted 7 October 2015
Available online 9 October 2015

Keywords:
Oxygen isotope
Tooth enamel
Sparidae
Iron Age
Paleo-environment
Tel Dor

ABSTRACT

This paper examines the potential of oxygen stable isotope composition of Sparidae (sea-bream) tooth enamel phosphate ($\delta^{18}O_P$) as an indicator of the habitat in which the fish were captured. The isotopic compositions of Sparidae molariform teeth recovered from the coastal site of Tel Dor (northern coast of Israel), from a sequence dated to the 12th–7th centuries BCE and from modern samples were studied. The $\delta^{18}O_P$ values of the archaeological specimens exhibited a wide range of values, varying between 21.3 and 25.2 ± 0.2‰.

While $\delta^{18}O_P$ values from the teeth dated to the 12th–9th centuries BCE resembled typical East Mediterranean coastal water, some of the later teeth, dated to the 9th–7th centuries BCE, exhibited higher values. The later values indicate tooth enamel deposition in a hyper-saline environment similar to $\delta^{18}O_P$ values of Sparidae observed at Bardawil Lagoon (Southeastern Mediterranean coast, east of the Suez Canal, Egypt). Prior to this study all Sparidae fish recovered at Tel Dor were regarded as evidence of local fishing activity. The current results exhibit, for the first time, that some of the Sparids may have been exported from the Bardawil Lagoon. We discuss, however, an alternative scenario, namely, the possible existence of saline lagoons near Tel Dor in antiquity.

1. Introduction

Fish remains are considered good indicators of the habitat in which they were captured, since their distribution is restricted by water salinity level and temperature, and they respond directly to changes in these parameters (Casteel, 1976; Schmölcke and Ritchie, 2010). Being ectothermal (body temperature = ambient water temperature), fish teeth and bone oxygen isotope composition ($\delta^{18}O_P$) record the ambient water $\delta^{18}O$ and the temperature of the water at the time of formation (*e.g.*, Longinelli and Nuti, 1973; Kolodny et al., 1983; Pucéat et al., 2010; Lécuyer et al., 2013). Indeed, $\delta^{18}O$ records of fish tooth enamel were used by several scholars to extract the upper ocean temperatures (Kolodny and Raab, 1988; Lécuyer et al., 2003; Pucéat et al., 2003), water mass exchange (Dera et al., 2009), and marine to brackish paleo-environmental conditions (Pelc et al., 2011; Barham et al., 2012; Fischer et al., 2012) throughout the Cretaceous period, as well as the ice volume effect over the Permian sea water (Chen et al., 2013). Recently, $\delta^{18}O_P$ of freshwater fish remains obtained from archaeological horizons were tested as an indicator of the geographical origin of the fish (Dufour et al., 2007; Otero et al., 2011). Surprisingly, although Mediterranean marine fish remains are highly abundant in well-dated archaeological sites along the East Mediterranean coast (Van Neer et al., 2005; Bar-Yosef Mayer and Zohar, 2010), they have not yet been used as proxies for the environmental conditions of the coastal habitats exploited by ancient civilizations.

The current study examines, for the first time, the potential of oxygen isotope values of Sparidae (gilt-head sea bream) tooth

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http://dx.doi.org/10.1016/j.jas.2015.10.004
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enamel recovered from archaeological horizons, as a proxy to determine their origin of habitats along the Eastern Mediterranean coast. Sparidae, especially *Sparus aurata* 1st molariform tooth are excellent as an archaeological proxy because they are easy to identify to species level, frequent in coastal and inland sites, and have been widely traded in the past (Van Neer et al., 2005; Bar-Yosef Mayer and Zohar, 2010). Crucially, *S. aurata* ecology, migration patterns and breeding behaviors are well understood as they are of commercial importance in present day aquaculture (Arabaci et al., 2010; Pita et al., 2002; Tancioni et al., 2003).

In this study we analyzed $\delta^{18}O_P$ values of archaeological Sparidae recovered at Tel Dor, from different chrono-stratigraphical horizons. These were compared to $\delta^{18}O_P$ values of modern Sparid teeth both from the East Mediterranean littoral and from a hypersaline lagoon (previously published; data of Kolodny et al., 1983); and also to a theoretical range of $\delta^{18}O_{PO4}$ calculated for the East Mediterranean littoral. Based on this comparison we discuss the relevance of our data in terms of the identification of the geographic/environmental origin of the Tel Dor Sparidae.

2. Background

2.1. Tel Dor

The archaeological site of Tel Dor is a large mound located on Israel's Carmel coast, about 30 km south of Haifa (Fig. 1). The site is flanked by a large open lagoon to the south and a bay to the north, which provided excellent locations for maritime activities. Dor is identified with D-jr of Egyptian sources, Biblical Dor, and with Dor/Dora of Greek and Roman sources. The documented history of the site begins in the Middle Bronze Age, ca. 2000 BCE, and ends in the Crusader period. From the Bronze Age to Roman times the site primarily functioned as a commercial *entrepôt* for commodities marketed up and down the East Mediterranean coast and a gateway between East and West (Gilboa and Sharon, 2008). From the perspective of this paper, Dor's importance lies in the evidence uncovered at the site for inter-regional exchanges during the early Iron Age (ca., mid-12th–mid-9th centuries BCE) - currently significantly more so than in any site along the East Mediterranean seaboard (Gilboa et al., 2015). Dor was a Phoenician town then, *inter alia* engaged extensively in trade with Egypt, again more so than in any site outside Egypt in this period, evidenced mainly by Egyptian containers at Dor (see below). Therefore, Dor holds a key for understanding emerging Phoenician commercial networks in the Eastern Mediterranean after the collapse of the Bronze Age world in the late 13th/early 12th centuries BCE. Ceramics, indeed, are the best surviving archaeological index for exchanges with Egypt (and other regions), but they (and their contents) comprised a fraction of the merchandize exchanged. This paper, therefore, is also part of a concerted attempt to identify the other commodities shipped from Egypt and its environs Dor (and vice versa), in order to shed light on the nature of these early Iron Age exchanges.

Studies on fish remains recovered from different excavation areas at Tel Dor exhibited that throughout the town's existence, fish played an important role in its economy (Raban-Gerstel et al., 2008; Bartosiewicz et al., in press). The identified fishes indicate intensive fishing along the littoral zone. In addition to the diverse composition of "local" fish, a group of "exotic"/non-local fish was identified. This category comprises Nile perch, *Latesniloticus*, and catfish of the genus *Bagrus* (Raban-Gerstel et al., 2008; Zidane, A., unpublished data). Their appearance at the site indicates that fish were part of the goods traded from Egypt. The fish were either consumed by Tel Dor inhabitants and/or possibly further distributed to other coastal or inland populations (Arndt et al., 2003; Van Neer et al., 2005). While exotic fish are relatively easily-identifiable when distributed through terrestrial trade routes, in coastal sites, the origin of species with a wide distribution along the eastern and western Mediterranean basin is impossible to pinpoint based on classical taxonomic identification.

2.2. Iron Age stratigraphy, dates and contexts

For the Iron Age (Ir), the period investigated here, excavations at Dor produced a very detailed chrono-stratigraphical sequence

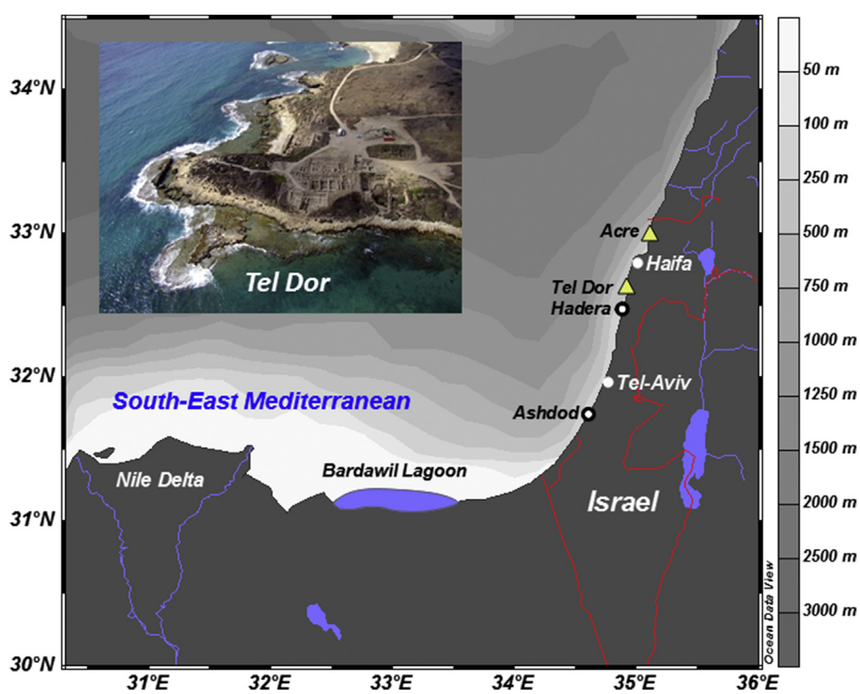

Fig. 1. Location of the archaeological site of Tel Dor and aerial photograph, including other sites mentioned in the text.

comprising 8 horizons spanning roughly the years 1150–650 BCE (Gilboa and Sharon, 2003, in press). Chronologically, the contexts that produced the teeth investigated here can be divided into three groups. In the stratigraphically 'Early group' we include 9 teeth originating from well-stratified contexts spanning the Ir1a *early* to Ir2a horizons (12th–9th centuries BCE), when Dor was a Phoenician town (*e.g.*, Gilboa and Sharon, 2003, 2008). The absolute chronology of these horizons in the Levant has been contested for about two decades, *inter alia* based on ^{14}C dating at Dor and elsewhere. In recent years, however, the gap between the various chronological stances has narrowed considerably (for all these issues, *e.g.*, Sharon et al., 2007; Finkelstein, 2011; Lee et al., 2013; all with references to previous studies). Therefore, and in order not to dwell here on the complex issue of calendaric chronology, the absolute dates indicated in this paper present general age ranges that will probably be acceptable to most scholars.

The six teeth of the 'Intermediate group' originate in various deposits belonging to one constructional fill of a monumental building and a related robbers' trench in Area D2, Phase 'Pre-7'. Both of them overlie the Ir2a level there (Phase D2/8a). The pottery in these two contexts was primarily of Ir2a date, but since the underlying level as well dates to Ir2a, both fill and trench should be considered late within this horizon. This group is 'Intermediate' in two respects. Firstly, stratigraphically it is later than the 'Early' group and earlier than the 'Late' group (below). Second, since the deposits of this group are constructional fills, they may contain redeposited items of the 'Early' horizons (though this was not evident in the pottery).

According to any chronological scheme, these late Ir2a contexts should largely date to the second half of the 9th century BCE, possibly even somewhat later. The two teeth of the 'Late group' belong to a context well dated to Ir2c, the Assyrian-occupation period at Dor, a time-span the chronology of which (late 8th and first half of 7th century BCE) is not contested (Gilboa and Sharon, in press).

2.3. Sparidae, morphology, ecology, and habitat

The family Sparidae (Perciformes, sea bream) comprises a diverse group of neritic fish with a wide geographic distribution in the Atlantic, Mediterranean, and the Black Sea (*e.g.*, Morett et al., 1999; Arabaci et al., 2010). The species *S. aurata* (gilt-head Sea bream; Linnaeus, 1758) and *P. caeruleosticus* (Blue spotted sea bream; Valenciennes, 1830) are characterized by grinding, molar-like teeth (Fig. 2), evolved for cracking hard-shelled organisms. Sparidae teeth are being replaced continuously throughout the fish's life and many times each year. Therefore, each tooth represents the season in which it has erupted, with the possible exception of winter when fish metabolism is lowest (Grigorakis et al., 2002).

Although the diet of *S. aurata* and *P. caeruleosticus* consists mainly of mollusks and echinoderms, it also includes diverse benthic fauna (Pita et al., 2002 and references therein). Both *S. aurata* and *P. caeruleosticus* are euryhaline species that migrate in early spring towards protected coastal waters in search for food (trophic migration). The life-history strategy of *S. aurata* and *P. caeruleosticus* also includes exploitation of shallow, warm, and hyper-saline lagoons during their spawning seasons (Morett et al., 1999; Mariani, 2006; Ahmed, 2011). In late autumn they return to the open sea for breeding. Most importantly, it was recognized that most of the growth of wild *S. aurata* happens during this migration, since the maximal deposition of the fish muscle and fat was recorded for late summer (Grigorakis et al., 2002 and references therein).

Both species are of high economic value as they may reach large body size. *S. aurata* can reach a maximum length (TL) of 70 cm while *P. caeruleosticus* may reach a maximum length of 90 cm (SL) (Bauchot and Hureau, 1990). As a result they are highly exploited for human consumption and bred for aquaculture.

3. Material and methods

3.1. Teeth collection, identification and measurements

We studied teeth of both archaeological and modern sparids. From a total NISP of ca. 16,000 fish remains studied at Dor, more than 1000 were identified as Sparidae (Zidane, unpublished data). Of those more than 60 were identified as *S. aurata* first molariform teeth, with a mean length of 7.6 ± 2 mm. From this sample we selected 11 large first molariform teeth of *S. aurata*. Six teeth identified as *P. caeruleosticus* were also selected for isotope analysis. The archaeological material was sampled from well-dated contexts of different chronological horizons at Tel Dor (see below).

The modern samples (n = 7 teeth) were taken from four fish from two species of native sparids (Sea bream). Three were of *S. aurata* (31.5–41 cm long) and one was of *P. caeruleosticus* (47–48 cm long), all caught in the Haifa Bay in September 2013 and March 2014 (Table 1). From the *S. aurata* 5 first molariform teeth were used for isotopic analysis (Fig. 2) and from the *P. caeruleosticus* two teeth were used.

The teeth were identified to species level based on reference collections of Mediterranean and Nilotic fish (housed at the University of Haifa, Israel and The Autonomous University of Madrid, Spain).

Each tooth used in this study was photographed and measured with a Dino-Lite Digital Microscope (model AM413T Dino-Lite Pro). For each tooth we recorded maximum length and maximum width.

3.2. Isotopes analysis

Sample preparation and analysis were conducted in the National Stable Isotope Facility, Indian Institute of Technology, Kharagpur, India, following the methodology of Bera et al. (2010). Each individual fossil tooth was cleaned by distilled water, dried, and the surficial enamel part (~0.2–0.4 mm layer) was sampled perpendicularly to the growth axis by a micro-dental drill. Pure phosphate from bio-apatite was extracted and precipitated in the form of Ag_3PO_4.

About 300 μg of Ag_3PO_4 were measured in a Delta Plus^{XP} mass spectrometer via a ConFlow interface. The oxygen isotope measurements are reported in the conventional δ-notation expressed in per mil against the international NIST 120C Phosphate Rock standard ($\delta^{18}O_{SW} = +22.65‰$) and Acros Silver Phosphate (ASP) standard ($\delta^{18}O_{SW} = +14.2‰$), where:

$$\delta_{Sample} = \left(R_{sample} / R_{Standard}\right) - 1)*10^3[\%\ \mathrm{VSMOW}]$$
$$R \text{ is } ^{18}O/^{16}O\text{ratio}$$

An inter-laboratory calibration confirms that the chemical separation method for Ag_3PO_4 is contamination-free and robust and the achieved precision is internationally comparable (Bera et al., 2010). The reproducibility of measurements carried out on tooth samples is close to 0.2‰.

3.3. Calculating the East Mediterranean $\delta^{18}O_{PO4}$ theoretical range

Since our data on the expected variations in $\delta^{18}O_p$values in modern sparids was relatively small (Table 1), we calculated a theoretical range of the East Mediterranean $\delta^{18}O_p$. For this

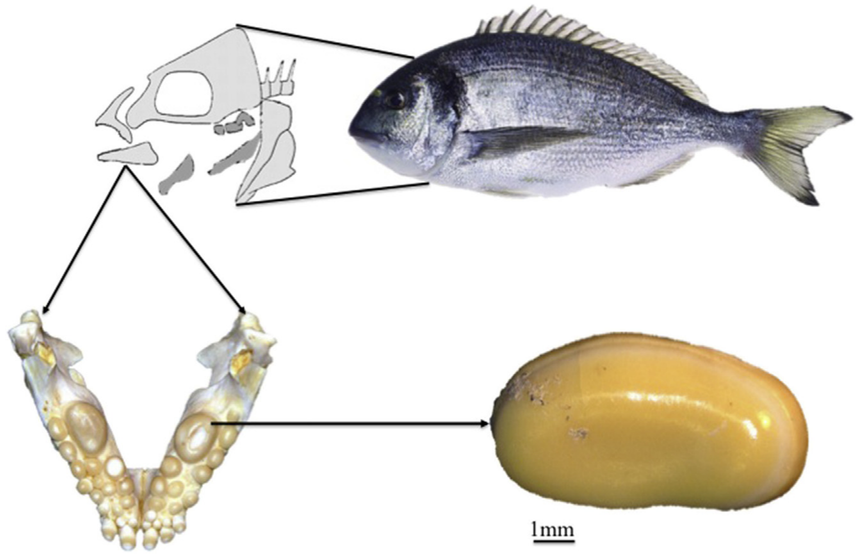

Fig. 2. Anatomic location of *Sparus aurata* dentary and the first molariform teeth.

calculation we used the phosphate temperature-dependent fractionation equation of Lécuyer et al. (2013), describing the relationship between the $\delta^{18}O_p$ of fish tooth enamel, and the ambient temperature and $\delta^{18}O_{SW}$ value. This equation has recently been calibrated with a carbonate temperature-dependent fractionation equation.

Data regarding water temperature was obtained from two coastal stations along the coast of Israel: Hadera and Ashdod (Fig. 1; MedGLOSS stations). For the oxygen isotopic composition of Mediterranean Sea-Water ($\delta^{18}O_{SW}$) we used the data of Sisma-Ventura et al. (2014), covering the entire Israeli coast.

4. Results

4.1. Sparidae teeth dimensions

The dimensions recorded for the teeth collected from modern *P. Caeruleosticus* and *S. aurata* were: length 5.42–5.53 mm and 5.64–11.07 mm, respectively (Table 1).

The Tel Dor Sparidae teeth sampled for this study were 4.29–6.09 mm long for *P. caeruleosticus*, and 6.59–11.25 mm long for *S. aurata* (Table 2). Based on the modern data we may conclude that these teeth belonged to relatively large, i.e. adult sparids.

4.2. Oxygen isotope ratio in modern and ancient teeth

The $\delta^{18}O_P$ values obtained from the molariform teeth of the modern *P. caeruleosticus* ($n = 2$) exhibited a low range between 21.5 and 21.6‰. For modern *S. aurata* ($n = 5$) the values vary between 21.7 and 22.5‰ (Table 1). Furthermore, Sparids captured at the end of summer (September 2013) and at the end of winter (March 2014) exhibited similar values (Table 1). The low variation in the $\delta^{18}O_P$ values obtained indicates similar ambient conditions, temperature and $\delta^{18}O_{SW}$ during tooth growth and deposition of tooth enamel. Our results also show that regardless of fish size and taxonomy, similar $\delta^{18}O_P$ values were recorded, indicating low variations during the fish life cycle.

The $\delta^{18}O_P$ values of the archaeological teeth are presented in Table 2. Six samples of *P. caeruleosticus*, of the Early group, have yielded $\delta^{18}O_P$ values ranging between 21.3 and 22.3‰. From this phase, three samples of *S. aurata* have yielded $\delta^{18}O_P$ values ranging between 21.6 and 23.0‰. *S. aurata* teeth from the Intermediate group exhibited a wider $\delta^{18}O_p$ range varying between 21.7 and 25.2‰. The $\delta^{18}O_p$ values of the two samples representing the Late group exhibited higher values, ranging between 23.5 and 25.2‰.

4.3. The $\delta^{18}O_{PO4}$ theoretical range

The East Mediterranean surface water temperatures generally range from 17.0 °C in late winter (February–March) and 30.0 °C in summer (July–August). Variations in $\delta^{18}O_{SW}$ recorded from the East Mediterranean are relatively small (Sisma-Ventura et al., 2014), ranging between 1.4‰ (February–March) and 1.8‰ (July–August). A 2.6‰ $\delta^{18}O_p$ theoretical range, between 21.1 and 23.7‰ was calculated for the two end-members: the temperatures and $\delta^{18}O_{SW}$ values of summer and winter, respectively (Fig. 3). We use the $\delta^{18}O_p$ theoretical range to identify fish typical of the Southeastern Mediterranean littoral (fish captured at the vicinity of Tel Dor). To

Table 1
Values of $\delta^{18}O_P$, measured on modern Sparidae teeth from left and right dentary (captured in Haifa Bay; Fig. 1).

Species	Collection time	Fish body Mass [gr]	Total length [cm]	Tooth length [mm]	$\delta^{18}O_{PO4}$ [‰ VSMOW]
P. caeruleosticus	Sep-2013	3500	48.5	5.53	21.5
				5.42	21.6
S. aurata	Sep-2013	1000	41.0	11.07	21.7
				10.56	21.9
S. aurata	Mar-2014	930	40.5	9.74	22.2
				9.85	22.5
S. aurata	Mar-2014	500	31.5	5.64	21.7

Table 2
$\delta^{18}O_P$ values measured for Tel Dor Sparidae teeth enamel according to eight chronological horizons spanning roughly 1150–650 BCE (age approximation; note explanations in Section 2.2.).

Sample I.D.	Sub-period	Locus	Area/Phase	Horizon date [BCE]	Species	Tooth length [mm]	$\delta^{18}O_{PO4}$ [‰ VSMOW]
451	**Early**	08D2-262	D2|13	c. 1150–1050	*S. aurata*	6.59	21.59
640		08D5-633	D5|12	c. 1150–1050	*P. caeruleostictus*	5.21	21.7
644		08D2-237	D2|12-9	c. 1050–1000/950	"	4.29	22.14
645		08D2-237	D2|12-9	c. 1050–1000/950	"	6.09	21.3
560		08D2-237	D2|12-9	c. 1050–1000/950	"	4.68	21.5
561		08D2-237	D2|12-9	c. 1050–1000/950	"	4.71	22.27
580		06D2-116	D2|9	c. 1050-1000/950	"	4.70	21.59
71		05D1-541	D1|10	c. 1000/950–850	*S. aurata*	10.92	22.31
734		06D5-049	D5|10	c. 1000/950–850	"	10.34	23.02
499	**Intermediate**	07D2-068	D2|Pre7	c. 900–800	"	9.53	25.16
452		07D2-068	D2|Pre7	c. 900–800	"	8.92	21.69
458		06D2-017	D2|Pre 7	c. 900–800	"	7.35	23.71
459		06D2-017	D2|Pre 7	c. 900–800	"	9.53	22.72
512		09D2-324	D2|Pre 7	c. 850–800	"	10.17	24.55
513		09D2-324	D2|Pre 7	c. 850–800	"	11.25	22.53
520	**Late**	05D2-802	D5|6a	c. 730–650	"	8.62	23.47
522		05D2-802	D5|6a	c. 730–650	"	8.42	25.23

identify fish of hyper-saline environments we use the $\delta^{18}O_p$ of modern *S. aurata* samples from the Bardawil lagoon (the south-eastern Mediterranean-East Egypt; Kolodny et al., 1983).

5. Discussion

Fish tooth enamel is resistant to digenesis alteration and therefore is regarded as a good marker for changes in isotopic composition of aquatic habitats (Pucéat et al., 2003; Dera et al., 2009; Otero et al., 2011 and references therein). Here we discuss the reliability of $\delta^{18}O_p$ values measured in Sparidae teeth recovered from well-dated contexts at the Tel Dor archaeological site as markers of the environment in which the fish were captured.

5.1. $\delta^{18}O_p$ as a tool to identify the fish habitat

Tel Dor sparids exhibit an exceptional wide range of $\delta^{18}O_p$ values: some are similar to the theoretical marine range expected for this region, while other display distinctively high $\delta^{18}O_p$ values, which differ from the expected range (Fig. 4). Otero et al. (2011) showed that 5‰ variations in the $\delta^{18}O_p$ of fossil fish reflect different aquatic habitats of the fish, each with varying evaporation rates and thus different $\delta^{18}O_W$ values. At Tel Dor, the high $\delta^{18}O_p$ values (NISP = 3 or 4) strikingly resemble the $\delta^{18}O_p$ values obtained from Spridae of the Bardawil lagoon (Kolodny et al., 1983).

The Bardawil lagoon (Fig. 1) is a large coastal lagoon 600 km^2 large with a maximal depth of 3 m. Due to the high rate of evaporation, the isotopic composition of the Bardawil water varies

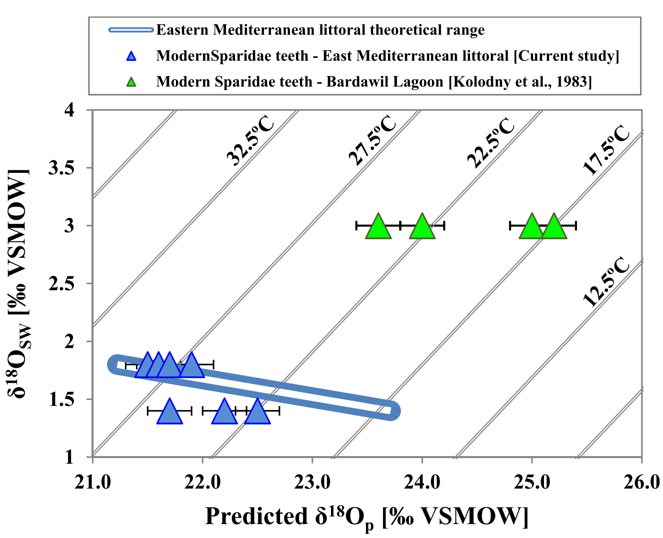

Fig. 3. Phosphate Oxygen isotope compositions ($\delta^{18}O_p$) of modern *S. aurata* and *P. caeruleostictus* teeth, sampled from the southeast Mediterranean littoral (current study) vs. the predicted $\delta^{18}O_p$ range of the study area presented on a plot of $\delta^{18}O_p$ versus $\delta^{18}O$ of sea-water ($\delta^{18}O_{SW}$), with an isotherm of bio-apatite deposition (Lécuyer et al., 2013). The $\delta^{18}O_p$ values of modern *S. aurata* from the Bardawil lagoon are presented for comparison on an average $\delta^{18}O_{SW}$ value of 3.0‰ (Kolodny et al., 1983).

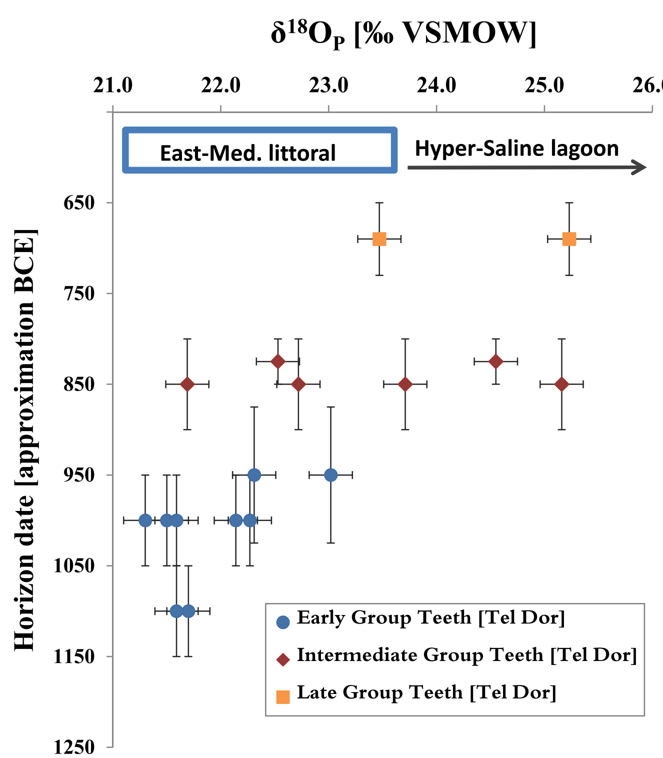

Fig. 4. $\delta^{18}O_P$ values of Tel Dor sparid teeth, according to eight chronological horizons spanning roughly 1150–650 BCE (age approximation; note explanations in section 2.2.). The southeast Mediterranean littoral $\delta^{18}O_P$ theoretical range and the predicted range for hyper-saline water bodies, developing from the southeast Mediterranean surface water are presented.

widely, between 2.2 and 7.5‰ (Kolodny et al., 1983). Despite the extreme ecological conditions, Sparidae heavily exploit this lagoon (Ahmed, 2011). According to Kolodny et al. (1983) Bardawil lagoon Sparidae are adapted to a $\delta^{18}O_W$ value around 3‰. Consequently, their teeth carry a high $\delta^{18}O_p$ value, varying between 23.6 and 25.2‰ (Fig. 3). Hence, the $\delta^{18}O_p$ values obtained from Tel Dor sparid teeth spread over the theoretical range of both habitats (Fig. 4) discussed in this paper, indicating two possible origins: the East Mediterranean littoral and a hyper-saline lagoon with environmental conditions similar to those in Bardawil. We therefore offer two possible scenarios to explain the observed high $\delta^{18}O_p$ values:

1. As evidence of environmental changes: due to relative stabilization of the Holocene sea rising, short-lived lagoons with varying salinity rates were formed in the vicinity of Tel Dor (Sneh and Klein, 1984; Galili and Weinstein-Evron, 1985; Raban and Galili, 1985).
2. As evidence of trade from Egypt: the distinct similarity between the high $\delta^{18}O_p$ values to those observed from sparids from the Bardawil lagoon, raises the possibility that some of Tel Dor sparids were not locally captured but imported from Egypt.

5.2. Possibility 1: varying $\delta^{18}O_p$ as indicating paleo-environmental changes

Lagoon environments of quasi-closed coastal bays, which receive water from alluvial, ground-water, and marine sources, are highly susceptible to environmental changes (Kaniewski et al., 2013). On a geological time scale they are mostly short-lived landscapes, highly dependent on the rate of sea level changes, climate changes, local tectonic events, and anthropogenic activity such as river damming.

In the East Mediterranean there are only a few records indicating coastal lagoon formation during historical periods. For example, pollen records of the Larnaca Salt Lake in southeast Cyprus, reveals an environmental shift from a sheltered marine embayment to a lagoon environment at ca. 1450–1350 cal yr BCE (Kaniewski et al., 2013). Sedimentological and paleontological records demonstrate that at the close-by Phoenician military harbor of Kition-*Bamboula*, the sheltered marine environment turned to a leaky lagoon ca. 150 BCE, and to a salt lake ca. 350 CE (Morhange et al., 2001). In the Nile delta it has been demonstrated that long-lived lagoons have existed over the last 7000 years (Stanley and Warne, 1993; Marriner et al., 2012).

Along the coast of Israel there are indications that sea level reached its present elevation (with a suggested error bar of ± 1 m) around 4000 years ago (Sivan et al., 2001) or even 3600 years ago (Porat et al., 2008), and since then it fluctuated above and mainly below mean sea level (MSL) up to 0.5 m (Sivan et al., 2004; Toker et al., 2012). The upper sand unit, now covering the Holocene sequence and exposed along the coast of Israel, is relatively young, with the oldest age (IRSL) of 5100 $\pm$ 500 BP measured on the Carmel coast near Tel Dor (Kadosh et al., 2004). All other sand ages are younger. This may suggest that when the sea reached its current MSL there was very little sand along the present coast, including around Tel Dor. As a result the sea could have flooded the lowest inland areas, forming lagoons. Raban and Galili (1985) suggested that during the 12th century BCE, Tel Dor was surrounded by a sea water lagoon extending from south to east. This proposed lagoon was probably relatively short-lived but may have still existed during the first half of the 1st millennium BCE. Such a lagoon would have provided a sheltered environment, an ideal spawning ground for local sparids.

5.3. Possibility 2: varying $\delta^{18}O_p$ as indicating trade connections

During the Iron Age, the port-town of Dor had close commercial liaisons with Egypt. This is especially demonstrated by the unusual number of Egyptian clay transport jars uncovered in its Iron Age levels, more so than in any Iron Age site outside Egypt (recent summary in Waiman-Barak et al., 2014). Ceramics, however, indeed comprise the best archaeologically-surviving indication for such contacts, but they, and their contents, were not the only commodity exchanged. Remains of exotic fish such as the Egyptian Nile Perch (*Lates niloticus*) and cat fish of the genus *Bagrus*, which appear in coastal and inland sites including Tel Dor, serve as marker of fish trade with Egypt (Van Neer et al., 2005; Raban-Gerstel et al., 2008).

Unlike the presence of Nilotic fish, the presence of Sparidae in coastal sites has always been regarded as evidence of local inshore fishing activity (Van Neer et al., 2005; Bar-Yosef Mayer and Zohar, 2010). In the present study, however, the distinctive isotopic values obtained from a few *S. aurata* teeth and their similarity to values measured for the Bardawi lagoon (Kolodny et al., 1983) present, for the first time, evidence that Tel Dor sparids could have arrived from two different habitats: from the nearby littoral zone and from the Bardawil lagoon. The Bardawil still plays an important role in Sparidae artisanal fishery (Ahmed, 2011).

We note, however, that chronologically speaking, the distribution of the potential Bardawil fish at Dor does not coincide with that of Egyptian jars. The latter are abundant in the early Iron Age, parallel to the 'Early' and 'Middle' groups as defined above and are extremely few later, when the teeth with exceptionally heavy $\delta^{18}O_p$ are attested. This, however, does not negate the possibility that fish from Egypt arrived in this later horizon (730–650 BCE), since Nile perch remains are also attested then at Tel Dor. Moreover, Dor's central role in East-Mediterranean trade in this period is well attested both textually and archaeologically, for example by the abundance of transport containers that arrived there from several East Mediterranean regions (Gilboa and Sharon, in press).

6. Summary

The current study demonstrates the significance of $\delta^{18}O_p$ composition obtained from Sparidae teeth as an innovative proxy that captures different marine habitats exploited by ancient populations. Ancient teeth from well-dated archaeological horizons between the 12th and 7th centuries BCE indicate that *S. aurata* recovered at Tel Dor originated from two different habitats: typical East Mediterranean coastal water and hyper-saline lagoons.

We offer two possible scenarios to explain the observed $\delta^{18}O_p$values: harvesting fish from hyper-saline lagoons was performed either in local lagoons that existed in the past or in the Bardwail lagoon. Considering the distinctive isotopic signature of fish inhabiting the Bardwail lagoon and the lack of solid information indicating similar hyper-saline lagoon formation near Tel Dor we postulate trade with Egypt/northern Sinai as the most probable explanation for the $\delta^{18}O_p$ patterns observed in the Tel Dor fish teeth.

The current study comprises a first step in the application of $\delta^{18}O$ analysis of Sparidae teeth recovered from well-dated archaeological sites as a new paleo-environmental proxy in the East Mediterranean. Applying this proxy to more teeth from various archeological sites will provide new insights regarding both environmental and cultural issues during historical time periods.

Acknowledgments

The fish remains used in this study are part of Anuar Zidane's Ph.D. research supported by the University of Haifa and ISF Grant

52/10. The Tel Dor excavations are co-directed by Ayelet Gilboa and Ilan Sharon (the Hebrew University). We deeply thank Ilan Sharon for his support and for implementing the excavation strategy that enabled this project. Tel Dor excavations are supported by the Wendy Goldhirsh Foundation, California. The authors would also like to thank the Irene Levi Sala CARE Archaeological Foundation for its financial aid to establish the fish reference collection. We are grateful to the University of Haifa for funding G. Sisma-Ventura's post-doc, matched by ISF grant 923/11. The field work that enabled this study was supervised by Yiftah Shalev of the University of Haifa (Areas D1 and D5) and Elizabeth Bloch-Smith of St. Joseph's University, Philadelphia (Area D2).

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