**Supporting Information**

**Tooth oxygen isotopes reveal Late Bronze Age origin of Mediterranean fish aquaculture and trade**

Sisma-Ventura Guya,b,c\*, Tütken Thomasb\*, Zohar Iritd,e, Pack Andreasc\*, Sivan Doritf,g, Lernau Omrie, Gilboa Ayelete, h, Bar-Oz Guye, h\*

a. Israel Oceanographic & Limnological Research, Haifa, Israel

b. Institute for Geosciences, Johannes-Gutenberg-University of Mainz, Mainz, Germany

c. Department of Isotope Geology, Georg-August-University of Göttingen, Göttingen, Gemany

d. Oranim Academic College, Kiryat Tivon, Israel

e. Zinman Institute of Archaeology, University of Haifa, Haifa, Israel

f. Department of Maritime Civilizations, Charney School of Marine Sciences

g. The Leon Recanati Institute for Maritime Studies, University of Haifa, Haifa, Israel

h. The Department of Archaeology, University of Haifa, Haifa, Israel

\*Corresponding authors: guy.siv@ocean.org.il (G. Sisma-Ventura); tuetken@uni-mainz.de (T. Tütken); Andreas.Pack@geo.uni-goettingen.de (A. Pack); guybar@research.haifa.ac.il (G. Bar-Oz)

**Dating of *S. aurata* remains from archaeological layers**

Archaeological periodisation in the Levant is mostly based on the seriation and stylistic development of the most common artifacts: flint objects in prehistoric times and mainly ceramic vessels from the Pottery Neolithic and onwards. These are pegged into an absolute (calendrical) time scale either by directly dating finds by chemical/physical means, the most commonly-used being 14C dating, or, for historical periods only, by historical dating of assemblages of artifacts or entire habitation levels. This too can be direct (such as by the occurrence of artifacts inscribed with the name of historically-known kings, or coins with well dated inscriptions), but also indirect—for example the presumed (and thus less certain) identification of an archaeological phenomenon (e.g., a destruction level) with a historically-known event. The dating of a single context/settlement is usually not based on data originating only from the specific site in question, but also takes into consideration information from all other relevant contemporaneous sites. After more than a century of extensive excavation in the southern Levant the general periodisation and chronology of the archaeological periods is well established and accepted, though uncertainties and concomitant debates continue at the margins, which are occasionally wide for certain archaeological periods1,2 (Table **S2**). For the fish specimens investigated in this study, no direct dating exists, neither for the items themselves, nor for the specific deposits (loci) in which they were found. Therefore, in Supplementary data, Table **S1** (the fifth column) we list the archaeological periods of the general strata in which they were found. The absolute dates given there (in brackets) usually follow the dates proposed by the excavators/researchers of the sites. They either comprise the whole range of the archaeological period in question, or, often—in cases where a more specific date could be pinpointed—a shortened age range within that period. The exception to this is the Iron Age, a relatively recent period from which most of the analysed specimens derive. The absolute dates of this period and especially its sub-periods are very significant historically since they overlap with crucial historical phenomena such as the rise of territorial states and kingship in the Levant. These dates have been a matter of controversy over the last decades, resulting in extensive radiometric dating at several sites3,4,5,6. This dating has narrowed the debate to ± 50 years, which is very close to the method’s limit of detection, and currently the discussion seems to be at an impasse. Consequently, the absolute dates for Iron Age items in supplementary data Table **S1** represent the entire chronological range that in our opinion is currently valid within the range constrained by 14C dating in the Levant.

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**Fig. S1**. Anatomic location of *Sparus aurata* dentary and the first molariform teeth in the jaw after Sisma-Ventura et al. (2015)28. The length of the first molariform tooth was used to estimate fish body mass and length.



**Fig. S2.** δ18OSW and salinity relationship of the Mediterranean surface water: former measurements of the Western and Eastern Mediterranean, taken during 1988-1989 [blue diamondsand blue circles] and during 2009-2010[blue triangles]; data compilation from Sisma-Ventura et al. (2016)37. The data of the Bardawil lagoon are plotted as dark blue squares31.



**Fig. S3:** Linear regression calculated for body size estimation (total length = TL) of *S. aurata,* fromthe first molariform tooth maximum length (modified after Desse and Desse-Berset, 1996)48.Six modern samples from the Southeast Med littoral were added in this study.



**Table S1:** *Sparus aurata* teeth used in this study, in chronological order1, δ18OPO4 valuesand molariform tooth length as markers for water salinity level and fish body size (Total length-TL and Body mass-BM), respectively.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Site** | **Sample** | **CAT#** | **Context** | **Archaeological Period** | **Tooth** | **Salinity** | **δ18OPO4** | **TL** | **BM** |
|  |  |  | **(locus, stratum)** |  | **Length [mm]** | **level** | **[‰ VSMOW]** | **[cm]** | **KG** |
| **Hatoula** | Tooth | 00183 | Square F; Lzz71 | PPNA (9,750-8,500 BCE) 2 | 4.10 | M | 22.0 | 28.61 | 0.37 |
|  | Tooth | 00215 | Square F; L71 |  | 10.6 | M | 21.9 | 49.55 | 1.90 |
|  | Tooth | 00221 | Square F; Lb70 |  | 9.50 | M | 23.4 | 46.01 | 1.52 |
|  | Tooth | 00225 | Square F; Lzz70 |  | 5.70 | M | 23.1 | 33.77 | 0.61 |
|  | Tooth | 00316 | Square G; L== |  | 7.10 | M | 22.5 | 38.28 | 0.88 |
|  | Tooth | 00232 | Square F; La69 |  | 11.2 | M | 22.7 | 51.49 | 2.13 |
|  | Tooth | 00297 | Square G; L == |  | 10.2 | M | 21.4 | 48.26 | 1.76 |
| **Hatoula** | Tooth | 00829 | Square F; Lb70 | PPNB (8,500-7,000 BCE) 2 | 12.3 | S | 24.1 | 55.03 | 2.60 |
|  | Tooth | 00757 | Square F; Ld66 |  | 8.40 | S | 25.4 | 42.47 | 1.20 |
|  | Tooth | 00590 | Square F; Lzz71 |  | 9.40 | M | 22.4 | 45.69 | 1.49 |
|  | Tooth | 00533 | Square F; Lc72 |  | 6.30 | S | 24.9 | 35.70 | 0.72 |
|  | Tooth | 00467 | Square F; L67 |  | 4.30 | M | 21.4 | 29.26 | 0.40 |
|  | Tooth | 00537 | Square F; Ld67 |  | 8.20 | M | 23.0 | 41.82 | 1.15 |
|  | Bone |  |  |  |  | M | 21.4 |  |  |
|  | Tooth | 00572 | Square F; Le69 |  | 9.70 | M | 23.2 | 46.65 | 1.59 |
|  | Tooth | 00704 | Square F; Le66 |  | 11.3 | S | 24.6 | 51.81 | 2.17 |
|  | Bone |  |  |  |  | M | 22.2 |  |  |
|  | Tooth | 00929 | Square F; Ld73 |  | 10.2 | M | 23.4 | 48.26 | 1.76 |
|  | Tooth | 00933 | Square F; Ld73 |  | 5.8 | M | 23.2 | 34.09 | 0.62 |
|  | Tooth | 00472 | Square F; L63 |  | 9.7 | S | 25.2 | 46.65 | 1.59 |
| **Ashkelon-Afridar**  | Tooth | 00095 | Basket 03913 | PPNC (7,000-6,500 BCE)3 | 11.7 | M | 22.8 | 53.10 | 2.34 |
|  | Tooth | 00158 | Basket 04254 |  | 5.90 | S | 26.4 | 34.41 | 0.64 |
|  | Tooth | 00267 | Basket 04382 |  | 14.6 | M | 23.0 | 62.44 | 3.78 |
|  | Tooth | 00275 | Basket 04192 |  | 7.10 | M | 21.1 | 38.28 | 0.88 |
|  | Tooth | 00301 | Basket 01090 |  | 9.70 | M | 22.6 | 46.65 | 1.59 |
| **Gilat** | Tooth | 00023 | Square H2; L961 | Chalcolithic (5,500-3,900/3,700 BCE)4 | 5.30 | M | 21.6 | 32.48 | 0.54 |
|  | Bone |  |  |  |  | M | 21.1 |  |  |
|  | Tooth | 00035 | Square B5; L16 |  | 12.6 | M/S | 23.8 | 56.00 | 2.74 |
|  | Bone |  |  |  |  | M | 22.6 |  |  |
|  | Tooth | 00023 | Square H2; L961 |  | 10.3 | M | 22.8 | 48.59 | 1.79 |
|  | Bone |  |  |  |  | M | 21.1 |  |  |
| **Ashkelon-Afridar** | Tooth | 00013 | L34 | EB I (3,800- 3,400BCE)5 | 11.9 | M | 22.7 | 53.74 | 2.42 |
|  | Bone |  |  |  |  | B | 20.1 |  |  |
|  | Tooth | 00013 | L34 |  | 8.20 | M | 23.1 | 41.82 | 1.15 |
|  | Bone |  |  |  |  | B | 20.3 |  |  |
| **Ashkelon - Barnea** | Tooth |  |  | EB I (3,550-3,000 BCE)5 | 10.8 | M | 22.4 | 50.20 | 1.98 |
|  | Tooth |  |  |  | 8.90 | M | 23.4 | 44.08 | 1.34 |
|  | Tooth |  |  |  | 9.60 | S | 24.6 | 46.33 | 1.56 |
|  | Tooth |  |  |  | 12.7 | M | 21.8 | 56.32 | 2.78 |
|  | Tooth |  |  |  | 9.40 | M/S | 23.7 | 45.69 | 1.49 |
| **Lachish** | Tooth | 00997 | Area S, L3938, Str VI | LB III (first half of 12th c. BCE) 6  | 6.70 | S | 24.8 | 36.99 | 0.80 |
|  | Tooth | 01093 | Area S , L3918, Str VI |  | 8.20 | S | 25.6 | 41.82 | 1.15 |
|  | Tooth | 01165 | Area S, L3927, Str VI |  | 8.20 | M/S | 23.5 | 41.82 | 1.15 |
|  | Tooth | 00226 | Area S, L3701, Str VI |  | 6.90 | S | 25.1 | 37.63 | 0.84 |
|  | Tooth | 00229 | Area S, L3701, Str VI |  | 7.40 | S | 24.7 | 39.24 | 0.95 |
|  | Tooth | 00237 | Area S, L3579, Str IV | IA II (late 9th/ 8th c. BCE) 6 | 7.30 | S | 24.1 | 38.92 | 0.93 |
|  | Tooth | 00238 | Area S, L3643, Str IVb |  | 6.20 | M/S | 23.9 | 35.38 | 0.70 |
|  | Tooth | 00227 | Area S, L670, Str IVc |  | 7.70 | S | 25.3 | 40.21 | 1.02 |
|  | Tooth | 00199 | Area S, L3643, Str IVb |  | 9.70 | S | 24.3 | 46.65 | 1.59 |
|  | Tooth | 00200 | Area S, L3670, Str IVc |  | 8.20 | S | 24.2 | 41.82 | 1.15 |
| **Tel Rehov** | Tooth | 01043 | Area D; L7951; local Str D9b | LB IIA (late 14th c. BCE) 7 | 8.00 | S | 25.1 | 41.18 | 1.10 |
|  | Tooth | 00999 | Area C, L8465; Str V | Late IA IIA (late 10th/ 9th c. BCE) | 9.20 | S | 24.7 | 45.04 | 1.43 |
| **Ashkelon** | Tooth | 00571 | Grid 38; Square 64; Layer S | Early IA I (second half of 12th c. BCE) 8,9 | 6.00 | S | 24.8 | 34.73 | 0.66 |
|  | Tooth | 01439 | Grid 38; Square 64; Layer S | Early IA I (second half of 12th c. BCE) | 8.60 | S | 25.5 | 43.11 | 1.26 |
|  | Tooth | 01439 | Grid 38; Square 64; Layer S | Early IA I (second half of 12th c. BCE) | 8.30 | S | 25.1 | 42.14 | 1.17 |
|  | Tooth | 01562 | Grid 38; Square 64; Layer 149 | Early IA I (second half of 12th c. BCE) | 10.6 | S | 26.1 | 49.55 | 1.90 |
|  | Tooth | 01440 | Grid 38; Square 64; Layer S | Early IA I (second half of 12th c. BCE) | 9.00 | S | 24.5 | 44.40 | 1.37 |
|  | Tooth | 01438 | Grid 38; Square 64; Layer S | Early IA I (second half of 12th c. BCE) | 8.80 | S | 25.0 | 43.75 | 1.31 |
|  | Tooth | 06192 |  | IA I (12th c. BCE) | 10.0 | S | 26.1 | 47.62 | 1.69 |
|  | Tooth | 06381 |  | IA I (12th-early 10th c. BCE) | 7.70 | S | 25.4 | 40.21 | 1.02 |
|  | Tooth | 06184 |  |  | 6.50 | M/S | 23.9 | 36.35 | 0.76 |
|  | Tooth | 07246 |  |  | 6.70 | S | 24.3 | 36.99 | 0.80 |
|  | Tooth | 06218 |  |  | 5.00 | M/S | 23.8 | 31.51 | 0.49 |
|  | Tooth | 06429 |  |  | 7.40 | S | 24.2 | 39.24 | 0.95 |
|  | Tooth | 06460 |  |  | 9.10 | S | 25.6 | 44.72 | 1.40 |
|  | Tooth | 06739 |  |  | 6.60 | S | 26.0 | 36.67 | 0.78 |
|  | Tooth | 06241 |  |  | 4.20 | S | 24.6 | 28.94 | 0.38 |
|  | Tooth | 06289 |  |  | 4.60 | S | 25.3 | 30.22 | 0.44 |
|  | Tooth | 06380 |  |  | 6.30 | S | 25.1 | 35.70 | 0.72 |
| **Tel Dor** | Tooth |  | Area D2/Phase13, L08D2-262 | IA I (mid-12th -mid 11th c. BCE)10,11 | 6.59 | M | 21.6 | 36.64 | 0.77 |
|  | Tooth |  | Area D1/Phase 10, L05D1-541 | Early IA IIA (late-10th-mid-9th c. BCE) | 10.9 | M | 22.3 | 50.58 | 2.02 |
|  | Tooth |  | Area D5/Phase 10, L06D5-049 |  | 10.3 | M | 23.0 | 48.72 | 1.81 |
|  | Tooth |  | Area D2/Phase pre-7, L07D2-068 | IA II (late-10th-early 8th c. BCE) | 9.53 | S | 25.2 | 46.11 | 1.53 |
|  | Tooth |  | Area D2/Phase pre-7, L07D2-069 |  | 8.92 | M | 21.7 | 44.14 | 1.35 |
|  | Tooth |  | Area D2/Phase pre-7, L07D2-017 |  | 7.35 | S | 23.7 | 39.08 | 0.94 |
|  | Tooth |  | Area D2/Phase pre-7, L07D2-017 |  | 9.53 | M | 22.7 | 46.11 | 1.53 |
|  | Tooth |  | Area D2/Phase pre-7, L09D2-324 |  | 10.2 | S | 24.6 | 48.17 | 1.75 |
|  | Tooth |  | Area D2/Phase pre-7, L09D2-324 |  | 9.53 | M | 22.5 | 51.65 | 2.15 |
|  | Tooth |  | Area D5/Phase 6a, L05D2-802 | Iron II (late 8th -mid-7th c. BCE) | 8.62 | M/S | 23.5 | 43.17 | 1.26 |
|  | Tooth |  | Area D5/Phase 6a, L05D2-802 |  | 8.42 | S | 25.2 | 42.53 | 1.21 |
| **Tel Miqne** | Tooth | 01063 | Str Vb; 4NW8.302 | IA I (11th/early 10th c. BCE) 12,13 | 6.70 | S | 24.7 | 36.99 | 0.80 |
|  | Tooth | 01063 | Str Vb; 4NW8.302 |  | 6.70 | S | 26.1 | 36.99 | 0.80 |
|  | Tooth | 01063 | Str Vb; 4NW8.302 |  | 5.20 | S | 25.1 | 32.16 | 0.52 |
|  | Tooth | 01063 | Str Vb; 4NW8.302 |  | 6.10 | S | 25.2 | 35.06 | 0.68 |
|  | Tooth | 01063 |  |  | 7.20 | S | 25.7 | 38.60 | 0.90 |
|  | Tooth | 00280 | Str IVa; 4NW24.151 | IA II (10th/9th c. BCE) | 5.80 | S | 24.3 | 34.09 | 0.62 |
|  | Tooth | 01266 | Str IVa; 4NW24.139 |  | 6.40 | S | 24.9 | 36.02 | 0.74 |
| **Jerusalem pool** | Tooth | 01000 |  | IA II (late 9th/early 8th c. BCE) 14  | 7.50 | S | 24.8 | 39.57 | 0.97 |
|  | Tooth | 01001 |  |  | 8.20 | S | 26.0 | 41.82 | 1.15 |
|  | Tooth | 01002 |  |  | 7.30 | S | 25.1 | 38.92 | 0.93 |
|  | Tooth | 01003 |  |  | 9.30 | S | 24.5 | 45.37 | 1.46 |
|  | Tooth | 01004 |  |  | 8.20 | M/S | 23.8 | 41.82 | 1.15 |
|  | Tooth | 01005 |  |  | 10.0 | S | 24.5 | 47.62 | 1.69 |
|  | Tooth | 01006 |  |  | 7.80 | S | 25.4 | 40.53 | 1.05 |
|  | Tooth | 01007 |  |  | 9.40 | S | 24.3 | 45.69 | 1.49 |
|  | Tooth | 01008 |  |  | 8.40 | S | 24.5 | 42.47 | 1.20 |
|  | Tooth | 01011 |  |  | 7.10 | M/S | 23.9 | 38.28 | 0.88 |
| **Tel Taninim** | Tooth | 0418 | Square A8; L1303; Basket 1004 | Byzantine (4th-7th c. CE) 15 | 9.10 | M | 22.7 | 44.72 | 1.40 |
|  | Tooth | 00057 | Square A8; L1303;Basket 1006  | 6.70 | M/S | 23.8 | 36.99 | 0.8 |
| **Halutsa** | Tooth |  | Square 4/04-C, Basket 39 | Byzantine (6th c. CE) 16 | 6.40 | S | 24.6 | 36.02 | 0.74 |
|  | Bone |  |  |  |  | S | 24.8 |  |  |
|  | Tooth |  | Area A, Basket 27 |  | 5.80 | S | 25.1 | 34.09 | 0.62 |
|  | Bone |  |  |  |  | M/S | 23.8 |  |  |
|  | Tooth |  | Square 4/07-2, Basket 72 |  | 7.10 | S | 25.3 | 38.28 | 0.88 |
|  | Bone |  |  |  |  | S | 24.2 |  |  |
| **Shivta** | Tooth |  | Area K, Basket 1693 | Byzantine (6th c. CE) 17 | 4.60 | S | 25.4 | 30.22 | 0.44 |
|  | Bone |  |  |  |  | S | 24.3 |  |  |
|  | Tooth |  |  |  | 5.60 | S | 24.8 | 33.45 | 0.59 |
|  | Tooth |  | Area A, Basket 3 |  | 6.30 | S | 25.6 | 35.70 | 0.72 |
|  | Bone |  |  |  |  | S | 24.7 |  |  |
| **Tamra** | Tooth | 00162 |  | Early Islamic (early 8th c. CE) 18 | 6.40 | S | 25.9 | 36.02 | 0.74 |
|  | Tooth | 00155 |  |  | 7.30 | S | 26.2 | 38.92 | 0.93 |
|  | Bone |  |  |  |  | S | 25.2 |  |  |

**M = marine, B = brackish, BCE = Before Common Era; c = century; IA – Iron Age; L = locus; EBA = Early Bronze Age; LBA = Late Bronze Age; S = hypersaline; Str = stratum**

1 Registration numbers are in different formats since they follow those assigned by the different excavators. Chronological resolution is determined by the nature of the contexts in which the bones and teeth were found.

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**Table S2:** The absolute chronology of the archaeological periods in the southern Levant following Sharon (2014) and Stern and Gilboa (1993).

|  |  |
| --- | --- |
| **Archaeological period** | **Years** |
| Neolithic (Pre Pottery - PPN) | 9,750 - 6,500 BCE |
| Neolithic (Pottery - PN) | 6,500 - 4,500 BCE |
| Chalcolithic (CAL) | 4,500 - 3,900/3,700 BCE  |
| Early Bronze Age (EBA) | 3,900/3,700 - 2,500/2,300 BCE |
| Intermediate Bronze Age (IBA) | 2,500/2,300 - 2,200/1,900 BCE |
| Middle Bronze Age (MBA) | 2,200/1,900 - 1,650/1,540 BCE  |
| Late Bronze Age (LBA) | 1,650/1,540 - 1,200/1,150 BCE |
| Iron Age (IA) | 1,200/1,150 - 600 BCE |
| Babylonian  | 600 - 530 BCE |
| Persian | 530 - 332 BCE |
| Hellenistic  | 332 - 63 BCE |
| Roman | 63 BCE - 324 CE |
| Byzantine (BYZ) | 324 - 638 CE |
| Early Islamic | 638 - 1,099 CE |

**Table S3:** Abundances (%) of identified fish remain from archaeological sites in Israel as function of their habitat, presented in chronological order.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Period** | **Site** | **Marine** | **Freshwater** | **Nile** |
| Natufian | El Wad1 | 100 |   |   |
| Natufian | Hatoula2,3  | 100 |   |   |
| PPN | Hatoula  | 99.7 | 0.3 |   |
| PPNC | Atlit Yam4 | 100 |   |   |
| PPNC | Ashkelon5 | 99.7 | 0.3 |   |
| Pottery Neolithic | Ziqim6 | 87.0 |   | 13.0 |
| Pottery Neolithic | Neve Yam7 | 100 |   |   |
| Late Chalcolithic | Namir Road8 | 98.9 | 1.1 |   |
| Early Bronze Age | Ashkelon-Afridar9 | 97.9 |   | 1.9 |
| Early Bronze Age I | Tel Qashish10 | 40.0 | 60.0 |   |
| Mid Bronze Age II | City of David11 | 66.7 | 11.1 | 22.2 |
| Late Bronze Age III  | Lachish12 | 64.5 | 6.1 | 29.4 |
| Late Bronze Age III  | Haruvit13 | 95.4 | 4.1 | 0.4 |
| Late Bronze Age II | Tel Dor-Area G 11-1214 | 25.7 |   | 74.3 |
| Late Bronze Age | Tel Harasim15 | 58.3 |   | 41.7 |
| Late Bronze Age | Timna16,17 | 97.9 | 2.1 |   |
| Late Bronze Age II | Tel Aphek18 | 87.5 |   | 12.5 |
| Late Bronze Age -Iron Age II | Tel Yoqneam19 | 35.1 | 8.1 | 56.8 |
| Early-Iron Age | Tel Dor Area D20 | 47.8 | 0.5 | 51.6 |
| Iron Age | Tel Dor-Area G 1020 | 88.6 | 1.8 | 9.6 |
| Iron Age | *el* Ahwat21 | 25.5 | 2.0 | 72.5 |
| Iron Age II | Tel Aphek22 | 40.0 | 20.0 | 40.0 |
| Iron Age II | Tel Harasim23 | 61.1 |   | 38.9 |
| Iron Age II | Jerusalem-pool24 | 75.1 | 17.5 | 7.5 |
| Iron Age II | City of David11 | 72.1 | 12.0 | 15.8 |
| Iron Age II | Jerusalem-Area G11 | 69.8 | 28.9 | 1.3 |
| Iron Age II | Jerusalem-Haophel25 | 68.1 | 14.9 | 17.0 |
| Roman | Caesarea Cespit 389826 | 89.0 | 11.0 |   |
| Early Roman-Byzantine | Ein Gedi27 | 51.5 | 48.5 |   |
| Persian, Helenistic, Byzantine | City of David11 | 47.1 |   | 52.9 |
| Persian, Byzantine | Tel Harasim28 | 57.1 |   | 42.9 |
| Early Byzantine | Upper Zohar29 | 84.8 | 0.6 | 14.6 |

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