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

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Past fish provenance, exploitation and trade patterns were studied by analyzing phosphate oxygen isotope compositions ($\delta^{18}O_{PO4}$) of gilthead seabream (*Sparus aurata*) tooth enameloid from archaeological sites across the southern Levant, spanning the entire Holocene. We report the earliest evidence for extensive fish exploitation from the hypersaline Bardawil lagoon on Egypt's northern Sinai coast, as indicated by distinctively high $\delta^{18}O_{PO4}$ values, which became abundant in the southern Levant, both along the coast and further inland, at least from the Late Bronze Age (3,550–3,200 BP). A period of global, postglacial sea-level stabilization triggered the formation of the Bardawil lagoon, which was intensively exploited and supported a widespread fish trade. This represents the earliest roots of marine proto-aquaculture in Late Holocene coastal domains of the Mediterranean. We demonstrate the potential of large-scale $\delta^{18}O_{PO4}$ analysis of fish teeth to reveal cultural phenomena in antiquity, providing unprecedented insights into past trade patterns.

Fishing was an essential economic component of many ancient societies, as evidenced by the presence of fish remains, fishing gears, and fish-associated artifacts in numerous archaeological sites world-wide[1–5]. In the southern Levant, past exploitation and trade of fish has been explored primarily based on the occurrences of fish bones in coastal, riverine and lake-side archaeological sites and through inference from the modern distribution patterns, habitat preferences and ecological niches of these fish species. In the Levant, this has mostly been done for fish that a priori were identified as 'exotic'. For example, the identification of key Nilotic species such as *Lates niloticus* (Nile perch) and *Bagrus* sp. (Bagrid catfish) in archeological sites of the southern Levant testified that long-range trade systems between Egypt and Canaan have emerged more than 5000 years ago (during the Early Bronze Age)[6–8].

The gilthead seabream (*Sparus aurata*, Linnaeus, 1758) frequently appears in archaeological sites of the southern Levant, since prehistoric times (Late Pleistocene)[4–6]. This species is characterised by thick-enamelled, molar-like teeth (Fig. S1), which are used for cracking shellfish (i.e., bivalves, gastropods and crustaceans)[9,10]. *Sparus aurata* is an euryhaline and eurytherm marine fish which migrates between near-shore, inshore (lagoons) and open sea environments[11–13]. Thus, while the appearance of *S. aurata* in inland sites clearly indicates long range trade systems[6,7], remains of this species in Levantine coastal sites have so far been interpreted as reflecting local fishing activity[6–8].

State of the art research methodologies provide multiple empirical ways to explore trade and maritime connections of desirable fish source marketing to distant places. For example, past provenance and long-range trade of fish from the North Atlantic have been studied using the C and N stable isotopes of bone collagen (Atlantic cod)[14–18], and by aDNA analysis[18,19]. However, fish bone C and N isotope analyses require the preservation of collagen, and they are limited to "young" fish because constant bone remodeling causes the isotopic signature to adjust to local conditions in adult fish[14,15]. In the North Aegean (northeast Mediterranean), these analyses showed no clustering with locality or species, and for both isotopes they demonstrated a general overlap between

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