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Fish in the desert: Identifying fish trade routes and the role of Red Sea parrotfish (Scaridae) during the Byzantine and Early Islamic periods

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ABSTRACT

Recent archaeological excavations in the Negev desert of the southern Levant have yielded a surprising and unprecedented amount of fish remains, found in the landfills at Byzantine (4th–7th century CE) and Early Islamic (7th–9th century CE) sites. The significant economic and dietary role of Red Sea fish, especially parrotfish (Scaridae), in addition to fish originating from freshwater habitats, including the Nile, as well as from the Mediterranean Sea, attest to the importance of fish in sophisticated trade networks, which facilitated the transport of fish from different aquatic habitats to the distant provinces. The discovery of Red Sea parrotfish at all three studied sites is of particular interest. Analysis of the Scaridae remains revealed their role as a flagship species of the Red Sea coral-reef fishery and as an essential commodity in the Byzantine and Early Islamic economic systems; as well as the presence of more than one Scaridae species. The study of skeletal element representation indicated that complete fish, larger than 23 cm in length (SL), were transported to the sites. The bone fragmentation patterns reflected typical traditional butchering during the desiccation processes. The fish remains recovered from the desert provide new insights into the infrastructure of commercial networks that enabled the transport of fish over long distances during periods of high demand for fish products.

1. Introduction

Fish remains recovered at inland sites have often been used as an indicator of commercial relationships and identified as luxury products (Arndt et al., 2003; Barrett et al., 1999, Barrett et al., 2011, Star et al., 2017, Van Neer and Depraetere, 2006, Van Neer and Ervynck, 1996, Van Neer et al., 2015, Van Neer et al., 2004, Van Neer et al., 2005). The more distant the original aquatic habitat, the higher the costs involved in their procurement. Nonetheless, it remains to be determined whether the development of long-range trade and the expansion of fishing efforts to more distant aquatic habitats indicate the emergence of commercial fishing as a response to a growing demand for fish products, or for luxury foods for the social elites.

In the Eastern Mediterranean the fish trade could have originated from four main aquatic habitats: the Nile (Egypt), freshwater rivers and lakes, the Mediterranean Sea, and the Red Sea (Figs. 1 and 2) (Hamilton-Dyer, 2001, 2007, 2011; Sisma-Ventura et al., 2019; Sisma-Ventura et al., 2018; Sisma-Ventura et al., 2015; Van Neer and Depraetere, 2006; Van Neer and Ervynck, 1996; Van Neer et al., 2015; Van Neer et al., 2004; Van Neer et al., 2005). While Nilotic and Mediterranean fish became common trade goods from the Chalcolithic period onward, our knowledge regarding the Red Sea fish exploitation in Antiquity is nonetheless meager (Sisma-Ventura et al., 2018, Sisma-Ventura et al., 2015, Van Neer and Ervynck, 2004, Van Neer et al., 2004, Van Neer et al., 2005). Several key species have served to indicate particular aquatic habitats, including Scaridae (parrotfish) as indicative of Red Sea fish commerce (Mashkour et al., 2016, Reich et al., 2007, Van Neer et al., 2004).

In this study we examine for the first time the economic role of fish during the Byzantine (mid-4th–7th century CE) and Early Islamic (mid-7th–9th century CE) periods, as estimated from fish remains recovered from sieved material at three inland sites of the Negev desert: Elusa, the capital of the province (Palaestina Tertia), and the nearby large villages of Nessana and Shivta (Fig. 1). The taxonomic composition of fish uncovered at each of these sites provides new lines of evidence regarding the commercial networks that enabled trade in perishable organic foods

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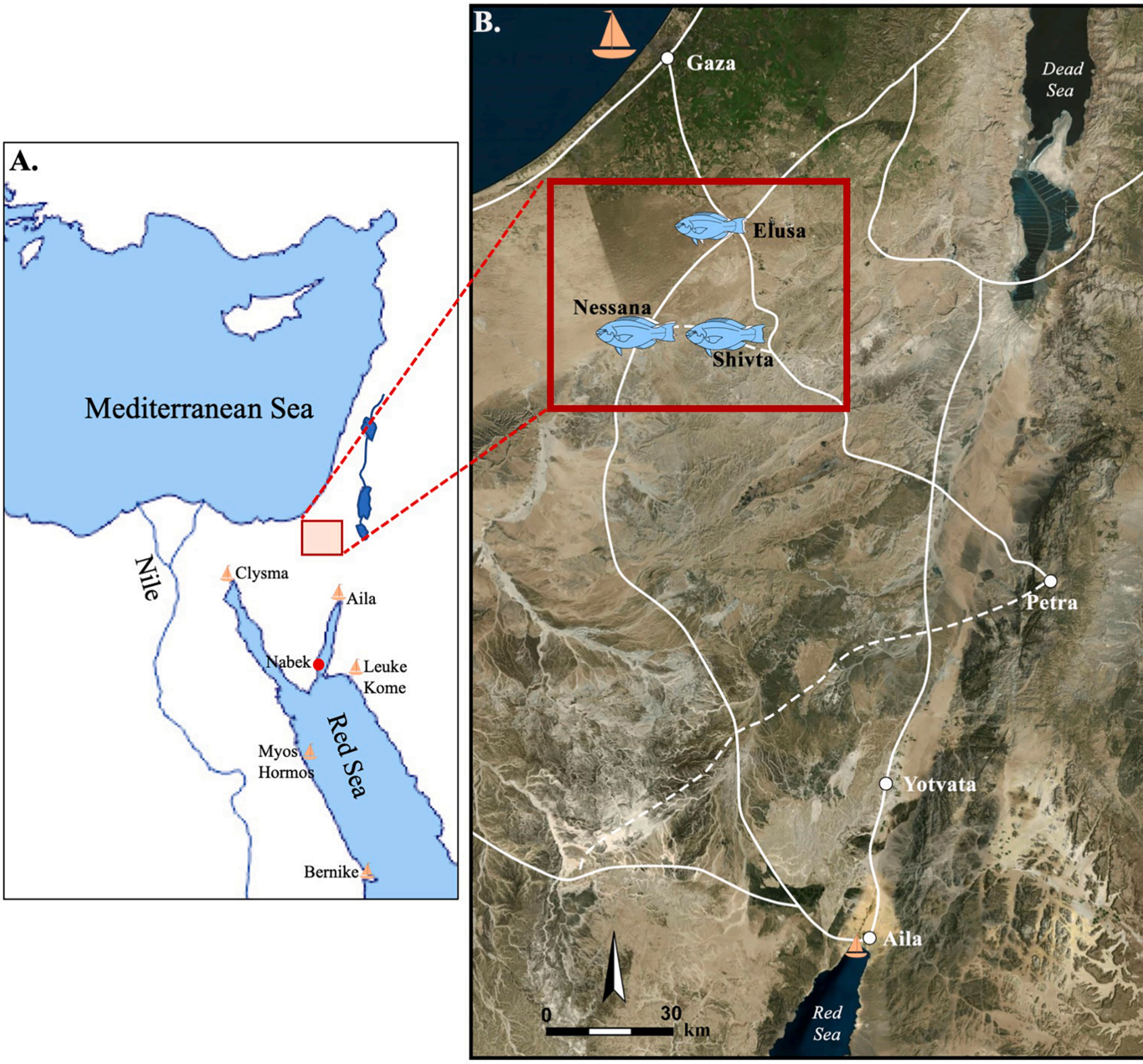

Fig. 1. Map showing: A. location of major ancient ports (serving small boats) in the southern and northern Red Sea, and Nabek oasis; B. location of the Negev sites referred to in this study. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

from distant locations. We specifically focus on Scaridae remains as a footprint of their origin of exploitation and fishing and processing methods, and in reconstructing trade routes from the Red Sea.

1.1. Archaeological sites and settings

The archaeological sites of Elusa, Shivta, and Nessana attest to a unique phenomenon in the history of marginal regions, demonstrating that economic prosperity and a sophisticated agricultural system flourished in the Negev desert, primarily between the 4th–6th century CE (Bar-Oz et al., 2019, Marom et al., 2019, Tepper et al., 2018). During that time the city of Elusa profited from its location along lucrative commercial trade routes linking between the Mediterranean Sea and the Red Sea. The agricultural installations recovered around Shivta and Nessana attested to widespread intensive large-scale dryland farming. Recent excavations in landfills and garbage mounds at these sites have revealed new information regarding the complex economy of the Byzantine settlement in the Negev (Bar-Oz et al., 2019, Fuks et al., 2020, Marom et al., 2019, Tepper et al., 2018). The garbage dumps of the three sites partially overlap chronologically, and incorporate three sub-periods: Middle Byzantine (5th–6th century CE); Late Byzantine (6th–7th century CE); and Early Islamic (7th–9th century CE).

Elusa: Located in the northern Negev region, about 20 km southwest of Beersheba (Fig. 1), this site started as a small waystation on the Nabataean trade route (3rd century BCE-2nd century CE). During the 4th century CE it developed into an important regional urban center of the Byzantine period (Goldfus et al., 2000, Negev, 1976). Elusa is frequently mentioned in Byzantine sources, including in Nessana papyri (Mayerson, 1983). A detailed study of the garbage dumps on the outskirts of the city revealed that public administration of the city declined in the mid-6th century CE, during the peak of the Byzantine period. Systematic excavation of two garbage mounds adjacent to the northern area of the settlement uncovered an abundance and rich variety of artifacts and organic refuse of household waste, including charcoal, seeds, and faunal remains. The faunal remains comprised aquatic fauna (mollusks, corals, and fish) and domesticated animals (Bar-Oz et al., 2019, Fuks et al., 2016, Mayerson, 1985).

Shivta: Situated about 40 km southwest of Beersheba (Fig. 1), this site was probably established during the Roman period (2nd century CE), and reached its zenith during the Byzantine period (4th–6th century CE).

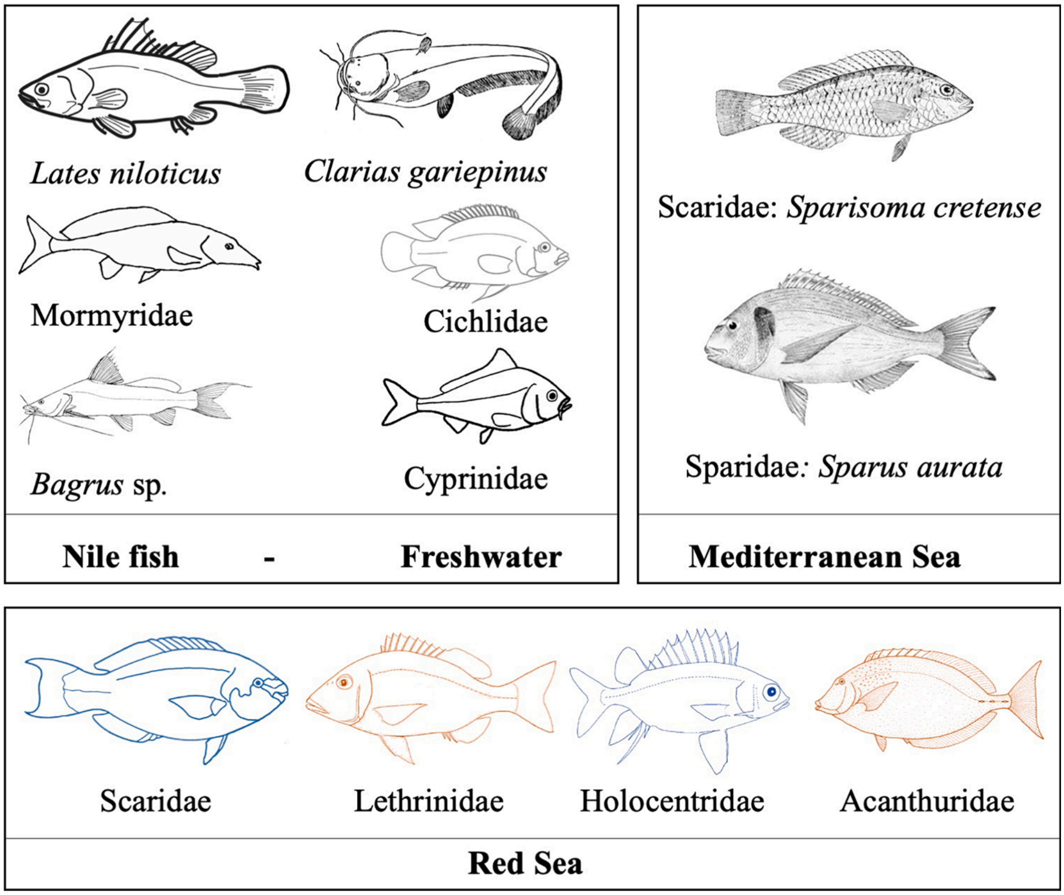

Fig. 2. Key fish species (not scaled to size) frequently used in the southern Levant as an indicator of commercial trade when recovered beyond their habitat of origin (Mediterranean Sea, Red Sea, Nile, and freshwater fish common to Levantine freshwater habitats). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

During the Early Islamic period (7th–9th century CE,) a reduced occupation is evident, before the site was totally abandoned (Tepper et al., 2018). Excavations in garbage deposits both within and on the outskirts of the site revealed a clear spatial chronology in trash management over time. Large dumps accumulated on the fringe of the village in Byzantine times, with smaller rubbish dumps inside the village, most of which were recovered in sediments of abandoned Byzantine houses dated to the Early Islamic period. The finds from both dump deposits included a large variety of botanical (Fuks et al., 2020, Langgut et al., 2020) and faunal remains (Marom et al., 2019, Tepper et al., 2018).

Nessana: Situated about 50 km southwest of Beersheba (Fig. 1) this site reached its peak prosperity during the Byzantine period (6th–7th century CE) and life in the village seems to have continued uninterrupted until the late 9th- beginning of the 10th century CE (Avni, 2007, Ruffini, 2011). Quantitative analyses of artifacts and biological remains from trash mounds on the outskirts of site revealed pronounced signs of continuous occupation between the Byzantine and Early Islamic periods (Butler et al., 2020, Fuks et al., 2020, Marom et al., 2019, Tepper et al., 2020).

2. Materials and methods

The fish remains were retrieved following on-site systematic 5 mm dry sifting of all excavated sediments. Wet sieving through 1 mm mesh was performed on 20 L of sediments from each excavated locus in order to maximize fine-scale retrieval of fish bones. To achieve maximal retrieval, all of the sifted material was sorted in the field and again in the laboratory and fish remains were carefully handpicked and sorted separately. A database was reconstructed for each of the fish assemblages (for both identified and unidentified remains), according to their locality at the sites. The chronology of the remains for Shivta (Tepper et al., 2018) and Nessana (Tepper et al., 2020) is based on cultural finds (pottery, glass, coins, etc.) and on radiocarbon dating for Elusa (Bar-Oz et al., 2019).

2.1. Taxonomic identification

Fish remains were identified using the osteological reference collection housed at the Laboratory of Archaeozoology, University of Haifa (IZ collection), and specimens from the ichthyological wet collection of the Steinhardt Museum of Natural History, Tel Aviv University. The osteological collection comprises a wide diversity of fish from the Mediterranean Sea, the Red Sea, the Jordan Rift Valley, Lake Kinneret, coastal rivers, and the Nile (Egypt). All skeletal elements were identified following the published terminology for fish remains (Cannon, 1987, Rojo, 1991, Wheeler and Jones, 1989).

Based on selected cranial and postcranial bones, taxonomic identification was performed to family level and, when possible, to genus and species level. In Nessana only selected Scaridae remains were identified. We were unable to separate between families possessing representatives in both the Mediterranean and the Red Sea (i.e. Sparidae, Serranidae, Scombridae, Mugilidae etc.), and between freshwater families with representatives in both the Nile and other freshwater habitats (i.e., Cyprinidae, Clariidae, Cichlidae) (Dierickx et al., 2017, Zohar, 2003, Zohar and Biton, 2011, Zohar et al., 2018, Zohar et al., 2014). Therefore, fish habitat was reconstructed from key species (Fig. 2): *Lates niloticus* (Latidae; Nile perch) and *Oreochromis niloticus* (Cichlidae; Nile Tilapia) represent Nilotic fish; *Sparus aurata* (Sparidae) and *Sparisoma cretense*

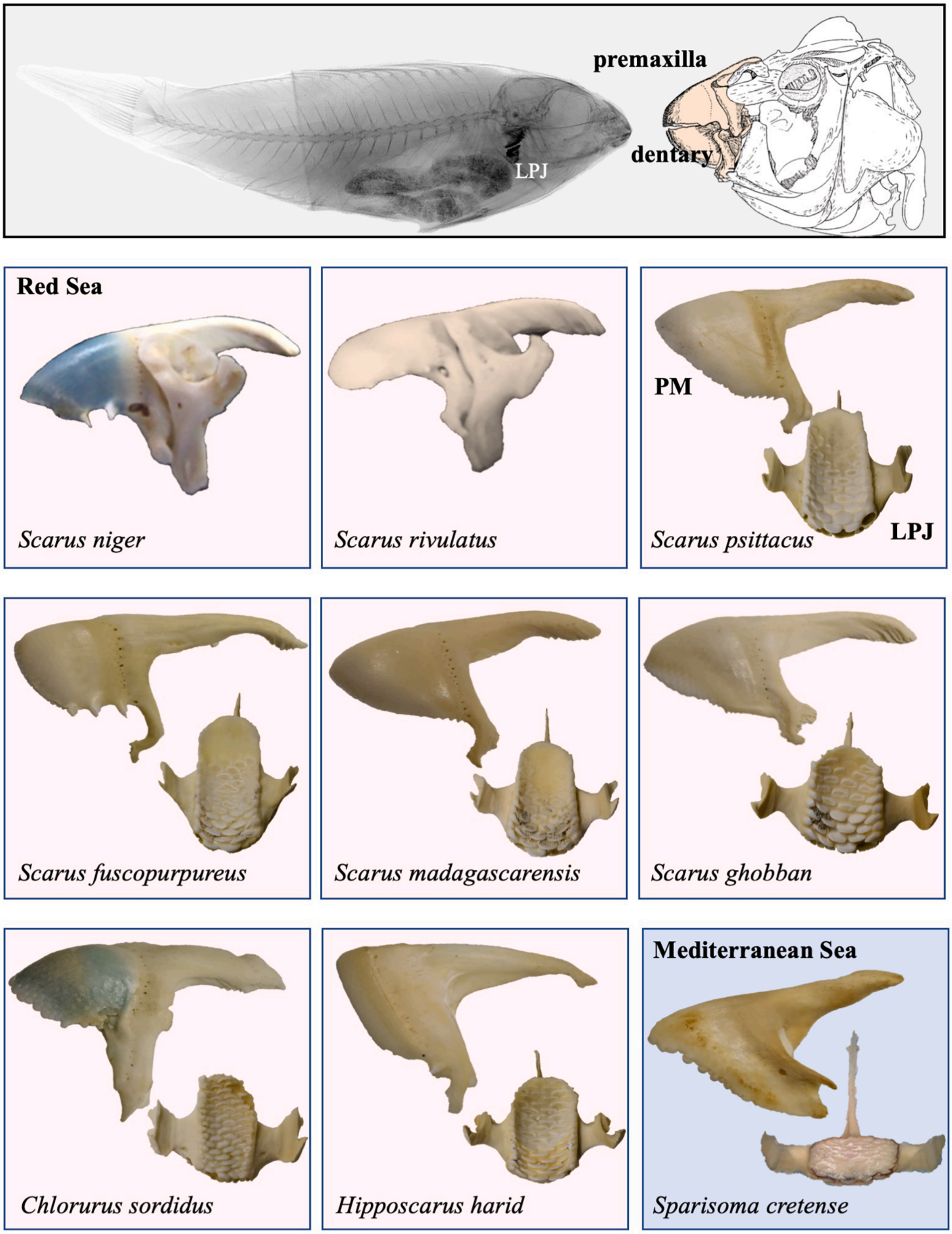

Fig. 3. Scaridae osteology: Top – Micro CT of Scaridae skeleton (*Sparisoma cretense* TAU # P13947), showing the number of vertebrae along the vertebral column and location of the dentary, premaxilla (PM), upper and lower pharyngeal jaws (LPJ). Bottom – PM and LPJ (when available) from selected species of Scaridae from the Red Sea (not scaled; Table S4) (after Bellwood, 1994; Gregory, 1959; Nanami, 2016), and of *Sparisoma cretense* from the Mediterranean Sea (photographs by Roee Shafir, Haifa University). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Scaridae) represents Mediterranean Sea fish; Scaridae (parrotfish, except the Mediterranean parrotfish), Lethrinidae (emperors), and Acanthuridae (surgeonfish) represent Red Sea fish. In the Eastern Mediterranean 10 species of Labridae (wrasses) are reported, all of small body size (<18 cm in standard length-SL) (Golani et al., 2006, Whitehead et al., 1984). Therefore, only the remains of large Labridae (>25 cm SL) were assigned to Red Sea wrasses.

2.2. Scaridae osteology

Scaridae identification is based on skeletons of 15 fish representing seven species of Red Sea parrotfish (Randall, 1986) and the single species endemic to the Mediterranean Sea (*Sparisoma cretense*; Mediterranean parrotfish) (Bernardi et al., 2000, Golani and Bogorodsky, 2010, Golani et al., 2006) (Table S1). We used the Micro CT to scan two

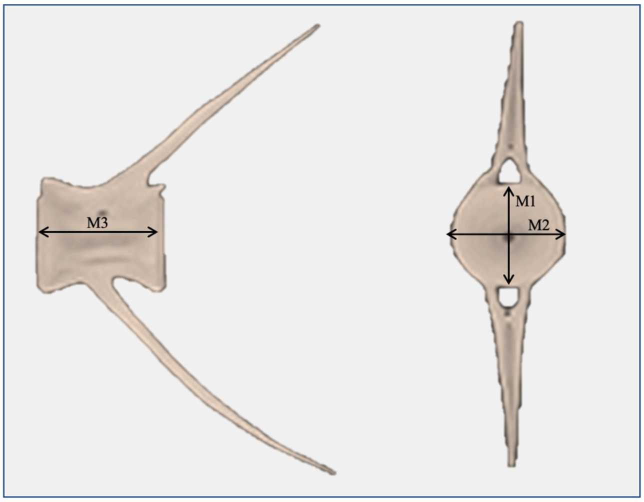

Fig. 4. Measurements performed on the vertebrae centrum (M1 = the greatest dorso-ventral height; M2 = the greatest mediolateral width (=centrum width); M3 = and the greatest craniocaudal length (=centrum height)).

Scaridae specimens stored at the Steinhardt Museum of Natural History (Tel Aviv University): Red Sea *Scarus* sp. (TAU#P7191) and Mediterranean Sea *Sparisoma cretense* (TAU # P13947). This allowed us to determine the number of vertebrae and to examine the anatomic location of the pharyngeal bone and teeth (Fig. 3)

Because we did not possess a full range of Red Sea species (Table S2), we also referred to published osteological papers (Bellwood, 1994, Bellwood et al., 2019, Choat et al., 1996, Rurua et al., 2020), and consulted with Prof. D.R. Bellwood (James Cook University, Townsville, QLD Australia). Identification of Scaridae remains to family level was performed on selected cranial and postcranial elements (Table S3). Identification to species level is particularly based on the distinctive beak-like structure of the dentary and premaxilla (PM) bones (Fig. 3), and the upper and lower pharyngeal jaw (LPJ) (5th ceratobranchial for the lower jaw and 3rd pharyngobranchials for the upper jaw) and teeth (Bellwood, 1994, Bellwood et al., 2019, Carr et al., 2006, Gobalet, 1989, Hamilton-Dyer, 2011, Rurua et al., 2020). Scaridae dentary and premaxilla teeth can be fused, either with teeth visible on the margin, as in *Sparisoma* sp. (Mediterranean Sea endemic species), or without any visible teeth, as in *Scarus* sp. (Bellwood, 1994, Bellwood et al., 2019, Carr et al., 2006, Gobalet, 1989, Hoey and Bonaldo, 2018, Nanami, 2016, Westneat, 2002) (Fig. 3).

2.3. Quantification

The number of identified specimens (NISP) was used as a basic quantitative unit for taxonomic abundance and for measurement of species diversity (Brillouin's Diversity Index- BH, for non-random collections), and evenness (Domínguez-Rodrigo, 2012, Grayson, 1991, Krebs, 1999, Marshall and Pilgram, 1993, Reitz and Wing, 1999, Zar, 1984). Taxa identified solely to family level were counted as a single taxon for species richness values (S'). Statistical analysis was performed with JMP Pro 15. Rarefaction curve to assess species richness from NISP was calculated with PAST v.4.03.

Variation in skeletal elements representation was calculated according to anatomic regions (Wheeler and Jones, 1989) and further grouped by postcranial and cranial regions (Butler, 1990, Zohar et al., 2001) (Table S3). State of bone preservation (percentage ratio of retrieved bone compared to a complete bone) was examined following the formula of weighted mean index (WMI) of fragmentation (Zohar et al., 2001). Signs of butchering were recorded from cut marks (Willis and Boehm, 2014, Willis et al., 2008) and from patterns of bone fragmentation. The latter were compared with fragmentation patterns documented from Red Sea fish butchered for immediate or later consumption (sun drying) by traditional Bedouin fishing communities at the Nabek oasis, Sinai (Egypt; Fig. 1) (Zohar, 2003, Zohar and Cooke, 2019). Signs of burning were recorded according to changes in bone color: black, gray, and white (Shahack-Gross et al., 1997, Shipman et al., 1984, Stiner et al., 1995).

2.4. Reconstructing Red Sea Scaridae body size

We estimated Scaridae body size (on family level) from osteometric measurements of the vertebrae centrum (Gabriel et al., 2012, Marrast and Béarez, 2019, Morales and Rosenlund, 1979, Nowroozi et al., 2012, Rurua et al., 2020, Thieren et al., 2012, Van Neer, 1989, Zohar et al., 1997). Scaridae vertebral column is composed of 24–25 vertebrae (including ultimate vert.) (Fig. 3) (Brainerd and Patek, 1998). On each vertebrae centrum, we performed three measurements, using a digital caliper with an accuracy of 0.02 mm (SHAHE, IP54). These comprised: the greatest dorso-ventral height (M1), the greatest mediolateral width (M2: also referred to as centrum width), and the greatest craniocaudal length (M3: also referred to as centrum height) (Fig. 4) (Gabriel et al., 2012). On the 14 extant Scaridae (Table S1), measurements were performed on each vertebra, according to its location along the vertebral column (NISP = 336 extant vert.). Examination of the extent of variation of each measurement along the vertebral column (of each fish), demonstrated that M3 (vertebrae centrum height) varied with location along the vertebral column (S.D. 5–17 mm), while M2 (centrum width) displayed a relatively small variation (S.D. $<$ 0.5 mm) along the vertebral column. Therefore, M2 is used as the best fitted measurement to examine variations in fish body size.

We performed M2 measurement on 315 archaeological vertebrae: 67 vertebrae from Shivta (57 Byzantine, 10 Early Islamic), 54 from Elusa (Byzantine period), and 194 from Nessana (4 Byzantine, 190 Early Islamic). Due to the small sample of fish in the reference collection, we were unable to create linear regressions for body mass estimation (Desse and Desse-Berset, 1994, Desse and Desse-Berset, 1996, Rurua et al., 2020, Zohar et al., 1997). A rough estimation of Scaridae body size was therefore performed through a comparison with the reference collection and published data (Table S1).

2.5. Ethnographic data

To reconstruct Scaridae fishing technologies and to evaluate the possibility of sustainable harvesting we used published data on Red Sea coral-reef fishery (Alwany et al., 2007, Alwany et al., 2009, Amin et al., 2019, Brokovich et al., 2006, Brokovich et al., 2008, Delaney et al., 2017, Meqdadi et al., 2017, Roberts and Ormond, 1987, Tesfamichael and Mehanna, 2016). Information on artisanal coral reef fishery in the Red Sea and on traditional fish processing was obtained from an ethnographic study of the Nabek oasis Bedouin community (Sinai, Egypt) (Zohar, 2003, Zohar and Cooke, 2019).

The Nabek oasis is located on the southeastern shore of the Gulf of Aqaba in southern Sinai, 20 km north of Sharm el Sheikh on the Red Sea coast (Fig. 1). It is situated at the end of a wide delta fed by several rivers, including Wadi Kid. The area is characterized by a shallow reef and hypersaline mangrove vegetation. The Nabek oasis is exploited by nomadic Bedouin from the *Muzeina* tribe, which is the largest tribe in Sinai and occupies the eastern shoreline Arensburg *et al.*, 1979; (Kobyliansky and Hershkovitz, 2002). Among the *Muzeina* families, some migrate seasonally between the seashore and the mountains, while others live in a sedentary fishing village at the Nabek oasis and practice intensive fishing all year round. There are also seasonal huts scattered along the beach, randomly used by different individuals or families for a short period (a few days at a time) (Zohar, 2003, Zohar and Cooke, 2019).

Table 1
Total number of fish remains (NISP) and fish taxonomic composition (S'= species richness, BH = Brillouin Index) in Elusa, Shivta, and Nessana, by period (*at Nessana only Scaridae were identified for this study).

Site	Period	Total NISP	Identified NISP	S'	BH	Evenness
Shivta	Byzantine	1978	405	15	1.31	0.23–0.333
	Early Islamic	1335	256	14	0.88	0.16–0.29
Elusa	Middle Byzantine	1316	218	12	1.73	0.46–0.63
Nessana*	Byzantine	510	10	1		–
	Early Islamic	7351	557	6		
Total		12,490	1446	22		

2.6. The economic role of Red Sea Scaridae through time

To estimate the economic role of Red Sea Scaridae, both by period and by geographical distribution, we compiled information from records of fish remains recorded from southern Levantine archaeological sites. This included data on the number of identified fish remains (NISP) at each site, levels of Scaridae taxonomic identifications, habitat (Mediterranean or Red Sea species), and references to the cited records. For comparison and identification of the extent of commercial activity at the study sites, we reviewed additional reports on Red Sea Scaridae recovered from Jordan and Egypt.

3. Results

3.1. From where did the fish originate?

A total of 12,490 fish remains (NISP; Table 1) were recovered at Shivta (NISP = 3313), Nessana (NISP = 7861), and Elusa (NISP = 1316), from cultural layers associated with two chronological and cultural periods: Byzantine (4th–7th century CE) and the Early Islamic (7th–9th century CE). From this assemblage 1446 fish remains were identified, representing 12 families of bony fish, two super-orders of Elasmobranchii (sharks and rays), and 22 taxa (Table 2; Fig. 5A). Analysis of the fish remains revealed that species richness (S') varied according to the NISP (Fig. 5B), showing the highest value in Byzantine Shivta (S'=15), a slightly lower value in the early Islamic layers (S'=14), and the lowest in Middle Byzantine Elusa (S' = 12).

Fish taxonomic composition (Table 2, Fig. 5A) demonstrates a significant difference between family's distribution by site (Shivta, Elusa), and in Shivta also between periods ($\chi^2 = 321.78$; $p < .0001$; $df = 24$; $r^2 = 0.1290$). In the Byzantine period of Elusa and Shivta Red Sea Scaridae were highly abundant (>40%); while in the Early Islamic period of Shivta the relative abundance of Scaridae decreases to 20% and the relative abundance of freshwater tilapinii (Cichlidae) increases to ca. 64% of the identified assemblage (Fig. 5A). A comparison between the origin of fish recovered in Shivta and Elusa, by period (Fig. 5C–D; Table 2) reveals a significant difference ($\chi^2 = 04.435$; $df = 8$; $r^2 = 0.1738$; $p < .0001$). In Elusa most of the fish originated from two habitats; Red Sea and Mediterranean Sea; while in Shivta, in addition to Red Sea fish, we found a preponderance of fish originating from freshwater habitats. Interestingly, in Shivta during the Early Islamic period the abundance of freshwater fish increased from 44% to 72%, between the Byzantine and Early Islamic period. Remains of Nilotic fish, *L. niloticus* (Latidae; Nile perch) were recovered from both Byzantine and Early Islamic Shivta; while *O. niloticus* (Cichlidae; Nile tilapia) remains were identified only from the Byzantine contexts. Since our research focused solely on the identification of Scaridae remains, future taxonomic studies regarding the rest of the fish remains will shed further light on the exploited species and aquatic habitats associated with these sites. Nonetheless, the consistent appearance of Nilotic fish with other freshwater fish that are common in the Nile, may suggest that all the freshwater fish originated from the Nile.

3.2. Scaridae exploitation

A total of 898 Red Sea Scaridae remains (ca. 7% of the entire assemblage; >60% of the identified assemblage) were identified from the three studied sites (Tables 2, S3; Fig. 5A). No remains of the endemic Mediterranean species *Sparisoma cretense,* were recovered. Out of the 18 extant species of Red Sea Scaridae (Golani and Bogorodsky, 2010), six species were identified: *Cetoscarus bicolor*, *Chlorurus gibbus, C. sordidus, Hipposcarus harid, Scarus ghobban* and *Cetoscarus bicolor/Bolbometopon muricatum*. The Scaridae originated from both Byzantine and Early Islamic contexts, exhibiting a high preponderance (40%) at Elusa and Shivta during the Byzantine period, and a reduction there during the Islamic period (20%) (Fig. 5).

3.3. Scaridae skeleton completeness and body size estimation

Analysis of the Scaridae remains revealed the presence of cranial and postcranial bones and a nearly complete absence of gill rakers (<0.5%), implying that complete fish were gutted and then transported (Fig. 6; Table S3). Measurements of vertebrae centrum width (M2) – 104 from the Byzantine period and 194 from the Early Islamic period – indicate a small variation in size (8.6 mm ± 2.3).

Body size estimation indicates an absence of fish smaller than 22 cm in standard length (SL), with fish ranging between 23 and 60 cm SL, and the majority between 23 and 40 cm SL (Fig. 7). Estimation of fish size-age relationship, based on the literature, indicated that at the age of 1.3 years Scaridae reach an average length (SL) of 20 cm; 42 cm at the age of 6 years; and >50 cm SL at the age of 10 years (Amin et al., 2019, Choat et al., 1996). Fresh fish of 20 cm SL weight ca. 130 gr, while fresh fish of 40 cm SL weight >1 kg. Scaridae remains recovered in the present study did not include small fish (<250 gr), and belonged to relatively large specimens (>2 years old) including some very large fish (>50 cm SL; >2 kg weight).

3.4. Red Sea coral-reef Scaridae exploitation by local artisanal fishermen

The Bedouin fishermen at the Nabek oasis (Zohar, 2003, Zohar and Cooke, 2019) exploit the shallow reef with throw nets, and within a relatively short time they collected 72 fish belonging to 5 families and 9 species (Table 3). The most common fish (87%) belonged to the Siganidae (53%; rabbitfish) and Acanthuridae (34% surgeonfish). Scaridae comprised 8% of their fish catch. All of the fish were immediately gutted and butchered. For bony fish, a single butchering method was employed, regardless of body size or anatomy (Zohar and Cooke, 1997, Zohar and Cooke, 2019). A lengthwise dorsal cut was performed with a steel knife, along the vertebral column. This cut started at the base of the caudal fin and extended to the anterior part of the skull, splitting the fish into two (Fig. 8; "butterfly" fish). The exposed entrails were discarded into the water along with the gills. Additional longitudinal and transverse cuts were performed to facilitate salt penetration and desiccation, leaving characteristic patterns of bone loss and fragmentation. Sharks (Chondrichthyes) were prepared differently: strips of meat were cut off and the skeleton was then discarded into the water (Zohar and Cooke, 1997, Zohar and Cooke, 2019). All fish were washed in the salty water and

Table 2
Taxonomic composition of fish remains, and their origin of habitat, identified at Shivta, Elusa, and Nessana to family, genus, and species level from the Byzantine and Early Islamic periods (Mediterranean Sea is marked as Med.).

Period	Site	Family	Species	Habitat	NISP	%
Middle Byzantine	Elusa	Chondrichthyes	Chondrichthyes	Med., Red Sea	8	3.7
			Myliobatis sp.	Med., Red Sea	8	3.7
			Selachimorpha	Med., Red Sea	1	0.5
		Scombridae	Scombridae	Med., Red Sea	2	0.9
		Serranidae	Serranidae	Med., Red Sea	15	6.9
		Sparidae	Sparidae	Med., Red Sea	22	10.1
			Sparus aurata	Med. Sea	2	0.9
		Mugilidae	Mugilidae	Med., Red Sea	46	21.1
		Scaridae	*Hipposcarus* sp.	Red Sea	1	0.5
			Scarus ghobban	Red Sea	10	4.6
			S. ghobban/S. gibbus	Red Sea	1	0.5
			Chlorurus sordidus	Red Sea	1	0.5
			Scaridae	Red Sea	94	43.1
		Cichlidae	Cichlidae	Freshwater/Nile	6	2.8
		Clariidae	Clariidae	Freshwater/Nile	1	0.5
Total Middle Byzantine	Elusa				**218**	**100**
Byzantine	Shivta	Chondrichthyes	Chondrichthyes	Med., Red Sea	3	0.7
		Serranidae	Serranidae	Med., Red Sea	9	2.2
			Epinephelus sp.	Med., Red Sea	1	0.2
		Sparidae	Sparidae	Med., Red Sea	12	3.0
		Mugilidae	Mugilidae	Med., Red Sea	18	4.4
		Acanthuridae	*Acanthurus* sp.	Red Sea	1	0.2
		Scaridae	*Chlorurus gibbus*	Red Sea	1	0.2
			Chlorurus sordidus	Red Sea	1	0.2
			Hipposcarus harid	Red Sea	2	0.5
			Scarus ghobban	Red Sea	6	1.5
			S. ghobban/H. harid	Red Sea	3	0.7
			Scaridae	Red Sea	159	39.3
		Siganidae	Siganidae	Red Sea	1	0.2
		Labridae	Labridae	Red Sea	4	1.0
		Cichlidae	Cichlidae	Freshwater/Nile	159	39.3
			Oreochromis niloticus	Nile	2	0.5
		Clariidae	Clariidae	Freshwater/Nile	10	2.5
		Cyprinidae	Cyprinidae	Freshwater/Nile	10	2.5
		Latidae	*Lates niloticus*	Nile	3	0.7
Total Byzantine	Shivta				**405**	**100**
Early Islamic	Shivta	Chondrichthyes	Chondrichthyes	Med., Red Sea	1	0.4
		Serranidae	Serranidae	Med., Red Sea	5	2.0
		Sparidae	Sparidae	Med., Red Sea	6	2.3
		Mugilidae	Mugilidae	Med., Red Sea	4	1.6
		Acanthuridae	*Acanthurus* sp.	Red Sea	1	0.4
		Labridae	Labridae	Red Sea	2	0.8
		Scaridae	*Cetoscarus bicolor*	Red Sea	1	0.4
			Chlorurus gibbus	Red Sea	1	0.4
			Chlorurus sordidus	Red Sea	1	0.4
			Hipposcarus harid	Red Sea	1	0.4
			Scaridae	Red Sea	48	18.8
		Cichlidae	Cichlidae	Freshwater	163	63.7
		Clariidae	Clariidae	Freshwater	17	6.6
		Cyprinidae	Cyprinidae	Freshwater	4	1.6
		Latidae	*Lates niloticus*	Nile	1	0.4
Total Early Islamic	Shivta				**256**	**100**
Byzantine	Nessana	Scaridae	Scaridae	Red Sea	10	100
Total Byzantine					**10**	**100**
Early Islamic	Nessana	Scaridae	*C. bicolor/B. muricatum*	Red Sea	3	0.5
			Chlorurus gibbus	Red Sea	1	0.2
			Hipposcarus harid	Red Sea	8	1.4
			Scaridae	Red Sea	529	95.0
			Scarus ghobban	Red Sea	11	2.0
			Scarus ghobban/Hipposcarus harid	Red Sea	3	0.5
			S. psittacus/S. niger	Red Sea	1	0.2
			Chlorurus sordidus	Red Sea	1	0.2
Total Early Islamic	Nessana				**557**	**100**

then laid out to dry on the exposed stones (Fig. 8), and afterwards hung from the roofs of the huts.

3.5. Fish consumption pattern

The recovered remains represent the refuse of fish cooked and consumed by the local inhabitants. No remains were recovered in a storage installation. At Shivta most of the fish remains were recovered within the site, including in alleys and in garbage middens inside buildings (Table 4), with most of the Nilotic fish being recovered from the garbage inside a building in Area K. At Elusa and Nessana, most of the fish remains were discovered in the large garbage mounds surrounding the sites. Regardless of the archaeological site, or the cultural period, all the fish remains recovered in the present study were well preserved (>80% of the bone was present). Signs of burning were relatively scarce on fish remains from Elusa and Nessana but were more

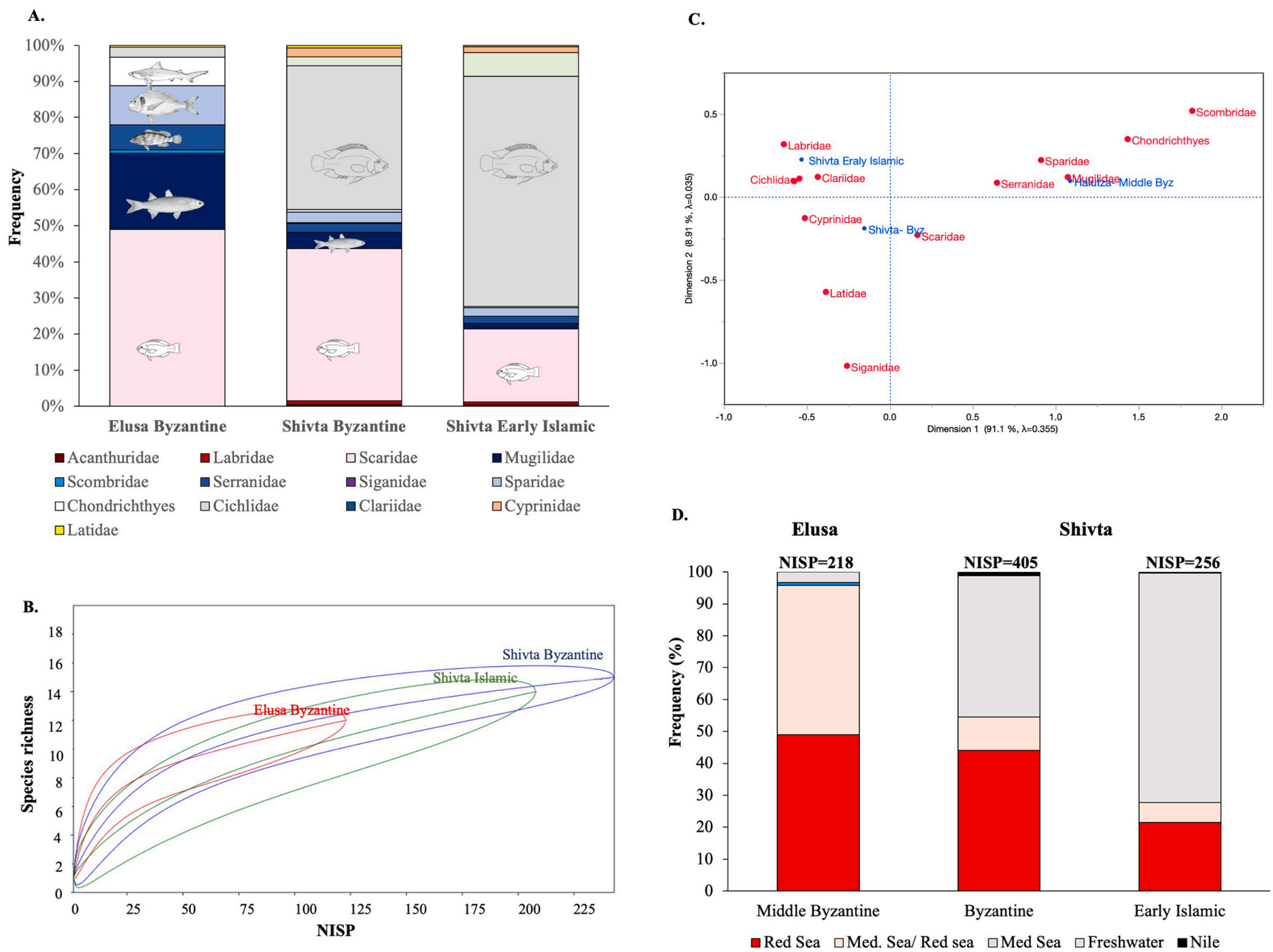

Fig. 5. Taxonomic composition of fish, identified to family level, recovered at Elusa and Shivta, by two periods: A. Relative abundance of the identified families; B. Rarefaction curve to assess the effect of sample size on species richness; C. Multiple Correspondence Analysis of taxonomic composition by site and period; D. Fish origin of habitat, by site and period (endemic Nilotic species: *O. nilotica* and *L. niloticus* were identified only in Shivta; Table 2).

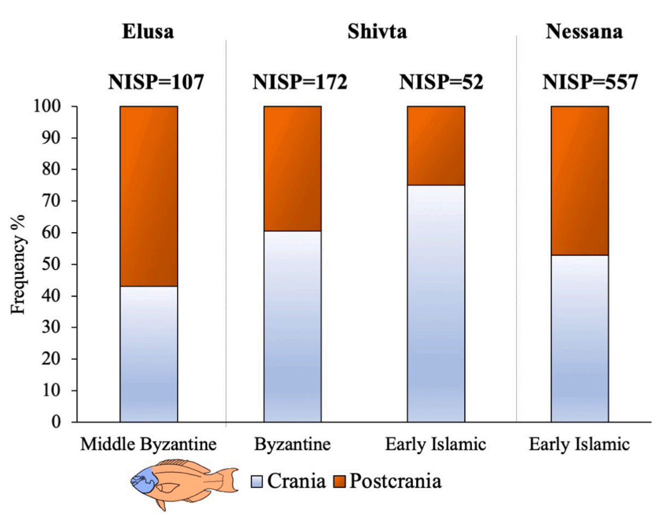

Fig. 6. Skeletal remains of Scaridae grouped by anatomic region (crania *vs.* postcrania) identified by site and period.

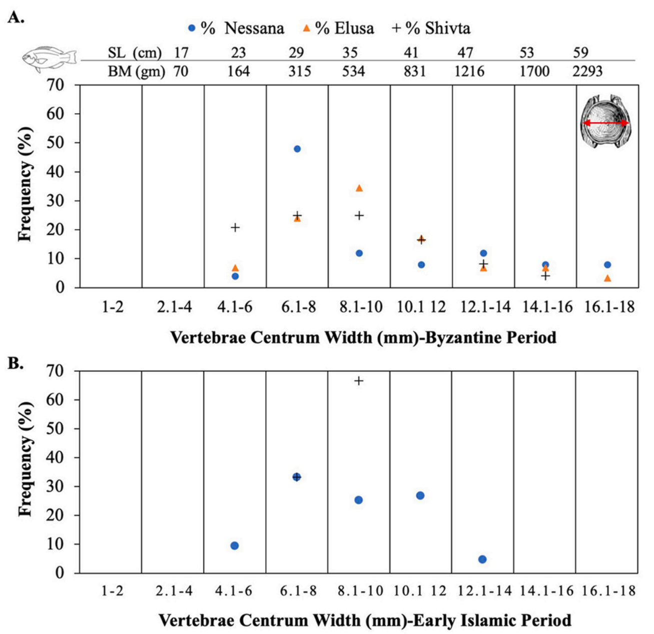

Fig. 7. Estimation of Scaridae body size (body mass – gr; and standard length – mm) reconstructed from selected thoracic vertebrae (M2-centrum width), by site and period: A. Byzantine period (NISP = 104); B. Early Islamic period (NISP = 194).

common in Shivta (5–19%; Table 4).

Evidence of burning was observed on 610 fish remains. At Shivta, out of the 453 burnt fish remains, 46 bones belonged to Scaridae (20 bones from the Byzantine period, 24 from the Early Islamic period). Most of the burnt Scaridae were recovered from the Byzantine period in the large garbage mounds surrounding the site, with the rest of the burnt fish being recovered from floors of buildings at the site. At Elusa, evidence of burning was observed on 82 fish remains, of which 19 bones belonged to Scaridae; all of which originated from garbage mounds surrounding the site. From the garbage mounds surrounding Nessana, four Scaridae bones were recorded as burnt from the Byzantine period and 71 from the Early Islamic period.

Man-made chopping marks, butchery marks, and fragmentation patterns indicative of fish butchering during processing for long-term preservation or immediate consumption (Zohar and Cooke, 1997, Zohar and Cooke, 2019), were identified on 11 bones at Shivta and on two bones at Elusa (Fig. 9). None of these bones showed signs of burning. Four of the identified butchering marks were found on Scaridae (Fig. 9A).

4. Discussion and conclusions

4.1. Sustainable fishing of Red Sea Scaridae

Scaridae play a key role in artisanal, small-scale, shallow-water, coral-reef fishing communities worldwide, providing a rich source of protein, omega-3 fatty acids, and vitamins (Aswani and Hamilton, 2004, Aswani and Sabetian, 2010, Bellwood et al., 2004, Campbell and Pardede, 2006, Suda, 2013, Thyresson et al., 2011). Artisanal fishery data from the Egyptian Red Sea (1950–1983; near Suez City) demonstrate that the most common fish families, caught by various methods (i.e., long line, hand line, gillnet, trammel net, beach seine from boats), are the Serranidae (groupers; 28%), followed by Lethrinidae (spangled emperor fish; 21–28%), and Acanthuridae (surgeonfish; 11–20%). Scaridae, which comprise 4–8% of the annual catch, are often captured in shallow-water and in hard coral reef zonation, using a wide variety of fishing devices, including hand spears, spear guns, lines, traps, and night spearing (Alwany et al., 2007, Campbell and Pardede, 2006, Delaney et al., 2017, Friedlander et al., 2012, Khalaf et al., 2018, Khalaf and Kochzius, 2002, Kirch, 1982, Kochzius, 2007, Oakley-Cogan et al., 2020, Thyresson et al., 2011).

Red Sea fish remains identified from the three Negev sites (>200 km from their habitat), exhibit a different pattern from that expected to represent Red Sea fishery (Fig. 4; Tables 2 and 3). Serranidae, Acanthuridae, and Labridae remains are scarce while Scaridae remains are abundant. This pattern of aquatic exploitation strengthens the idea that Scaridae were a preferred and targeted species, exploited from the shallow coral reef, imported inland, and used as a staple food with a high commercial value (Fig. 1). This conclusion is further supported by the estimation of Scaridae body size (Fig. 7), indicating the absence of young fish (<23 cm SL) and the presence of large and adult fish, similar to the sustainability patterns observed in artisanal coral-reef fishing communities (Aswani and Hamilton, 2004, Aswani and Sabetian, 2010, Thyresson et al., 2011).

4.2. Commercialism and trade routes of Red Sea fish

A review of Red Sea Scaridae remains recovered in the southern Levant indicates that they were being transported inland as early as the Iron Age (Jerusalem, Tel Ashkelon, Tel Garisa; Table 5 and refs within; Fig. 10) (Lernau, 2011, Reich et al., 2007, Van Neer et al., 2004, Van Neer et al., 2005). From a chronological and cultural perspective, it is only from the Roman period that we witness an increase in the appearance of transported Red Sea fish in general, and Scaridae in particular, reaching a peak during the Byzantine period and decreasing in Crusader times, as evident from their remains at more than 41 archaeological sites (Tables 5 and S5; Fig. 10). A comparison with fish remains reported from northern Jordan, Syria, Turkey, and Egypt suggests that Red Sea fish were transported across a relatively limited geographical area, in contrast to the wide geographical trade routes observed for fish originating from the Nile (Table S5) (Van Neer and

Table 3
Summary data of fish butchered by traditional fishermen at the Nabek oasis, southern Sinai (Egypt), including taxonomic group and body size.

Family	Species	Common name	No.	%	Body Mass (gr) Range	Mean
Acanthuridae	*Acanthurus nigrofuscus*	Spot-cheeked surgeonfish	24	33.3	52–1130	152
	Acanthurus sohal	Sohal surgeonfish	1	1.4	110	
Belonidae	*Tylosurus* sp.	Needlefish	2	2.8	494–910	702
Mullidae	*Upeneus* sp.	Goatfish	1	1.4	128	
Scaridae	*Scarus niger*	Dusky parrotfish	3	4.2	204–1780	828
	Scaridae	Parrotfish	3	4.2	126–222	178
Siganidae	*Siganus luridus*	Dusky spinefoot	24	33.3	96–316	195
	Siganus rivulatus	Rivulated rabbitfish	7	9.7	178–248	214
	Siganus sp.	Rabbitfish	7	9.7	66–178	100
	Total		**72**			

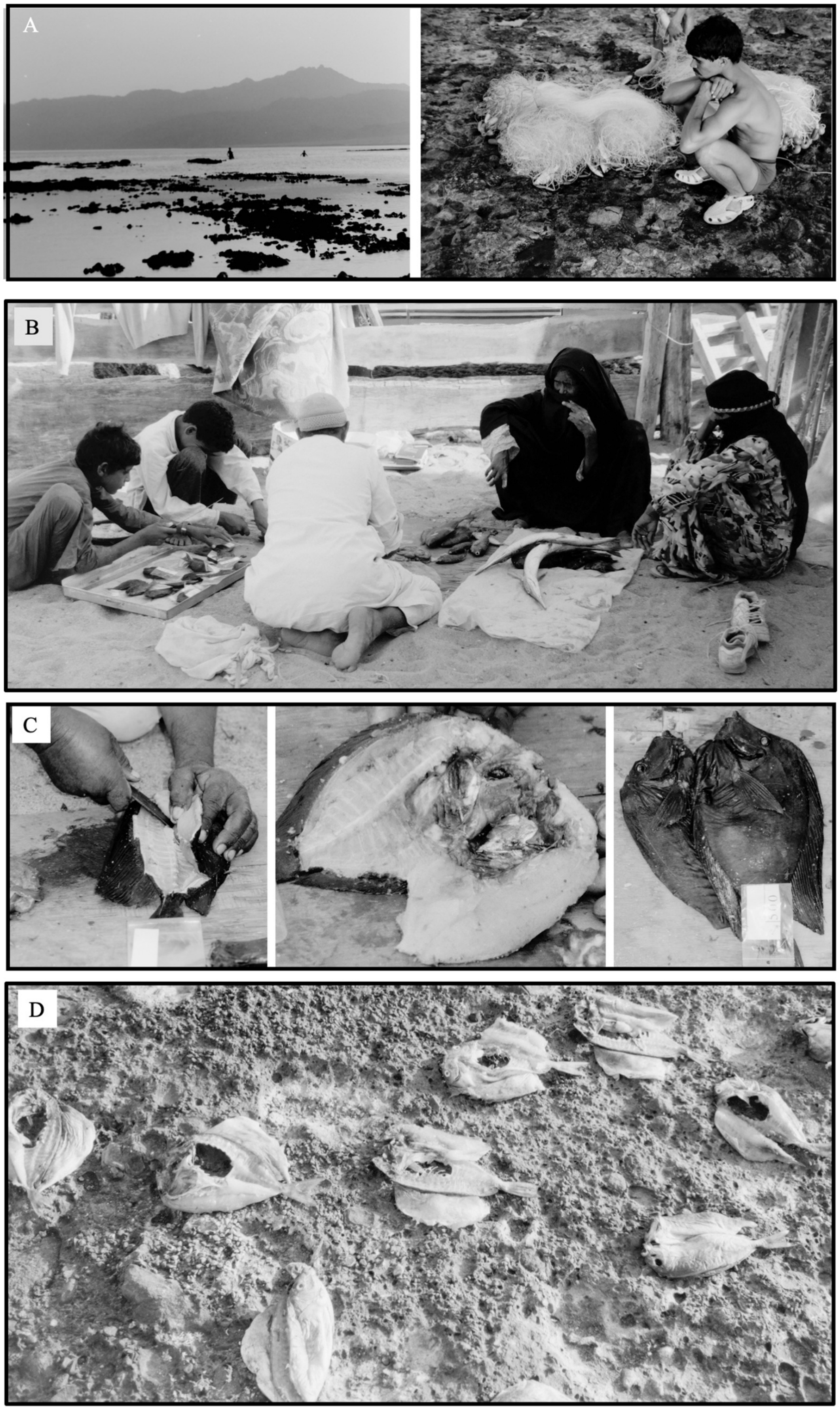

Fig. 8. Artisanal Bedouin fisherman from Nabek Bay, Sinai (Egypt), exploiting parrotfish: A. Fishing in the coral-reef shallow water; B. Fish butchered by Nabek Bedouin (Sinai, Egypt) for immediate consumption and long-term preservation; C. fish butchered lengthwise ("butterfly" fish); D. Fish sun-drying on the coral reef (photographs by Irit Zohar).

Table 4
Signs of burning observed on fish remains recovered at Shivta, Elusa, and Nessana, according to period and excavation context (within-site includes small garbage piles, alleys, and domestic buildings. The large and organized garbage mounds were located outside the site; *at Nessana only Scaridae were analyzed).

			Not Burnt		Burning Signs		Total
Site	Period	Context	NISP	%	NISP	%	NISP
Shivta	Byzantine	Within site	1,679	93.6	114	6.4	1,793
		Garbage mounds	152	82.2	33	17.8	185
	Early Islamic	Within site	1,029	77.1	306	22.9	1,335
Total Shivta			**2860**	**86.4**	**453**	**13.6**	**3,313**
Nessana	Byzantine	Within site	6	60.0	4	40.0	10
	Early Islamic	Garbage mounds	486	87.3	71	12.7	557
Total Nessana			**492**	**86.7**	**75**	**13.3**	**567**
Elusa	Byzantine	Garbage mounds	**1,234**	**94.2**	**82**	**5.8**	**1,316**

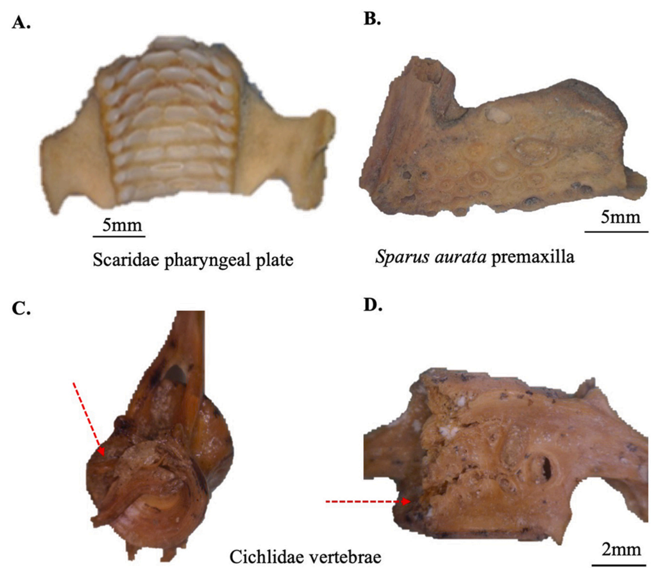

Fig. 9. Chopping marks observed on selected fish remains: A. Red Sea Scaridae lower pharyngeal bone (LPJ) from Early Islamic garbage midden at Shivta (Area K); B. Mediterranean Sea *Sparus aurata* (#148) premaxilla recovered at Elusa Area A; C. Freshwater Cichlidae thoracic vertebrae (#4059) exhibiting chopping marks; D. Cichlidae precaudal vertebrae (#440) with a cut mark recovered at Shivta.

Ervynck, 2004, Van Neer et al., 2004, Van Neer et al., 2005; Studer, 2016; Schmid and Studer, 2007; Studer, 2008; Van Neer and Ervynck, 1998; Van Neer and Waelkens, 2007).

The increase over time in the import and commercialism of Red Sea fish observed in the southern Levant, can be correlated with the expansion of maritime network activity that, according to historical documentation, reached its climax in the Byzantine period (4th–7th century CE), connecting between the Red Sea, India, Africa, Arabia, and the Mediterranean Sea (Al-Nasart, 2012, Mayerson, 1996, Thomas, 2009, Tsiamis et al., 2009, Ward, 2007). Among these locations, Clysma (Suez; Fig. 1) was a significant port, with Trajan's Canal linking the Red Sea with the Nile, enabling maritime transportation to the Mediterranean Sea (Mayerson, 1996, Ward, 2007). The recovery of fish originating from at least three habitats (Red Sea, Nile, and Mediterranean Sea), and other cultural finds originating from Gaza, may suggest that in addition to land transportation from Aila port (south Jordan, Gulf of 'Aqaba), Red Sea fish were transported to the Negev sites from Suez (Clysma port; Fig. 1) through Gaza port (Al-Nasart, 2012), together with fish caught in the Nile and the Mediterranean Sea. The reduction in Red Sea fish and increase in freshwater fish, some endemic to the Nile, as observed in Shivta for the Early Islamic period, and the later abandonment of the Negev commercial center, may be correlated with the decline of Clysma port and decrease in the maritime transport of Red Sea products (Power, 2012).

4.3. Fish processing

Red Sea modern-day artisanal Bedouin still preserve Scaridae and various other Red Sea fish, by salting and wind and sun drying (Zohar, 2003, Zohar and Cooke, 2019) (Figs. 8, 11A). Evidence of the antiquity of this method for parrotfish butchering and long-term preservation was recovered at Myos Hormos (Islamic period; Egypt, Quseir al-Quadim), where a unique dried parrotfish was found, as well as parrotfish skulls split into halves (Fig. 11B) (Hamilton-Dyer, 2011, Thomas, 2011). Since the parrotfish studied here represent consumed fish, a similarity with the above butchering methods can be concluded only from the fragmentation pattern observed on a Scaridae cleithrum (Fig. 11C) and a Sparidae premaxilla (Fig. 9B). Similarly, ostraca discovered in the eastern Egyptian desert at the Roman quarry site of Mons Claudianus, display a list of fish species, including exported, desiccated, Scaridae (Marzano, 2013, Thomas, 2009): 277). The large number of Red Sea fish remains, including Scaridae (Tables 5, S5), recovered at archaeological sites distant from the Red Sea further strengthens the notion of economic and dietary demands for desiccated Red Sea fish, with Scaridae among them, and their long-distance transportation across both maritime and land routes (Hamilton-Dyer, 1994, 2011, Van Neer et al., 2015, Van Neer et al., 2006, Van Neer et al., 2004, Van Neer et al., 2013, Van Neer et al., 2007).

Table 5
Summary of Scaridae (parrotfish) remains recovered from the southern Levant (Fig. 10), according to the total number of fish bones (NISP), NISP of identified Scaridae, taxon identified, and habitat (Mediterranean Sea is marked as 'Med'; Late Roman-1st–3rd century CE; Byzantine-4th–7th century CE; Early Islamic-7th–10th century CE). Sites sieved with 5 mm mesh are marked with *.

Site	Period	Total NISP	Scaridae NISP	Taxon	Habitat	Ref.
Tel Qatif	Chalcolithic	129	3	Scaridae	Med Sea?	(Van den Brink et al., 2016, Van Neer et al., 2005)
Jerusalem Pool	IA	6891	1	Scaridae	Red Sea	(Reich et al., 2008)
Tel Gerisa	IA II			Scaridae	Red Sea	(Van Neer et al., 2004, Van Neer et al., 2005)
Tel Askelon 38	IA II	3890	8	Scaridae	Red Sea	(Lernau, 2011)
Ein Gedi *	Roman and Byzantine	47	2	Scaridae	Red Sea	(Lernau, 2005)
			3	*Scarus ghobban*	Red Sea	
			1	*Scarus gibbus*	Red Sea	
			5	Scaridae.	Red Sea	
Ein Boqeq	Late Roman and Early Byzantine	360	150	Scaridae.	Red Sea	(Lernau, 1986, Van Neer et al., 2004)
Horvat Karkur Illit *	Byzantine	1,650	1	*Sparisoma cretense*	Med Sea	(Figueras, 2004)
			128	Scaridae	Red Sea	
Jerusalem, Armenian monastery	Byzantine	n.d	n.d	Scaridae	Red Sea	(Van Neer et al., 2004)
	Early Islamic	n.d	n.d	Scaridae	Red Sea	
Tamara	Late Roman and Early Byzantine	351	189	Scaridae	Red Sea	(Lernau, 1986)
Tel Ashqelon	Grid 38 Byzantine	n.d	n.d	Scaridae	Red Sea	(Van Neer et al., 2004)
	Early Islamic	n.d	n.d	Scaridae	Red Sea	
	Islamic and Crusader Period	n.d	n.d	Scaridae	Red Sea	
	Early Moslem			*Sparisoma cretense*	Med Sea	
Tel Malhata	Roman/Byzantine			*Scarus* sp.	Red Sea	(Van Neer et al., 2004)
Upper Zohar*	Early Byzantine	2325	171	Scaridae	Red Sea	(Lernau, 1995)
Givati	Abassid		8	Scaridae	Red Sea	Lernau, personal com.
Taninim	Byzantine		2	*Sparisoma cretense*	Med Sea	(Fradkin and Lernau, 2006)
Beit Shean Tsafrir & Foerster	Late Roman-Byzantine	n.d.	1	Scaridae	Red Sea	Lernau, personal com.
Nahal Amram	Roman/Early Islamic	43	15	Scaridae	Red Sea	(Horwitz et al., 2018)
			3	*Scarus gibbus*	Red Sea	
Qarantal	Roman		1	Scaridae	Red Sea	Lernau, personal com
Yishai	Roman		18	Scaridae	Red Sea	Lernau, personal com.
Elat Elot	Early Islamic	408	5	*Scarus* sp.	Red Sea	(Lernau, 1998)

4.4. Exploitation of Red Sea fish and Scaridae

Surprisingly, in contrast to the large number of Red Sea fish remains recovered at archaeological sites (Tables 5, S5), historical documents referring to trade in Red Sea fish are rare. Greek and Roman texts by Aristotle (Hist. An. 8.2) and Pliny (Pliny HN 9.29) include descriptions of the dietary role of Mediterranean Scaridae (*Sparisoma cretense*). In an historical document from Nessana, a church official complains about a shortage of shipments of "skarou" or "skaros"; translated as parrotfish (Kraemer, 1958). Another papyrus from Nessana (Kraemer, 1958), features a demand for "pickled fish", probably relating to either fish sauce (garum, salsamenta) or dried and salted fish, again without mentioning the origin of the fish or their names. The only documentation regarding Red Sea Scaridae appears on an ostracon from the fort of Maximianon (El Zarqa), located 63 km inland from the eastern Egyptian Red Sea coast. It mentions salted or dried Scaridae (translated from the Greek *Temachia karou*), alluding to the state of preservation of the exported Scaridae from the Roman port of Quseir al-Qadim (Myos Hormos) on the Egyptian Red Sea coast (Hamilton-Dyer, 2011, Thomas, 2011).

Historians regarded the Nile, and the fish within it, as a "gift to Egypt" (Griffiths, 1966). Zooarchaeological studies have demonstrated the important role of Nilotic fish in the development of trade routes, commercialism, and as a marker of social status (Raban-Gerstel et al., 2008, Van Neer et al., 1997, Van Neer and Ervynck, 2004, Van Neer et al., 2006, Van Neer et al., 2004, Van Neer et al., 2007, Van Neer et al., 2005). The study of fish remains recovered from the three desert sites of Elusa, Nessana, and Shivta, demonstrates for the first time the important economic and dietary role of Red Sea fish, especially parrotfish (Scaridae) in the development of maritime and terrestrial commerce. The observed diversity in exploited aquatic habitats characterizes the maritime activity of the Egyptians, who transported goods from Suez and from the Nile to the Mediterranean coast and further inland. As observed at the Negev sites, a flourishing Red Sea transport characterizes the Byzantine period, while in the Early Islamic period we can observe a reduction in the commerce and consumption of Red Sea fish and an increase in freshwater and Nilotic fish.

5. Ethics statement

The modern fish used in this study were purchased from the local fishermen.

Author contributions

I.Z. and G.B.O conceived the main conceptual ideas. R.B. and I.Z. performed the identification and analyses of the fish remains, and analysed the data. I.Z. performed the Ethnographic study in Sinai, and the Micro CT. G.B.O and Y.T. performed the archaeological excavations. All authors discussed the results and contributed to the final version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

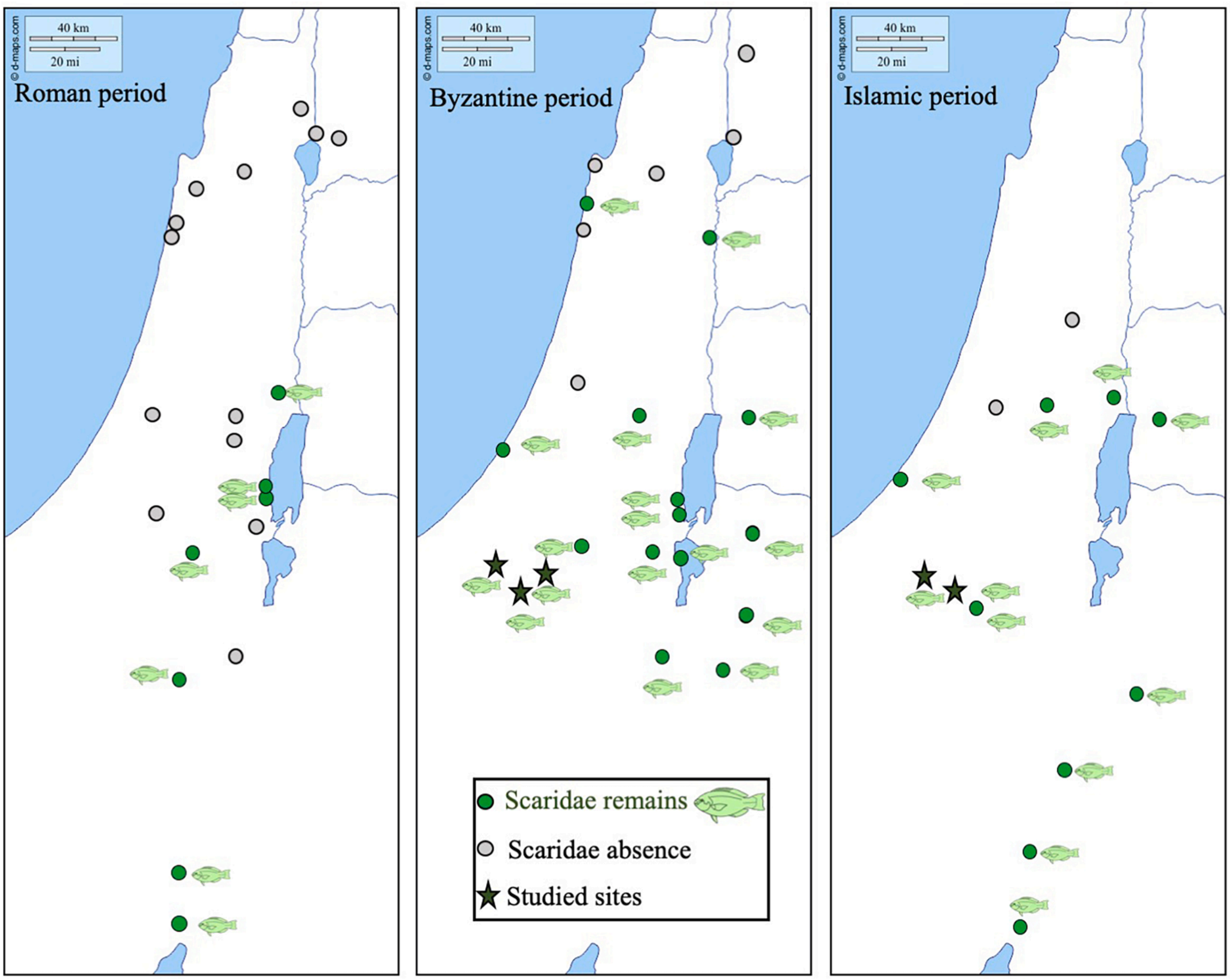

Fig. 10. Occurrence of Scaridae (parrotfish) remains (green) at selected archaeological sites (listed in Table 5): A. Roman; B. Byzantine; and C. Early Islamic (gray = sites without parrotfish remains; green star = studied Negev sites). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

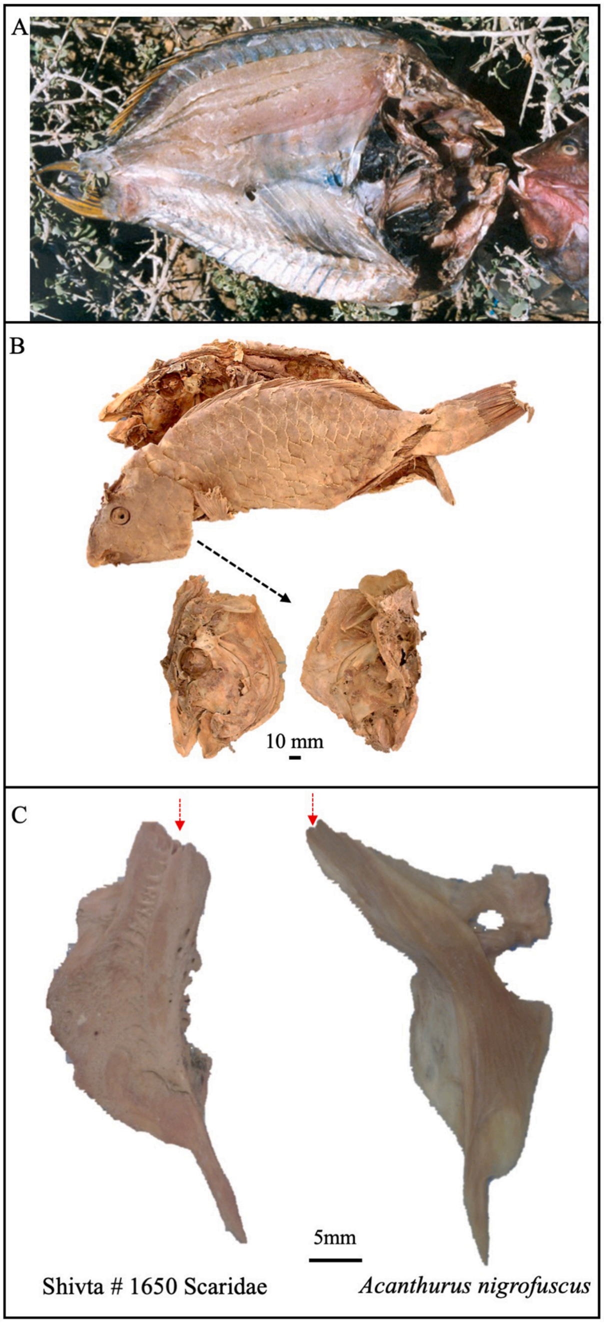

Fig. 11. A. Drying Scaridae ("Butterfly cut") for long-term preservation by wind and sun drying, by artisanal Bedouin fisherman from Nabek Bay, Sinai, Egypt (photographed by Irit Zohar); B. Dry parrotfish and split skulls recovered from the Islamic layer (trench 13) of Myos Hormos (Egypt, Quseir al-Quadim) (photograph courtesy of Sheila Hamilton-Dyer) (Hamilton-Dyer, 2011); C. Scaridae cleithrum recovered at Shivta (#1650) *vs.* cleithrum belonging to *Acanthurus nigrofuscus* butchered by Nabek oasis Bedouin (photographed by Irit Zohar).

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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.2021.102808.

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