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Fish Processing During the Early Holocene: A Taphonomic Case Study from Coastal Israel

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Study of fish bones recovered from coastal archaeological sites requires careful taphonomic analysis in order to determine whether the fish bone assemblage is naturally or culturally derived, and how fish may have been processed by humans. We analysed a grey triggerfish (*Balistes carolinensis*) assemblage from Atlit-Yam, a submerged Pre-Pottery Neolithic site (8140–7550 BP) off the Mediterranean coast of Israel, using multiple taphonomic criteria and quantitative analyses. The clumped distribution of remains, the high bone scatter frequency, the presence of a few burnt bones, the bones' state of fragmentation, the absence of a correlation between bone density and bone frequency, the low species diversity and wide range of body sizes represented, all point to a culturally derived assemblage. The high percentage of identifiable elements, the occurrence of most skeletal elements, and the virtual absence of branchial region bones, are compatible with fish gutted for immediate or later consumption, and incompatible with the expected of refuse. Cranial bones and first dorsal spines of large individuals were missing, apparently a result of size-dependent butchering methods. The emergent picture is of a pile of fish gutted and processed in a size-dependent manner, and then stored for future consumption or trade. This scenario suggests that technology for fish storage was already available, and that the Atlit-Yam inhabitants could enjoy the economic stability resulting from food storage and trade with mainland sites.

Keywords: *BALISTES CAROLINENSIS*, FISH PROCESSING, FISH STORAGE, FISH TRADE, NEOLITHIC, TAPHONOMY, TRIGGERFISH

Introduction

Reconstructing the environmental and cultural circumstances under which animal bones are deposited is the major goal of zooarchaeology. To this end zooarchaeologists must gain insight into the taphonomic processes involved in the history of a faunal assemblage. While there is a growing literature on mammal bone modifications (e.g., Andrews, 1995; Binford, 1981; Blumenschine, Marean & Capaldo, 1999; Bonnichsen, 1989; Bonnichsen & Sorg, 1989; Coard & Dennell, 1995; Gifford, 1981; Lyman, 1994; Noe-Nygaard, 1977, 1989; Rabinovitch, Bar-Yosef & Tchernov, 1996), fewer studies have dealt with fish bone taphonomy (e.g., Butler, 1993, 1996; Lubinski, 1996; Nicholson, 1996*b*; Stewart, 1994; Van Neer & Morales, 1992). Considering the importance of fish to the diet of many prehistoric and historic communities, study of fish bone taphonomy is of major significance.

We carried out a detailed taphonomic study of grey triggerfish (*Balistes carolinensis*) skeletal remains recovered from a submerged Pre-Pottery Neolithic C site (*c*. 8140–7550 BP, uncalibrated). We used multiple criteria as well as quantitative analyses in order to identify the nature of fish use and consumption strategies. The site, Atlit-Yam, is located 10 km south of Haifa Bay (Figure 1), about 300–400 m west of the

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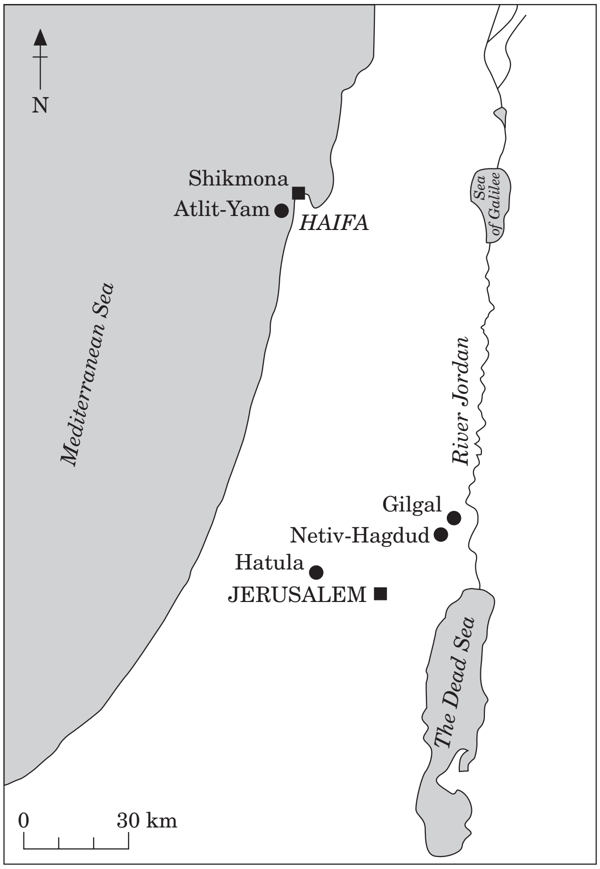

Figure 1. Location map of Atlit-Yam and other Pre-Pottery Neolithic sites in Israel.

present shoreline, at a depth of 8–12 m (Galili *et al.*, 1993; Zohar *et al.*, 1994). During the early Holocene (*c.* 10,000 years ago) the Mediterranean Sea level was about 30 m lower than today (van Andel & Lianos, 1983) and the eastern coastline was more than 1 km offshore from the present. Coastal sites of that period, such as Atlit-Yam, are currently submerged (Galili, 1987; Galili, Kaufman & Weinstein-Evron, 1988). Atlit-Yam is the largest and best preserved submerged prehistoric settlement uncovered along the Mediterranean coast (Galili, Kaufman & Weinstein-Evron, 1988). It provides insight into the food procurement and processing capabilities of human populations that were adapting to coastal habitats at a time of increasing regional social complexity (Hershkovitz & Edelson, 1991; Hershkovitz & Galili, 1990).

Fish assemblages in coastal sites may represent natural or cultural accumulations. Several studies have attempted to discern between the two types of assemblages and have suggested some tentative criteria (Butler, 1987, 1990, 1993, 1996; Stewart, 1991, 1994; Stewart & Gifford-Gonzales, 1994; see Table 1). These include taxonomic diversity; skeletal element proportion (similar to complete fish skeleton in natural assemblages); degree of representation of robust skeletal elements (found to be over-represented in natural assemblages); bone density (bones with low density tend to be lost in natural assemblages); body size range (no individuals under 350 mm have been found in natural assemblages in Lake Turkana (Stewart, 1991), but Van Neer (1993), found mainly small individuals among the fish remains from a small season pool); bone scatter frequency (low in natural assemblages); bones bearing signs of human activity (cut marks and burning found in cultural assemblages). The complexity of taphonomic processes, the high variability in fish processing methods, and the paucity of evidence suggest the need for using multiple criteria for characterizing fish bone assemblages. Nevertheless, the majority of fish remains studies, so far, draw conclusions from a limited number of criteria, and tend to ignore quantitative evidence altogether.

In cultural assemblages, questions arise regarding the way fish have been used. Do the fish assemblages represent refuse (remains of meals or inedible or economically unimportant fish, or parts removed during fish processing), or do they represent fish stored for future consumption? Little zooarchaeological research has focused specifically on fish refuse. Van Neer & Pieters (1997) found a large number of bones, almost all belonging to one species (Plaice, *Pleuronectes platessa*), that were almost all tail, head, and gill elements, some bearing cut marks, which they reconstructed as remains of processed plaice. Several ethnographic studies addressed this issue. Belcher (1998) carried out ethnographic research in Pakistan, and demonstrated that fish refuse is dominated by postcranial bones of small fish and by some cranial bones of large fish, discarded outside the house. Most of the cranial bones demonstrate chop-marks and intense trauma (Belcher, 1998: 170–172). A similar pattern of smashed skull bones of large fish was observed in the surrounding landscape of the western side of Lake Turkana (Stewart & Gifford-Gonzales, 1994). A refuse midden of the Inupiat Eskimo, Alaska, which included fish debris disposed after a cleaning episode, was described briefly but with no taphonomic detail (Chang, 1991).

The relationship between fish processing methods and bone survival through time, has received more attention but is still poorly understood (Barrett, Nicholson & Cerón-Carrasco, 1999; Bullock, 1994; Colley, 1984, 1986, 1990; Cutting, 1955; Nicholson, 1996*a*, Stewart, 1989; Stewart & Gifford-Gonzales, 1994; Van Neer & Ervynck, 1996; Van Neer & Pieters, 1997). Nicholson (1996*a*, 1996*b*) points out that the majority of fish bones are totally destroyed by broiling. Fish processing techniques for immediate consumption and/or long-term preservation vary from region to region and sometimes even within regions (Barrett, 1997; Barrett, Nicholson & Cerón-Carrasco, 1999; Belcher, 1994, 1998; Burt, 1988; Gifford-Gonzales, Stewart & Rybczynski, 1999; Hoffman, Czederpiltz & Partlow, 2000; Poulter, 1988; Stewart, 1982; Stewart & Gifford-Gonzales, 1994). For example, in Lake

Table 1. Characteristic of natural versus cultural fish remains (compiled from: Butler, 1987, 1990, 1993; Landon, 1992; Stewart, 1989, 1991; Stewart & Gifford-Gonzales, 1994; Van Neer, 1993)

Criteria	Natural assemblage	Cultural assemblage
Taxonomic diversity (Brillouin's Index)	May represent the natural fauna of the littoral, or be low due to catastrophic dath of a single species	May be low or high, depending on fishing method and fishing areas
Bone Scatter Frequency (BSF)	Low in breaker zone (Stewart, 1989, 1991) and can be high for tidal pools (Van Neer, 1993)	High
Morisita Index of dispersion	Random or repulsed distribution	Clumped distribution
Body size	Individuals smaller than 350 mm may be absent (Stewart, 1989, 1991) but see Van Neer, 1993 for tidal (seasonal) pools	Various sizes dependent on fishing methods
Size distribution calculated from cranial and postcranial bones	No difference	Different results due to size-dependent methods of fish processing
Bone density versus frequency	Correlated	No correlation
Skeletal element presentation (SI=observed versus expected)	Relatively complete skeletons with cranial and postcranial bones (obs=exp)	Incomplete skeletons (obs≠exp)
Fragmentation Index (VMI of fragmentation)	Low	High in refuse Low in stored fish
MNI versus WMI	Correlation between WMI of fragmentation and MNI from different bones	No correlation between WMI of fragmentation and MNI from different bones
Burning signs	None	High frequency in refuse Low frequency on stored fish
Cut marks	None	May be formed

Victoria, in Pakistan, and in Panama fishermen treat fish according to their size. Several processing methods are applied, leaving different and recognizable modifications on the bone assemblages (Belcher, 1994, 1998; Stewart, 1991; Stewart & Gifford-Gonzales, 1994; Zohar & Cooke, 1997).

Processing techniques can be elucidated if fish bones are recovered in their original storage area. Facilities for storing fish vary tremendously; fish can be stacked upon the ground, or piled upon drying racks, and may also be packed in perishable materials such as palm leaves (Burt, 1988; Stewart, 1982). However, remains of fish stored for future consumption are expected to show some common traits: they are expected to exhibit a clumped distribution, to include all skeletal elements excepting those removed during processing, and the bones may bear cut marks (although those are only infrequently encountered) (Barrett, 1997; Barrett, Nicholson & Cerón-Carrasco, 1999; Belcher, 1998; Bullock, 1994; Cerón-Carrasco, 1994; Gifford-Gonzales, Stewart & Rybczynski, 1999; Stewart, 1991). For example, in Balakot, the Indus valley (4000–2700 BC), a large number of fish remains, representing mainly one species, were recovered in two room complexes. These remains suggest that the site may have been used for drying and storing fish for inland trade (Belcher, 1998).

Drying fish in the sun or over smoking fires is considered the universal technique practised since early time, although the time of its beginning is not yet known (Cutting, 1955; van Elsbergen, 1997). Clear evidence for fish drying and salting, however, is available only from a fairly late period (Barrett, 1997; Barrett Nicholson & Céron-Carrasco, 1999; Brewer & Friedman, 1989; Cutting, 1955; van Elsbergen, 1997). Fish storage for the short- or long-term offers economic stability and the potential for trade with inland populations. For example, the appearance of Mediterranean Sea fish in Neolithic inland sites (Bar-Yosef & Heller, 1987; Bar-Yosef *et al.*, 1991; Davis, 1985; Lernau & Lernau, 1994) may testify to trade relations with coastal populations.

We carried out a detailed quantitative taphonomic study of grey triggerfish remains from Atlit-Yam, in an attempt to develop a framework for identifying fish processing methods, based on fish bones remains in archaeological contexts. Our specific goals were the following:

(a) To determine whether triggerfish were part of the economy of Atlit-Yam inhabitants. Because Atlit-Yam is a submerged site, an alternative is that the fish remains represent a natural accumulation in this marine environment.

(b) If the fish remains represent a culturally derived assemblage, we asked (1) whether the remains represent refuse or do they reflect fish storage for the short- or long-term; and (2) what were the processing techniques practised by Atlit-Yam inhabitants?

We asked a series of research questions to determine the depositional history of the Atlit-Yam triggerfish assemblage, and answered them using species diversity index, dispersion indices, skeletal part frequency analyses, bone density, survival index, fragmentation index, and population body-size structure. These research

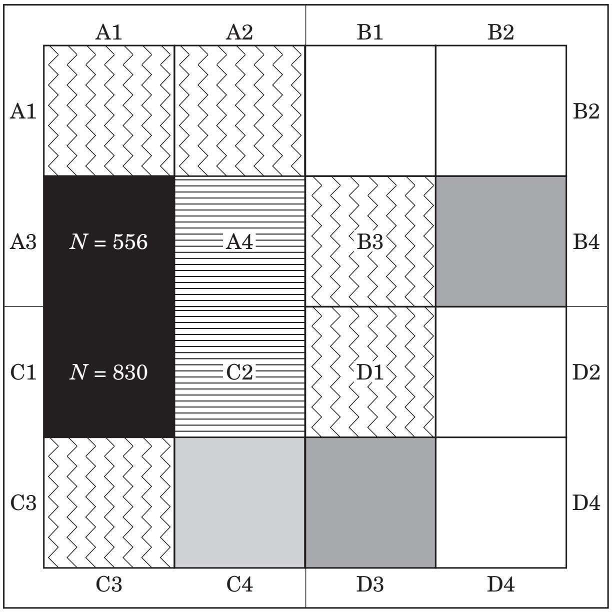

Figure 2. Frequency distribution of 3255 triggerfish remains recovered at locus 10A (divided to four squares: A, B, C, D, and 16 subsquares of 1 sq m each). ■>500 bones; ▤>250 ▢>150 ▢>25; ▨<10; □ no bones. BSF=203 bones per sqm.

questions were designed to provide insight into the fishing economy of Atlit-Yam inhabitants during the 6th millennium BC.

The Faunal Assemblage

Over 6500 fish remains were recovered at a single locus of 4 sqm (Locus 10A; Figure 2) in Atlit-Yam, of which 3777 were identified (Galili *et al.*, 1993). Locus 10A didn't have well defined borders. Some archaeological finds, such as flint flakes, were recovered in the clay at this locus. The fish remains were collected by sieving in fresh water through a 1 mm mesh.

The fish remains represent 10 species belonging to six families of acanthopterygian teleosts (*Balistidae*—1 species, *Carangidae*—1 species, *Mugilidae*—1 species, *Serranidae*—3 species, *Sciaenidae*—1 species, and *Sparidae*—3 species) (Galili *et al.*, 1993). The vast majority of the fish remains (*c*. 97%) were identified as *Balistes carolinensis* (Grey triggerfish) (Galili *et al.*, 1993; Zohar *et al.*, 1994).

The triggerfish remains include 2089 bones representing 44 different skeletal elements, 153 teeth, 515 scales, and 498 fin rays (Table 2). The minimum number of individuals (MNI=76) was calculated based on the most common bone in the assemblage, the basal pterygiophore.

Are the fish remains a naturally or culturally derived assemblage?

The location of Atlit-Yam, under 10 m of water, and the lack of structural features at locus 10A, suggest that fish remains recovered at that locus may be a natural accumulation rather than the result of cultural activity. To answer this question we used parameters that have been derived from several taphonomic studies carried out in different parts of the world. Each covered a specific depositional scenario which may be site-, taxon-, or region-specific. Therefore, we see great significance in using a wide variety of parameters to characterize our fish bone assemblage. Future research that will add to these studies will enable us to fine-tune our understanding of depositional scenarios. Here we used the following parameters: taxonomic diversity, bone scatter frequency, index of dispersion, burn marks, body size range, and relationship between density and survival.

Taxonomic diversity: taxonomic breadth can help distinguish between natural and cultural activity (Butler, 1987; Morales & Van Neer, 1994; Stewart, 1991). We calculated species diversity by using Brillouin Index (and not Shannon-Wiener function) since our sample is not random and the total number of species is unknown (Krebs, 1989). Moreover, Brillouin index is most sensitive to the abundances of the rare species in the sample, and is nearly identical to the Shannon-Wiener function (Krebs, 1989). Brillouin Index of diversity was calculated according to the following formula (Krebs, 1989: 362–365):

$$H = \frac{1}{N}\log_2\left(\frac{N!}{n_1!n_2!n_3!\ldots}\right)$$

where H is Brillouin's index, N is the toal number of individuals in the entire collection, n_1 is the number of individuals (NISP) belong to species 1, and n_2 is the number of individuals (NISP) belong to species 2, etc.

We assume that in a natural accumulation of fishes, we might find the taxonomic diversity representative of the fish occupying the nearshore habitats. When human fishing activity is involved, diversification of fishing strategies may enlarge or reduce taxonomic diversity (Morales & Van Neer, 1994; Stewart, 1991; Van Neer, 1993). In order to examine this assumption we compared the species diversity index calculated at locus 10A with recent data (Ogerek, 1999) on a recent fish community from a littoral rocky reef habitat in Shikmona-Haifa bay (Figure 1). This area has similar conditions to the ones at the littoral rocky area of Atlit-Yam, 8000 years ago.

In the Shikmona-reef 35 species, belonging to 18 different families, were collected (Ogorek, 1999). The most common families were the Blenniidae and the Gobiidae (Ogorek, 1999).

The Brillouin's diversity index calculated for the fish recovered at locus 10A is of 1·18 species (H=0·1724), and of 13·58 species (H=2·608), for the fish from Shikmona-reef. It is clear that the species diversity index is higher for the natural collection than at Atlit-Yam (13·58 versus 1·18 species). Moreover

Table 2. Frequency distribution of triggerfish skeletal element structures recovered at Atlit-Yam (Locus 10A), compared to a full triggerfish skeleton and to the expected values

Skeletal region	Observed bones in Atlit-Yam		Observed bones in fresh triggerfish		Expected value for Atlit-Yam		Regional contribution		
	N	%	*N*	%	*N*	%	χ^2	*P*	*df*
Neurocranium	389	18·6	22	14·1	295	14·1	29·95	<0·001	1
Oromandibular region	269	12·9	24	15·4	321	15·4	8·42	<0·001	1
Hyoid region	96	4·6	25	16·0	335	16·0	170·51	<0·001	1
Branchial region (gill arch)	9	0·4	33	21·2	442	21·2	424·18	<0·001	1
Opercular apparatus	120	5·7	8	5·1	107	5·1	1·58	ns	1
Total cranial	883	42·2	112	71·8	1500	71·8			
Appendicular skeleton	342	16·4	21	13·5	281	13·5	13·24	<0·001	1
First dorsal spine region	294	14·1	5	3·2	67	3·2	769·10	<0·001	1
Vertebral column	570	27·3	18	11·5	241	11·5	449·13	<0·001	1
Total post cranial	1206	57·8	44	28·2	589	28·2			
Total	2089	100·0	156	100·0	2089	100·0	1866·1	<0·001	7

Neurocranium Expected Value: 22/156 × 2089 = 295.

Balistes carolinensis that accounts for the overwhelming majority of fish at Atlit-Yam (*c.* 97%) is not represented at Shikmona. Also Carangidae that are pelagic species appear only at Atlit-Yam.

Natural deaths of fish in the coastal waters of Israel are rare and have been shown to involve small numbers of fish of a wide range of species (Goren pers. com). Although there can be cases of natural deaths of a single fish species, such a scenario involving triggerfish is unknown in Israel, where triggerfish comprise less than 1% of the annual catch (Golani, pers. com.). Therefore, the overwhelming dominance of triggerfish in the Atlit-Yam assemblage is congruent with the expected in a culturally derived rather than naturally derived fish assemblage.

Bone scatter frequency (BSF): calculated as the average number of bones per sqm, (*N* bones/m^2) reflects depositional processes (Stewart, 1989, 1991, 1994). It is expected to be higher for culturally derived than naturally derived assemblages (Stewart, 1989, 1991, 1994). Also, culturally derived bone assemblages are expected to be clumped, contrasting with naturally derived fish assemblages that are expected to have random or uniform distributions (unless under very specific topographic or limnological conditions, such as a seasonal pool [Van Neer, 1993]). The dispersion (random, uniform or clumped) of the triggerfish remains in locus 10A at Atlit-Yam was calculated by dividing the locus into 16 quadrates of 1 m^2, and by using the Morisita Index of dispersion according to the formula (Krebs, 1989, Box 4·5 p. 152: see further calculation for standardization):

$$I_d = n\left[\frac{\Sigma x_i^2 - \Sigma x_i}{(\Sigma x_i)^2 - \Sigma x_i}\right]$$

where I_d is Morisita' index of dispersion, n is the sample size; x_i is the sum of the bone counts in each quadrats ($x_1 + x_2 + x_3$), and; x^2 is the sum of bone counts in each quadrats squared ($x_1^2 + x_2^2 + x_3^2 +$).

Table 3. Burning signs on triggerfish skeletal elements recovered at Atlit-Yam

Skeletal element stucture	Total no.	Burned bones	
		No.	%
Neurocranium	389	14	3·6
Oromandibular region	269	11	4·1
Hyoid region	96	6	6·2
Opercular apparatus	120	6	5·0
Appendicular skeleton	258	13	5·0
Pelvic complex	84	7	8·3
First dorsal spine region	294	78	26·5
Branchial arch	9	0	0·0
Vertebrae	570	21	3·7
Total	2089	156	7·46

Bone distribution in locus 10A at Atlit-Yam (Figure 2) was clumped ($I_p = 0{\cdot}58$, $P < 0{\cdot}01$; Krebs, 1989), conforming with that expected of a culturally derived accumulation. Bone scatter frequency value (BSF = 203 bones per sqm) was higher by several orders of magnitude than that found in a naturally derived assemblage at modern Lake Turkana and Crater Lake (i.e., 0·04–0·06) (Stewart, 1989, 1991, 1994).

Burn marks: the occurrence of burn marks is taken to indicate human activity (Nicholson, 1993; Stewart & Gifford-Gonzales, 1994). A small percentage of the bones at locus 10A (7.5%), mainly those of the first dorsal spine region, bear burning signs (Table 3). These also suggest human activity.

Size range: Stewart (1989, 1991) studied a naturally derived fish assemblage which did not include fish smaller than 350 mm in length. While little is known of the effects of predator activity or of wave action on the dispersal of either small or large fish elements post-mortem, she suggested that there is little chance that isolated elements of small fish would survive abrasive shore deposition (Stewart, 1991). On the other hand, Van Neer (1993) found mainly small fish represented in a small pool seasonally connected with a larger body of water, and suggested that this pool served as a nursery for younger fish individuals, which were subsequently trapped in the pool when it dried up.

Reconstruction of the lengths of Atlit-Yam triggerfish (Zohar *et al*., 1994; Zohar, Dayan & Spanier, 1997; see also discussion ahead) demonstrates that the majority of fish were shorter than 350 mm. The natural conditions at Atlit-Yam at the sea shore more closely resemble those at the shore of large lake rather than a temporary pool, in terms of wave action. Moreover, triggerfish do not use temporary or tidal pools as nurseries. Therefore, the size distribution of triggerfish is more compatible with an assemblage that was not accumulated under natural activity of wave action.

The relationship between bone density and survival: in natural bone assemblages that suffer severe post-depositional processes we expect to find a relationship between bone density and survival (Butler, 1994; Lyman, 1984; Lyman, Houghton & Chambers, 1992). Such a relationship may also arise as a result of human activity (Binford, 1981; Lyman, 1984; Lyman, Houghton & Chambers, 1992). However, a lack of relationship between bone density and bone survival suggests that bone breakage and bone loss patterns reflect human activities related to butchering and processing methods (Butler, 1994; Nicholson, 1992).

Bone density was measured for three recent triggerfish as in Falabella, Vargas & Melendez (1994). Bones were weighed and then soaked in varnish and dried. The dried bones were placed individually in a special water container and their volume was measured by rising water levels. Triggerfish bone densities were obtained by dividing bone weight by volume. We calculated the correlation between bone density of each bone and bone frequency at locus 10A (Table 4).

No correlation was found between the frequency of the bones in Atlit-Yam and their density value (Spearman rank correlation: $r=0{\cdot}105$, tied $z=0{\cdot}453$, tied $P>0{\cdot}650$). These results conform with other studies (Falabella, Vargas & Melendez, 1994; Nicholson, 1992), which suggest no relationship between fish bone density and bone survival, in culturally derived assemblages. The absence of a relationship between bone density and survival suggests that triggerfish bone loss and bone damage in locus 10A reflect human activity.

In sum, the taphonomic evidence from Atlit-Yam clearly shows that the triggerfish assemblage is a culturally derived fish assemblage.

Table 4. Fresh triggerfish bone density and frequency at Atlit-Yam (locus 10A)

Bone	Triggerfish density	Frequency* (%)
Articular	2·32	1·23
Atlas	1·14	1·04
Axis	1·21	1·23
Cleithrum	1·10	3·41
Dentary	1·06	1·50
Ethmoid	0·70	1·32
Frontal	0·73	2·58
Hyomandibular	0·89	2·33
Maxilla	0·97	0·86
Opercular	1·12	0·92
Pelvis	1·23	2·30
Postcleithrum	1·22	2·30
Prefrontal	0·55	0·64
Premaxilla	1·03	0·95
Preopercular	1·16	2·76
Quadrate	1·25	1·75
Supracleithrum	0·84	1·20
Tail vertebrae	1·00	0·64
Urohyal	1·42	0·27
Vomer	1·08	0·80

*The frequency was calculated from the total sample of 3255 triggerfish remains recovered at locus 10A.

What type of human activity do the triggerfish remains reflect?

Having established that the Atlit-Yam triggerfish assemblage reflects human activity, the next question is what type of human activity it indicates. Are the fish remains human refuse, or are they stored food? A clumped distribution is compatible with fish storage, but may also reflect a refuse pile (Van Neer & Pieters, 1997). The triggerfish remains were recovered close to wall foundations (*c*. 3–4 m), but their deposition gives no clue regarding their role in the inhabitants' economy. It is therefore necessary to use other criteria in order to distinguish between storage and refuse (parts removed during fish processing for immediate or long term consumption, or remains of meals),

Van Neer and Pieters (1997) suggested that during processing the gill region is discarded and tossed into the refuse. This suggests that we may be expected to encounter a high proportion of bones of this region in refuse. Ethnographic studies demonstrated that in Pakistan, butchery waste of fresh fish is represented by the branchial arch and the pectoral girdle (Belcher, 1998). In Panama, butchery waste of fish prepared for drying and salting is represented by the branchial arch and few cranial bones (Zohar & Cooke, 1997). Stewart & Gifford-Gonzales (1994) examined fish waste sites that consisted primarily of epaxial spines discarded on capture of fish. The fish processing site consisted mainly cranial elements and vertebrae were poorly represented.

When we deal with remains of a meal, Landon (1992) suggested that poor preservation will characterized the animal remains, resulting in a low percentage of identifiable bones. Belcher (1998) demonstrated that in Pakistan small fish skulls are chewed and swallowed, while the vertebrae are removed and discarded. Larger fish (>250 mm) are chopped into pieces of 5 cm^2, and then cooked. As a result little will be left of the cranial remains of small fish, while refuse of large fish (>250 mm), will be represented mainly by cranial bones, some of which exhibit cut marks. Belcher also noted that remains from the meal are discarded in the house courtyard.

Stewart & Gifford-Gonzales (1994) studied fish remains from base camps and demonstrated that over 50% of the skulls were apparently smashed for brain extraction. Burning signs were found on 11% of the bones, as a result of roasting, which was found to be more destructive than broiling (Stewart & Gifford-Gonzales, 1994). Nicholson's (1996*a*) experiments on the effect of cooking on fish bones showed that boiling clearly accelerated diagenesis, while other forms of cooking did not appear to have this effect.

The triggerfish remains recovered at locus 10A do not resemble refuse since most of the skeletal elements were identified (Table 2), including cranial and post-cranial bones with low percentages of burning signs (Zohar *et al*., 1994). We also found that the gill region was heavily under-represented in Atlit-Yam (see section ahead), suggesting that fish were gutted elsewhere and accumulated in locus 10A area.

The nature of the remains suggests that triggerfish were processed for immediate or delayed consumption. In case of accumulation for immediate consumption, only a catastrophic event would have created such an assemblage, and no signs for such a catastrophe are found in the site. Moreover, ethnographic evidence from Ghana, where triggerfish are used in large quantities, demonstrates that they are consumed after salting and drying and only in rare occasions they are consumed fresh (Essuman & Diakite, 1990; Nerquaye-Tetteh, 1986).

Thus, the mode of preservation of the Atlit-Yam triggerfish is compatible with fish storage for long-term consumption rather than refuse.

What were the processing techniques practised in Atlit-Yam?

Encountering a large pile of stored fish is an excellent opportunity for studying fish processing techniques. Fish processing can be reconstructed based on the bones lost in this process and based on bone fragmentation patterns (Zohar & Cooke, 1997).

Body part representation: the relative distribution of different skeletal elements may be used to investigate fish processing methods and to separate between culturally and naturally derived assemblages (Barrett, 1997; Butler, 1996; Hoffman, Czederpiltz & Partlow, 2000; Stewart, 1991). In Atlit-Yam, triggerfish bone

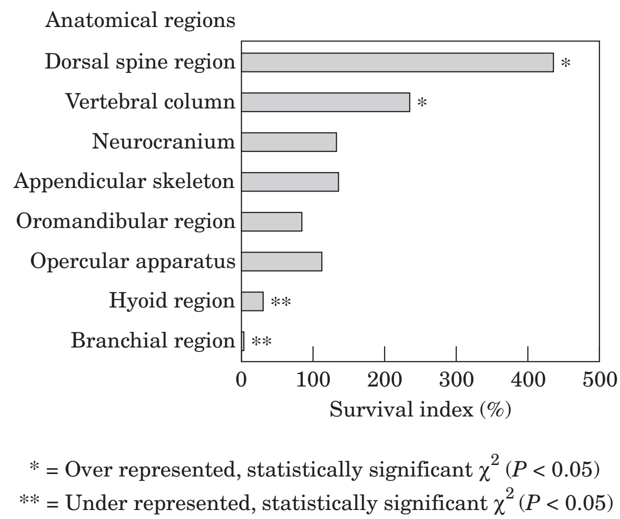

Figure 3. The survival index (SI) of Atlit-Yam triggerfish bones grouped into eight anatomical regions.

frequency distribution was calculated for 44 different skeletal elements from eight anatomical regions (following the terminology of Wheeler & Jones, 1989; Table 2): neurocranium, oromandibular region, hyoid region, branchial region (includes the gillraker), and opercular apparatus (of the cranium), as well as the first dorsal spine region, appendicular skeleton, and vertebral column (of the post-cranium, posterior to the first trunk vertebra). The bone frequency distribution was also calculated for fresh triggerfish for comparison with the data obtained from locus 10A.

In order to test for differences in representation of the skeletal elements due to fish processing, we calculated a survival index. The survival index (SI) was expressed as the ratio between number of observed bones (NISP) to number of expected bones (per skeletal element) [SI=(no. of observed bones/no. of expected bones) × 100]. The expected frequencies were calculated based on the relative frequency of each skeletal element in a fresh triggerfish skeleton, multiplied by the total number of observed triggerfish bones in Atlit-Yam [Expected Value=(no. of bones in a fresh triggerfish/total no. of bones in a fresh triggerfish) × (total no. of observed triggerfish bones in Atlit-Yam)].

The triggerfish remains survival index (SI) is high for the vertebrae and dorsal spine region (over-representation, Figure 3), and low for the branchial arch, hyoid region and pelvic girdle (under-representation, Figure 3). The under-represented regions may reflect their low survivorship in the sediment due to environmental factors. Alternatively, they may reflect human activity such as fish gutting and butchering (Van Neer & Pieters, 1997; Zohar & Cooke, 1997).

The composition of the triggerfish bone assemblage in Atlit-Yam indicates that most of the skeletal elements were present (Table 2). Only bones from the branchial arch region are almost entirely absent

(χ^2=424·183; df=1, Table 2 and Figure 3). Absence of branchial arch region is compatible with fish gutting for immediate or delayed consumption (Van Neer & Pieters, 1997; Zohar & Cooke, 1997).

Vertebrae are over-represented in our bone assemblage with a frequency of 27·3% (versus 11·5% expected value χ^2=449·13; df=1, Table 2 and Figure 3). Vertebral over-representation is a well-known bias in culturally deposited fish assemblages, contrary to naturally deposited assemblages, where vertebrae are represented in similar proportions to those of a complete fish (Stewart, 1991).

Thus, body part representation of Atlit-Yam triggerfish is compatible with human activity of fish gutting for immediate or delayed consumption.

Bone fragmentation patterns: a high frequency of skeletal part representation, as reflected in NISP per bone, may reflect a high occurrence of a body region, but may also reflect high bone breakages. Bones that are highly fragmented may be counted several times, and consequently may appear over-represented.

A fragmentation index was used to evaluate the preservation status of triggerfish bones. For terrestrial mammalian bone assemblages this index is used as an indicator for marrow extraction. For the triggerfish bone assemblage from Atlit-Yam, it may reflect the butchering methods practised and resistance to post-depositional deterioration (Bullock, 1994; Zohar & Cooke, 1997). Fragmentation status was determined for each bone, according to the amount of the remaining bone, as follows (Figure 4): "complete" (approximately 91–100% of bone remaining); "slightly fragmented" (71–90% of bone remaining); "partially fragmented" (51–70% of bone remaining); "highly fragmented" (30–50% of bone remaining), and "small fragments" (approximately 25% or less of bone remaining). In order to standardize the degree of fragmentation for 44 groups of bones from eight anatomic regions, their weighted mean index (WMI) of fragmentation was calculated (Table 5). The WMI expresses the mean degree of fragmentation calculated from the relative frequency (Xi) of each bone in the five fragmentation categories (i.e., fragments size of: 100%; 80%; 60%; 40%; 25%) [WMI= Σ(Wi*Xi)/100]. We then correlated the survival index (SI) and the WMI of fragmentation for each anatomic region.

We found a negative correlation between the value obtained for the bones by each index (SI and WMI) (Figure 5: Spearman rank correlation, $r = -0{\cdot}458$; $P<0{\cdot}004$). Since fragmentation may be the cause for this negative correlation, we compared between WMI of fragmentation and MNI values for the most common bones (Table 6). Some of the bones with high value of MNI such as the basal pterygiophore, dorsal spines, cleithrum, etc., are highly fragmented (WMI of fragmentation <50%) while bones with low value of MNI (e.g. premaxilla, dentary, supracleithrum) are

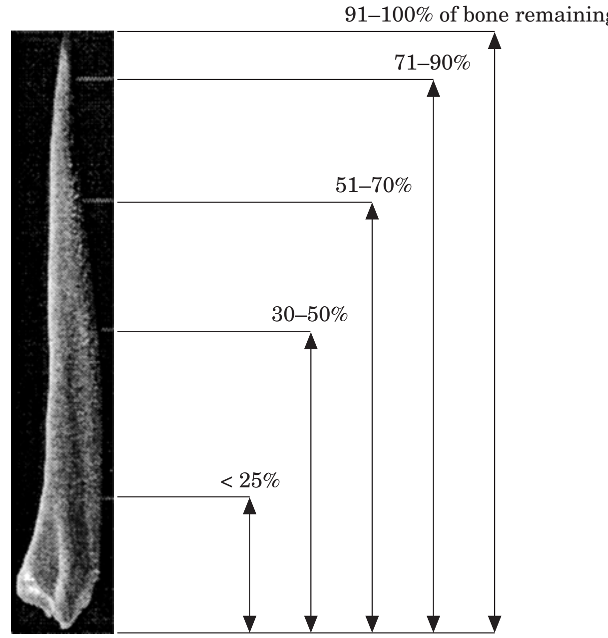

Figure 4. Classes of bone fragmentation, according to the amount of the remaining bone. Classes of bone fragmentation: Complete: approximately: 91–100% of bone remaining; Slightly fragmented: 71–90% of bone remaining; Partially fragmented: 51–70% of bone remaining; Highly fragmented: 30–50% of bone remaining; Small fragments: approximately 25% or less of bone remaining.

hardly fragmented (WMI>70%). This demonstrates that fragmentation did not influence the high survival values of the bones.

If fragmentation affected bones present at Atlit-Yam, it can have done so only to the neurocranium. In Atlit-Yam, the triggerfish neurocranium bones survival index (Figure 3) demonstrates higher presentation values than expected (18·6% versus 14·1%, χ^2=29·953; df=1, Table 2). Moreover, when the ratio between vertebral and cranial bones is calculated, a ratio of 0.55 was obtained for Atlit-Yam compared to 0·2 in a fresh triggerfish. This result is opposite to those of other studies demonstrating that the neurocranium bones were the least well preserved bones in archaeological sites (Butler, 1993; Coard & Dennell, 1995; Lubinski, 1996; Nicholson, 1996*a*; Wheeler & Jones, 1989). The high representation of fragmented neurocranial bones in Atlit-Yam suggests that the skulls were damaged during fish processing.

In sum, the overall pattern of triggerfish skeletal element abundance at locus 10A was not driven by bone fragmentation. Rather, it reflects fish processing techniques.

Body size distribution: analysing size distributions of fish on the basis of different skeletal elements allows us to discern patterns in fish exploitation, and to determine whether the deposits are culturally or naturally derived (Butler, 1993, 1996; Stewart, 1989). If all bone elements have an equal chance of survival then

Table 5. Frequency (%) of triggerfish skeletal elements by structure, according to the five fragmentation categories and their weighted mean index (WMI), in Atlit-Yam

	Frequency of bones (%) in each one of the five fragmentation categories					
Skeletal element structure	100%	80%	60%	40%	25%	WMI
Neurocranium	9·6	6·7	17·9	27·0	38·8	46·2
Oromandibular region	62·3	5·7	11·1	11·8	9·0	80·5
Opercular region	3·3	16·7	35·0	30·0	15·0	53·4
Hyoid region	4·2	17·7	28·1	30·2	19·8	52·2
Branchial region	77·8	22·2	0·0	0·0	0·0	95·6
First dorsal spine region	5·7	7·2	11·4	33·4	42·2	42·2
Appendicular skeleton	11·8	20·7	33·4	26·9	7·2	60·9
Vertebral column	50·6	0·0	0·1	0·3	49·0	63·0

Neurocranium WMI=[(9·6 × 100)+(6·7 × 80)+(17·9 × 60)+(27·0 × 40)+(38·8 × 25)]/100=46·2%.

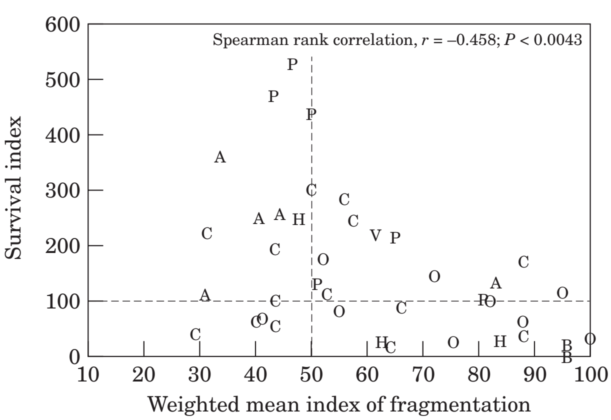

Figure 5. *Balistes carolinensis* survival index versus weighted mean index (WMI) of fragmentation. The WMI of fragmentation is calculated using five classes of bone fragmentation. A=Appendicular skeleton; B=branchial arch; C=Neurocranium and dorsal spine; O=Oromandibular region; P=post crania; V=Vertebral column.

reconstructing body size frequencies from different bones should result in similar body size frequencies (Wheeler & Locker, 1985). If, on the other hand, fish are processed according to size, with small fish processed in a different way than large fish are (Stewart, 1991; Zohar & Cooke, 1997), then reconstructing fish size frequencies using different skeletal elements will result in different body size patterns.

Size distributions (standard length and body mass) of the triggerfish population were calculated using bones of different anatomic regions (cranial and post-cranial) by applying the linear regression (natural logarithms) method (Zohar, Dayaan & Spanier, 1997). We selected three of the most abundant bones from different anatomic regions, which were easy to identify and to measure: the dorsal postcleithrum, ethmoid, and first dorsal spine. The reconstructed standard length frequencies of the fossil population presents a wide spectrum of lengths ranging from *c.* 100 mm to 400 mm SL (Figure 6). This result suggests the use of non-selective fishing methods by Atlit-Yam inhabitants.

However, a comparison of the body size distributions obtained from each bone reveals clear differences. Based on the dorsal postcleithrum (N=82), mean body mass of the triggerfish at Atlit-Yam is 521·15 g (range: 64·9–2471·45 g) and mean standard length is 229·65 mm (N=75, range of 122·45–420·9 mm; Figure 6). On the other hand, when estimation is based on the ethmoid (N=36) and the first dorsal spine (N=69), the means for both body length and body mass are significantly lower (one way ANOVA; F=10·55, df=2,184, P<0·0001, F=10·37, df=2,168, P<0·0001 respectively for body mass and standard length). Based on the ethmoid, mean body mass at 268·85 g (range of 72·4–941·1 g) and mean standard length at 189·8 mm (range of 127·3–302·9 mm). Similar values were obtained by using the first dorsal spine (BM: $\bar{x}$=271·25 g; range: 54·74–1103·98 g; SL: $\bar{x}$=189·97 mm; range: 115·4–320·54 mm) (Scheffe contrasts; P=0·999 for body mass and standard length).

The significantly different size distributions obtained using different skeletal elements suggest that dorsal spines and some neurocranial bones of large individual triggerfish at Atlit Yam are missing. This differential loss suggests the use of size-dependent methods for processing triggerfish at Atlit-Yam. In Panama, for example, fish butchering is size-dependent and in large marine catfish the first dorsal spine is removed and later a ventral cut is performed through the skull (Zohar & Cooke, 1997). In this procedure the first dorsal spine and its base will be lost and some neurocranial bones are damaged (ethmoid, vomer). A similar procedure may have been used by the inhabitants of Atlit-Yam while butchering larger triggerfish, resulting in the loss of the larger first dorsal spines and cranial bones.

Discussion

The analysis of fish remains from coastal or submerged sites is a challenging task. The first step is to

Table 6. Minimum number of individuals (MNI) and weighted mean index (WMI) of fragmentation calculated from different bones of grey triggerfish recovered at Atlit-Yam

Bones	Count	MNI	WMI
1st dorsal spine	79	73	46·63
2nd dorsal spine	60	60	49·85
3rd dorsal spine	36	36	65·04
Angular	11	8	100·00
Articular	40	15	95·12
Basal pterygiophore	102	76	43·10
Basioccipital	26	—	43·51
Branchial arch	9	8	96·00
Ceratohyal	10	2	84·00
Cleithrum	111	40	33·67
Dentary	49	15	72·07
Ectopterygoid	8	4	75·48
Epiotic	6	—	64·24
Ethmoid	43	43	56·00
Exoccipital	14	—	29·29
Frontal	84	12	57·56
Hyoid apparatus	1	1	90·00
Hyomandibular	76	38	47·69
Maxilla	28	16	54·88
Metapterygoid	24	1	41·31
Opercular	30	13	66·26
Palatine	21	10	87·90
Parasphenoid	34	—	31·30
Pelvis	75	11	44·26
Postcleithrum	75	22	40·44
Prefrontal	21	9	40·16
Premaxilla	31	13	81·93
Preopercular	90	44	50·00
Prootic	33	—	43·58
Pterosphenoid	11	9	88·07
Pterotic	19	—	43·69
Quadrate	57	29	52·08
Scapula	33	—	31·00
Supracleithrum	39	15	83·08
Supraneural	17	10	81·10
Supraoccipital	20	—	52·75
Urohyal	9	1	62·72
Vomer	26	16	88·00

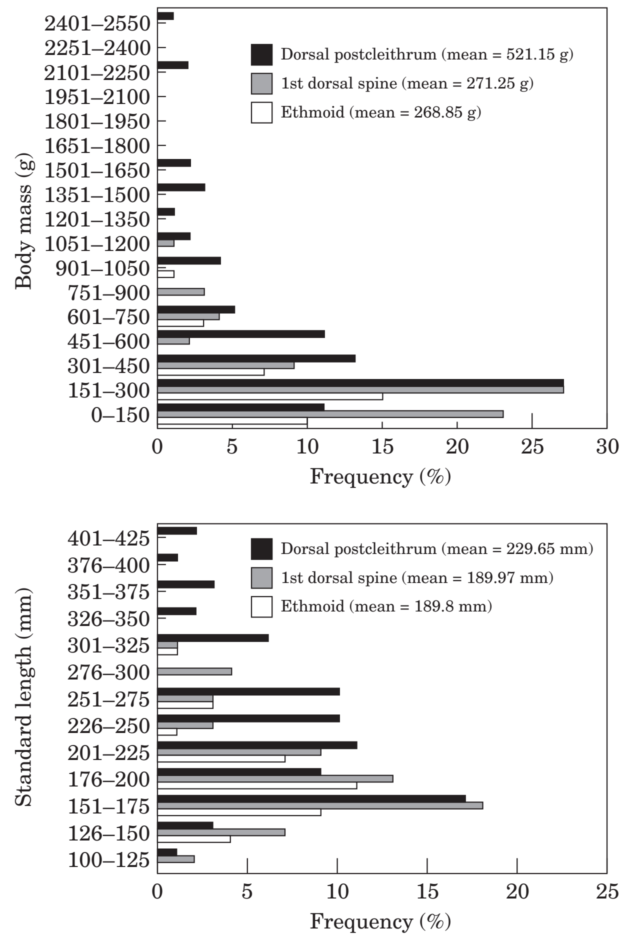

Figure 6. Triggerfish body size (body mass and standard length) estimated from the ethmoid, the first dorsal spine, and the dorsal postcleithrum.

discern between human and natural agents of fish accumulation. We are primarily concerned with human-derived assemblages, and for those we attempt to reconstruct the activities involved—fishing, processing, and storing. The wide diversity of fishing methods and the complexity of natural accumulation processes, the diverse methods for processing fish, and the different storage types, all require that a wide set of criteria be employed for the analysis of fish bone remains from archaeological sites (Table 1).

In our analysis of grey triggerfish (*Balistes carolinensis*) remains from the submerged site of Atlit-Yam, we used a wide array of tests to elucidate the nature of this fish bone accumulation. The clumped distribution of the bone remains and the high bone scatter frequency in locus 10A (4 sqm), together with the occurrence of burnt bones, suggest human activity. Moreover, the absence of a correlation between bone density and bone frequency suggests that bone loss was predepositional and reflects human activity. Species diversity, with one highly dominant species and low taxonomic diversity further supports this hypothesis. Most of the skeletal elements are present, but bones of the branchial region are strongly under-represented. The virtual absence of branchial region bones is compatible with fish gutted for immediate or later consumption, and incompatible with the expected of a naturally derived assemblage. Our analysis ruled out the possible bias of bone fragmentation generating apparent over-representation. Triggerfish body size reconstruction estimated from different cranial and postcranial bones points to a large range of body sizes, including small ones which would not be expected under conditions of natural accumulation. However cranial bones and first dorsal spines of large individuals were missing, apparently a result of size-dependent butchering methods.

The emerging picture is of a pile of fish stored at a specific location. The fish were trapped irrespective of size, but after gutting were processed in a size-dependent manner. It appears that fish smaller than 250 g were preserved in their entirety, while the heads of larger fish (>250 g) were removed or damaged during butchering. Differential treatment based on body size and morphology has been observed in several fishing communities around the world (Belcher, 1994; Burt, 1988; Stewart, 1982; Stewart, 1989; Zohar & Cooke, 1997). In Panama small fish (<325 mm) are butchered entirely with their skull intact while large fish (>325 mm) are butchered by a longitudinal dorsal cut, starting at the base of the caudal fin and extending to the anterior part of the skull. The first dorsal spine and predorsal plate of large marine catfish (*Ariidae* sp.) are removed and discarded before the fish are cut (Zohar & Cooke, 1997). Similar processing could explain the absence of dorsal spines of large triggerfish in Atlit-Yam. In Kenya (Lake Turkana), fish smaller than 250 mm in length are processed entirely while larger onces (>250 mm) are decapitated (Stewart, 1989; Stewart & Gifford-Gonzales, 1994).

Ethnographic comparisons with recent-day populations, and the occurrence of scales in the Atlit-Yam assemblage, suggest that triggerfish were gutted and then processed for long-term consumption with their skin, as is the practice in present-day populations in different parts of the world (Essuman & Diakite, 1990; Zohar & Cooke, 1997). In Ghana, dried and salted triggerfish contribute significantly to the local food supplies and to the daily meals. Triggerfish, primarily those with a body mass of 75 g and over and a length of 150 mm and over are processed for long-term consumption by salting and sun-drying (Caveriviere, 1987; Essuman & Diakite, 1990; Koranteng & Quaatey, 1990; Nerquaye-Tetteh, 1986). The salted and dried triggerfish are packed tightly for storage in round, traditional mud ovens and covered with polythene sheets. Because of the salt level, tough skin and low fat, a well processed triggerfish will keep for months (Nerquaye-Tetteh, 1986).

In sum, Atlit-Yam is the earliest prehistoric community in the eastern Mediterranean that exhibits evidence for intensive fishing, fish processing, and fish storage. Fish storage allows long-term preservation and trade with inland populations, economically significant activites. Our results explain the occurrence of marine fish bones in inland sites (such as Hatula near Jerusalem, Gilgal and Netiv Hagdud in the Jordan Valley) 8000 years ago (Bar-Yosef & Heller, 1987; Bar-Yosef *et al*., 1991; Davis, 1985; Lernau & Lernau, 1994), a result of trade with coastal communities.

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