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Dessin de pêche au thon à la senne de plage, représentée sur une hydre mycénienne de l'île de Naxos (Hadjianastasiou 1991). Crédits : Nikoleta Tsiligiri/ *Drawing of tuna fishing with beach seine net depicted on a Mycenean hydria from Naxos Island (Hadjianastasiou 1991). Credits: Nikoleta Tsiligiri*.

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Catching tuna in the Aegean: biological background of tuna fisheries and the archaeological implications

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ABSTRACT
Fishing for tuna in the Aegean goes back several millennia. Their bones are found in archaeological excavations and their biology, capture, processing and consumption are described in written sources of the historical era. The archaeology of tuna fishing, however, is still poorly understood and its economic importance in the Eastern Mediterranean has only recently been explored. This paper contributes to the emerging discourse around tuna and their economic and cultural significance by attempting an in-depth understanding of tuna and related fish species as a resource. It presents in some detail the biology and ethology of tuna in the context of the Aegean Sea. These are crucial factors to their exploitation by humans; they control the timing and location of their appearance and they render certain fishing and processing methods more appropriate than others. The paper also discusses some of the implication of the biological features of tuna and related species on the manner of their capture and to the development of cultural values around them. It also considers the heuristic value of these observations in the archaeological research. The examination of the biological characteristics of tuna and related members of the Scombridae family suggests that their exploitation should in fact be seen not as that of single species but of a range of different species, which share certain common characteristics, but differ in terms of size, migration timing, processing potential and quality of flesh. In this framework the exploitation of the migratory fish, of which tuna is the most emblematic, appears as a coherent activity, which was less vulnerable to yearly fluctuations in the presence of fish schools at any given fishing location. Being thus complex and flexible, it provided economic opportunities and it acquired significant cultural value for the Eastern Mediterranean cultures throughout the passage of time.

KEY WORDS
Tuna fishing, archaeology of fishing, zooarchaeology, Scombridae.

RÉSUMÉ

Capturer des thons dans la mer Égée : contexte biologique des pêcheries thonières et leurs implications archéologiques.

La pêche au thon dans la mer Égée remonte à plusieurs millénaires. Leurs ossements se trouvent dans des fouilles archéologiques et leur biologie, leur capture, leur traitement et leur consommation sont décrits dans des sources écrites historiques. L'archéologie de la pêche au thon est cependant encore mal connue et son importance économique en Méditerranée orientale n'a été explorée que récemment. Cet article contribue à l'émergence d'un discours autour des thons et de leur importance économique et culturelle en tentant une compréhension approfondie des thons et des espèces de poissons apparentées, en tant que ressource. Il présente en détail la biologie et l'éthologie des thons, qui sont des facteurs cruciaux pour leur exploitation par l'homme. Ces caractéristiques contrôlent le moment et le lieu de leur apparition et rendent certaines méthodes de pêche et de traitement plus appropriées que d'autres. L'article examine également certaines des implications des caractéristiques biologiques des thons et espèces apparentées sur les modalités de leur capture et sur le développement des valeurs culturelles qui les entourent. Il considère aussi la valeur heuristique de ces observations dans la recherche archéologique. L'examen des caractéristiques biologiques des thons et des membres apparentés de la famille des Scombridae suggère que leur exploitation devrait en fait être considérée non pas comme celle d'une seule espèce, mais comme celle d'un ensemble d'espèces différentes, qui partagent certaines caractéristiques communes, mais diffèrent en termes de taille, de moment de migration, de potentiel de transformation ou de qualité de la chair. Dans ce cadre, l'exploitation des poissons migrateurs, dont le thon est le plus emblématique, apparaît comme une activité articulée, moins vulnérable aux fluctuations annuelles de la présence des bancs de poissons sur un lieu de pêche donné. Étant ainsi complexe et flexible, elle offrait des opportunités économiques et a acquis au fil du temps une valeur culturelle significative pour les cultures de la Méditerranée orientale.

MOTS CLÉS
Pêche au thon,
archéologie de la pêche,
zooarchéologie,
Scombridae.

INTRODUCTION

Tuna is an emblematic fish. Fish bones, representations in art and written sources all indicate that the capture of tuna was definitely part of the fishing regimes in the Aegean from the 11th millennium BP right down to the present day (for the earliest evidence for tuna fishing, see review and references in Mylona 2016). Tuna entered the archaeological and historical literature as early as the 19th and the early 20th centuries. Several early works have stressed its importance for this geographical area, mainly for the historical periods, especially Hellenistic and Roman (Rhode 1890; Eberl 1892; Keller 1913: 382-393; Steier 1936: cols 720-734). Towards the end of the 20th century, the importance of tuna, along with that of other marine resources was questioned and seriously downplayed (e.g., Gallant 1985; Jameson *et al.* 1994: 309-314; but see Bintliff 1977: 117-122, 240-244). Current research has reconsidered tuna and their economic and cultural significance in the past (e.g., Lytle 2006; 2016b; Mylona 2008; Marzano 2013; Felici 2018; Theodoropoulou 2018). However, the details of tuna fisheries, the technology involved, the organization required for its capture and the embeddedness of all this in economy and culture are less well known, especially in the context of the Eastern Mediterranean and the Aegean Sea.

The archaeological visibility of tuna fishing is an open issue. The fishing methods attested historically and ethnographically (Rhode 1890; Lytle 2006: 37-68; García Vargas & Florido del Corral 2007; Di Natale 2012) involve the specialized use of a number of otherwise common fishing tools (nets, hooks, ropes, stone weights) and special arrangements of space on the highly unstable and changeable wave line. Preservation of these items is unlikely and their identification as related to tuna fishing is far from obvious. The best chances for the archaeological documentation of ancient tuna fishing are the actual evidence of the fish (fish bones, chemical traces in pottery) and of their processing (salting vats, salted-fish trading amphorae).

The exploitation of Scombridae is the result of a complex process of decision-making on the part of the fishermen, which takes into account issues of technology, time, work power, the market, even the very existence of fish-processing establishments. All these decisions, however, are made against the constraints and opportunities that are offered by the nature of the fish. Therefore, the understanding of the biology and ethology of tuna and related species in specific geographical contexts is crucial for the appreciation of their exploitation and their significance[1].

This paper offers an introduction to tuna as a resource, and presents their specific biological and ethological characteristics that are pertinent to their capture and processing in the context of the Aegean Sea and Eastern Mediterranean more generally (Fig. 1). It highlights the importance of the local conditions in the study of past fisheries. It also discusses the implications of these features for tuna exploitation with examples drawn from prehistoric and historical Aegean. The term "tuna" is used here in a generic sense to denote members of the Scombridae family.

1. The seminal work by Ponsich & Tarradell (1965) on *garum* and fish processing industries in western Mediterranean introduced this type of consideration in the study of past fisheries. Relevant observations are found in literature but they are mostly incidental and on specific taxa or locations. The discourse around fishing and fish preservation in western Mediterranean differ considerably from the discourse on eastern Mediterranean (e.g., Mylona & Nicholson 2018) and it is not discussed here in any detail.

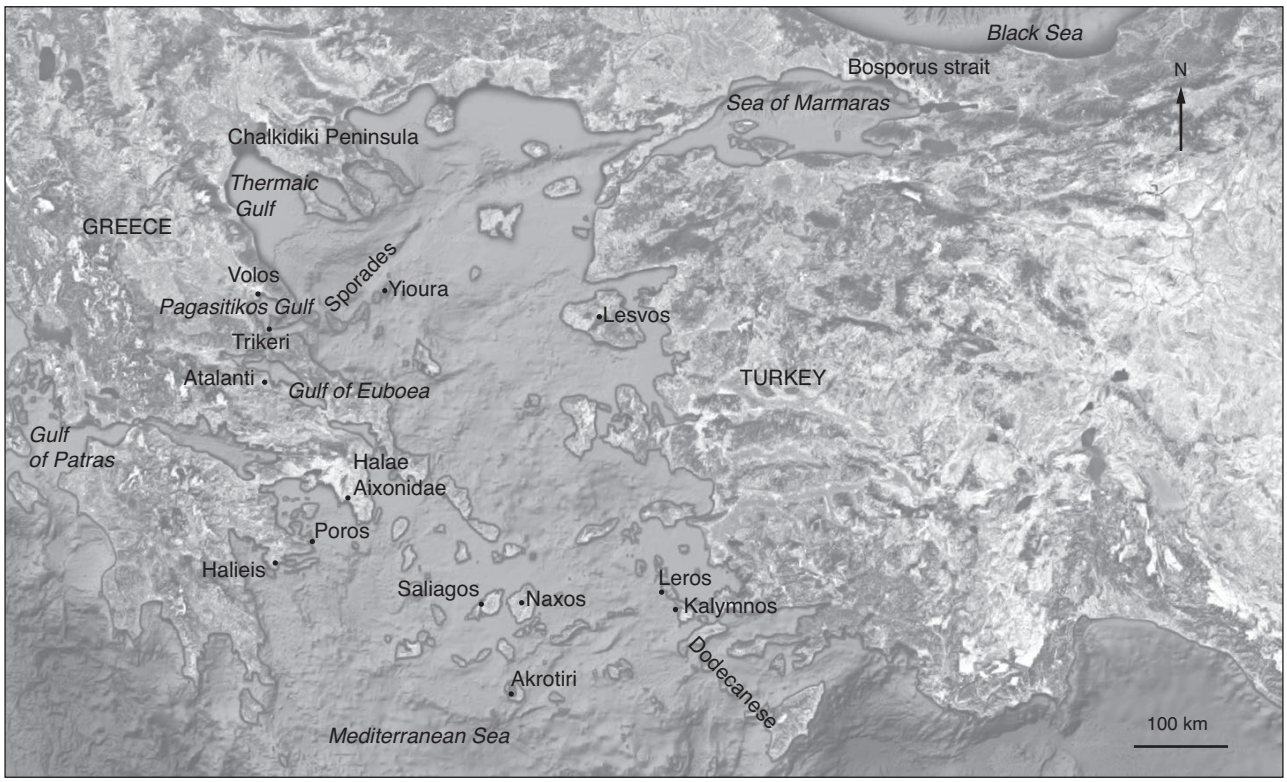

Fig. 1. — Map of the Aegean Sea with sites mentioned in the text noted on it. Credits: V. Triggas.

UNDERSTANDING TUNA AS A RESOURCE

Knowledge of the biology and ethology of animals, their specific characteristics and habits is a basic research tool of zooarchaeology. These features may pose restrictions on the way the animals can be captured or managed, or, alternatively, they may offer opportunities which make such efforts easier (Martin 2000; Pickard & Bonsall 2004: 277-283). By knowing how the animals behave, we can have an understanding of what is possible for humans to do with them. Certain fish species, for example, tend to search for food by sight rather than smell. Fishermen take advantage of it and attract them with shiny or feathery baits that simulate the natural prey of those fish. For this type of fish, bait with a strong smell but poor visual impact would be ineffective. The mating behavior of parrotfish offers another example. It had inspired, already in antiquity, a special method of capture (Oppian, *Halieutika,* IV. 74-111), which survived, almost unchanged, over the centuries to the modern era (Lefkaditis 1941: 238-241; Potamianos 1950: 127-129).

Tuna and other migratory species share certain biological and behavioral characteristics, which lead to the development of certain widespread capture and processing methods. These characteristics can have heuristic value for the archaeology of tuna fishing, as they can lead researchers to make plausible hypotheses regarding seasonality, fishing technology, possible location of ancient fishing grounds and landing spots and, thus, the location of processing installations. Additionally, species-level identification of Scombridae bones recovered in archaeological excavations can lead to more accurate inferences of the fishing methods involved, depending on the targeted species and of fishing-management schemes practiced in antiquity.

The practical and location-specific impact of the tuna's biology and ethology to fishing in localities along their migration routes is crucial to understanding tuna as a resource. There are a few studies on tuna-fishing communities scattered all over the world (e.g., Akimichi 1975; Meltzoff & Lipuma 1986; Gillett 1987), including the Mediterranean, although in this last case very few such communities still survive, and then mostly in the Western Mediterranean (e.g., Sicily, Sardinia, Morocco). These studies seldom follow strict anthropological/ethnographic protocols (e.g., Collet 1993; Addis *et al.* 2012). They are mostly literary, based on the first-hand experience of the authors (e.g., Maggio 2000), or they are records compiled by fisheries scientists who are involved in management and conservation of tuna populations (e.g., Rainmondo 1969; Rubino & Dessy 1994; Ravazza 2007; Abid *et al.* 2012). In the Aegean and the Black Sea, no such studies exist (except Paraskevopoulou 1936). There is, however, a group of publications which provides ethnographic information of the type discussed here but embedded in essays on archaeology, biology, travelling or some other topic (e.g., Apostolides 1883; Faber 1883; Panagiotopoulos 1914; Athanasopoulos 1923, 1924, 1925, 1926; Ninni 1923; Devedjian 1926; Belloc 1961; Bintliff 1977: 130l, part i, map 1; Felici 2018: 195-213). In this group could be included those historical written sources, covering the last 2500 years. Literary texts, inscriptions, legal and tax documents make up some of them (for a review of such documents from Classical and Roman Aegean, see Lytle 2006 and

Felici 2018; for Ottoman documents in Istanbul, see Örenç *et al.* 2014). These sources, additionally, inform us on the way people in antiquity understood tuna, its biology and its exploitation. Although this is an issue relevant to the present paper it will not be discussed here (but see Felici 2018: 39-107).

Tuna fishing has undergone a massive transformation in the last decades all over the world and in the Mediterranean more especially. Technological advancements, which involve the use of large-scale fishing tools (e.g., plastic nets or long lines several thousand meters long, ICCAT 2006-2016), advanced technologies for the location of fish in the water (e.g., sonar and satellite imaging – Brehmer *et al.* 2007; Klemas 2013) and the subsequent tapping of new fishing grounds (offshore or in very deep waters, Yang & Gong 1987; Ward & Hindmarsh 2007) have increased the amount of landed tuna and related fish and have driven certain fish stocks, including tuna, to the verge of collapse. Additionally, the fishing of tuna is heavily regulated by international laws and agreements. The demands of the global market (Constance *et al.* 1995; Bonanno & Constance 1996, 2008; Ellis 2009) affect the exploitation of tuna everywhere. These factors are all features of the modern world (from the second part of the 20th century onwards) and they are not helpful in understanding tuna fishing in antiquity. They do, however, have an impact on the relevance of anthropological and modern ethnographic studies as analogies for tuna fishing in the past. The function of the *tonnara* in Favigniana, in south-west Sicily, for example, described in detail by Theressa Maggio (2000) and the organization of the fishermen involved in its workings, echo descriptions of large-scale tuna fisheries in the past (e.g., Lytle 2006: 68-113), but their vastly different cultural and economic contexts make any direct connection between the two rather problematic.

THE PHYSIOLOGY OF THE SCOMBRIDAE (TUNA, BONITOES AND MACKERELS)

When we talk about tuna fishing we usually envision the large, impressive bluefin tuna (*Thunnus thynnus* (Linnaeus, 1785)). To truly understand this sector of fishing, though, one that is involved with different genera in a whole fish family, the Scombridae should be considered as a group. These are fish that differ vastly in size, from the small chub mackerel (*Scomber colias* (Gmelin, 1789)), to the massive bluefin tuna. Despite the difference in size, they do share certain common characteristics, which define their fisheries and also their processing. Details on the biology and ethology of the Scombridae that are summarily and selectively presented here are based on reviews by Collette & Nauen (1983), Block & Stevens (2001) and Sharp & Dizon (2012), on geographically specific studies that are mentioned in the text and on the Field Manual of International Commission for the Conservation of Atlantic Tuna (ICCAT 2006-2016).

In the Aegean and in the Black Sea, several Scombridae species are encountered, but they are not all equally well researched and known (ICCAT 2006-2016). Additionally, in earlier biological and, even more so, in classical literature there is considerable confusion of identification and terminology (e.g., Thompson 1947: 79-90, esp. 80; Lytle 2016a with extensive bibliography and discussion of erroneous identification of *ἀμία* as *Sarda sarda* (Block, 1793) by early scholars). In this article, the members of the Scombridae family that are exploited in the Aegean will be presented not in a taxonomic order (Collette *et al.* 2001), but by size. From the point of view of their fisheries and their consumption, this is a most pertinent feature.

Large-size Scombridae: true tuna

Two species in this group are found in the Aegean, the bluefin tuna (*Thunnus thynnus*) and the albacore tuna (*Thunnus alalunga* (Bonnaterre, 1788)). Their maximum length and weight differ considerably. But where they overlap in their respective size-range, they cannot be separated on the basis of their bones, which look identical (Fig. 2). Although these fish are fairly large when mature, they can also be caught when younger and thus much smaller.

Thunnus thynnus *(Linnaeus, 1785) – Bluefin tuna, κόκκινος τόνος/όρκυνος*

It is the emblematic tuna, the largest fish in the Mediterranean. Bluefin tuna is a cosmopolitan, highly migratory, a schooling fish, able to tolerate a wide range of environmental conditions (Arrizavalaga *et al.* 2015). Its presence, feeding and reproduction is strongly influenced by these environmental conditions, such as the temperature and salinity of the water, and for this reason its migration trajectories fluctuate from year to year (Druon *et al.* 2011; Fromentin *et al.* 2014). Its current absence from the Black Sea, which on literary and historical evidence appears as a rich fishing ground and also possibly a reproduction area in the past, is the result of such changing conditions (including industrial pollution) since the 1970s (Mackenzie & Mariani 2012).

The maximum reported length of bluefin tuna exceeds 4 m and its maximum reported weight is 726 kg, (although there exist unverified reports by fishermen for individuals of 900 kg; Mather *et al.* 1995). Bluefin tuna in the Mediterranean reach maturity when approximately four years old (at 110-120 cm[2], 25-30 kg; Fromentin 2006) and that is the age/size at which we expect them to perform their first reproduction migration. Tuna exhibit a rapid growth in the first years, but they keep growing all through their life, which may reach 30 years. There is a standard correlation between their age and length/weight (Arena *et al.* 1980). A bluefin tuna has a high metabolic rate, which allows it to maintain its body temperature in a wide range of environments and also to achieve very high swimming speeds. As a result, its blood is copious and bright red, being rich in oxygen.

Spawning of bluefin tuna in the Mediterranean, especially in the eastern basin, has been a much-debated issue. It is generally agreed that it takes place in the warm waters (> 24 °C) of specific and restricted locations: around the Balearic Islands,

2. Length figures refer to "fork length", from the tip of the nose to the point where the tail divides into two parts.

Fig. 2. — *Thynnus* sp. bones from Late Classical strata (400-300 BC) at Kalaureia, Poros island. Scale bar: 4 cm. Credits: D. Mylona, Kalaureia excavations photographic archive.

Sicily, Malta, Cyprus (Fromentin 2006), all well-known tuna-fishing areas in antiquity (Curtis 1991: 116-118, 129), as well as the Black Sea in the past (Piccinetti & Piccinetti-Marfin 1993). It usually occurs in May-June (Heinisch *et al.* 2008; Damalas & Megalofonou 2012). The exact spawning grounds, i.e., the locations towards which the reproduction migrations head, are still not well known. Bluefin tuna form dense schools on the reproductive leg of their migration and less dense ones after spawning and on their return trip to their feeding grounds. Young individuals feed mostly on zooplankton and older ones prey on schools of small pelagic fish and on cephalopods, such as squid (Sarà & Sarà 2007). Both juveniles and adults move through the water column; the older bluefin tuna can reach as deep as 500-1000 m (e.g., Brill *et al.* 2002). It is agreed that bluefin tuna tend to aggregate and feed along ocean fronts, where food availability is highest (Druon *et al.* 2011).

The frequency, timing and movements of bluefin tuna in the Aegean are reported from several sources, of different dates. Often there is no correspondence between their findings (Ninni 1922; Athanasopoulos 1923, 1924, 1926; Belloc 1961; Lefkaditou *et al.* 1988). Modern data (post-1980s) on bluefin tuna populations in the Aegean are relatively few compared to other Mediterranean areas. According to the most recent of these reports, bluefin tuna in the Aegean tend to appear in larger numbers at certain areas on their migrating route(s) (e.g., the Chalkidiki peninsula, northern gulf of Euboea, Sporades), but there is a diffused presence of tuna in other zones, such as Dodecanese or Lesvos (Lefkaditou *et al.* 1988). However, Ninni (1922) reported that tuna migrated north towards the Black Sea in two groups. The largest of them skirted the coasts of Asia Minor and the adjacent islands, including the Dodecanese, and the smaller group crossed the channel between Euboea and the mainland to enter the Pagasetic Gulf. The bluefin tuna schools were denser just off the Bosporus straits and along the Marmara Sea (Di Natale 2015 and references therein). The exact timing of the fishing for bluefin tuna in various locations in the Aegean varies considerably, but it roughly occurs in spring (spawning migration) and in autumn (feeding migration).

Most of the available reports are based on data provided by modern fishing vessels, which use fishing gear that is either very large (e.g., large nets several hundred meters long, and long lines several kilometers long) or recently introduced in the area (e.g., Japanese pole and line fishing for bluefin tuna in the Kavala Gulf after the 1980s, Lefkaditou *et al.* 1988). These vessels have access both to spawning and to feeding bluefin tuna. Although relevant data map the timing and geographic distribution of bluefin tuna in the Aegean, not all of them can be used as a predictive tool in research on tuna fishing in antiquity, where the available technology posed certain restrictions as to which fishing grounds and resources could be accessed. Certain observations, however, are useful. Medium-sized bluefin tuna (30-100 kg), for instance, are found off many of the Aegean coasts throughout the year, while large tuna (over 150 kg) are abundant only from April to September (Mather *et al.* 1995: 66, 67). It seems likely that the first category represent fish that feed in the area, while the second category are fish on the reproductive run, visiting the area to spawn.

Besides the time of the year and the inshore or offshore location of fishing operations, the lunar phase appears to be another important factor in tuna fishing. It has been observed that the probability of catching bluefin tuna exhibits a periodicity that coincides with the lunar circle and is linked to their predatory behavior. Fishermen in the Aegean refer to certain rich catches as the "full moon of May tuna" (Damalas & Megalofonou 2012). Additionally, Greek and Turkish fishermen at the beginning of 20th century, echoing Aristotle (*HA* 598b), reported that bluefin tuna migrate

keeping their right eye towards the coast (Ninni 1923), so that their schools move anti-clockwise along the coasts. This observation is crucial to the prediction of their occurrence in different locations, and also to the construction of tuna fishing gear (see "Implications of Scombridae physiology to their fisheries in antiquity"). Also relevant to the nature of tuna fisheries in the area (in terms of location and fishing gear) is the observation that, if a tuna school is encountered in the shallow coastal areas, it is more likely to be a large one (Damalas & Megalofonou 2012).

Thunnus alalunga *(Bonnaterre, 1788) – Albacore, τόνος μακρόπτερος*
Albacore is a large, cosmopolitan, migratory fish, reaching a maximum length of 140 cm and a maximum weight of 60.3 kg. A common length for mature individuals is 100 cm (Froese & Pauly 2019). It is not encountered in the Black Sea. Albacore tuna seldom come close to the shore and they prefer wide, open waters, where they spawn. Their migration routes are fairly uncertain. Their schools are not as large and dense as some other tuna and they are not often mixed with other species. For physiological reasons, young albacore are not able to move up and down the water column, so they tend to stay near the surface. That is why today they are more efficiently caught by surface gear, while the adults are caught at all depths (ICCAT 2006-2016).

In the Aegean, the fishing period for the albacore tuna is from mid-August to November, with the most important fishing area nowadays stretching between the Sporades and the Chalkidiki Peninsula. Less important areas are the Gulf of Patras, and the islands of Lesvos, Kalymnos, and Leros. Most of the fish caught are two to three years old and they are captured in their feeding area of concentration (De Metrio *et al.* 1989).

Medium-size Scombridae
The medium-size Scombridae include small tuna and pelamids. The members of this group that are found in the Aegean – the little tunny (*Euthynnus alletteratus* (Rafinesque, 1810)), the skipjack tuna (*Katsuwonus pelamis*) and the atlantic bonito (*Sarda sarda*) – are fairly easily identified on the basis of some of their bones (e.g., Godsil & Bayers 1944).

Euthynnus alletteratus *(Rafinesque, 1810) – Little tunny, Black skipjack, τονυάκι/καρβούνι*
The little tunny is a schooling migratory fish, which is found all over the Mediterranean and the Black Sea. It occurs in inshore waters, but occasionally it can be found in offshore waters too. In the Mediterranean, it can reach a maximum length of about 1 m and a maximum weight of 12 kg, but its common length is 85 cm (Valeiras & Abad 2006c). In the northern Aegean and on the north coast of Cyprus it is generally smaller, with sizes and weights most commonly ranging from 45-80 cm and 2.5-7 kg respectively (Kahraman 2005). Little is known on the migration of this species. In the Mediterranean, spawning takes place from May to July. It is caught by coastal fisheries, often artisanal, from February to June (Valeiras & Abad 2006c). Fishing efforts in eastern Mediterranean (Aegean and Cyprus) peak in April and May (Kahraman 2005). Its flesh is suitable for preservation (e.g., salting, canning) and it is often used as a substitute for the pelamid (*Katsuwonus pelamis* Linnaeus, 1758) (Papanastasiou 1976: 499, 500).

Katsuwonus pelamis *(Linnaeus, 1758) – Skipjack tuna, Κατσουβόνεια παλαμίδα/ λακέρδα/τονοπαλαμίδα*
This is a highly migratory, cosmopolitan species, which forms large schools in warm/temperate waters. These often follow larger animals, such as whales and sharks. Their maximum recorded fork length is 110 cm and maximum recorded weight is 34.5 kg. Common length of mature individuals is 80 cm. It is absent from the Black Sea, but its status in the Mediterranean and in the Aegean more specifically is very unclear. ICCAT records (ICCAT 2006-2016) state that this species does not occur in the Mediterranean or the Black Sea. However, its presence is mentioned in various publications and in some of them it is described as common (for several cases in the Aegean Sea, see Papakonstantinou 1988: 136). Papanastasiou (1976: 500-503, based on Ananiadis 1970: 298, who, nevertheless, refers to *Sarda sarda* which is also called παλαμίδα in Greek) suggests that spawning in the Greek Seas and along the North African coast takes place from April to September. Referring to both skipjack tuna and Atlantic bonito, which share the common name *pelamid,* he provides a migration calendar, which describes specific fishing grounds in particular months of the year, where they are caught by purse-seines and tuna traps (*thynneia*). Smaller individuals have more tender meat. In the Turkish market, pelamids (*Katsuwonus* and *Sarda*) are known with different names depending on their weight (palamite: 0.5-1 kg; bonito: 2-4.5 kg; torik: 4.5-7 kg; lackerdit: over 7 kg), even though they are not distinct taxonomically (Papanastasiou 1976: 502, 503).

Sarda sarda *(Block, 1793) – Atlantic bonito, ρίκι/παλαμίδα*
Atlantic bonito is a migratory schooling fish that reaches a maximum length of 85-91.4 cm, depending on location and a maximum weight of 5 kg. Its common length and weight are 50 cm and 2 kg. (Valeiras & Abad 2006a). Little is known about the physiology and behavior of this species. The best-studied area is the Black Sea and the Sea of Marmara. Atlantic bonito is also found in the Aegean. Bonitos migrate along the coasts over very large distances; tagged individuals have been located in the Black Sea and later in the Western Mediterranean. The issue of its spawning grounds in the area of Eastern Mediterranean is still uncertain. In the Mediterranean and the Aegean, the spawning season is from May to July (Valeiras & Abad 2006a). Bonitos from the Aegean Sea move through the Marmara into the Black Sea for reproduction in spring and back to the Aegean in autumn, from September onwards, but it appears that there are bonito schools that do not migrate to the Sea of Marmara or the Black Sea at all (Demir 1963; Yoshida 1980). For their migration routes within the Aegean some information is provided by Papanastasiou

(1976: 502, 503), citing Ananiadis 1970: 298), though without distinguishing between *Sarda sarda* and *Katsuwonus pelamis*[3]. Adult bonitos prey on schooling sardine, anchovy, mackerel, white bait and other small pelagic fishes.

Bonitos are exploited by coastal fisheries, often artisanal. Their catches are locally very important in economic terms (e.g., Black Sea, Devedjian 1926: 16-23; Oray *et al.* 1997; Zengin *et al.* 2005) and they are systematically used for processing.

Small-size Scombridae

Among the smaller Scombridae species in the Aegean, the bullet tuna (*Auxis rochei* (Risso, 1810)) is clearly identified on the basis of its bones. The two kinds of mackerels (*Scomber scombrus* (Linnaeus, 1758) and *Scomber colias* (Gmelin, 1789)) are only distinguished by certain anatomical elements, such as the dentary and the hyomandibular, while the vertebrae, the most commonly preserved element, are indistinguishable.

Auxis rochei *(Risso, 1810) – Bullet tuna, Κοπάνι/τορνέτα*

Maximum length for bullet tuna is around 50 cm and maximum weight is around 1.9 kg, depending on the fishing area they come from (Valeiras & Abad 2006b). Common length in the Aegean is 36-38 cm. It is widely distributed in the Mediterranean and the Black Sea. Bullet tuna are preyed upon by tuna, sharks and dolphin fish. They have a strong schooling behavior and they form large schools of similar sized individuals. They are often confused with *Auxis thazard*, which are morphologically similar (but rather uncommon in the Aegean). In the summer they swim near the surface and approach land, while in the winter they move to deeper waters. They are mostly caught with surface gear (Valeiras & Abad 2006b; Papanastasiou 1976: 498, 499).

In the Aegean (especially its eastern coasts) the spawning period is reported to be from May to September with the peak observed in June, July and August (Bök & Oray 2001; Kahraman *et al.* 2010: 6816). Bullet tuna is caught in all parts of the Aegean, the only restricting factor being the accessibility of certain areas to the dominant fishing gear (in this case, the round nets called gri-gri in Greek and Turkish) (Koli & Platis 1998: 33). In the spring catches, most of the fish are 34-36 cm in length, while the smallest ones are 28-30 cm. In summer catches the most common size is 18-20 cm long, while some individuals can be very small indeed (10-12 cm) Koli & Platis 1998: 64, 65).

Scomber scombrus *(Linnaeus, 1758) – Atlantic mackerel, σκουμπρί*

The maximum length for Atlantic mackerel is 60 cm and its maximum weight is 3.4 kg, while commonly it is about 30 cm (Froese & Pauli 2019). Atlantic mackerel, one of the smaller members of the Scombridae family, are cosmopolitan migratory and schooling fish that approach the coast twice a year, in spring and in autumn, when they swim near the sea surface. In the winter, they move to deeper waters. Spring-caught Atlantic mackerels are very lean as opposed to the late summer-autumn catches, which are much fatter and suitable for preservation. In the Aegean they are caught from March to August. The rest of the year they are also occasionally caught, but in much smaller numbers. Atlantic mackerel is also found in the Black Sea (Papanastasiou 1976). They are prey to several larger Scombridae.

Scomber colias *(Gmelin, 1789)*[4] *– Chub mackerel, κολιός*

The maximum length for chub mackerel is 64 cm and its maximum weight is 2.9 kg, while commonly they may be about 30 cm long (Froese & Pauly 2019). In the Aegean Sea, these sizes appear to be considerably lower (Papanastasiou 1976: 508). Chub mackerel are found both in the Aegean and in the Southern Black Sea (Hernández & Ortega 2000: 9). They school with other pelagic fish such as other members of their genus or sardines (Froese & Pauli 2019). Adults stay near the seafloor during the day and ascend to the surface at night; thus, they are often caught at nighttime, attracted by lights. In the Aegean, they approach the coast in summer. Schools comprise fish of similar size; those of adults are more compact and structured (Collette & Nauen 1983). Spawning season is in summer. In the Black Sea, spawning is reported to take place from June to August, and in the Sea of Marmara from May to July (Hernández & Ortega 2000: 13, table 3, with references).

Other species

The discussion about the fishing of tuna and related species should also extend to certain marine animals that do not belong to the Scombridae family, but that are often caught together with them, exhibit seasonal migratory schooling behavior and are often either prey or predators to Scombridae. These animals are: the swordfish (*Xiphias gladius* Linnaeus, 1758), the amber jack (*Seriola dumerili* Risso, 1810) the dolphin fish (*Coryphaena hyppurus* Linnaeus, 1758), the sardine (*Sardina pilchardus* (Walbaum, 1792)), the anchovy (*Engraulis encrasicolus* (Linnaeus, 1758)), the horse mackerel (*Trachurus trachurus* (Linnaeus, 1758)), the garfish (*Belone belone* (Linnaeus, 1761)), various types of sharks as well as sea mammals, such as the dolphin and the sea turtle (*Caretta caretta* (Linnaeus, 1758)) (Sarà 1980; also Vacchi *et al.* 2000). Many of these animals were also processed in ways similar to tuna, in the same processing establishments (typically, Di Natale & Di Sciara 1994; Bernal-Casasola 2016: 198 with references). They will not be further discussed in this paper.

3. November-December: off the Chalkidiki peninsula, Thermaic Gulf, Trikeri area near Volos; January-February: Skiathos, Skopelos, northern Euboic Gulf, Pagasetic Gulf, Atalanti; March: Skyros; early April: return trip to Black Sea.

4. The taxonomic nomenclature for this genus presents some problems of consistency in the current literature. Although *S. japonicus* Houttuyn, 1782 and *S. colias* are now accepted to be two distinct taxa (Collette 1999; Infante *et al.* 2007), there is no consistency in the world marine life registers (e.g., WoRms http://www.marinespecies.org/, last consultation on 13/01/2021; FishBase https://www.fishbase.de, last consultation on 13/01/2021) as to their geographical distribution and to their presence in the Mediterranean. This inconsistency is expressed by the fact that in current publications in marine biology both names are used with the addition of a third one, *Scomber colias japonicus* (e.g., Kiparissis *et al.* 2000; Cengiz 2012; Karachle 2017).

IMPLICATIONS OF SCOMBRIDAE PHYSIOLOGY TO THEIR FISHERIES IN ANTIQUITY

The exploitation of tuna in the Aegean was practiced, at least until the Roman period, alongside the dominant, small-scale coastal fishing. Remarkably, in southern Aegean sites dating from the Bronze Age to Classical antiquity, over 90% of the consumed fish in each case were picarels, bogues, small combers, damsel fish and an assortment of young sea bream, caught among the rocks in the shallows (for a list of the sites and detail on the individual assemblages, see Mylona 2008: 38-41, 62, 63; 2016: 65-77; 2020). Fishermen in the Aegean did not regularly practice open-sea or deep-water fishing. Rather, their activities were restricted to inshore, shallow waters.

Fishing technology in the Aegean also was conservative and enduring, and included a variety of fishing tools and techniques designed to target the inshore marine resources (Rose 1994: 155-188; Powell 1996: 77-166). Fishing tools were mostly made of perishable organic materials, such as fibrous plants, wicker, reeds, which thus set limits to the strength and the size of the tools. For example, a net made by natural fibers (e.g., the rare example from the Bronze Age site of Akrotiri on Thera, Moulherat *et al.* 2004; Mylona 2014) could not be made to extend several hundred meters in length, like modern nylon nets, because it would become too heavy and difficult to handle; neither could it drag large amounts of fish, as its organic yarns would not be strong enough. Fishing vessels, powered mostly by rowing, were more suitable for fishing methods of a slower pace and clearly unsuitable for chasing fish (Powell 1996: 102-104; Bekker-Nielsen 2005: 85-88 for a discussion of fishing methods applied to Scombridae fishing in antiquity, as these emerge by the written sources see Felici 2018: 63-97).

Tuna and other migratory fish, being pelagic, spend most of their life in open seas, some of them at considerable depths. As such, they inhabit parts of the sea that ancient fishermen did not venture into. This observation, albeit largely valid, has yet created considerable confusion amongst archaeologists, especially with respect to the discourse on Mesolithic cultural contacts crossing the seas. Because of the pelagic nature of tuna, several researchers assume that their capture implies open-sea fishing and the use of boats: thus they view tuna fishing as the trigger for sea crossings (Webb 1999: 26; Powell 2011; Starkovich *et al.* 2017; for the inaccurate use of oceanographic and ecological terminology in literature on ancient fishing, Pickard & Bonsall 2004). However, twice a year pelagic migratory fish enter the coastal zone, approach the shore and thus become accessible to fishermen who are active in that zone. They can then be caught with some of the fishing methods and tools used for the inshore fish resources, such as nets or spears.

These fish are among the few fish species encountered in the open sea. They swim over long distances and at considerable speed. This feature apparently fascinated Aegean mariners, at least as early as the 3rd millennium BC; this is probably the reason why tuna was chosen as a figurehead on Early Cycladic (3200-2000 BC) ships, as depicted on the enigmatic frying pans (Coleman 1985).

Tuna and related species appear seasonally at any fishing location along their migration route. Their migration is governed by two basic needs: reproduction and feeding. At a specific time of the year, which slightly varies among different species, sexually mature fish migrate towards areas that offer favorable spawning conditions (e.g., the right temperature and salinity levels). Afterwards, they return to their areas of origin that are more suitable for feeding. They tend to follow the same routes every year, with a certain degree of variation that is dictated by changing environmental conditions. Some years they fail to appear altogether, or only a fraction of the schools may approach the usual passages near the coast. This phenomenon has lead researchers to suggest that tuna was an abundant but unpredictable resource and that, for this reason, it played a minor economic role in the Aegean in antiquity (e.g., Gallant 1985: 27). However, uncertainty and unpredictability in the short-term was an inherent feature not only of fisheries but also of agriculture in the Mediterranean and, more specifically, in the Aegean. People in antiquity, as in the more recent past, had developed mechanisms for coping with this (Garnsey 1988; Halstead & O'Shea 1989; Halstead 1990; Gallant 1991)[5]. The fact that, in Hellenistic and Roman periods, issues pertinent to tuna fishing (e.g., the lease of *thynneia* and watch towers, the profits from tuna fisheries) were regulated by the state in an official, long-term manner (inscriptions on stone, Lytle 2006: 113-145), is an indication that in the long-run and, at least in favorable locations, uncertainty of tuna fisheries was accepted and offset by various means.

Another physiological characteristic of tuna can be used as a proxy indication of the type of fishing practiced in the past. Only mature fish, i.e., fish that exceed a certain age/size perform long distance reproduction migrations. Noteworthy here is the fact that most bluefin tuna bones found in prehistoric sites across the Aegean are from mature individuals, i.e., from fish larger than 110-120 cm in length (e.g., Rose 1994: 434-443). This is an indication that their capture was done during the reproductive migration of the fish near the coast and not in the open sea.

On the other hand, very large individuals (> 200 cm in length) are extremely rare in the archaeological record, even in sites with large tuna bone assemblages (e.g., Mesolithic Cave of Cyclops, island of Yioura, Mylona 2011; Powell 2011; Late Neolithic Saliagos, Rose 1994: 437, 438; for a record of tuna remains of historical date, Mylona 2008: 38-41; for a short discussion of the phenomenon, Mylona 2016: 74). The largest individuals (> 200 cm in length) have been found in historical contexts (e.g., the Hellenistic strata in the sanctuary of Poseidon at Kalaureia on Poros, Mylona, study in progress). This observation introduces an additional parameter in the interpretation of archaeological tuna bone assemblages: the choice on the part of fishermen. It seems that, for the most part, the largest, and so heaviest and strongest tuna were probably avoided, for

5. These responses are not discussed here, but they include diversification in the exploitation of marine resources, with fishermen and fish processers becoming involved in other occupations, such as agriculture, navigation, etc.

reasons that are not clear (Mylona 2016: 74)[6]. Therefore, their absence from the archaeo-ichthyological assemblages should not automatically be interpreted as a natural absence of large tuna.

Depending on size, various Scombridae feed either on smaller species of the same family or on other small pelagic fish, such as sardines and anchovies. The Scombridae themselves, especially those of smaller size (small-bodied species or young individuals of larger-bodied species) are also preyed upon by other larger fish and marine mammals, such as sharks and dolphins. Thus, the presence of feeding tuna is often closely correlated to the presence of prey species, which are in themselves important fishing resources. The northern Aegean is a typical feeding ground for several large Scombridae because it hosts large schools of prey fish, i.e., sardines, anchovies, mackerels (Machias *et al.* 2007 ; Damalas & Megalofonou 2012: 701). This implies that all these species can be exploited together, and that their remains will be found in the same contexts. At the Sanctuary of Poseidon at Kalaureia, tuna, bonito and swordfish bones are indeed found in the same context, probably reflecting their simultaneous presence in the waters around the island (Mylona 2015). In the Roman *cetariae* (fish-salting installations) in the Western Mediterranean, sardines, anchovies, shark and marine mammal flesh were salted along with Scombridae (e.g., Botte 2009: 53-57; Bernal-Casasola 2016: 198; Bernal-Casasola *et al.* 2016). This further supports the idea that both predator and prey species were captured there, allowing the workings of the *cetariae* to be diversified.

Tuna are nowadays often caught by hook and line (in their various configurations), as well as by long-lines. The technology involved is simple and generic and could be used to catch most fish. This was probably not a commonly used technique in antiquity for tuna and most other Scombridae. Tuna on their spawning migration do not feed, so they would not respond to bait. Spent fish on their migration back to their feeding grounds could be baited, but for most Scombridae species the return trip to feeding grounds is done by dispersed, fast moving schools which often – but not always – move some distance away from the shore. Their capture by hook and line, by long-line or any other variation of this tool, would involve the ability of the fishermen to swiftly approach the passing fish. Given the technological restrictions of fishing tools and vessels, this type of fishing is not optimal.

Nets, mostly beach seine nets, offer better possibilities. The use of such a type of technology is amply documented throughout antiquity for the capture of various types of fish. Ancient authors as well as a number of early modern researchers describe this method in detail (Lefkaditis 1941:142-143, 151-152; von Brundt 1984: especially 158-164; Alfaro-Giner 2010; Felici 2018: 80-88). The use of nets, seine nets and beach seine nets for the capture of tuna in prehistory and in historical times is documented both in the written record and in art. Philostratus, Aelian and Oppian, for instance, describe tuna fishing with nets in the first centuries of the common era (references and discussion in Lytle 2006: 56-68), while a decorated Mycenaean hydria from Naxos depicts the capture of tuna in a beach seine in the 12th century BC (Fig. 3; Hadjianastasiou 1991).

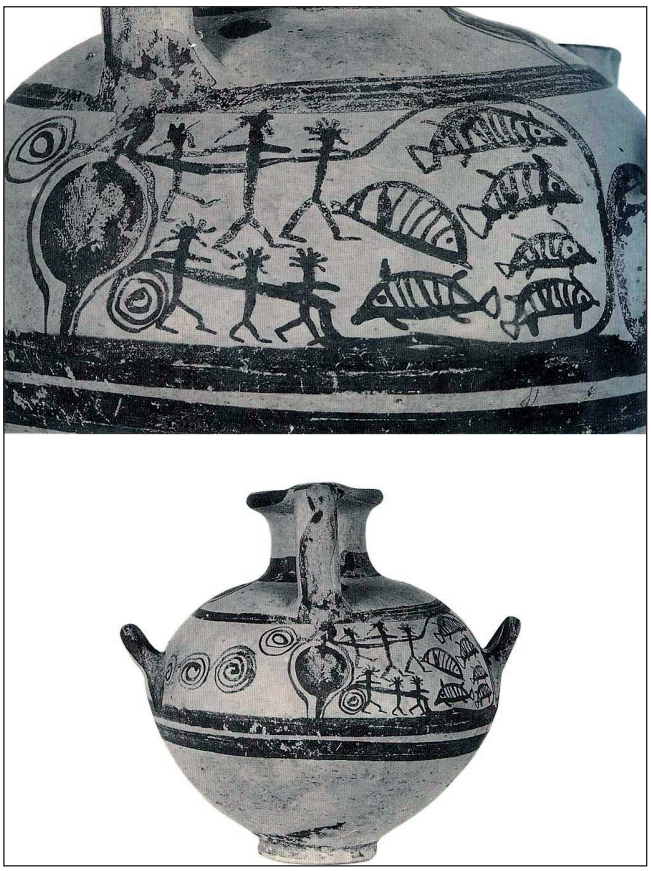

Fig. 3. — Beach seine fishing scene on a Mycenean hydria (12th *c.* BC) from Naxos. The large fish in the net are probably tuna (reproduced from Hadjianastasiou 1991).

The use of nets for tuna fishing could produce large amounts of fish. Depending on the species synthesis of the passing schools, the landed catch would be either uniform (one species/one size catch) or more varied (one dominant species and several additional ones). The chub mackerel (*Scomber colias*) remains in the Mesolithic strata in the Cave of Cyclope at Youra probably fall within the first case. They are all the same size and no other Scombridae species in the assemblage are of this size. It thus seems that they represent a compact chub mackerel school made up of a single species (see commentary on the species, in footnote 3). Mackerel do not approach the coast as much as larger tuna. This implies that boats were needed to catch the mackerel (Mylona 2011; Powell 2011). In Bronze Age Akrotiri on Thera, the young men on the so-called "Little Fishermen" fresco are depicted with fish that probably originated from passing schools that included more than one species. One fisherman holds two bunches of dolphin fish – another migratory seasonal fish, which are all of a similar size. The second holds three fish of different species, little tunny or bullet tunny, again of similar size (Fig. 4).

6. Aristotle in the 4th century BC mentions that the flesh of the old tuna (thus the largest ones) was of bad quality even for salting; Aristotle, *HA* VIII, 30.

Fig. 4. — Wall painting of one of the two Little Fishermen from the so called West House at Akrotiri, Thera. The fish he holds are little tunny (*Euthynnus alletteratus* Rafinesque, 1810) or bullet tunny (*Auxis rochei* Risso, 1810) (reproduced from Doumas 1992).

The "Little Fishermen" fresco illustrates the capture of seasonal fish, with two representative species that appear in the waters around the island at the same time of the year (Economidis 2000; Mylona 2000).

In recent centuries, typical – and especially productive – fishing tools for tuna are the fish traps, known as *thynneio, dalyan, almadraba* or *tonara* in various locations along the Mediterranean coasts (these terms are used in the publications referred to in this paper, see also Ponsich & Tarradell 1965: 93). These are large-scale establishments, which functioned in a strictly organized manner within the context of a feudal system and that of the market (e.g., García-Vargas 2016 on the *almadrabas* of the Western Mediterranean). The function of tuna traps is based on the fact that schools of various Scombridae species tend to swim along the coast, very near the shore, in an anti-clockwise manner, unable by their physiology to turn back. The fishermen set up a system of poles and nets in the shallow waters that create a kind of labyrinth. These nets cut across the path of the fish and lead them towards an enclosed, controlled area, where they are captured. Often nets carried by boats extended the reach of the trap into the open sea, when the tuna schools were approaching. Watch "towers", either wooden poles in the water or high rocks on the beach, facilitated the proper timing of the endeavor. Clubbing and spearing were probably practiced at this stage to catch the fish and bring them out of the water. The whole process requires a synchronized action of a large number of fishermen, and it is intense and violent (Sarà 1980; García-Vargas & Florido del Corral 2007; for a vivid description, Maggio 2000: 118-125). There is an ongoing debate as to whether this type of trap existed in the Aegean in antiquity (discussion in Lytle 2006: 54-68). These large fish traps stand at one end of a whole range of arrangements, which also encompasses smaller and simpler versions (Fig. 5). These latter are less elaborate arrangements of nets and poles, which function much nearer the shore (e.g., Koukoules 1952: Πιν. Θ, 2). They would require a smaller investment in nets and other resources and a smaller working force, but they would also be less productive, as they can only tap a small fraction of the schools that happen to come very close to the shore. The archaeological visibility of tuna traps is very poor. In the Western Mediterranean, the most secure evidence for their presence in the past is a dense scatter of anchors on the seabed near the coast, which represent the anchoring of the net components of the trap (Trakadas 2010). In the Aegean no such find has been identified so far although their presence in antiquity is attested in literary and epigraphic record (Lytle 2006; Mylona 2008: 49).

The ability of tuna to swim fast and withstand wide-ranging water temperatures is linked to the fact that they have a very developed circulatory system, which provides the fish with sufficient oxygen and energy (Korsmeyer & Dewar 2001). This sets tuna apart from other fish and led ancient Greeks to consider tuna as the only fish clearly suitable for sacrifice to the gods (Mylona 2008: 91). In tuna festivals in Attica (deme of Halae Aixonidae) and in the Argolid (Halieis), the first tuna of the season were sacrificed to Poseidon (Mylona 2008: appendix 1). Slaughtered tuna shed an abundance of red blood, much like terrestrial animals, e.g., cattle.

The presence of so much blood in tuna has consequences on the ability to preserve their flesh. Tuna cannot be kept fresh as long as other fish of similar size. They must be consumed or processed immediately after their capture, unless they are

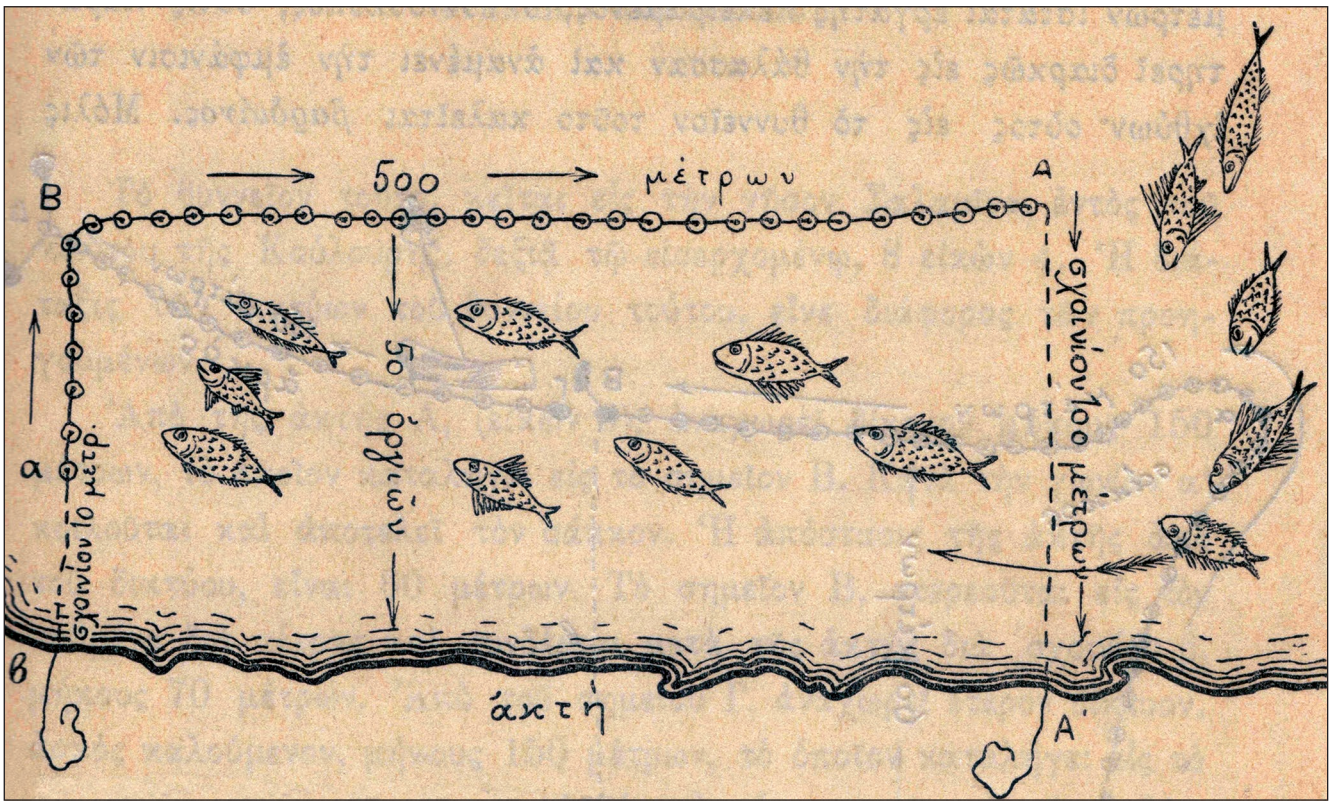

Fig. 5. — Sketch of a thynneion (stationary tuna trap) at Kandylio a few short distance north of Halieis (reproduced from Panagiotopoulos 1914).

rapidly gutted, beheaded and drained of their blood. Given the fact that tuna are usually landed in considerable numbers, a large working force and an intensive output of labor is required immediately after landing in order to ensure preservation.

CONCLUSIONS

The gregarious nature of tuna and related species, their seasonal abundance and their shared biological and ethological characteristics make these fish a particularly desirable resource. In the Aegean, they have been exploited from as early as the 9th millennium BC to modern times. In this area and elsewhere in the Mediterranean during historical times, they supported a particularly lucrative fish processing business. Tuna fisheries and the culture developed around them have left archaeological and historical traces, which can be explored and used in a dual way. On the one hand, they can shed light on a wide range of economic and cultural activities in the past. On the other, they can, under certain conditions, provide data of historical depth to modern approaches to fishing and conservation research.

Reproduction and feeding migrations frame the yearly life-rhythms of tuna and other Scombridae. These ethological characteristics, along with the tendency of Scombridae to form large and dense schools, are so strong and all-encompassing that they defined and shaped the way the fish were exploited. The locations where the fisheries developed are coastal areas along the migration routes of the fish. The timing of fishing endeavors was dictated by the timing of their migrations. The different Scombridae species exhibit variation in timing of migration. This offered fishermen the opportunity to expand the exploitation of this resource over a period of several months, thus setting the foundations for viable fish-processing industries/workshops, which took advantage of abundant and repeated landings. In certain historical periods, these industries were developed all along the Mediterranean coasts, including the Aegean.

The technology around the exploitation of these fish was initially based on commonly available fishing tools and methods, but it gradually developed specialized forms, designed to take advantage of the particular habits and behaviors of the species. These methods ranged from the simple and small-scale to complex, large and elaborate, depending on chronology, location, as well as the economic and social context of the fishing endeavors. However, they all shared a feature, namely that the fishing of tuna and related species required a communal effort and the involvement of many people with different skills. This is particularly relevant to archaeological and historical research. Tuna fishing not only could provide large amounts of food, but it also got deeply embedded in local economy and culture.

Understanding the biological and ethological traits of tuna and related species is important in archaeology because these can have heuristic value, being consistent as well as species-specific, to some degree. Bones of tuna and other Scombridae found in archaeological excavations can often be identified down to species-level. A comprehension of the biology of

these species allows us to understand the organization of the fishing in question, its timing, scale, and other parameters. Conversely, the presence, behavior, timing and school composition of these fish, can all be used as guides to predict potential locations of archaeological remains of fishing settlements or fish-processing installations.

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