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A NOTE ON THE DISTRIBUTION AND BIOLOGY OF *OCYTHOE TUBERCULATA* (CEPHALOPODA: OCYTHOIDAE) IN THE ADRIATIC SEA

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OCYTHOE TUBERCULATA
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ADRIATIC SEA

ABSTRACT. – Recently, three females of the rare pelagic species *Ocythoe tuberculata* (Rafinesque, 1814) were recorded in the Eastern Adriatic Sea. One specimen was collected near the northern shore of the island Koločep in May 2006, while another was collected near the northern shore of the island Hvar in June 2006. The third individual was found near the northern shore of island Korčula in March 2007. Morphometric measurements, including beak dimensions, were recorded from all specimens after preservation. The smallest female (ML: 77 mm) was immature while the other two, with mantle lengths 178 and 202 mm, were mature females, for which potential fecundity estimates were 180 000 and 220 000 respectively. Oocyte size ranged from 0.1 to 3.9 mm, with oocytes smaller than 0.2 mm predominating in the ovary of both mature females. Remains of fish and gelatinous plankton organisms were found in the two non-empty stomachs examined. Occasional findings of *O. tuberculata* in the eastern Adriatic Sea are discussed in relation to the water masses circulation (ingressions from the eastern Mediterranean) and the species biological characteristics.

INTRODUCTION

The monotypic family species, *Ocythoe tuberculata* (Rafinesque, 1814) is a bi-central epipelagic octopus distributed mostly in subtropical waters with low productivity, Mediterranean Sea included (Nesis 2003). This species occurs from the sea surface to about 200 m depth. In the North Pacific large females *O. tuberculata* are commonly caught in drift nets set in the upper 10 m of the water at night, while the daytime habitat is unknown (Roper & Sweeny 1976). Moreover, data on the geographical distribution of this species come from beak and tissue remains which have been recorded from the stomach contents of large pelagic predators like sharks (Dunning *et al*. 1993), large pelagic fishes and dolphins (Clarke 1986, Peristeraki *et al*. 2005, Blanco *et al*. 2006) and foraging marine birds (O'Shea 1997). This species exhibits extreme sexual dimorphism in size. Females attain large sizes, up to 350 mm in mantle length (ML), while males are dwarfs, probably not exceeding 30 mm ML (Roper & Sweeney 1976), and often live in the non-living test of pelagic salps and doliolids for their temporary floating habitat (Jatta 1896, Naef 1923, Hardwich 1970, Okutani & Osuga 1986). Very little is known about the reproduction pattern of *O. tuberculata*. In males the only spermatophore produced, fills a specific hectocotylus cavity and during the copulation the hectocotylus becomes detached and forms an active, autonomous spermatophore carrier (Naef 1923). This species is characterised by producing a large number of relatively small eggs (Naef 1923, Roper & Sweeney 1976) and continuous spawning (Laptikovsky & Salman 2003). Female of *O. tuberculata* is the only known cephalopod with a true swimbladder (Packard & Wurtz 1994) and the only known ovoviviparous cephalopod that incubates eggs in the long, winding oviducts until paralarve hatch (Jatta 1896, Naef 1923, Laptikhovsky & Salman 2003).

Information on *O. tuberculata* in the Mediterranean Sea is sparse and consists mainly of faunistic recording (Jatta 1896, Naef 1923, Robson 1932, Ruby & Knudsen 1972, Sanchez 1980, Bello 1986, Katagan & Kocatas 1990, Katagan *et al*. 1993, Corsini & Lefkaditou 1994, Ezzeddine-Najai 2001, Lefkaditou & Kallianiotis 2006).

Only few data are available on the diet of this species. Robson (1932), Nixon (1987) and Cardoso & Paredes (1998) have reported some general aspects of diet for individuals from the eastern Atlantic, while no published data exist for the Mediterranean. There are some scarce data on the number of eggs and egg size of *O. tuberculata* from the western (Naef 1928) and eastern Mediterranean Sea (Laptikhovsky & Salman 2003) and the Australian waters (Roper & Sweeney 1976). In all cases only one female was found and described.

Scientific knowledge about this species in the eastern Adriatic Sea is very scarce and limited because it is rarely encountered and hence has not been the object of systematic investigations. First data about its occurrence is given by Ninni (1884) and Kolombatović (1890). Occasional findings of several specimens between the end of the 19th century and 1980 were obtained from the list of the Adriatic cephalopod fauna (Bello 1990), while Milišić (2000) considered this species as rare without any precise data on records. Although it has been sporadically found in the Adriatic Sea, this is the single record of this rare species in the Adriatic Sea within almost 30 years.

The aim of this paper is to present data regarding a new record of *O. tuberculata* in the eastern Adriatic Sea. Some morphological characters including beak measures and preliminary information on the diet and the reproductive biology of this species are given. In addition, previous records of this species in the Adriatic Sea and its occurrence in relation to the water masses circulation are discussed.

MATERIALS AND METHODS

Three females were collected by fishermen along the Croatian coast of the Central Adriatic Sea (Donje Čelo Cove in Koločep Island on the 25 May 2006; Grabovac Cove in island Hvar on the 10 June 2006 and Korčula Harbour in island of Korčula on the 17 March 2007) (Fig. 1).

The specimens were stored frozen for further examination in the laboratory. Dimensions were measured to the nearest mm and total weight was determined to the nearest 0.01 g; beak dimensions were also taken according to Clarke (1962, 1986).

The digestive and reproductive systems were also examined. The stomachs were removed and stomach wet weight (SW) with an accuracy of 0.01 g was recorded. Prey items were sorted by direct observation of stomach content under stereomicroscope at 25x and 40x magnification. Identification of prey taxa was based on identifiable hard structures resistant to digestion.

The whole reproductive systems of all females were removed and the ovary and oviducts were weighed wet with an accuracy of 0.01 g. Samples were preserved in alcohol for further analyses in the laboratory. To estimate oocyte number and length frequency in ovaries and oviducts, the methodology of Laptikhovsky & Salman (2003) was adopted. Three 0.4-0.6 g samples were taken from different parts of the ovary and weighed with accuracy ± 0.001 g. In each ovarian sample oocytes were counted and 100-200 randomly sampled oocytes were measured in major axis under 40x magnification to determine length frequencies. In the same manner counts and measurements were taken for the oviductal eggs. The embryonic stages of eggs were defined according to Naef (1928).

All specimens of *O. tuberculata* are deposited in the Cephalopod collection of the Institute of Oceanography and Fisheries in Split, Croatia.

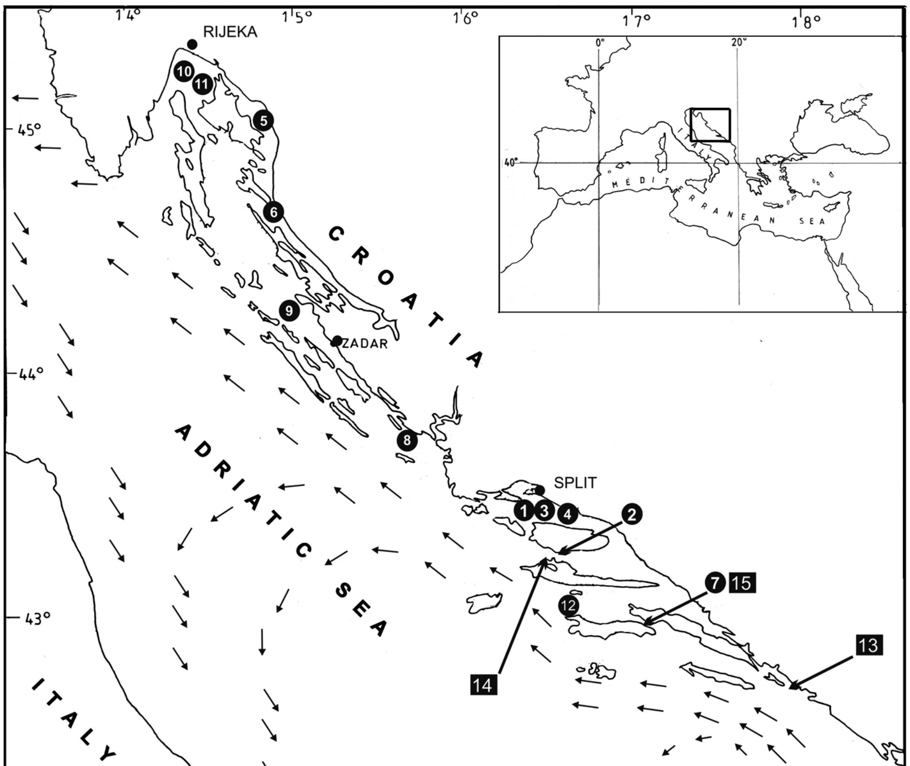

Fig. 1. – Map positions of *Ocythoe tuberculata* captures in the Adriatic Sea (historical and current study data) with the generalized scheme of surface water circulation (according to Zore-Armanda 1967). 1 - Kolombatović (1890), 2 - Bol (Brač Island) (1889), 3,4 - Split (1890 and 1904), 5 - Senj (1909), 6 - Jablanac (1913), 7 - Korčula (1930), 8 - Murter (1950), 9 - Olib (1950), 10,11 - Kvarner Bay (1960 and 1964), 12 - Vela Luka (Korčula Island)(● records derived from Bello, 1990); 13 - Donje Čelo Cove, Koločep Island (25 May 2006), 14 - Grabovac cove, Hvar island (10 June 2006), 15 - Korčula Harbour, Korčula Island (17 March 2007)(■ records from this study).

RESULTS

Morphometry

The mantle lengths of the examined females were 202 mm, 178 mm and 77 mm. The external morphology and the color pattern of these individuals agree with the description of Jatta (1896) and Nesis (1987). The main morphological measurements are presented in Tables I & II.

The beaks are distinctive and have a small rostrum pinched in at the side with an obtuse jaw angle (Fig. 2). The values of the crest length/hood length ratio (CL/HL) determined for lower beaks were between 1.71 and 1.93. Based on the data of the specimens found in the Adriatic Sea and those from the South-Eastern Aegean Sea (Corsini & Lefkaditou 1994) the linear regression of lower rostral gap length against body weight was obtained (Fig. 3).

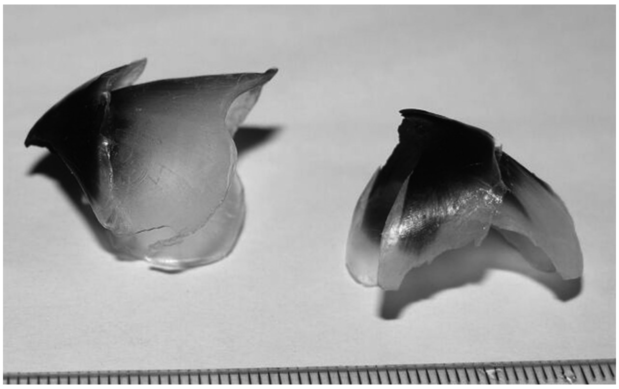

Fig. 2. – Upper and lower beak of *O. tuberculata* (ML = 178 mm) collected in the Eastern Adriatic Sea. Each line on the bottom measures 1 mm.

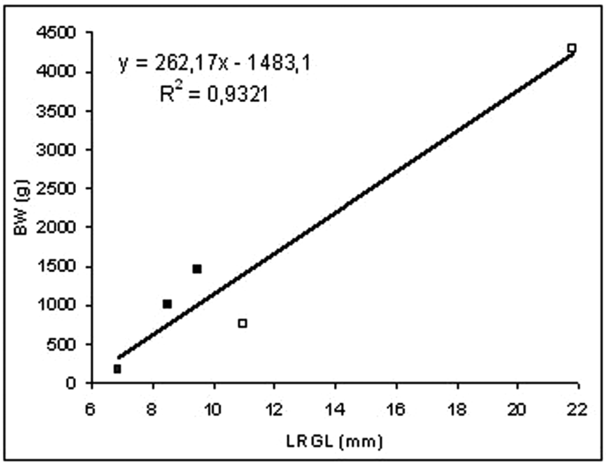

Fig. 3. – Relationship between the body weight (BW) and the rostral gap length of the lower beak (LRGL) for the species *O. tuberculata* (□ - specimens from the South-Eastern Aegean Sea, ■ - specimens from the Adriatic Sea).

Diet

The stomach of the first specimen (ML = 178 mm; SW = 2.30 g) was completely empty and contained no trace of food. The stomach of the largest female (ML = 202 mm; SW = 15.10 g) was filled with decomposed food remains. Among the semidigested food mass, two otoliths, scales and operculum parts were recognized and identified as remains of the species, a bogue (*Boops boops*). No trace of other prey items were found. The stomach content of the third individual (ML = 77 mm; SW = 4.66 g) was highly decomposed and difficult to identify. However, based on the general appearance of the remains they probably belong to some gelatinous plankton organisms.

Fecundity

The individual with the mantle length 77 mm was immature (juvenile). No oocytes were found in the oviducts, and those in the ovary were completely immature and very small, not exceeding 0.1 mm in major axis. The

Table I. – Body measurements of *O. tuberculata* specimens collected in the Eastern Adriatic Sea: BW, body weight, TL, total length, ML, mantle length, AL, arm length.

BW (g)	TL (mm)	ML (mm)	AL1 (mm)	AL2 (mm)	AL3 (mm)	AL4 (mm)
1457.76	572	202	285 (broken)	285	266	330
1006.40	540	178	356	282	280	358
171.94	305	77	142 (broken)	163	147	207

Table II. – Beak dimensions (in mm) of *O. tuberculata* specimens collected in the Eastern Adriatic Sea: U, upper beak, L, lower beak, CL, crest length, HL, hood length, WL, wing length, RGL, rostral gap length (A-ML = 202 mm, B-ML = 178 mm, C-ML = 77 mm).

	UCL	UHL	UWL	URGL	LCL	LHL	LWL	LRGL
A	27.77	17.25	16.21	13.15	21.26	12.35	19.90	9.48
B	26.23	15.91	15.20	12.92	20.11	11.74	18.28	8.51
C	18.47	10.22	8.72	7.79	14.04	7.28	11.28	6.87

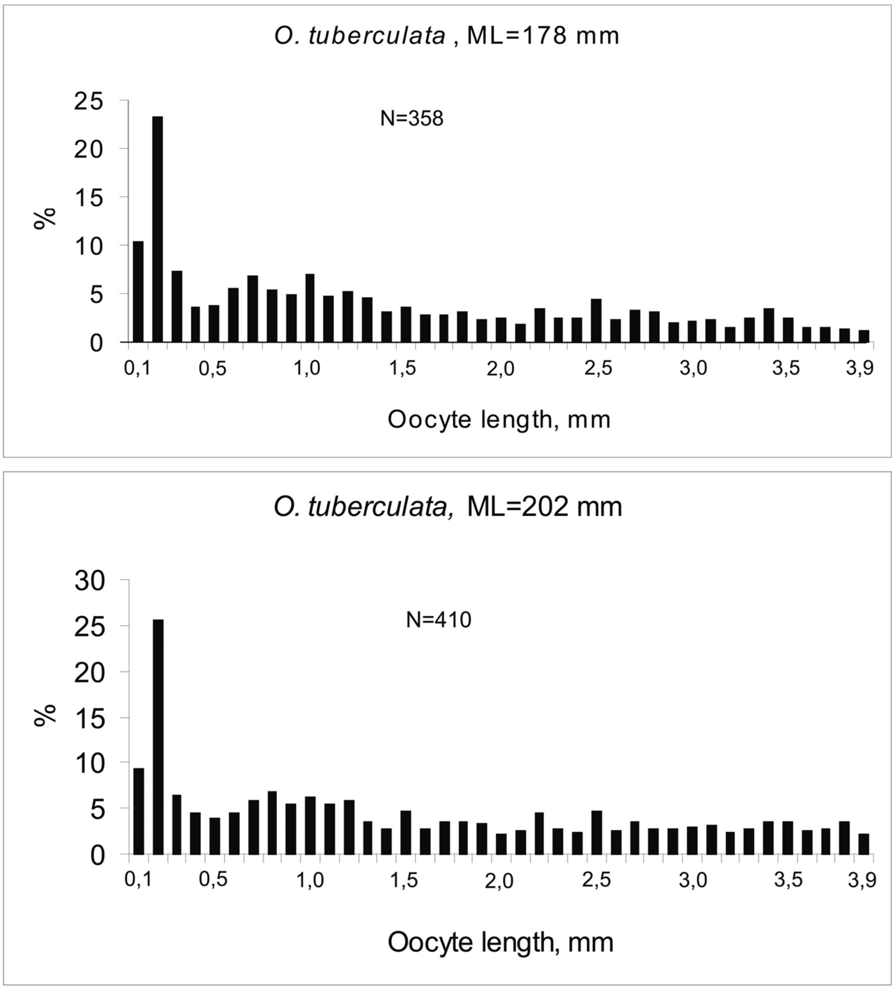

Fig. 4. – *Ocythoe tuberculata*, oocyte size distribution in the ovaries (including oviducts) of two mature females collected in the Eastern Adriatic Sea.

other two specimens were mature and contained maturing and fully mature oocytes. The ovary of the smaller mature female (ML = 178 mm) weighed 35.81 g and represented 3.55% of the body weight. This ovary contained about 157 000 oocytes. The ovary of the larger mature specimen (ML = 202 mm) weighed 125.5 g, representing the 8.60% of the body weight. This ovary comprised about 173 000 oocytes. In both mature females the size of the ovarian oocytes was highly variable, indicative of the different stages of oocyte development. Ovarian oocytes were bright yellowish in color. Their size ranged from 0.1 to 3.9 mm; oocytes of 0.2 mm were predominant (Fig. 4) and represented 23.3% and 25.5% of the total oocyte number in the ovary. The eggs present in the oviduct were larger and brownish yellow in color. In oviducts of the smaller female 21 000 eggs were found, while in larger female 25 000 eggs were counted. Recently fertilized eggs (2.1-2.5 x 1.1-1.5 mm) were placed in the proximal part of the oviduct, while in the distal part they attained Naef's stage V and VI (2.5-2.7 x 1.3-1.7 mm). The potential fecundity was 180 000 and 220 000 for smaller and larger female, respectively.

DISCUSSION

The estimated potential fecundity of the collected specimens (180 000 and 220 000) is similar to the value reported for *O. tuberculata* from the eastern Mediterranean (Laptikhovsky & Salman 2003), which is greater than that estimated in the western Mediterranean (Naef 1923) and in the Australian waters (Roper & Sweeney 1975). As there are no other published data in the Mediterranean about the fecundity it was not possible to make assumptions on relation between the size of the animal and the number of oocytes. Naef (1923) mentioned that the oviducts of the studied female contained about 100 000 eggs, from which those in the distal oviductal part were approximately the middle of embryonic development, whereas the eggs further proximally located were less developed and uncleaved. The data for the ovary were not presented. However, the egg mass of the female from Australian waters (Roper & Sweeney 1976), among the largest recorded to date (310 mm ML), comprised 104 000 eggs in the ovarian sac and oviducts. These eggs were all nearly identical in size and unfertilized. No small oocytes were found in the ovary neither spermatophores in the mantle cavity. Laptikhovsky & Salman (2003) assumed that this female was either spent and had no sperm left to fertilise remaining eggs, or was at an advanced spawning stage.

As the late stages of embryonic development in the oviducts were not detected neither any of the incubated eggs were yet in the hatching stage, we assume that both females were at the beginning of reproductive phase. The similar situation is recorded by Laptikhovsky & Salman (2003) in a specimen from the Aegean Sea. This specimen was caught in September, while mature females analyzed in this study were caught in May and June; the same period for which Sanchez (1980) and Corsini & Lefkaditou (1994) reported their records for this species on the Catalonian coast and in the Aegean Sea, respectively. Based on the fact that all mature females were found in the late spring-early autumn period all over the northern part of the Mediterranean Sea, and that all of them had eggs at early stages of development, we assume the existence of seasonal latitudinal migrations – summer in European shores, and winter in Africa shores, as well as seasonality of spawning with the presumably majority of populations beginning to reproduce in early summer. However, despite the records mentioned above, biological knowledge on this octopus is rather limited and its movements are still poorly known.

The average size of ripe eggs of our specimens were very close to those examined by Laptikhovsky & Salman (2003) (2.5 X 1.5 mm) and were larger than those previously reported by Naef (1928) (2.0 x 0.9 mm) and Roper & Sweeney (1976) (1.75 x 1.0 mm). In addition, the developmental stage of eggs in the oviduct are identical to those reported by Laptikhovsky & Salman (2003). It is however possible to connect the latitude of the geographical distribution of *O. tuberculata* to their high fertility and egg dimensions. Laptikhovsky & Salman (2003) assume that this shift in reproductive strategy is linked with the high stability and productivity of the Ismir Bay (Eastern Aegean Sea) in contrast to the unstable open seas (Rocha *et al.* 2001). According to the similar fecundity and egg diameter, females from the Adriatic Sea, most probably, belong to the same population as those from the Aegean Sea.

Ocythoe tuberculata beaks are very similar to those of Argonautidea and *Vitreledonella richardi*, but differ in the jaw angle and the leading edge of the beak leans further forward (Clarke 1986). Our values for the crest/hood ratio of the lower beaks (1.72, 1.71 and 1.93) are in the known crest/hood ratio range for this species proposed by Clarke (1962), Sanchez (1980), Smale *et al.* (1993) and Corsini & Lefkaditou (1994).

Information on the diet and feeding habits of *O. tuberculata* are very scarce and limited. The diet of *O. tuberculata* based on pteropod and heteropod molluscs was found by Robson (1932) and Cardoso & Paredes (1998), while Nixon (1987) found sardines and crustaceans in the stomach content of a female individual. Information presented here are amongst the first data about their diet in the Mediterranean. *Boops boops* is a benthic and semipelagic species, with migrations from the bottom to the surface during night (Bauchot & Hureau 1986, Jardas 1996). Therefore it is not surprising that this species occurred as a prey in the stomach of a predator also inhabiting epipelagic layers, as *O. tuberculata*. Generally speaking, the diet of *O. tuberculata* is rather similar to that of other epipelagic octopods from the superfamily Argonautoidea; genera *Argonauta* (Robson 1932, Nesis 1977) and *Tremoctopus* (Thomas 1977, Garcia-Dominguez & Castro-Aguirre 1991) that mainly prey upon heteropods, pteropods, small fish and crustaceans. However, because of the small amount of material available for the study, no further considerations can be made regarding prey preferences of this species.

Knowledge about *O. tuberculata* in the Adriatic Sea is relatively poor with only few published records on occasional findings. The occurrence of this species in the Adriatic Sea was recorded for the first time by Ninni (1884). Kolombatović (1890) reported some findings from the eastern part of the central Adriatic Sea with exact locations where specimens were caught (wide area near Split), while Gamulin-Brida & Ilijanić (1972) only cited previous references. In addition, findings of several specimens from locations in the eastern Adriatic Sea, collected in period between the late 19th century and 1980, have been noted in the study of Bello (1990). Since 1980 there were no published data on findings of this rare species in the Adriatic Sea.

Cephalopod species list that have resulted in recent years from sampling either by commercial bottom trawl (Casali *et al.* 1998, Mandić 1984, Pastorelli *et al.* 1995) or the experimental bottom trawl with higher vertical opening used during the MEDITS bottom trawl surveys (Ungaro *et al.* 1999, Krstulović-Šifner *et al.* 2005) in different parts of the Adriatic Sea, never included *O. tuberculata*. This could be at least partly attributed to the fact that this is an epipelagic species, for the proper sampling of which different kinds of fishing gears should be used.

As referred by Lefkaditou & Kallianiotis (2006) most of the records of this species, including those presented here, concern isolated females collected near the coasts in a few meters of depth during spring and early summer. Factors inducing this movements are still poorly known. The distribution of *O. tuberculata* in the Adriatic seems to be confined to the eastern side, i.e. along the Albanian, Montenegrinian and Croatian coasts, which can be related to the Adriatic gyre that follows a counter-clockwise pattern (Buljan & Zore-Armanda 1976, Bello 1990). The eastern Adriatic is under an intensive influx of eastern Mediterranean waters, prevailingly in the surface and intermediate layers down to at least 400 m depth, especially during winter and spring, which influenced the increase in salinity and temperature (Zore-Armanda 1981,

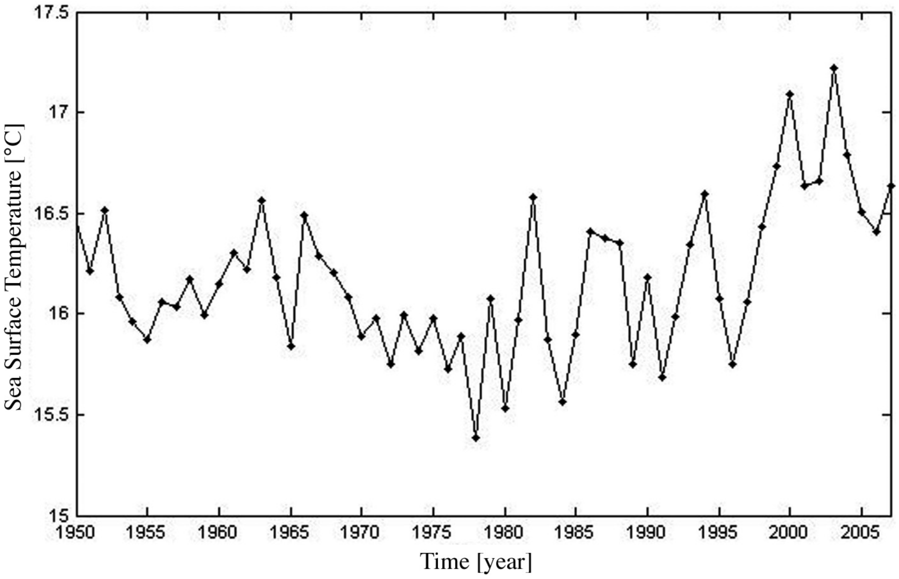

Fig. 5. – Inter-annual variability of mean sea surface temperatures (SST) obtained from the NCEP/NCAR reanalysis grid data for 42°N 17°E (http://cdc.noaa.gov).

Manca *et al*. 2005). It is known that incidentally periods of intensive impact of the Mediterranean upon the Adriatic, called the Adriatic ingressions (Zore-Armanda 1981) may be linked with some rare events in marine life, such as the appearance of large schools of *Tremoctopus violaceus* in the North Adriatic (Lane 1974) and thermophilic fish species (Dulčić & Grbec 2000, Dulčić *et al*. 2004). These species, probably coming from the Mediterranean, enter the Adriatic following the north-westward current on their way from the Otranto Strait toward the northern Adriatic. A similar distribution pattern related to the seawater flow was supposed for *O. tuberculata* in the southern Aegean Sea (Corsini & Lefkaditou 1994). Furthermore, it was suggested that these individuals were probably transported from the open waters of the SE Mediterranean due to the strong currents from the south-east prevailing in these waters. Milišić (2000) noted that, in Croatian coast, it can be occasionally found near shore after intensive southward winds. Prevailing southeastern winds during winter and spring could transport associated animals towards the coast and would explain the appearance of these species, especially poikilotherm ones as *O. tuberculata*, in this area. From the faunistic point of view, southern Adriatic waters represent a very important biogeographical area that joins the Mediterranean fauna. Lately, this finding coincides with the increasingly frequent records of thermophilic fish species in Adriatic waters (Dulčić & Grbec 2000, Dulčić *et al*. 2004). There was considerable year-to-year variability in the mean sea surface temperature off the southern Adriatic coast in last two decades (Fig. 5). During this period, a clear increase the sea surface temperature was observed, especially since 1997, when SST anomalies were about +1.2 °C. The current interest in climate change sets our data as evidence to support the change in species distribution associated with the increase of the sea temperature.

These findings raise the question whether this species is a constant inhabitant or just sporadically enters Adriatic waters following the counterclock wise gyre entering from the Mediterranean Sea.

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