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Recent findings of *Ommastrephes bartramii* (Cephalopoda: Ommastrephidae) in the eastern Mediterranean and the implication on its range expansion

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Abstract

The neon flying squid *Ommastrephes bartramii* is found circumglobally in subtropical, temperate waters and sustains important fisheries in the North Pacific, but it is rarely encountered in the Mediterranean Sea. During the last decade, and particularly since 2004, the frequency of its presence in the Aegean Sea and nearby regions has increased, raising a question about a change in the species distribution and abundance in this area. In this study, we reviewed the literature on *O. bartramii* findings in the Mediterranean Sea and present new data describing body and beak morphometry, diet and the maturity of specimens recently collected from the easternmost basins. According to data from the entire Mediterranean Sea, collected individuals reached 66 cm in mantle length (ML), wherein only females were larger than 32 cm in ML. An isometric growth in body weight (BW) was shown, whereas the growth of the lower beak rostral length (LRL) was allometrically positive in relation to the ML. Occasional catches by jigs during experimental cruises provided most of the individuals recorded in the period from 1982-1992. In contrast, the most recent records are primarily comprised of mature females collected on or near the shore in the eastern basin and of predominantly smaller individuals from the western basin caught by professional jigging fisheries. The distribution of the specimen recorded from the Aegean Sea indicates an association between the species distribution and the circulation of the warm Levantine Intermediate Water. The more frequent observations of moribund spawning females at the periphery of the Cretan Sea are indicative of a spawning ground at this area. The suspected recent increase of *O. bartramii* abundance in both the northeastern and northwestern basins might be due to the warming of upper sea layers, which has been observed since the mid-1980s and is considered to be the main factor driving the northward expansion of the warm-water species' range within the Mediterranean Sea.

Keywords: Cephalopods; *Ommastrephes bartramii*; Distribution; Mediterranean Sea; Spawning grounds; Climatic effect.

Introduction

The neon flying squid *Ommastrephes bartramii* Lesueur 1821 has been recognised as a unique species of the genus *Ommastrephes* after a series of investigations, which confirmed the proposals of PFEFFER (1912) and CLARKE (1966) who stated that *O. bartramii* and *O. caroli* represented respectively younger and older individuals of the same species (ZUEV *et al.*, 1975). According to the latest revision of the distinct characteristics of the six genera in the Ommastrephinae subfamily by YOUNG & VECCHIONE (2008, in ROPER *et al.*, 2010), *Ommastrephes* is the only among them that lacks large subcutaneous or visceral photophores.

Ommastrephes bartramii is a true oceanic species that is typically encountered throughout all ontogenetic stages at the surface, sub-surface and bathypelagic layers up to 1500 m in the high seas and is generally avoiding areas with a bottom depth less than 200 m and seamounts (ROPER *et al.* 2010).

This species is widely distributed in the subtropical and temperate zones of worldwide oceans, predominantly residing at sea surface temperatures between 10° and 25° C (ROPER *et al.*, 2010). The highest population densities associated with the warm Kuroshio current have been encountered in the northwestern Pacific Ocean, where the species has been targeted by international jigging and driftnet fisheries, the latter of which has ceased activities since the end of 1992 (BOWER & ICHII, 2005). In the Atlantic Ocean, the foraging *O. bartramii* are concentrated seawards from the subtropical anticyclonic gyres and into the waters of the North Atlantic Current and the Mediterranean Sea (ZUEV *et al.*, 1976). The species has been more abundant in the south-eastern part, up to 19° N of the North Atlantic Ocean, where seasonal changes in its

distribution correlated with seasonal changes in the 22-23° C surface layer temperatures (ZUEV & NIGMATULIN, 1977). Best exploratory jigging yields in the south-western Atlantic were also correlated with surface temperatures of 22-24° C (BRUNETTI & IVANOVIC, 2004). The results of exploratory surveys performed in various regions of the Atlantic Ocean revealed that *O. bartramii* may be a potential candidate for a directed jigging fishery, concomitant with further research to understand the species ecology (LETA, 1989; VECCHIONE & GALBRAITH, 2001; BRUNETTI & IVANOVIC, 2004).

Similar to most cephalopod species in the Mediterranean Sea, *O. bartramii* is considered to be a temperate, subtropical species that entered from the Eastern Atlantic after the Messinian salinity crisis and the opening of the Strait of Gibraltar 5.33 million years ago (MANGOLD & BOLETZKY, 1988, NESIS 2003). From a review of data collected during Russian research cruises in the Atlantic Ocean and the Mediterranean from 1952-1974, as well as data from published literature between 1835 and 1973, ZUEV *et al.* (1976) concluded that this squid is common in the Mediterranean and in the Aegean Sea on the Peloponnesus meridian. BELCARI (1999), from a review of the *O. bartramii* records in Italian waters from 1977 to 1990, noted that the squid is rarely caught in small numbers, yet it is practically absent from the fish markets. More recently, POTOSCHI & LONGO (2009) reported that, though infrequently, *O. bartramii* is captured by jigs targeting *Todarodes sagittatus* off the Aeolian islands in the southern Tyrrhenian Sea.

This paper aimed to review all available data on *O. bartramii* specimens from the Mediterranean Sea, including new data on body and beak morphometry, diet and the maturity of specimens recently collected

from the eastern Mediterranean. The mantle length (ML)–body weight (BW) and lower beak rostral length (LRL)–mantle length (ML) regression equations, based on available data from the Mediterranean Sea, are provided. Finally, the temporal range of the species distribution in this area is discussed in relation to the circulation of the water masses and the recent changes in oceanographic regimes due to climate effects.

Materials and Methods

Since 2003, nineteen *O. bartramii* specimens have been recorded in the Aegean Sea and adjacent regions (Fig. 1, Table I). Five were brought to the laboratories at the Hellenic Centre for Marine Research in Crete and Athens, the Biology Department of the University in Thessaloniki or the Department of Hydrobiology of the Ege University in Ismir. Basic measurements, characteristic appendices (beaks, sucker rings) and photographs of the remaining specimens were taken and examined by direct observers at the original location.

The species identification and its distinction from the most abundant large *Ommastrephid* in the Mediterranean, *Todarodes sagittatus*, was based primarily on the following characteristics:

- The length of the *Ommastrephes bartramii* tentacular club is shorter than that of the *Todarodes sagittatus*, which extends almost up to the base of the tentacles; this characteristic is easily visible, even in photographs.
- The fixing apparatus at the carpus of the tentacular club, on which 4 to 6 small suckers are located proximal to the first smooth knob (Fig. 2a)
- The presence of side pockets by the funnel pit (Fig. 2b).
- The dentition in the rings of larger manus

suckers in the tentacular clubs, where the teeth are enlarged in each quadrant (Fig. 2c).

- A more prominent ridge on the internal side of the upper beak in *O. bartramii* than in *Todarodes sagittatus* (Fig. 2d).

All of the specimens examined in the laboratory were in good condition. They were measured and dissected while they were still fresh or soon after being defrosted, except for the specimen stranded in Chalkidiki, for which more detailed morphometric measurements were taken after its fixation in a formalin solution.

Dorsal mantle length (DML), total length (TL), mantle circumference (MC), fin length (FL), fin width (FW), head length (HL), arm length (AL-x), tentacle length (TL-x) and tentacle club length (TCL-x) were measured to the nearest millimetre, whereas body weight (BW) was approximated to 10 g.

The standard dimensions of the beaks according to CLARKE (1962) (rostral length: RL, hood length: HL, crest length: CL, wing length: WL, distance between jaw angles: JAd of both upper: U and lower: L mandibles, amplitude of the lateral wall: LWa in the upper beak and length of base line: BL in the lower beak), as well as the sucker diameters (maximum arm sucker diameter: ASDmax, maximum tentacle sucker diameter: TCSDmax) were measured to the nearest 0.1 mm using callipers.

In addition, information on the gonad maturity, mating signs and stomach content were recorded.

For reviewing the species records in the Mediterranean Sea, the synonyms for *Ommastrephes bartramii*, including *Ommastrephes caroli* and *Stenoteuthis bartramii*, were also considered. The records are listed in chronological order, displaying information about the date/year, location and method of collection, along with data for the mantle

Table 1
Records of *Ommastrephes bartramii* in the Mediterranean Sea.

| Record No | Date / Year of finding | Location | Collection way | Number of specimens | ML (mm) | Size BW (g) | Sex | Reference |
|-----------|------------------------|--------------------------------------|--------------------------|---------------------|---------|-------------|-----|----------------------------------|
| 1 | < 1905 | Gulf of Lions (Banyuls-Sur-Mer) | stranded | 1 | | | | Lozano-Rey, 1905 |
| 2 | 24/3/1910 | NE Adriatic Sea (off Vodice) | | 1 | 165 | | | Gamulin-Brida and Ilijanić, 1965 |
| 3 | 10/1/1967 | Gulf of Taranto (off Galipoli) | fished at 70-100m | 1 | 108 | | | Torchio, 1967 |
| 4 | 6/2/1967 | Gulf of Taranto (Porto Cesareo) | stranded | 1 | 540 | ~ 6000 | | Torchio, 1967 |
| 5 | 1/3/1982 | N. Tyrrhenian Sea (off Capraia Isl.) | purse-seine at 70m | 1 | 600 | 10900 | | Biagi, 1990 |
| 6 | March 1986 | NW Adriatic Sea (off Falconara) | pelagic trawl | 1 | 560 | | F | Guescini and Manfrin, 1986 |
| 7 | April 1988 | S. Tyrrhenian Sea (off Ustica Isl.) | drifting pelagic net | 1 | 613 | 9412 | F | Ragonese and Jereb, 1990 |
| 8 | summer 1989 | S. Tyrrhenian Sea | trammel net | 1 | 137 | 185 | | Ragonese <i>et al.</i> , 1992 |
| 9 | 1988-1993 | Ligurian Sea | Isaac Kid Midwater Trawl | 1 | | | | Orsi-Relini <i>et al.</i> , 1994 |
| 10 | 14/8/1989 | Ligurian Sea (43° 49' N, 9° 07' E) | jigging | 5 | 110-175 | | | Orsi-Relini, 1990 |
| 11 | 9/12/1989 | Ligurian Sea (43° 43' N, 9° 09' E) | jigging | 3 | 195-213 | | M | Orsi-Relini, 1990 |
| 12 | 9/12/1989 | Ligurian Sea (43° 43' N, 9° 09' E) | jigging | 1 | 255 | | F | Orsi-Relini, 1990 |

(continued)

Table 1 (Continued)

| Record No | Date / Year of finding | Location | Collection way | Number of specimens | Size | | Sex | Reference |
|-----------|------------------------|--|----------------------|---------------------|---------|---------|-----|-------------------------------|
| | | | | | ML (mm) | BW (g) | | |
| 13 | 5/2/1990 | Ligurian Sea (44°08' N, 9°07' E) | jigging | 1 | 275 | | F | Orsi-Relini, 1990 |
| 14 | 11/3/1990 | S. Tyrrhenian Sea | drifting pelagic net | 1 | 597 | 7540 | F | Ragonese <i>et al.</i> , 1992 |
| 15 | 17/3/1990 | S. Tyrrhenian Sea | jigging | 1 | 525 | 5260 | F | Ragonese <i>et al.</i> , 1992 |
| 16 | 17/5/1990 | SE Aegean Sea (36°10' N, 26°01' E) | jigging | 1 | 560 | 8500 | F | Katagan <i>et al.</i> , 1992 |
| 17 | 18/9/1990 | SE Aegean Sea (36°46' N, 26°32' E) | jigging | 1 | 157 | 95 | F | Katagan <i>et al.</i> , 1992 |
| 18 | 19/9/1990 | SE Aegean Sea (35°54' N, 26°32' E) | jigging | 6 | 210-260 | 300-500 | F | Katagan <i>et al.</i> , 1992 |
| 19 | 19/9/1990 | NW Levantine Sea (36°46' N, 28°01' E) | jigging | 2 | 275 | 550-600 | F | Katagan <i>et al.</i> , 1992 |
| 20 | 19/9/1990 | NW Levantine Sea (36°46' N, 28°01' E) | jigging | 1 | 320 | 1050 | M | Katagan <i>et al.</i> , 1992 |
| 21 | 11/12/1990 | NW Levantine Sea (36°39' N, 28°45' E) | jigging | 1 | 370 | 1680 | F | Katagan <i>et al.</i> , 1992 |
| 22 | 9/3/1991 | NW Levantine Sea (36°39' N, 28°45' E) | jigging | 1 | 268 | 710 | F | Katagan <i>et al.</i> , 1992 |
| 23 | 10/12/1991 | SE Aegean Sea (36°46' N, 26°32' E) | jigging | 1 | 160 | 130 | F | Katagan <i>et al.</i> , 1992 |
| 24 | 11/12/1991 | NW Levantine Sea (36°39' N, 28°45' E) | jigging | 3 | 195-260 | 510-700 | F | Katagan <i>et al.</i> , 1992 |
| 25 | 20/11/2002 | NE Aegean Sea (Ismir Bay) | floating near shore | 1 | 550 | 6700 | F | Akyol and Sen, 2004 |

(continued)

Table 1 (Continued)

| Record No | Date / Year of finding | Location | Collection way | Number of specimens | Size | | Sex | Reference |
|-----------|------------------------|---|-----------------------------|---------------------|---------|--------|-----|----------------------------|
| | | | | | ML (mm) | BW (g) | | |
| 26 | Oct. 2002, Sept. 2003 | Ligurian Sea | jigging | 91 | 135-285 | | | Relini and Garibaldi, 2005 |
| 27 | 21/10/2003 | NE Levantine Sea (north off Cyprus) | jigging | 1 | 165 | 159 | | present report |
| 28 | 11/3/2004 | Thermaikos Gulf (N. Potidea) | stranded | 1 | 608 | 7200 | F | Vafidis et al., 2008 |
| 29 | March 2004 | NE Aegean Sea (north of Tenedos Isl.) | floating near shore | 1 | 660 | ~9000 | F | present report |
| 30 | April 2004 | Eastern Aegean Sea (Izmir Bay, off Karaburun) | floating near shore | 1 | 610 | ~10000 | F | present report |
| 31 | June 2004 | SE Aegean Sea (Kusadasi bay) | floating near shore | 1 | 520 | ~7000 | F | present report |
| 32 | 11/2/2005 | SE Aegean Sea (off Bodrum) | | 1 | | 8000 | | present report |
| 33 | May 2006 | Thyrrhenian Sea (39° 05' N, 9° 18' E) | trawl | 1 | 562 | 6569 | F | Cuccu <i>et al.</i> , 2009 |
| 34 | 13/9/2006 | Gulf of Taranto | dip-net | 4 | 150-230 | | | Bello, 2007 |
| 35 | 20/3/2007 | SE Aegean Sea (Crete Isl, Karteros) | stranded | 1 | 552 | 5900 | F | present report |
| 36 | 9/2007-12 2008 | S. Tyrrhenian Sea (off Aeolian islands) | jigging | 379 | | | | Potoschi and Longo, 2009 |
| 37 | 13/1/2008 | SW Aegean Sea (Myrtoan Sea) | hake long-line at 550-620 m | 1 | | | | present report |

(continued)

Table 1 (Continued)

| Record No | Date / Year of finding | Location | Collection way | Number of specimens | Size | | Sex | Reference |
|-----------|------------------------|---|---------------------------------|---------------------|---------|--------|-----|----------------|
| | | | | | ML (mm) | BW (g) | | |
| 38 | 14/1/2008 | SW Aegean Sea (off Apollonia Milos Isl.) | floating near shore | 1 | | 7000 | | present report |
| 39 | 15/1/2008 | SW Aegean Sea (off Chania, Crete Isl.) | floating near shore | 1 | | 4200 | | present report |
| 40 | 4/3/2008 | SE Aegean Sea (off Amoydara, Crete Isl.) | stranded | 1 | 533 | | F | present report |
| 41 | 2/6/2008 | SE Aegean Sea (Crete Isl., Karteros) | floating near shore | 1 | 580 | | F | present report |
| 42 | 8/4/2008 | NW Levantine Sea (off Kastelorizo Isl.) | swordfish drifting long-line | 1 | 470 | | | present report |
| 43 | 2/3/2009 | SE Ionian Sea (Spiazta, Peloponnesos) | stranded | 1 | 535 | 5830 | F | present report |
| 44 | 17/3/2009 | SE Aegean Sea (off Goyrnes, Crete Isl.) | floating near shore | 1 | | | | present report |
| 45 | 12/1/2010 | Argolikos Gulf (Karathonas bay) | drifting near shore | 1 | | | | present report |
| 46 | 9/3/2010 | SW Aegean Sea (off Chania, Crete Isl.) | | 1 | | 8100 | | present report |
| 47 | 11/10/2010 | NW Aegean Sea (off Skyros Isl.) | trawl | 1 | | | | present report |
| 48 | 16/3/2011 | SE Mediterranean (off Terapetra, south Crete Isl.) | sport fishery | 1 | | ~12000 | | present report |

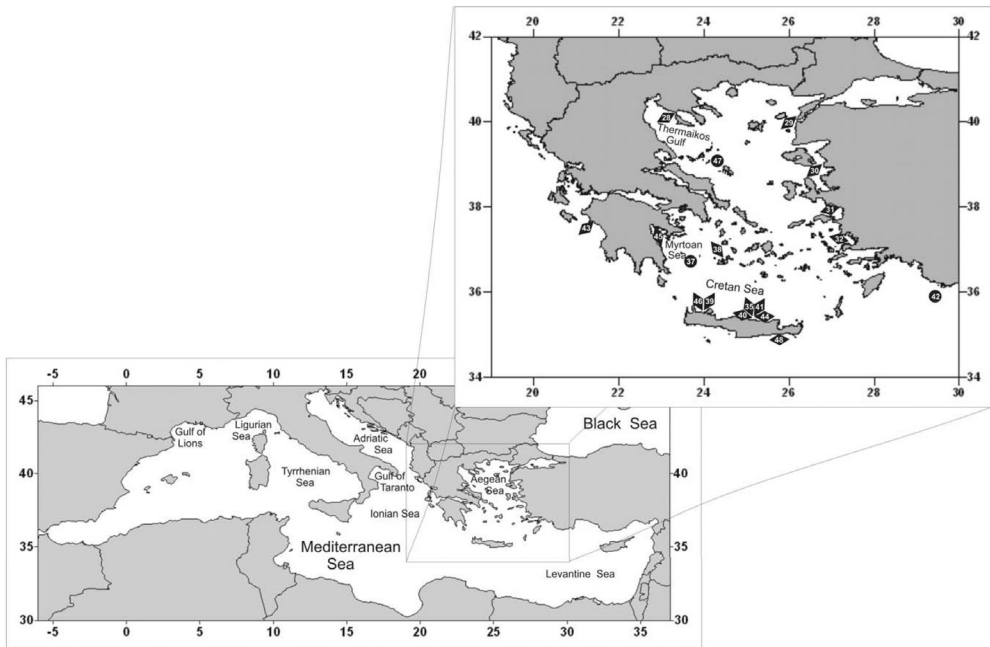


Fig. 1: Distribution of recent *Ommastrephes bartramii* records from the Aegean Sea and neighbouring areas of the Eastern Mediterranean. Records of stranded or drifting individuals collected from shallow waters are marked by diamonds (◆), whereas those caught by fishing gear over deep waters are denoted by circles (●).

length range, body weight and sex of collected specimens.

The regression equation for the DML-BW relationship was derived based on data available from the entire Mediterranean, whereas the equation for the DML-LRL relationship was computed only with specimens sampled from the eastern Mediterranean. The best fitted model for each regression was selected according to the best adjusted R^2 of standard curves tested by the statistical software STATGRAPHICS 4.0.

Results

Recorded sightings of the neon flying squid, *O. bartramii*, in the Mediterranean

Sea through March 2011 are presented in Table 1. Four males and 32 females are included, with ML ranges of 19.5-32 cm and 25.7-66 cm, respectively. The majority of individuals reported in the western Mediterranean were caught during professional and experimental jigging off the western Italian coasts (ORSI-RELINI & GARIBALDI, 2005; POTOSCHI & LONGO, 2009) during the last decade. There was a scarcity of species records from the Ionian and Adriatic Seas, which primarily described single, stranded specimens, with the exception of one female caught by pelagic trawl in the NW Adriatic (GUESCINI & MANFRIN, 1986). The catch of a few individuals by drifting long-lines targeting swordfish since the mid-1970s in the South

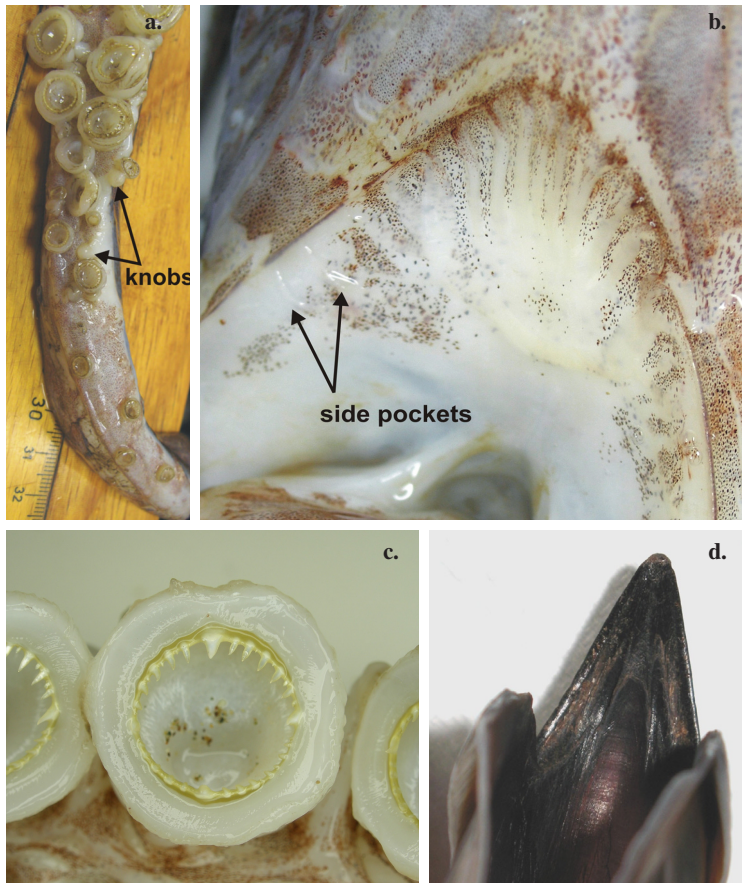


Fig. 2: *Ommastrephes bartramii* - (a) a carpus of the tentacular club with adhesive suckers and knobs, (b) a funnel pit with side pockets, (c) tentacular sucker rings with four longer teeth forming a cross and (d) a ridge formed at the internal side of the upper beak rostrum

Adriatic was mentioned by BELLO (1990) without any further details. Information on the specimens from the eastern Mediterranean until 2000 has been based on experimental jigging catches during the Turkish seasonal acoustic surveys of 1990-1991 in the SE Aegean and NW Levantine Seas. The most recent records primarily describe females collected individually on or near the shore.

The exact locations of the species sightings in the eastern Mediterranean are shown

in Figure 1. Data on the body morphometry, including the maturity and diet information for individuals examined in the laboratory, are shown in Table 2, whereas data on the dimensions of the available beaks are presented in Table 3.

All of the large individuals from the Aegean and Ionian Seas examined in the laboratory were fully mature or partly spent females, and spermatophores were observed in the buccal membrane of some of them.

The regression of the body weight (BW)

Table 2
Body dimensions (in mm), maturity and prey type of examined *Ommastrephes bartramii*
females from the Eastern Mediterranean during the period of 2004-2009.

| Record No | 28 | 34 | 40 | 41 | 43 |
|-----------|--------------------------------|------------------|------------------|--------------|--------------|
| DML | 608 | 552 | 533 | 580 | 535 |
| TL | | 1300 | | | 1410 |
| MC | 465* | | | | 415 |
| FL | 295* | | 249 | | 265 |
| FW | 455* | 422.5 | 448 | | 425 |
| ALI | 283* | 235 | 352 | 363 | 315 |
| ALII | 347* | 244 | 375 | 355 | |
| ALIII | 350* | 310 | 375 | 333 | 368 |
| ALIV | 345* | 290 | 282 | | 367 |
| TCL | 640* | 728 | 835 | 742 | 765 |
| ASDmax | | 7 | | | 13 |
| TCSDmax | | 10 | | | 12 |
| Maturity | fully mature | fully mature | partly spent | fully mature | partly spent |
| Prey type | cephalopod, fish, Mysidacea | cephalopod, fish | cephalopod, fish | empty | empty |

Table 3
Beak measurements (in mm) of *Ommastrephes bartramii* specimens
from the Eastern Mediterranean Sea.

| Record No | 21 | 23 | 27 | 28 | 29 | 31 | 35 | 40 | 41 | 42 | 43 |
|-----------|------|------|------|------|------|------|------|------|------|------|------|
| DML | 370 | 160 | 165 | 608 | 660 | 520 | 552 | 533 | 580 | 470 | 535 |
| URL | 8.3 | 5.3 | 4.5 | 20 | 15.4 | 13.9 | 14.5 | 14.6 | 13.1 | 11.5 | 14.5 |
| UHL | 24 | 14.1 | 13.5 | 47.2 | 50.8 | 42.8 | 39.7 | 46.2 | 40.1 | 31.4 | 42.7 |
| UCL | 35.4 | 17.2 | | 60.7 | 60.8 | 54.1 | 53.0 | 52.1 | 45.3 | 41.7 | 53.4 |
| UWL | 13.9 | 7.3 | | 18.8 | 21.2 | 19.5 | 14.2 | 14.0 | 11.9 | 10.7 | 14.7 |
| ULWa | | | | 31.7 | | | 22.5 | 23.5 | 23.3 | 19.8 | 23.3 |
| UJA | | | | 13 | | | 11.0 | 11.1 | 9.8 | 8.7 | 11.1 |
| LRL | 8.1 | 4.8 | 3.8 | 12.3 | 14.3 | 13.1 | 13.4 | 13.5 | 12.0 | 10.4 | 14.0 |
| LHL | 8.8 | 5.0 | 5.5 | 14.9 | 14.6 | 12.8 | 9.9 | 12.3 | 11.0 | 9.6 | 11.3 |
| LCL | 19.9 | 9.2 | 9.5 | 30.7 | 31.5 | 29.8 | 24.3 | 25.5 | 23.2 | 20.6 | 27.7 |
| LWL | 13.2 | 5.9 | 5.8 | 28.6 | 24.5 | 22.1 | 20.9 | 23.6 | 18.4 | 16.6 | 21.7 |
| LBL | 22.5 | 10.0 | 11.1 | 38.4 | 42.2 | 33.5 | 31.5 | 29.2 | 28.0 | 24.3 | 27.5 |
| LJA | | | 16.5 | 16.9 | | | 11.1 | 10.2 | 10.1 | 9.8 | 11.5 |

(in g) to the dorsal mantle (DML) (in mm) was best fitted by the following exponential equation:

$$BW = 49.2456 + \exp(0.0089 \times DML),$$

$$R^2 = 0.97 (N=30)$$

The relationship of the lower rostral length (LRL) (in mm) compared to the DML (in mm) was best described by the following multiplicative model:

$$ML = 36.2613 \times LRL^{1.069}, R^2 = 0.95 (N=11)$$

Discussion

Geographic distribution and association to water mass circulation

Studies in the North Pacific have shown that the *O. bartramii* distribution and abundance strongly correlated with the water temperature. Specifically, spawning grounds correlated with a sea surface temperature (SST) range of 21-25°C, whereas the feeding grounds and migrating routes, where jigging and drift-net fisheries perform catches, were observed in the 6-15°C range at a 200 m depth (BOWER & ICHII, 2005), and the optimum SST varied from 10 to 22°C according to the season (CHEN *et al.*, 2007). In addition, the zooplankton abundance has been attributed to promoting suitable biological conditions for the formation of neon flying squid fishing grounds (CHEN *et al.*, 2007). Changes in environmental conditions, driven by Kuroshio current bending, were observed to play an important role in the inter-annual variation of CPUE, influencing both squid recruitment and aggregation at the spawning and feeding grounds, respectively (CAO *et al.*, 2009).

Most of the *O. bartramii* records in the eastern Mediterranean are distributed along the eastern Aegean and the periphery of the Cretan Sea (Fig. 1). This pattern of distribution correlates with the circulation of the warm Levantine Intermediate Water (LIW), which enters into the Aegean through the eastern straits of the Cretan Arc, moves northward along the Turkish coast and spreads into Cretan Sea, predominantly occupying the subsurface layer up to 200 m deep (STER-

GIOU *et al.*, 1997), where dense *O. bartramii* schools have been observed (KATAĞAN *et al.*, 1992). During the winter when the circulation pattern is generally cyclonic and strong convective mixing occurs in the Cretan Sea, waters with LIW characteristics extend from the surface down to 750-1000 m. However, during the summer, the influence of the Asia Minor Current (AMC) that drives the LIW into the Aegean is less pronounced (THEOCHARIS *et al.*, 1993). A temporal variation in *O. bartramii* abundance, which is at a maximum in autumn, decreases from the winter to the spring and is completely absent during the summer, was demonstrated by seasonal recordings of *O. bartramii* concentrations by echosounders in the SE Aegean-NW Levantine (KATAĞAN *et al.*, 1992). This variation seems to correlate with the seasonal presence of the LIW. The seasonal variation observed in the most recent findings from the South Aegean, with a higher frequency in the winter and early spring, is consistent with previous observations.

Spatio-temporal distribution and biological characteristics of recorded specimens

All squids, either found stranded or drifting in shallow waters, dissected in this study were spawning females, which is likely similar to the stranded or moribund individuals collected from different areas (Table 1) and is indicative of the reduction in their capability for active locomotion due to spawning and the rising of their buoyant bodies towards the surface, as observed in several cephalopod species (BOYLE & RODHOUSE, 2005). Because large females appear to be sighted more frequently along the north coast of the island of Crete, the deep basin of the Cretan Sea may be an *O. bartramii* spawning area.

Conversely, the capture of relatively

smaller individuals during jigging off of western Italian coasts (ORSI-RELINI, 1990; POTOSCHI & LONGO, 2009) may indicate the existence of important feeding grounds in the Ligurian and the Tyrrhenian Seas, characterised by permanent cyclonic gyres and colder waters (LONGHURST, 1995; CORDERO *et al.*, 1999). Younger individuals (ML < 143 mm) have been mainly caught in August-September (POTOSCHI, personal communication), whereas largest ones (ML: 560-660 mm) have been caught from April to June, during which a significant warming of the Tyrrhenian Sea surface waters was observed in 1985-2006 (NYKJAER, 2009). Older records of large females in the southern Tyrrhenian (RAGONESE & JEREB 1990; RAGONESE *et al.*, 1992; CUCCU *et al.*, 2009) have also been reported during the spring (Table 1), which may indicate a seasonal species migration to the southernmost areas for spawning. However, there is a paucity of available data, thus a more systematic collection of information describing *O. bartramii* catches is needed to determine its definitive distribution and seasonal variation.

Vertical distribution and availability to fishing gear

ROPER & YOUNG (1975) revealed that open sea Ommastrephids, like *O. bartramii*, occur primarily in the upper few hundred meters during both the day and the night. However, some individuals are observed at great depths, which are in agreement with the presence of this species' remains in the stomach content of a *Centrocygnus coelolepis* specimen caught at 2220-2240 m in the western Mediterranean (VILLANUEVA, 1992). According to Japanese investigations, individuals smaller than 20 cm ML mainly inhabit surface waters, whereas, as shown by biotelemetry, adult squids

are distributed from 0-100 m during the night but migrate to depths of 150-350 m near the Sub-arctic Frontal Zone and below 400 m in more oligotrophic southern areas of the Pacific Ocean during the day (BOWER & ICHII, 2005). Although the eastern Mediterranean is considered to be one of the most oligotrophic marine areas, echosounder records have shown that *O. bartramii* form dense schools at 200-250 m depths during the day and at bottom depths of 800-2200 m at night, moving up to 40 m depths only when the vessel lights are switched on (KATAĞAN *et al.*, 1992).

The scarcity of *O. bartramii* records in the Mediterranean could be attributed to the mesopelagic distribution of the species and the lack of either professional or experimental systematic mid-water fishing in the open sea. Fishing gears that have captured predominantly smaller specimens include jigs (ORSI-RELINI, 1990; KATAĞAN *et al.*, 1992; ORSI-RELINI & GARIBALDI, 2005; POTOSCHI & LONGO, 2009), drifting long-lines (BELLO, 1990; specimen No 42 in Table 1 of the present study), drift nets (RAGONESE & JEREB, 1990), purse seines (BIAGI, 1990) and pelagic trawls (GUESCINI & MANFRIN, 1986; ORSI-RELINI *et al.*, 1994) as well as three records of bottom trawling (SÁNCHEZ *et al.*, 1998; CUCCU *et al.*, 2009; specimen No 47 in Table 1 of the present study) and a single individual caught by a bottom long-line used for hake in the SW Aegean (Table 1).

The pelagic habitat of this species may also be supported by the presence of its remains in the stomach contents of large pelagic fishes and dolphins (BELLO, 1991; SALMAN, 2004; ÖZTÜRK *et al.*, 2007; ORSI-RELINI & GARIBALDI, 2005; PEDÁ *et al.*, 2009; SALMAN & KARAKULAK, 2009).

Climatic effect and perspectives on the fisheries

Since 2007, the repeated recurrent sightings of individuals stranded or floating in near shore waters of the Aegean Sea have become a popular subject of public discussion, which may be attributed to the increase in fisherman attention to rarely caught species due to the recent invasion of venomous alien species (Lefkaditou *et al.*, 2010). However, this attention may also be indicative of a recent increase in *O. bartramii* abundance in the Eastern Mediterranean, favoured by the more pronounced warming of upper sea layers observed in this area since 1994 (RAITSOS *et al.*, 2010).

The geographical spread of species with affinities to warm water, similar to most species that enter from the Atlantic into the Mediterranean, has been observed in the Mediterranean region since the 1980s and correlates with direct and indirect recent global warming effects (BIANCHI, 2007)

Because of the “meridionalisation” of the Mediterranean Sea, more intensive efforts should be devoted to the monitoring of the northward expansion of indigenous and allochthonous thermophilic species. Additionally, a parallel study of the evolution in water mass circulation may be undertaken to detect biodiversity changes, particularly in the top mid-water predators. Currently, *O. bartramii* represents a small part (<3%) of Ommastrephids targeted by jigging fisheries off of the Aeolian islands (POTOSCHI & LONGO, 2009). Developing directed jigging fisheries for *O. bartramii* and the association of this species with the water mass circulation in the southern Aegean, Ligurian and Thyrrenian Seas should be a priority for further investigations.

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