

Research article

Marivagia stellata gen. et sp. nov. (Scyphozoa: Rhizostomeae: Cepheidae), another alien jellyfish from the Mediterranean coast of Israel

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Abstract

Two specimens of an unknown jellyfish species were collected in Bat Gallim and Beit Yannai, on the Mediterranean coast of Israel, in June and July 2010. Morphological characters identified it as a cepheid (Cnidaria, Scyphozoa, Rhizostomeae). However, the specimens showed remarkable differences from other cepheid genera; unlike *Cephea* and *Netrostoma* it lacks warts or knobs centrally on the exumbrella and filaments on oral disk and between mouths, and it differs from *Cotylorhiza* in its proximally loose anastomosed radial canals and in lacking stalked suckers and filaments on the moutharms. We thus describe it herein as *Marivagia stellata* gen. et sp. nov. We also present the results of molecular analyses based on mitochondrial cytochrome oxidase I (COI) and 28S ribosomal DNA, which support its placement among the Cepheidae and also provide its barcode signature. This new find is the fourth introduced scyphozoan species recorded in the Mediterranean. The presence of a sexually mature specimen collected as far back as 2006, and the occurrence of the species this summer at sites nearly 90 kms apart, indicate the existence of an established population.

Key words: *Marivagia stellata*, new genus, new species, Cepheidae, jellyfish, alien, Mediterranean, mitochondrial cytochrome oxidase I (COI), 28S ribosomal DNA

Introduction

The first record of Scyphomedusae from the Mediterranean coast of Israel consisted of a single sentence: "During the winter large jellyfish of the species *Rhizostoma pulmo* and *Aurelia aurita* are washed on to the beach, where they may be found, after storms" (Bodenheimer 1935). In 1990, Galil et al. recorded the presence of seven species of Scyphomedusae off the coast of Israel, including three alien species: *Cassiopea andromeda* (Forskål, 1775), *Phyllorhiza punctata* von Lendenfeld, 1884, and *Rhopilema nomadica* (Galil, 1990).

Keller (1888) reported that already in 1886 large numbers of *C. andromeda* inhabited the Suez Canal and the adjoining lagoons south of Lake Timsah. The species was first recorded in the Mediterranean from Cyprus by Maas (1903). The half century that passed between Maas' report and the next Mediterranean record might excuse Schäfer's (1955) statement that the species "bisher aus dem Mittelmeer unbekannt

war" (so far undescribed for the Mediterranean Sea). Schäfer reported the occurrence of very young specimens (2–30 mm) on Neokameni, a small volcanic island near Thira, Aegean Sea, where the medusae flourished in rocky pools with water temperatures reaching up to 36°C due to volcanic activity. *Cassiopea andromeda* occurs along the Levantine coastline (Goy et al. 1988; Spanier 1989; Bilecenoğlu 2002) and was recently reported from Malta (Schembri et al. 2010).

Phyllorhiza punctata was first sighted in the Mediterranean in 1965, off the Israeli coast, and since 2005 its presence has been recorded regularly (Galil et al. 1990; Galil et al. 2009). Ephyrae and medusae of *P. punctata* were collected off Lefkada Island, on the Ionian coast of Greece, in 2005 and 2006, and the population has apparently occurred there for a number of years (Abed-Navandi and Kikinger 2007). In 2009 a single specimen was photographed off Tavolaro Island, Sardinia, Italy (Boero et al. 2009).

Though appearing occasionally in small aggregations, the Mediterranean populations of *C. andromeda* and *P. punctata* have thus far remained small. In contrast, *R. nomadica* is notorious for the huge swarms it has formed each summer since the mid 1980s along the SE Levantine coast. The jellyfish swarms adversely affect tourism, fisheries and coastal installations. The annual swarming results each year in envenomated victims suffering burning sensation, eurythema, papulovesicular and urticaria-like eruptions that may last weeks and even months after the event (Benmeir et al. 1990; Silfen et al. 2003; Yoffe and Baruchin 2004; Sendovski et al. 2005). Coastal trawling and purse-seine fishing are disrupted for the duration of the swarming due to net clogging and inability to sort yield "It is not uncommon that fishermen, especially purse seiners, discard entire hauls due to the overwhelming presence of poisonous medusae in their nets" (Golani and Ben Tuvia 1995). Jellyfish-blocked water intake pipes pose a threat to desalination plants, cooling systems of port-bound vessels and coastal power plants: in the summer of 2001 Israel Electric removed tons of jellyfish from its seawater intake pipes at its two largest power plants.

Here, we report the detection of a previously unknown jellyfish species off the Mediterranean coast of Israel. Its morphological characters placed the species among the cepheid scyphozoans. However, since it differed markedly from known cepheid genera, mitochondrial cytochrome oxidase I (COI) gene sequences and 28S ribosomal DNA large subunit (LSU) were analyzed and compared with scyphozoan sequences in GenBank. The results of the genetic study supported its placement among the Cepheidae and we describe it herein as *Marivagia stellata* gen. et sp. nov. The new find is the fourth introduced scyphozoan species recorded in the Mediterranean.

Materials and methods

Study site and sampling

The earliest specimen was collected off Tel Shikmona (lat. 32°49.3'N, long. 34°57'E), on the southern rim of Haifa Bay, in January 2006. It was photographed, preserved, sent for identification and lost. On June 29, 2010, a larger specimen was collected off Bat Gallim (lat. 32°50'N, long. 34°57'E), on the southern rim of Haifa Bay, and on July 7, 2010, a smaller

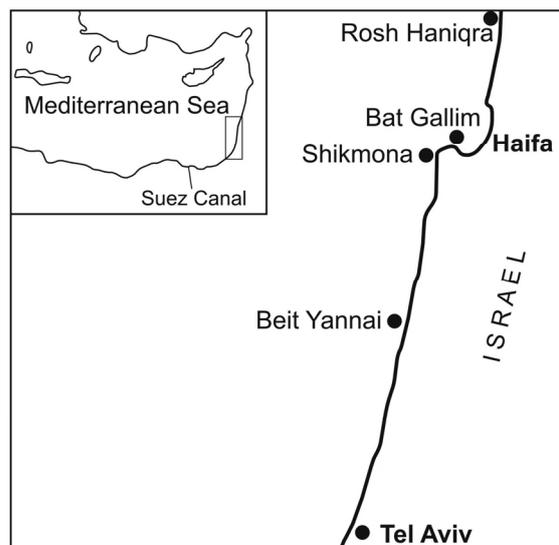


Figure 1. Map of study area with sampling locations.

specimen was collected off Beit Yannai (lat. 32°22.6'N, long. 34°52'E), both specimens were preserved and photographed. Photographs taken in June 2010 off Rosh Haniqra (lat. 33°05'N, long. 35°01'E) showed a live specimen (Figure 1).

Two tissue samples were taken from the specimen collected off Bat Gallim and placed in 15ml tubes containing 1.5ml lysis buffer (0.25 M Trisborat pH 8.2, 0.1 M EDTA, 2% SDS, 0.1 M NaCl and 0.5 M NaClO₄) and an equal volume of Phenol/Chloroform/isoamyl alcohol (25:24:1).

Molecular analysis

DNA extraction

The tissue tubes were mixed by vortex for 1-5 min and 1ml of the mixture transferred to new 1.5ml tubes for centrifugation (10min at 14,000g, 4°C). The aqueous phase was further extracted with equal volume of Phenol/Chloroform/isoamyl alcohol (25:24:1) followed by additional extraction with chloroform/isoamyl alcohol (24:1). The DNA was precipitated with absolute ethanol, washed with 70% ethanol (X2) and resuspended in 50µl of RNase - DNase free DDW.

PCR amplification

PCR amplification of the mitochondrial gene, cytochrome C oxidase subunit I (COI) was performed according to Folmer et al. (1994) using the COI marine invertebrates' universal

primers (HCO2198r, 5'TAAACTTCAGGGTG ACCAAAAATCA 3' and LCO1490f, 5'GGTCAACAAATCATAAAGATATTGG 3'. One µl of diluted DNA (1:50) from each sample was added to a reaction mixture containing 5µM of each primers and DreamTaq™ DNA polymerase (Green PCR Master Mix 2×; Fermentas) in a total solution volume of 50µl. Reaction conditions were as followed: 74°C for 10sec and 95°C for 5 min followed by 35 cycles of 95°C for 1 min, 45°C or 1 min and 72°C for 1 min and additional elongation step of 72°C for 10 min. Amplification of the 28S ribosomal DNA large subunit (LSU) was performed according to Bayha et al. (2010), using the primers Aa_L28S21 GAACRGCTCAAGCTTAAATCT and Aa_H28S1078 GAAACTTCGGAGGGAAC CAGCTAC. The PCR products were screened on 1.2% agarose gel. The same PCR primers had also been used for direct sequencing of the PCR products (Macrogen Inc, South Korea).

Sequence analyses

Sequences results from the PCR product were verified using the “Barcode of Life Data Systems (BOLD)” Identification System (IDS) for COI (<http://www.boldsystems.org/views/idrequest.php>) and by BLAST comparison (<http://blast.ncbi.nlm.nih.gov/Blast.cgi>) for COI and 28S ribosomal DNA. Twelve COI sequences and eighteen 28S ribosomal DNA LSU of Rhizostomaeae genera (COI Accession numbers: EU373724 *Rhopilema esculentum*; EU373728 *Nemopilema nomurai*; EU363342 *Phyllorhiza punctata*; EU363346 *Cephea* sp1; EU363345 *Cephea* sp2; AB563740 *Cassiopea andromeda*; AY319468 *Cassiopea xamachana*; AY319470 *Cassiopea frondosa*; EU363348 *Acromitus* sp.; EU363344 *Crambionella orsini*; and AY737239 *Catostylus mosaicus*. 28S ribosomal DNA Accession numbers: HM215009 *Thysanostoma thysanura*; HM194823 *Versuriga anadyomene*; HM194824 *Cephea cephea*; HM194825 *Phyllorhiza punctata*; HM194829 *Crambionella orsini*; HM194832 *Catostylus mosaicus*; HM194833 *Acromitus* sp.; HM194836 *Crambione mastigophora*; HM194838 *Cassiopea ornata*; HM194839 *Cotylorhiza tuberculata*; HM194847 *Rhopilema esculentum*; HM194848 *Rhizostoma pulmo*; HM194850 *Rhopilema verrilli*; HM194853 *Stomolophus meleagris*; HM194856 *Pseudorhiza haeckeli*; HM194871 *Cassiopea andromeda* and HM194872 *Cassiopea*

frondosa, were chosen for further alignment and editing using BioEdit (Hall 1999) and ClustalX (Thompson et al. 1997). The phylogenetic and molecular evolutionary analyses was conducted using MEGA version 4 (Tamura et al. 2007) and PAUP* version 4.0b10; (Swofford 2002). The best fit model of nuclear substitution was selected in jModeltest 0.1.1 (Posada 2008) based on likelihood score of 88 models and AIC criterion.

Systematic results

Marivagia Galil and Gershwin gen. nov.

Type species: *Marivagia stellata*, sp. nov., designated herein.

Diagnosis: Cepheidae completely lacking exumbrellar central dome, papillae or knobs, with only microscopic warts and ridges; lacking subumbrellar filaments or other appendages between the mouths or on the oral plate; with 3 adradial canals between rhopaliar canals, anastomosing loosely in proximal 2/3 and complexly in distal 1/3.

Etymology: The genus name is derived from the Latin, ‘*mari*’ – sea, ‘*vagus*’ – wanderer.

Marivagia stellata Galil and Gershwin sp. nov. (Figures 2-5).

Holotype: Bat Gallim, south of Haifa Bay, Israel, coll M. Kadosh, 29 June 2010; 142 mm bell diameter. Deposited in the National Collections of Natural History at Tel Aviv University (TAU Co 35073)

Paratype: Beit Yannai, Sharon plain, Israel, coll L. Sade, 7 July 2010; 70 mm bell diameter. Deposited in the South Australian Museum (SAM H1647).

Other material: 1 specimen, 150 mm bell diameter, Shikmona, south of Haifa Bay, Israel, coll S. Usvyatsov, 8 January 2006, photographed, preserved but lost. A photograph taken at Rosh Haniqra, June 2010, by G. Rilov (Figure 4).

Type locality: Bat Gallim, south of Haifa Bay, Israel.

Diagnosis: As for genus.

Description of holotype: Exumbrella lacking conspicuous warts, papillae or knobs; ornamented only with a series of pigment marks as described below (Figure 2A), which overlay microscopic raised dots and ridges. Subumbrella

Figure 2. *Marivagia stellata* gen. et sp. nov., holotype. **A.** Aboral view. **B.** Oral view. Photograph by B.S. Galil.

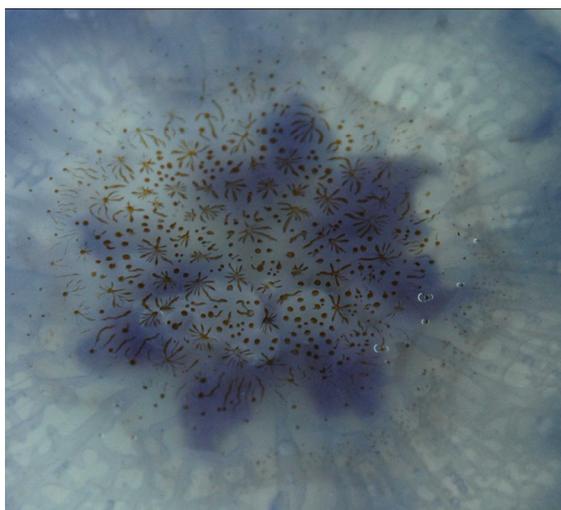
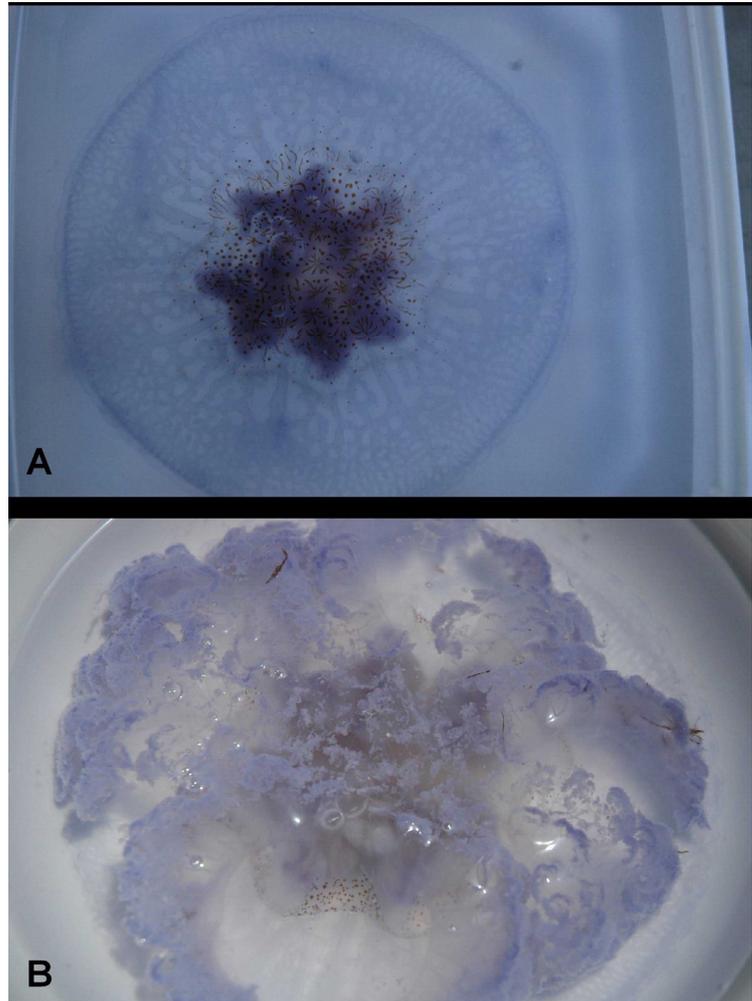


Figure 3. *Marivagia stellata* gen. et sp. nov., holotype. Close up of exumbrellar pigmentation pattern. Photograph by B.S. Galil.



Figure 4. *Marivagia stellata* gen. et sp. nov., specimen photographed at Rosh Hanikra, Israel, June 2010, by G. Rilov.

Figure 5. *Marivagia stellata* gen. et sp. nov., holotype, preserved. **A.** Detail of lappets and rhopalium. **B.** Lappets and radial canal venation. **C.** Subumbrellar gelatinous radial ridges. Photographed using Nikon SMZ800 binocular with Achro 0.5X lens and TV lens C0.45X and Olympus XC30 camera with AnalySIS Soft Imaging System. Photograph by G. Paz.

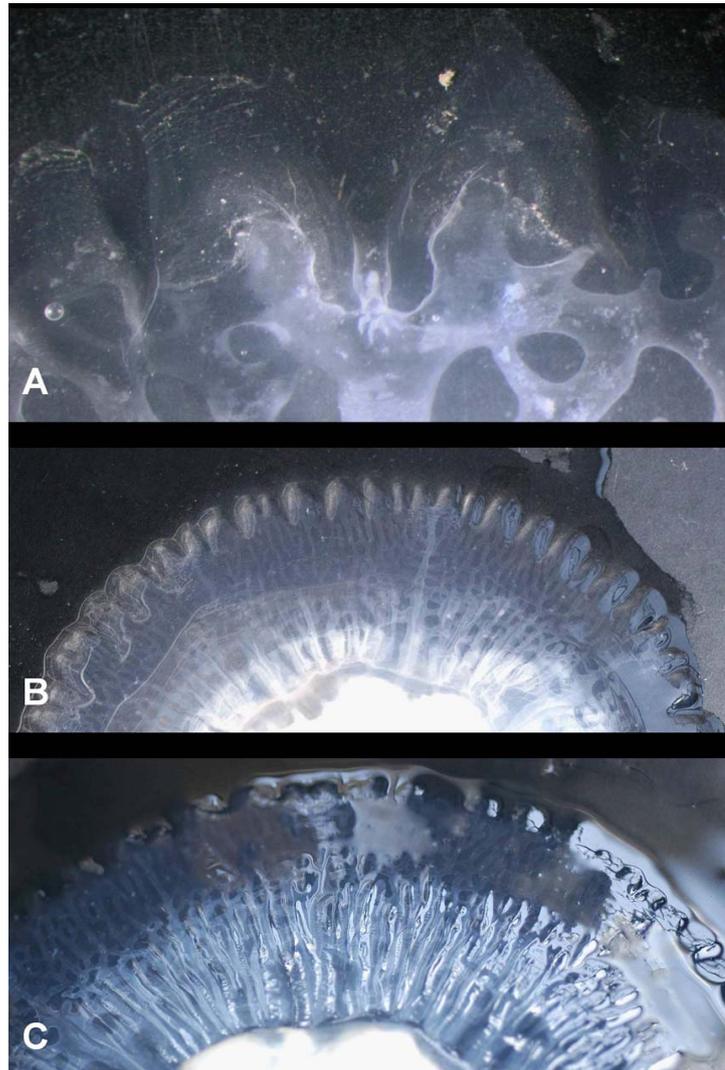


Table 1. Comparison of primary diagnostic characters of genera in the family Cepheidae.

GENUS	RADIAL CANALS	EXUMBRELLAR MORPHOLOGY	SUBUMBRELLAR APPENDAGES
<i>Cephea</i> Péron & Lesueur, 1810	8 main & >3 secondary canals free proximally, anastomosed distally	Central dome with warts	With numerous filaments between mouths
<i>Cotylorhiza</i> Agassiz, 1862	8 main & up to 13 short secondary canals completely anastomosed throughout	Smooth central dome without warts	Mouth arms with stalked suckers, plus filaments
<i>Netrostoma</i> Schultze, 1898	8 main & 3 secondary canals free proximally, anastomosed distally	Central dome with large warts or a single large knob	With numerous filaments on oral disk and between mouths
<i>Marivagia</i> n.gen.	8 main canals free proximally, 3 secondary canals anastomosed proximally	Exumbrellar surface lacking central dome, warts, or knobs	Lacking filaments on oral disk and between mouths

with approximately 9 gelatinous radial ridges per octant, extending from peripheral edge of gastro-gonadal region halfway to margin, ending abruptly (Figure 5C). Peripheral region of bell inverted in life.

Oral arms 8, shorter than bell radius, triangular in cross section with adaxial side convex, recurved; bi-forked halfway, with 6 branches along adaxial sides of arm, each further branched, dendritic, with feather-like mouths; lacking appendages between mouths (Figure 2B). Radial canals (Figure 2A, 5B): Rhopaliar canals 8, widest near centre, with sinuous to diverticulated edges, anastomosing with inter-rhopaliar canals in distal half. Inter-rhopaliar canals 3 per octant (total of 32 canals projecting from gastro-gonadal region); loosely anastomosed in proximal 2/3 of bell, complexly anastomosed in outer 1/3 of bell; with numerous blind diverticula, especially in proximal region where main canals have not yet anastomosed.

Lappets 7-9 per octant, of two types, all well defined by thick, raised, gelatinous, projections of bell margin: typically 6 velar lappets per octant large, broad, tongue-shaped; 1 or 2 per side flanking each rhopalium smaller, shorter, narrower; with blind projections of anastomosing radial canal network (Figure 5A, B).

Rhopalia 8, 4 perradial and 4 interradial, within W-shaped niches (Figure 4A); niches entirely covered over on exumbrellar side, lacking subumbrellar protective membrane, such that rhopalium is directly exposed to water flow on subumbrellar side.

Oral plate lacking any sort of appendages (Figure 2B). Body open to outside only through 4 very small interradial funnels, lacking pillars and arches; gastric and genital systems continuous. Gonads 4, interradial, crescentic with concavity facing outward toward bell margin, entirely enclosed.

Color in life translucent bluish-white jelly, with conspicuous pattern of reddish stars, dots and streaks clustered in centre third of exumbrella, confined in a rounded eight-pointed star-shaped region over the stomach and gonad region; gonads pale whitish; subumbrellar surface of stomach region densely covered with small reddish dots; subumbrellar surface of canal region unpigmented; jelly of oral arms translucent whitish, mouthlets pale purplish blue (Figures 2A, B; Figure 3). The distinctive coloration is evident at all sizes observed.

Etymology: The species name is derived from the Latin, *stella* – star, for the dots and star-burst like pattern on the exumbrella.

Systematic Remarks: Cepheidae is one of the well-described families of scyphozoan jellyfish, its genera well defined based on the historically used morphological features. It has been recently recognized as robustly monophyletic based on sequence data from two nuclear genes: 18S and 28S rDNA (Bayha et al. 2010).

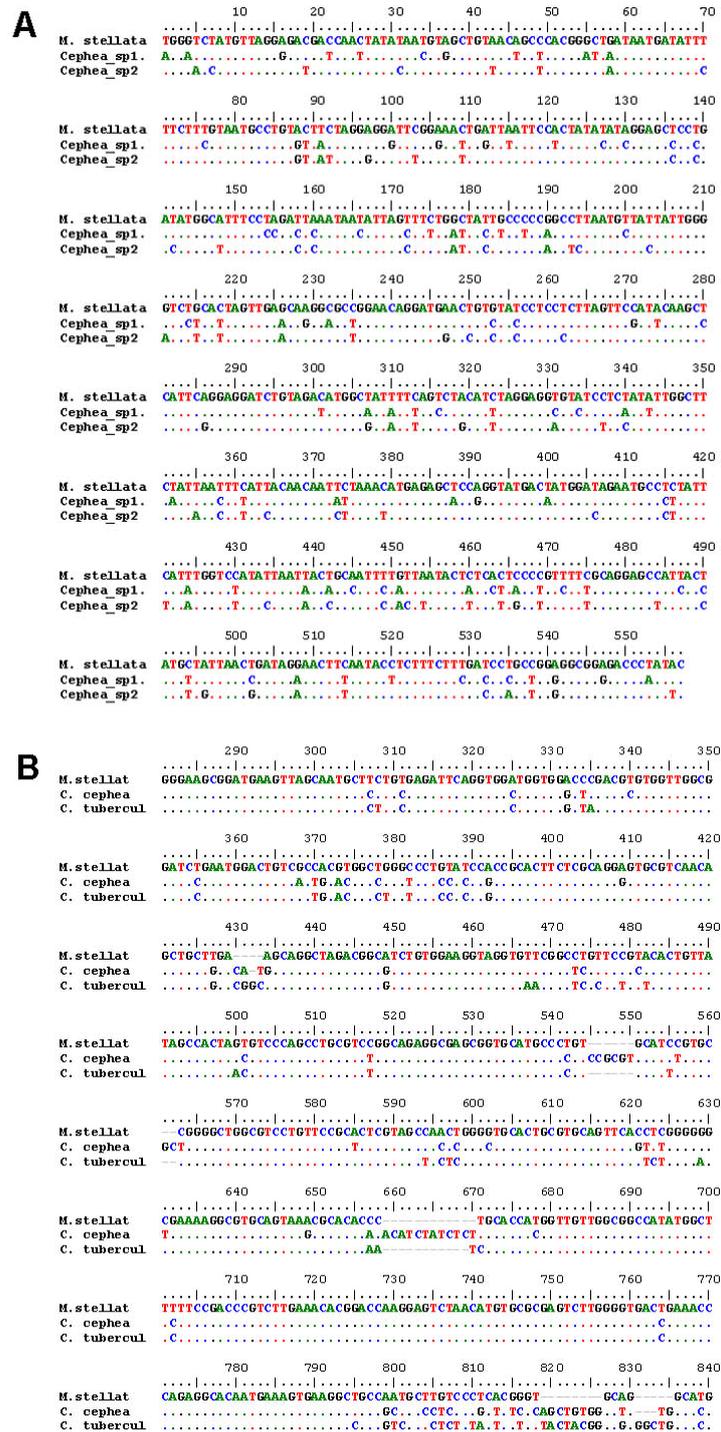
Marivagia stellata gen. et sp. nov. is readily identifiable from the three cepheid genera (*Cephea* Péron & Lesueur, 1810, *Cotylorhiza* Agassiz, 1862, *Netrostoma* Schultze, 1898) by its unique combination of characters (Table 1). Like all cepheids, *Marivagia* has feathery mouthlets and eight main radial canals (four perradial and four interradial) corresponding with the eight rhopalia; however, *Marivagia* differs in having the main canals free proximally but the secondary canals (i.e., the adradials) anastomosed (cf. Stiasny 1923). *Marivagia* resembles *Netrostoma* in possessing only three adradial canals per octant, but differs from the latter in its exumbrellar and subumbrellar structures. Like *Cotylorhiza* its exumbrella lacks warts; however, *Marivagia* is the only cepheid lacking a central dome and appendages between the mouths. Given the remarkable morphological differences from other cepheid genera, it could not be reasonably placed in an existing genus without major restructuring of the generic recognition criteria and family taxonomy, which we believe would introduce unwarranted nomenclatural instability into the family.

Molecular results

COI markers are preferably used as the ‘barcode’ flag for most animal life, indicating that the COI gene consistently identifies species where authenticated reference sequence data exists and is considered useful for species recognition.

Sequence analysis of *M. stellata* mitochondrial gene, cytochrome C oxidase subunit I (COI) (accession number HQ127369), revealed its genetic similarity to two *Cephea* spp. (EU363346 *Cephea* sp. 1; EU363345 *Cephea* sp. 2). At present the sequences submitted to GenBank as *Cephea* spp. 1 and 2 lack precise taxonomic definition and thus preclude further discussion of their relation to *M. stellata*. Neighbor-Joining tree with 336 COI sequences of all scyphozoan species obtained from GenBank again places

Figure 7. Sequences alignment of cepheid species and *Marivagia stellata* gen. et sp. nov: A. COI sequence; B. 28S ribosomal DNA (partial sequence).



M. stellata lacks exumbrellar papillae and oral tendrils, and has starburst-like pigmentation centrally on its exumbrella. *Cephea octostyla* is characterized by exumbrellar papillae and numerous tendrils and clubs between the mouths

(Forskål, 1775: pl. 29), whereas *M. stellata* lacks such structures. Ehrenberg (1835) described *Cephea vesiculosa* from the Red Sea, characterized by a series of radiating furrows on the exumbrella, a cluster of filaments on the oral

disk and a reddish color. Agassiz (1862) considered it sufficiently distinctive to warrant selection of a new genus - *Polyrhiza* (see Mayer, 1910: 260, for a thorough review), but later workers considered the species probably identical to *Netrostoma coerulescens* and the genus doubtful (see summary of historical nomenclature in Kramp, 1961: 357). Whatever its identity, it is clearly distinguished from *M. stellata*. *Cotylorhiza erythraea* was described from the Suez Canal (Stiasny 1920, 1921) as having the 4-6 adradial canals in each octant completely anastomosed with the main canals, and clubs between the mouths, whereas *M. stellata* lacks subumbrellar clubs and though its 3 adradials per octant are completely anastomosed, the main canals are not.

Since the appearance of *R. nomadica* off the Southeastern Levant, the first author has kept track of the scyphozoans off the Mediterranean coast of Israel assisted by a network of lifeguards, commercial fishermen, environmental wardens, and members of the public whose interest was raised by articles in the popular media. It is highly unlikely that a large native littoral species, markedly different from all known scyphozoans in the Mediterranean, would remain unknown till the 21 century. As the Southeastern Levant has been inundated by alien biota, it is likely *M. stellata* is an alien as well. This would not be the first case a species new to science has been described as an alien in the Mediterranean: *Alpheus migrans* (Lewinson and Holthuis, 1978) was collected off the Mediterranean coast of Israel in 1977 and recognized as an Erythrean alien, its status confirmed 25 years later with a record collected off the Egyptian coast of the Red Sea (Dworschak and Pervesler 2002). It is unclear whence *M. stellata* has arrived; yet, the native range of nine out of ten alien species recorded off the Israeli coast is the Indo-Pacific Ocean, the Indian Ocean or the Red Sea (Galil 2007), and one could argue that the Indo-Pacific is a hot-spot for cepheids. One fifth of the alien species recorded in the Mediterranean Sea have been primarily introduced by vessels, and a recent increase in shipping-related invasions was noted (Galil 2009). This rise was attributed to different factors: (1) the growth in shipping volume throughout the Mediterranean (30% of the international sea-borne trade originates or is directed to the Mediterranean ports or passes through the Mediterranean Sea (www.rempec.org)); (2) changing trade patterns that result in new shipping routes; (3) improved

water quality in port environments; (4) augmented opportunities for overlap with other introduction vectors; and (5) rising awareness and research effort (Galil 2006). It is widely believed that transportation of the sessile scyphozoan polyp stages on ship hulls or drilling rigs is a likely dispersal method (Larson and Arneson 1990), and the occurrence of *M. stellata* in the vicinity of Haifa Bay, next to a major port, suggests that this is indeed plausible. The presence of sexually mature specimens both winter and summer, and at sites nearly 90 kms apart, indicates the possibility of a locally established population.

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