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First Record of Two Species of Parasitic Copepods on Immigrant Pufferfishes (Tetraodontiformes: Tetraodontidae) Caught in the Eastern Mediterranean Sea

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Abstract

Two species of parasitic copepods, representing families Caligidae and Taeniacanthidae, are reported for the first time from two immigrant species of pufferfishes (Tetraodontiformes: Tetraodontidae), indigenous for the Indo-pacific region but now established in the eastern Mediterranean. The recorded parasites are: *Caligus fugu* Yamaguti and Yamasu, 1959 found in the mouth cavity of two immigrant species from the Red Sea: *Lagocephalus suezensis* Clark and Gohar, 1953 and of *Lagocephalus spadiceus* (Richardson, 1845) and *Taeniacanthus lagocephali* Pearse, 1952 found on the gill filaments and inner operculum of *L. spadiceus* (Richardson, 1845). The presently reported finding of *Caligus fugu* constitutes a new parasite record for *L. suezensis* and *L. spadiceus*. Neither of the two copepod species have previously been recorded in the Mediterranean. Both fish hosts were caught in the Mediterranean waters off the Turkish coast.

Keywords: Lessepsian migration, *Caligus*, *Taeniacanthus*, parasite.

Doğu Akdeniz'den Yakalanan Balon Balıkları (Tetraodontiformes: Tetraodontidae)'nda İki Parazittik Kopepod Türünün İlk Kaydı

Özet

Caligidae ve Taeniacanthidae familyalarına dahil iki parazitik kopepod türünün, İndo-pasifik kökenli olup doğu Akdeniz'e yerleşen göçmen Balon balıkları üzerinden ilk kez bildirimi yapılmıştır. Bildirimi yapılan parazitlerden *Caligus fugu* Yamaguti ve Yamasu, 1959 Kızıl deniz'den göç etmiş balon balıkları, *Lagocephalus suezensis* Clark ve Gohar, 1953 ve *Lagocephalus spadiceus* (Richardson, 1845)'un ağız boşluğunda; *Taeniacanthus lagocephali* Pearse, 1952 ise yine *L. spadiceus*'un solungaç filamentleri ve solungaç kapağının iç kısımlarında bulunmuştur. Burada bildirimi yapılan *Caligus fugu, L. suezensis* ve *L. spadiceus* için yeni bir parazit kaydı oluşturmaktadır. Bildirilen parazitlerin Akdeniz'den daha önce kaydı bulunmamaktadır. Konak balıkların ikisi de Türkiye Akdeniz kıyılarından yakalanmıştır.

Anahtar Kelimeler: Lespsiyen göçü, *Caligus, Taeniacanthus*, parazit.

Introduction

The term 'Lessepsian migration' (also referred to 'Erythrean immigration') is used to describe the immigration of Red Sea biota into the Mediterranean Sea that has taken place since the opening of the Suez Canal (Por, 1978; Foka *et al*., 2004). As a result of the Erythrean immigration, the marine fauna of the eastern Mediterranean has been rapidly changing (El-Rashidy and Boxshall, 2010). In particular, a substantial number of Red Sea fishes have been recorded in the eastern Mediterranean (Golani *et al*., 2002; Zenetos *et al*., 2008). According to Bilecenoğlu *et al*. (2002) a total of 33 Erythrean fish species have been reported from Turkish coasts.

As a consequence of the rapid changing in the Mediterranean ichthyofauna, increasing attention has recently been paid to the determination of parasitic copepods carried on Erythrean immigrant hosts (Boxshall and El-Rashidy, 2009; El-Rashidy and Boxshall, 2010, 2011). In this paper we present new data on Mediterranean sightings of two fish parasites, previously known from the Indo-Pacific and Japan. We presume that these two parasites have been carried into the Mediterranean on their Erythrean immigrant hosts. Co-invasion of the fish and their parasites has previously been reported for parasitic copepods, gill parasitic monogeneans and for

endoparasitic digeneans on fish hosts (Fischthal, 1980; Diamant *et al*., 1999; Pasternak *et al*., 2007; El-Rashidy and Boxshall, 2010; 2011). In addition to co-invasion of parasites and their hosts, the phenomenon of host switching of some parasitic copepods was reported by El-Rashidy and Boxshall (2010). The latter record was also the first one for the native Mediterranean hosts and Erythrean immigrant hosts. Therefore, proper identification and monitoring of the influx alien parasite species in the Mediterranean is important for future development of strategies intended to prevent possible invasive parasite infections, which may negatively impact fish farming and the fisheries industry.

This paper presents the discovery of two parasitic copepods: *Caligus fugu* Yamaguti et Yamasu, 1959 and *Taeniacanthus lagocephali* Pearse, 1952 on two immigrant puffer fishes *Lagocephalus suezensis* and *Lagocephalus spadiceus* (Tetraodontiformes: Tetraodontidae), respectively. The host fish were caught in the eastern Mediterranean Sea and they both became new host for the former parasite.

Materials and Methods

Parasites were collected from the mouth cavity and gills of two fish species of the family Tetraodontidae: specimens of *Taeniacanthus* were removed from the gill filaments and also inside the operculum of *L. spadiceus*, caught by otter trawl in İskenderun Bay, near Yumurtalık, Turkey (36°45′30.11″ N 35°43′08.75″ E) and specimens of *Caligus* were collected from the mouth cavity of *L. suezensis* and *L. spadiceus* caught by otter trawl in the same region. The parasites were preserved in 70% ethyl alcohol. Specimens of *Taeniacanthus* were cleared in lactic acid for 2 h prior to examination using an Olympus SZX16 dissecting microscope and Olympus BX51 compound microscope. All specimens (subsamples) were identified to the species level consulting Yamaguti and Yamasu (1959), Dojiri and Cressey (1987), Lin and Ho (2006), Boxshall and El-Rashidy (2009). Intact specimens and various appendages were photographed with a digital camera on an Olympus SZX16 dissecting microscope and Olympus BX 51 compound microscope respectively. The scientific and common names of fishes used in this article follow Froese and Pauly (2011), while the morphological terminology of copepods follows Huys and Boxshall (1991).

Results

Caligus fugu Yamaguti et Yamasu, 1959
Synonymy : *Caligus lagocephali* Pillai, 1961

The parasitic copepod we found in the mouth cavities of *L. suezensis* and *L. spadiceus* in Mediterranean waters off the Turkish coast was identified as *C. fugu* based on the following characteristic morphological features (Figures 1a; 1b). Additionally, as this parasite was included in the *Caligus productus* species group described by Boxshall and El-Rashidy (2009), the present authors identified *C. fugu* using the key to species in Boxshall and El-Rashidy (2009). Body proportions and description of salient morphological features of our adult female specimens are as follows: (1) Total body length: 3.343 mm (*n*=6); (2) Cephalothorax: 1.181×1.10 mm; (3) Genital complex (1.242×0.83 mm) 1.52 times longer than abdomen and has no distinct postero-lateral lobes; (4) Abdomen 2-segmented, with first somite (0.622×0.39 mm) 3.27 times longer than anal somite (0.19×0.23 mm); (5) The combined length of genital complex and abdomen (2.054 mm) approximately twice (1.74 times) as long as cephalothorax (1.181 mm); (6) Caudal rami longer than wide, 0.089×0.066 mm; with 6 pinnate setae; (7) Sternal furca with tapering tines; (8) Maxilliped with large, well developed, tapering process proximally on medial margin (Figure 1c); (9) Swimming leg 1 with 2-segmented exopod and unsegmented vestigial endopod. Distal exopodal segment (90×29 μm) without setae on posterior margin, tipped with 1 terminal seta at inner distal angle bearing short setules, and 2 bifid spiniform process along distal margin, plus 1 distal spine. First exopodal segment (166×28 μm) ornamented with row of setules along free posterior margin. Endopod lobate. Protopod armed with lateral plumose seta and short medial seta (10) Spine and seta formation and formula of the legs 2 through 4 and also legs 5 and 6 as given in the original description made by Yamaguti and Yamasu (1959).

Distinguishing features of our male specimens are as follows: (1) Mean body length 1.844 mm (1.76-1.92) which is slightly smaller than previous measurements reported in Yamaguti and Yamasu (1959) and Boxshall and El-Rashidy (2009); (2) Cephalothorax: 0.987×0.838 mm; (3) Genital complex (0.444×0.237 mm) approximately 1.69 times longer than abdomen; (4) Abdomen 2-segmented, with second somite (0.172×0.154 mm) about 2.09 times longer than the first somite (0.082×0.141 mm); (5) Caudal rami longer than wide (0.078×0.058 mm); (6) Post-antennal process strongly curved than that of female; (7) Maxiliped with corpus bearing conspicuous, sharply-pointed process on myxal margin (Figure 1d); (8) Sternal furca with straight tines; (9) Ornamentation of legs 1 to 5 similar to those of female.

Material Examined: 6 adult females and 4 males collected from the mouth cavities *L. suezensis* and *L. spadiceus* caught in İskenderun Bay (36°45′30.11″ N 35°43′08.75″ E), north eastern Mediterranean coast of Turkey on 28 December 2011, by A. Yanar: deposited in the Natural History Museum, London (BMNH 2012.220-223); remaining

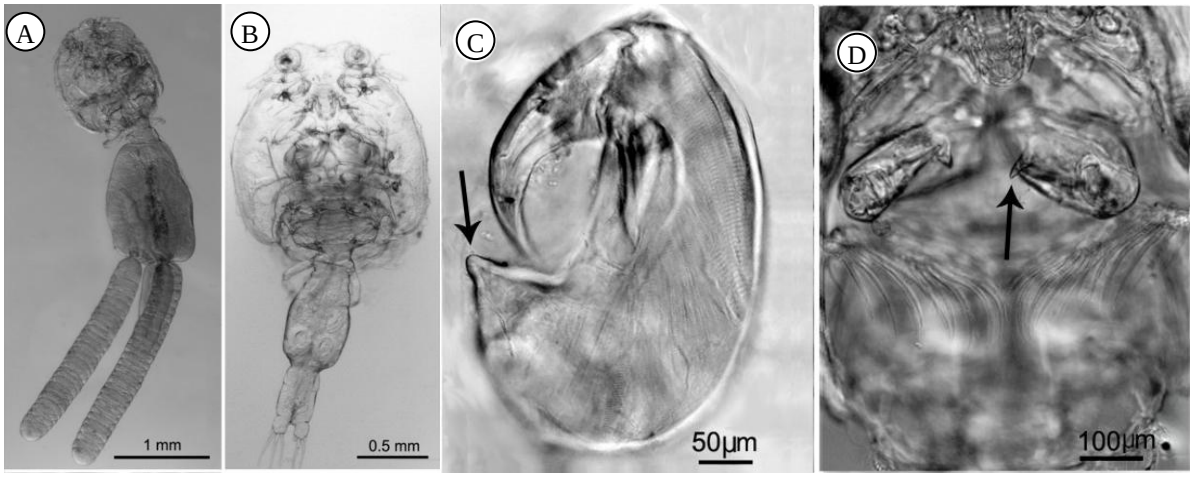

Figure 1. Light microscopy images of *Caligus fugu* infecting the mouth cavity of *Lagocephalus spadiceus* and *Lagocephalus suezensis*; A. Habitus of an adult female (dorsal view). B. Habitus of an adult male (dorsal view). C. Well developed, tapering process of the female maxilliped (*black arrow*). D. Sharply-pointed process on the myxal margin of the male maxilliped (*black arrow*).

material deposited in the personal collection of the first author. The prevalence of *C. fugu* on *L. spadiceus* was 80% (28 of 35 hosts parasitized) and 34.7% (8 of 23 hosts parasitized) on *L. suezensis*.

Distribution: Inland Sea of Japan, India (Kerala), Mediterranean (presently reported study)

Hosts: Tetraodontidae: *Takifugu rubripes* (Temminck et Schlegel, 1850) (as "*Sphaeroides rubripes"*), *Takifugu alboplumbeus* (Richardson, 1845) (as "*S. alboplumbeus"*), *Takifugu niphobles* (Jordan et Snyder, 1901) (as "*S. niphobles"*), *Takifugu pardalis* (Temminck et Schlegel, 1850) (as "*S. pardalis"*). Additional fish hosts reported recently by Nagasawa *et al*. (2010) were: *Takifugu poecilonatus* (Temminck et Schlegel, 1850) and *Lagocephalus wheeleri* Abe, Tabeta et Kitahama, 1984.

Synonymy: *Caligus lagocephali* Pillai, 1961 reported from *Lagocephalus inermis* (Temminck et Schlegel, 1850).

New Hosts: Tetraodontidae: *L. suezensis* Clark et Gohar, 1953, *L. spadiceus* (Richardson, 1845) (presently reported study).

Remarks

The morphological features of our adult females revealed similarities both in shape and morphometrics to *C. fugu* as described by Yamaguti and Yamasu (1959). The body proportions of our females are also in the range given by Boxshall and El-Rashidy (2009). However, our males differ slightly from those of Yamaguti and Yamasu (1959) in having relatively smaller body length, 1.84 (1.76-1.92 mm) (vs. 2.0-2.4 mm). The most distinguishing characters of *C. fugu* are the well developed processess located proximally on the inner margin of the female maxilliped and additionally, male maxiliped with corpus bearing conspicuous, sharply-pointed process on myxal margin. These characters are shared by our specimens. Our observations confirm that the parasitic copepods we found in the mouth cavities of *L. spadiceus* and *L. suezensis* are clearly identifiable as *C. fugu* Yamaguti et Yamasu, 1959.

Taeniacanthus lagocephali Pearse, 1952
Synonyms : *Irodes lagocephali* (Pearse, 1952)
Taeniacanthus sabafugu Yamaguti et Yamasu, 1959

Parasitic copepods found on the gills of *L. spadiceus* in Mediterranean waters off the Turkish coast were identified as *T. lagocephali* based on the following characteristic morphological features (Figures 2a, 2b). These features of the adult female are: (1) Body size (1.9 mm mean body length (n = 5); (2) Prosome (1.578 mm mean length) composed of cephalothorax (1st pedigerous somite fused with cephalosome), wider than long (518×668 µm) and 3 pedigerous somite as wide as cephalothorax; (3) Urosome comprised of 5th pedigerous somite, genital double-somite and 3 free abdominal somites; (4) Genital double-somite wider (191.16 µm) than long (97 µm); (5) All abdominal somites wider than long and each bearing row of spinules on posterior margin of ventral side; (6) Ventral surface of anal somite with 4 interrupted rows of spinules and row of spinules on each posterolateral corner (Figure 2c); (7) Caudal rami bearing 7 setae (seta 1 minute) and additional 4 short 2 long setae; (8) Rostral area with sclerotised structures in ventral area; (9) Antennule 7 segmented; armature formula 5, 15, 5, 3, 4, 2+1 aesthetasc, 7+1 aesthetasc; (10) Antenna composed of coxobasis and 3 endopodal segments; coxobasis with a distal seta; 2nd and 3rd endopodal segments fused and bearing 2 pectinate processes with 1 seta on each; 3 claw like

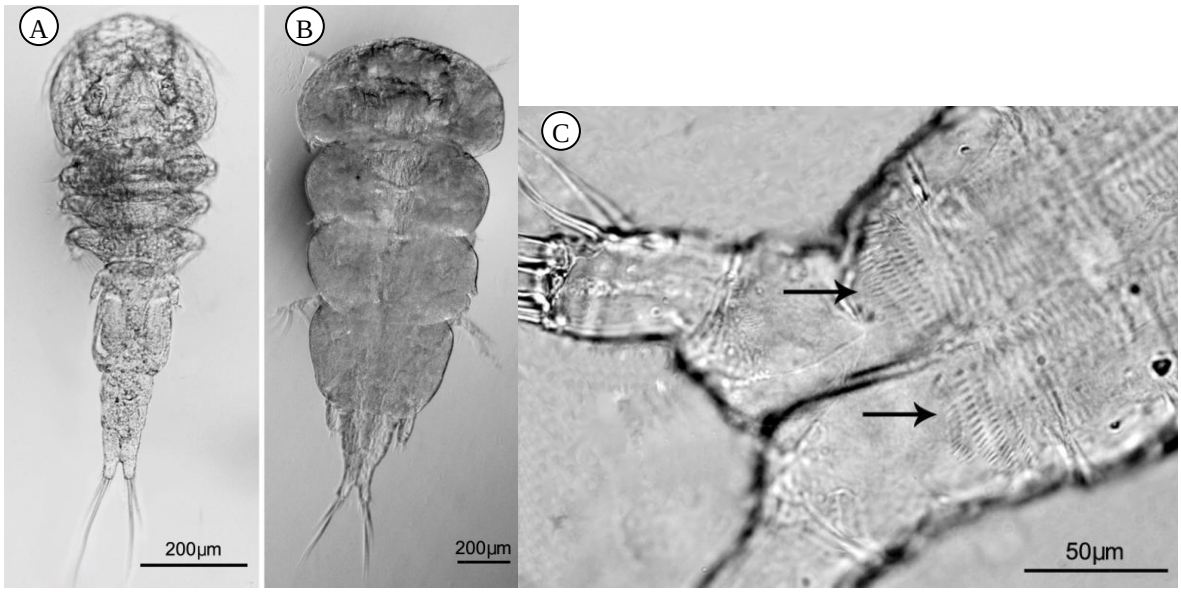

Figure 2. Light microscopy images of *Taeniacanthus lagocephali* infecting the gills of *Lagocephalus spadiceus*; A. Habitus of an adult male (dorsal view). B. Habitus of an adult female (dorsal view). C. Four rows of spinules (*black arrows*) on the ventral surface of the female anal somite.

spines and 4 setae; 2nd endopodal segment ornamented with rows of spinules; (11) Post-antennal process, paragnath, mandible and maxillule are all the same in shape as mentioned in previous re-descriptions (Dojiri and Cressey, 1987; Lin and Ho, 2006); (12) Maxilla two segmented; syncoxa unarmed; basis armed with 2 subequal pinnate spines and a tiny seta; (13) Maxilliped 3 segmented; syncoxa large, irregularly-shaped and unarmed; basis with 2 subequal naked setae; endopod elongate, curved distally, bears 1 naked setae and a short protuberance in basal region; claw with rows of denticles on distal third and a digitiform process at the tip; (14) spine and setal formula of the swimming legs 1 to 4 as follows (Spines are given in Roman numerals and setae are in Arabic numerals):

	Coxa	Basis	Exopod	Endopod
Leg 1	0-1	1-1	1-0; 9	0-1; 7
Leg 2	0-0	1-0	I-0; I-1; II,I,4	0-1;0-1; I,I,3
Leg 3	0-0	1-0	I-0; I-1; II,I,5	0-1;0-1; I,I,2
Leg 4	0-0	1-0	I-0; I-1; II,I,4	0-1;0-1; I,I,1

(15) Leg 5, two segmented; proximal segment bearing 1 outer pinnate setaand row of spinules on distal margin; distal segment carrying 3 spiniform and 1 seti form processes distally. (16) Leg 6, with three long pinnate setae.

Distinguishing characters of adult male specimens are as follows: (1) Mean body length 0.87 mm; (2) Cephalothorax wider than long (269×312 µm) and comprising about 30.6% of total body length; (3) Genital complex slightly longer than wide (154×146 µm); (4) 2nd pedigerous somite 134×244 µm; (5) 3rd pedigerous somite 82×210 µm; (6) 4th pedigerous somite 69×168 µm; (7) 5th pedigerous somite wider than long (64×154 µm); (8) Abdomen 3-segmented all abdominal segments wider than long and the second abdominal segment shortest; (9) Caudal rami longer than wide (36×25 µm); (10) Maxilliped with a patch of truncate spinules and 2 setae at the inner margin of corpus; inner basal corner of the claw bearing 4 setae and serrated distally; (11) Setal formula and ornamentation of leg 1,4,6 were as in female. Each spine on last two exopodal segments of Leg2, carrying distal flagellum. Last endopodal segment of Leg3, with straight spines; Leg 5, two segmented, each segment with rows of spines.

Material examined: 5 adult females and 2 males collected from the gills of *L. spadiceus* caught in İskenderun Bay (36°45′30.11″ N 35°43′08.75″E), north eastern Mediterranean coast of Turkey on 20.01.2011, by A.A. Özak: deposited in the Natural History Museum, London (BMNH 2012.220-223); remaining material deposited in the personal collection of the first author. The prevalence of *T. lagocephali* on *L. spadiceus* was 94% (47 of 50 hosts parasitized).

Distribution: Japan, Brazil, India, Gulf of Mexico (Coast of Mississippi, Alabama, Texas), West Africa, Taiwan, Mediterranean (presently reported study)

Hosts: Tetraodontidae: *Lagocephalus laevigatus* (Linnaeus, 1766), *L. spadiceus* (Richardson, 1845), *Lagocephalus inermis* (Temminck and Schlegel, 1850), *Lagocephalus gloveri* Abe and Tabeta, 1983, *Lagocephalus wheeleri* Abe, Tabeta and Kitahama, 1984.

Remarks

The majority of the morphological features of our specimens revealed similarities in shape and morphometry to *T. lagocephali* which was re-described by Dojiri and Cressey (1987) and Lin and Ho (2006). However, our specimens differ slightly from those of Dojiri and Cressey (1987) and Lin and Ho (2006) in having relatively smaller body length (1.9 mm). Dojiri and Cressey (1987) reported the total body length of 2.20 mm while it was 2.07 mm in Lin and Ho (2006). According to Dojiri and Cressey (1987), one of the most distinguishing characters of this species was the existence of digitiform process at the tip of maxilliped claw, besides having three pedigerous somites (2^{nd}, 3^{rd}, 4^{th}) which were almost equal in width with the cephalothorax. These distinguishing characters were also observed in our specimens. However, present authors also determined two differences between the re-descriptions made by Dojiri and Cressey (1987) and Lin and Ho (2006). Lin and Ho (2006) reported 4 setae on the third segment of the antennule while Dojiri and Cressey (1987) reported 5 setae on the same segment, which we also observed in our specimens. Secondly, 3 rows of spinules reported in the ventral surface of the anal somite by Lin and Ho (2006) while 4 rows of spinules were reported by Dojiri and Cressey (1987). Present authors also observed 4 rows of spinules (Figure 2c).

In males all structures revealed the same ornamentation given in the re-description of *T. lagocephali*. However, mean body length (0.87mm) of our specimens was slightly shorter than the previously reported body length (0.92 mm). Secondly, cephalothorax comprising about 30.6% of the total body length while it was 25% in previously re-described males (Dojiri and Cressey, 1987).

Our observations and measurements confirm that the parasitic copepod we found on the gills of *L. spadiceus* is clearly identifiable as *T. lagocephali*, as previously re-described by Dojiri and Cressey (1987) and by Lin and Ho (2006).

Discussion

In the Mediterranean Sea a total of 28 species of *Caligus* was listed in the review of Raibaut *et al*. (1998). However, 7 of 28 species can be treated as *nomina nuda* (as suggested by G.A.Boxshall, personal communication). According to our knowledge, since the establishment of the list by Raibaut *et al*. (1998) 2 more valid species; *Caligus temnodontis* Brian, 1924 (reported by Özak *et al*., 2010) and *Caligus uranoscopi* Vaissière, 1955 (reported by Ramdane *et al*., 2010) have been added to the list of species of *Caligus* reported from Mediterranean fishes. Additionally, *Caligus mugilis* Brian, 1935 and *Caligus scribae* Essafi, Cabral et Raibaut, 1984, previously described valid species, were not included in the list of Raibaut *et al*. (1998). The discovery of *C. fugu* in the Mediterranean Sea (presently reported study), together with those previous and recent reports mentioned above, bring the total number of valid species of *Caligus* to 26 (Table 1).

Caligus fugu was first discovered in the Inland Sea of Japan and described by Yamaguti and Yamasu (1959). All other reports and brief descriptions were given from Japan by the following authors: Yamaguti (1963), Ogawa and Yokoyama (1998), Boxshall and El-Rashidy (2009), Nagasawa *et al*. (2010). Additionally, the same species was reported as *Caligus lagocephali* by Pillai (1961, 1967, 1985) from India. However, it was placed in synonymy with *C. fugu* by Boxshall and El-Rashidy (2009).

In the presently reported study; the geographic distribution of *C. fugu* is extended from Japanese waters to the Mediterranean Sea. Moreover, two new hosts; *L. spadiceus* and *L. suezensis* are included in

Table 1. List of species of *Caligus* Müller, 1785 reported from Mediterranean fishes

1. *Caligus affinis* Heller, 1865
2. *Caligus diaphanus* von Nordmann, 1832
3. *Caligus brevicaudatus* A.Scott, 1901
4. *Caligus belones* (Krøyer, 1863)
5. *Caligus pageti* Russel, 1925
6. *Caligus coryphaenae* Steenstrup et Lütken, 1861
7. *Caligus mauritanicus* Brian, 1924
8. *Caligus vexator* Heller, 1865
9. *Caligus dicentrarchi* Cabral et Raibaut, 1985
10. *Caligus minimus* Otto, 1821
11. *Caligus dieuzeidei* Brian,1932
12. *Caligus ligusticus* Brian, 1906
13. *Caligus serrani* Richiardi,1880*
14. *Caligus pelamydis* Krøyer, 1863
15. *Caligus lessonianus* Risso, 1826**
16. *Caligus lepidopi* Richiardi, 1880*
17. *Caligus lichiae* Brian, 1906
18. *Caligus centrodonti* Baird, 1850
19. *Caligus pagelli* Delamare Deboutteville et Nunes-Ruivo, 1958
20. *Caligus bonito* Wildson, 1905
21. *Caligus fissus* Richiardi, 1880*
22. *Caligus productus* Dana, 1852
23. *Caligus smaris* Richiardi, 1880*
24. *Caligus hyalinus* Czernivsky,1868
25. *Caligus elongatus* von Nordmann, 1832
26. *Caligus alalongae* Krøyer, 1863
27. *Caligus trachini* Richiardi, 1880*
28. *Caligus trachuri* Richiardi, 1880*
29. *Caligus mugilis* Brian, 1935
30. *Caligus scribae* Essafi, Cabral et Raibaut, 1984
31. *Caligus temnodontis* Brian, 1924
32. *Caligus uranoscopi* Vaissière, 1955
33. *Caligus fugu* Yamaguti et Yamasu,1959

**Nomen nudum*

** Transferred to unspecified genus by Margolis *et al*. (1975)

the host list of *C. fugu*.

The family Taeniacanthidae C.B. Wilson, 1911 currently comprises about 103 species belonging to 17 genera (Tang *et al*., 2011) which live parasitic on sea urchins and fishes (Boxshall and Halsey, 2004). Thus far, 43 of 103 valid species in the family have been included to the genus *Taeniacanthus* Sumpf, 1871 which shows a wide geographic distribution. However, in the Mediterranean the genus *Taeniacanthus* was represented by only 2 species; *Taeniacanthus balistae* (Claus, 1864) reported from *Balistes carolinensis* Gmelin, 1789 and *Taeniacanthus gobi* (Brian, 1906) parasitic on *Gobius cobitis* Pallas, 1811 (see Raibaut *et al*., 1998). The species of *Taeniacanthus* we collected showed the same morphological characteristics reported in the previous re-descriptions made by Dojiri and Cressey (1987) and Lin and Ho (2006). Therefore, the discovery of *T. lagocephali* presented in this study, together with those previously reported two species, bring the total number of species of *Taeniacanthus* in Mediterranean to three.

Taeniacanthus lagocephali was previously recorded by: Pearse (1952), from Texas coast, USA, Yamaguti and Yamasu (1959 as "*Taeniacanthus sabafugu*") from Japan; Pillai (1963 as "*Irodes lagocephali*") from India; Yamaguti (1963) from Japan; Ho (1969) from Gulf of Mexico; Devi and Shyamasundari (1980) from India; Pillai (1985) from India; Izawa (1986) from Japan; Dojiri and Cressey (1987) from Brazil, Japan, Mississippi, Alabama, Gulf of Mexico, Texas; Boxshall and Montu (1997) mentioned the samples from Brazil examined by Dojiri and Cressey(1987); Lin and Ho (2006) from Taiwan; Özak *et al*. (presently reported study) from the eastern Mediterranean. The North Atlantic, South Atlantic, North Pacific and Indian Ocean were mentioned as the geographic distribution of *T. lagocephali* by Kabata (1979).

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