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Sea lice (Copepoda: Caligidae) of Turkey, with the discovery of *Caligus quadratus* Shiino, 1954 in the Mediterranean Sea and the re-description of a rare caligid copepod, *Caligus scribae* Essafi, Cabral & Raibaut, 1984

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Abstract The current status of the caligid copepods parasitic on marine fishes off Turkey is reviewed and an updated checklist comprising a total of 24 species, belonging to three different genera, *Caligus* O. F. Müller, 1785, *Euryphorus* H. Milne Edwards, 1840 and *Lepeophtheirus* von Nordmann, 1832, is presented together with habitus illustrations and a key to all 24 species. Two of the species of caligids listed herein constitute new records for Turkish waters. The first, *Caligus quadratus* Shiino, 1954, a well-known species of the genus, was collected from the common dolphin fish, *Coryphaena hippurus* Linnaeus. The second, *Caligus scribae* Essafi, Cabral & Raibaut, 1984, a very rare and poorly known member of the genus, was sampled from a new teleost host, the parrot fish, *Sparisoma cretense* (Linnaeus). Both fish species were caught in north-eastern Mediterranean waters off the Turkish coast. *Caligus quadratus* is only briefly described based on key diagnostic characters whereas a full re-description is provided for *C. scribae,* as the only description available for this species is incomplete and lacks detail. *Sparisoma cretense* is a new host record for *C. scribae.* In addition, this is the first report of *C. quadratus* from the Mediterranean.

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Introduction

Caligid copepods, commonly referred to as "sea lice", are ectoparasites predominantly reported from a broad range of marine fishes and are important pests of finfish aquaculture (Johnson et al., 2004; Costello, 2009; Boxshall, 2018). With the most recently discovered new species, *Caligus chinglonglini* Ohtsuka & Boxshall, 2019 and *C. kajii* Ohtsuka & Boxshall, 2019, the family Caligidae Burmeister, 1835 now comprises a total of 508 valid species belonging to 30 valid genera and is the largest family within the order Siphonostomatoida (see Ohtsuka & Boxshall, 2019). Among these, the genera *Caligus* O. F. Müller, 1785 and *Lepeophtheirus* von Nordmann, 1832 are the most species-rich and contain the most commercially problematic species, including *Caligus elongatus* von Nordmann, 1832, *C. rogercresseyi* Boxshall & Bravo, 2000 and *Lepeophtheirus salmonis* (Krøyer, 1837). These species cause high mortalities in aquaculture, resulting in significant commercial losses in the salmon farming industry (Johnson et al., 2004; Boxshall, 2018). In addition, there are some reports indicating that sea lice may function as vectors for important fish diseases such as infectious salmon anemia (ISA) which is a major disease threat for wild and cultured salmon stocks in particular (Nylund et al., 1994; Oelckers et al., 2014).

Johnson et al. (2004) presented a detailed list of caligids causing serious disease problems on different

finfish cultured in brackish and marine waters. *Caligus minimus* Otto, 1821 is a major health hazard for both cultured and wild European seabass, *Dicentrarchus labrax* (Linnaeus) and multiple infestations have already been reported from Turkish marine waters (Tareen, 1982; Tokşen, 1999; Cengizler et al., 2001; Özak, 2007; Uluköy & Kubilay, 2007; Canlı, 2010; Özer & Öztürk, 2011; Yalım et al., 2014; Er & Kayış, 2015). Since the early 1980s, numerous caligid copepods have also been reported from wild marine fishes (e.g. the flathead grey mullet, *Mugil cephalus* Linnaeus, common sole, *Solea solea* (Linnaeus), tub gurnard, *Chelidonichthys lucerna* (Linnaeus), sand steenbras, *Lithognathus mormyrus* (Linnaeus), and Atlantic bluefin tuna, *Thunnus thynnus* (Linnaeus) etc.) found in seas off Turkey. Besides having a significant economic value for Turkish fisheries, most of these fish species also have great potential for aquaculture in Turkey. Some of these sea lice host species (e.g. the common guitarfish, *Rhinobatos rhinobatos* (Linnaeus), and the Atlantic bluefin tuna, *Thunnus thynnus*) are listed as endangered species by the International Union for Conservation of Nature (IUCN) (Notarbartolo di Sciara et al., 2007; Collette et al., 2011). For these reasons, correct diagnosis of species identity of caligid copepods is the vital first step in developing control or management strategies against these harmful fish parasites, both for aquaculture and aquatic conservation studies.

The aim of this paper is to present an updated checklist and a key to species of Turkish caligid copepods together with the first report of two additional species, *Caligus quadratus* Shiino, 1954 and *Caligus scribae* Essafi, Cabral & Raibaut, 1984, not previously reported from Turkish marine waters.

Caligus quadratus is a well-known species and is therefore only briefly re-described based on the morphological characters of new material collected from *Coryphaena hippurus* Linnaeus (Coryphaenidae) caught in İskenderun Bay, Turkey. In addition, *C. quadratus* is added to the *Caligus bonito*-species group which was established by Boxshall (2018), based on the novel morphological data obtained from the detailed re-examination of the appendages. This is the first report of *C. quadratus* from the Mediterranean.

Caligus scribae is one of the poorly known and rare members of the genus *Caligus* and has not been reported since its original description which was based on material collected from *Serranus scriba* (Linnaeus) (Serranidae) caught in Mediterranean waters off Kerkennah Islands, Tunisia (Essafi et al., 1984). Although Essafi et al. (1984) provided a reasonably detailed description of *C. scribae*, certain structural details of important diagnostic characters, such as the terminal spines on the distal exopodal segment of leg 1, the terminal segment of the male antenna, the maxilliped of both sexes etc., remain unknown. Attempts to locate the type-material of *C. scribae* were unsuccessful as the location of any type-material was not given by Essafi et al. (1984). Therefore, newly collected material of *C. scribae* from the teleost host *Sparisoma cretense* (Linnaeus) (Scaridae) captured in north-eastern Mediterranean waters, off Arsuz in İskenderun Bay, Turkey, is used to supply additional detailed information on the morphology of this rare parasite. The newly collected material was identified by reference to the original description of *C. scribae* by Essafi et al. (1984).

Materials and methods

The new material of *C. quadratus* was sampled from the gill cavity and gill filaments of the common dolphin fish *Coryphaena hippurus* (n = 3), (mean total body length: 73 ± 3 cm), caught in İskenderun Bay, Turkey. The material of *Caligus scribae* was collected from the ventral body surface, near the ventral fins of the parrot fish *Sparisoma cretense* (n = 5) (mean total body length: 19 ± 2 cm), captured from the north-eastern Mediterranean waters, off Arsuz in İskenderun Bay, Turkey. All fish samples were purchased from local fishermen working in port of Karataş and Arsuz in İskenderun Bay. The majority of the material of other caligid copepods, previously reported from the Turkish marine fishes, was obtained from the collections of the Aquatic Parasitology Museum of the Faculty of Fisheries in Cukurova University (CUMAP), Adana, Turkey, for examination and preparing habitus drawings. These are: *Caligus adanensis* Özak, Sakarya & Boxshall, 2019 (CUMAP-COP/2018-3, 4); *C. apodus* (Brian, 1924) (CUMAP-COP/2013/4); *C. bonito* C. B. Wilson, 1905 (CUMAP-COP/2019-1, 2); *C. brevicaudatus* A. Scott, 1901 (CUMAP-COP/ 2013-1,2); *C. dakari* van Beneden, 1892 (CUMAP-COP/2016-1); *C. diaphanus* von Nordmann, 1832 (CUMAP-COP/2016-2); *C.*

lagocephali Pillai, 1961 (CUMAP-COP/2012-1); *C. lichiae* Brian, 1906 (CUMAP-COP/2017-4, 5, 6); *C. ligusticus* Brian, 1906 (CUMAP-COP/2015-2, 3); *C. macrurus* Heller, 1865 (CUMAP-COP/2015-1); *C. minimus* Otto, 1821 (CUMAP-COP/2007-1); *C. mulli* Rodrigues, Özak, Silva & Boxshall, 2018 (CUMAP-COP/2017-29, 30); *C. pageti* Russel, 1925 (CUMAP-COP/2013/3); *C. solea* Demirkale, Özak, Yanar & Boxshall, 2014 (CUMAP-COP/2014-1); *C. temnodontis* Brian, 1924 (CUMAP-COP/2010-1, 2); *C. vexator* Heller, 1865 (CUMAP-COP/2018-7); *C. zei* Norman & T. Scott, 1906 (CUMAP-COP/2019-7); *Euryphorus brachypterus* (Gerstaecker, 1853) (CUMAP-COP/2012-2); *Lepeophtheirus acutus* Heegaard, 1943 (CUMAP-COP/2014-2); *L. europaensis* Zeddam, Berrebi, Raibaut & Gabrion, 1988 (CUMAP-COP/2018-6); *L. lichiae* Barnard, 1948 (CUMAP-COP/2018-5). However, attempts to locate the Turkish material of *Caligus pelamydis* Krøyer, 1863 were unsuccessful as the location of the Turkish specimens of *C. pelamydis* was not given by Tareen (1982). Therefore, 1 female and 1 male of *C. pelamydis* collected by Thomas and Andrew Scott and deposited in the collections of the Natural History Museum, London (NHMUK:1913.9.18.87-96) were used for the habitus drawings. The copepods, preserved in 70% ethanol, were cleared in lactic acid for 2 h, then placed on a cavity slide and mounted as temporary preparations in a drop of lactic acid. Measurements were made using an ocular micrometer and are given in millimetres unless otherwise stated; they are presented as the range followed by the mean in parentheses. The drawings were made with the aid of a camera lucida on an Olympus BX-51 differential interference contrast (DIC) microscope.

Imaging techniques applied by Kamanli et al. (2017) were used to visualize some of the confusing appendages of *C. quadratus* using a Zeiss LSM 700 confocal laser scanning microscope (CLSM); Drishti software (version 2.6.4) (Limaye 2012) was used to process CLSM images. Morphological terminology follows Boxshall (1990) and Huys & Boxshall (1991) and host fish names are according to FishBase (Froese & Pauly, 2020).

Family Caligidae Burmeister, 1835
Genus *Caligus* O. F. Müller, 1785

Caligus quadratus Shiino, 1954

Host: *Coryphaena hippurus* Linnaeus (Perciformes: Coryphaenidae (n = 3, caught on 15.ii.2019).
Locality: North-eastern Mediterranean waters, off Yumurtalık in İskenderun Bay, Turkey.
Material examined: Newly collected 5 females (CUMAP-COP/2019-3) and 1 male (CUMAP-COP/2019-4) specimens stored in the collections of the Aquatic Parasitology Museum of the Faculty of Fisheries in Cukurova University (CUMAP), Adana, Turkey.
Site on host: Gill cavity and filaments.

Description

Adult female [Based on 5 specimens; Figs. 1–4.] Total body length 5.8–6.7 (6.1, n = 5) excluding caudal setae. Dorsal cephalothoracic shield longer than wide 1.91–2.01 × 1.69–1.8 (1.95 × 1.77), suborbicular with slightly convex lateral margins. Frontal plate with pair of large lunules. Thoracic zone of shield wider than long, 0.79–0.9 × 1.18–1.27 (0.86 × 1.22); posterior margin of thoracic zone of shield extending slightly beyond posterior end of lateral zones. Fourth pedigerous somite slightly wider than long, 0.41–0.47 × 0.46–0.53 (0.45 × 0.5), forming neck-like transition between cephalothorax and genital complex. Genital complex longer than wide 1.59–1.67 × 1.32–1.39 (1.63 × 1.36) with parallel lateral margins and slightly lobate posterolateral corners; length of genital complex about 83.6% of length of dorsal cephalothoracic shield. Abdomen 1-segmented, 2.27–2.35 × 0.48–0.53 (2.31 × 0.5), length of entire abdomen 1.24 times longer than genital complex. Caudal ramus longer than wide 0.10–0.15 × 0.07–0.11 (0.13 × 0.09), armed with 6 plumose setae. Antenna (Figs. 1B, 2A) uniramous, 3-segmented; proximal segment with short, rounded posterior process (Fig. 2A, white arrowhead); middle segment subrectangular, unarmed; distal segment with distally-curved claw bearing large, spine-like seta proximally and slender distal seta plus small knob present on inner margin of claw (Fig. 2A, black arrowhead). Postantennal process (Figs. 1C, 2A) weakly curved, ornamented with 2 papillae each with 3 sensillae; similar papilla with 3 sensillae located on body surface, adjacent to process. Maxillule (Fig. 1D), comprising anterior papilla bearing 3 unequal setae and posterior blunt-tipped dentiform process. Maxilliped (Fig. 1E) comprising robust proximal segment (corpus) and distal subchela

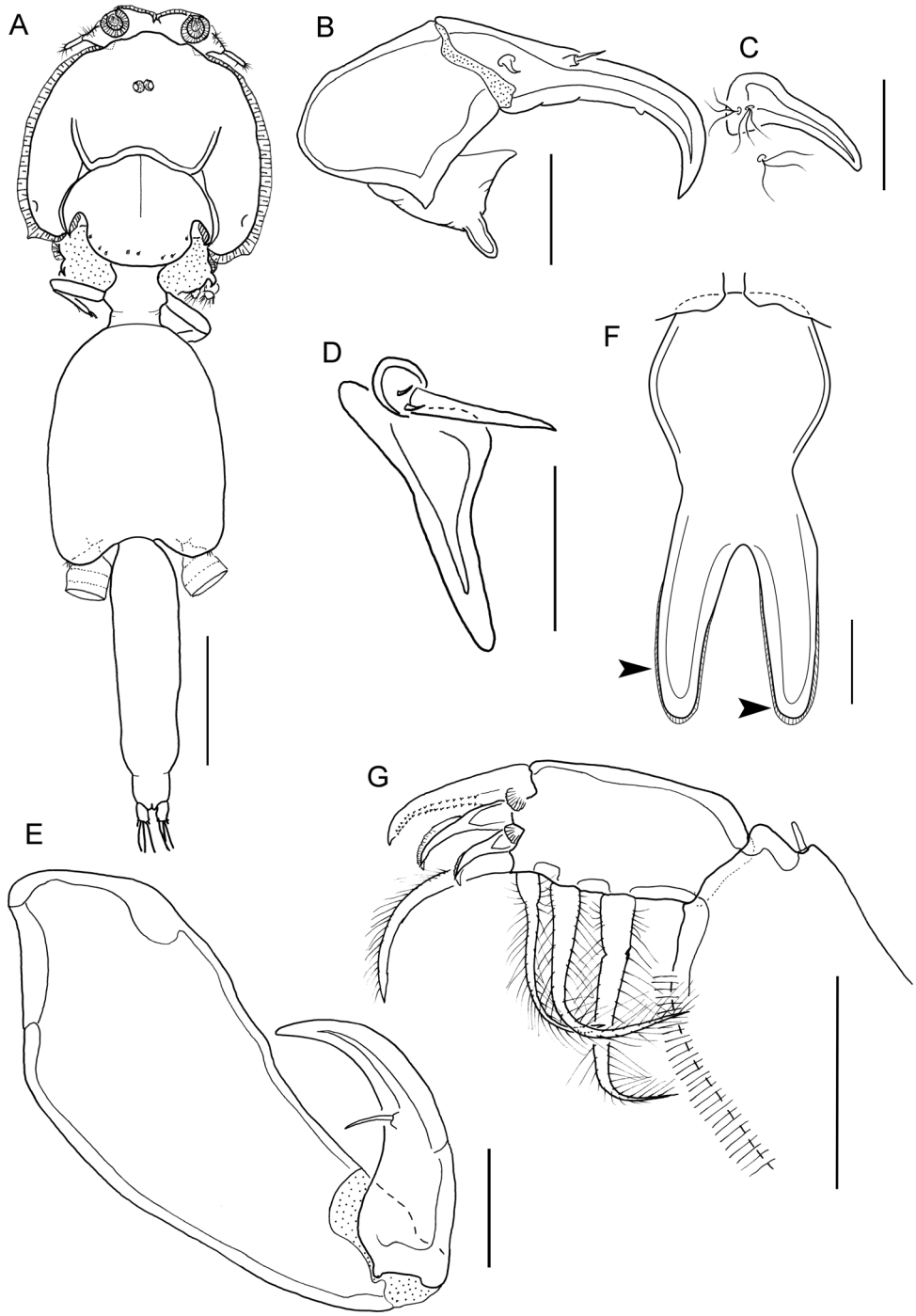

Fig. 1 *Caligus quadratus* Shiino, 1954, female. A, Habitus, dorsal view; B, Antenna; C, Postantennal process; D, Maxillule; E, Maxilliped; F, Sternal furca; G, Distal exopodal segment of swimming leg 1. *Scale-bars*: A, 1 mm; B–E, G, 100 μm; F, 50 μm

representing fused endopodal segments plus claw; subchela armed with small seta at base of claw. Sternal furca (Figs. 1F, 2B) with subrectangular box and slightly divergent tines each with flange and rounded tip. Distal exopodal segment of leg 1 (Figs. 1G, 2C) with 3 plumose setae on free posterior margin (Fig. 2C, arrowheads) and 4 terminal elements; outermost element (spine 1) finely serrated along

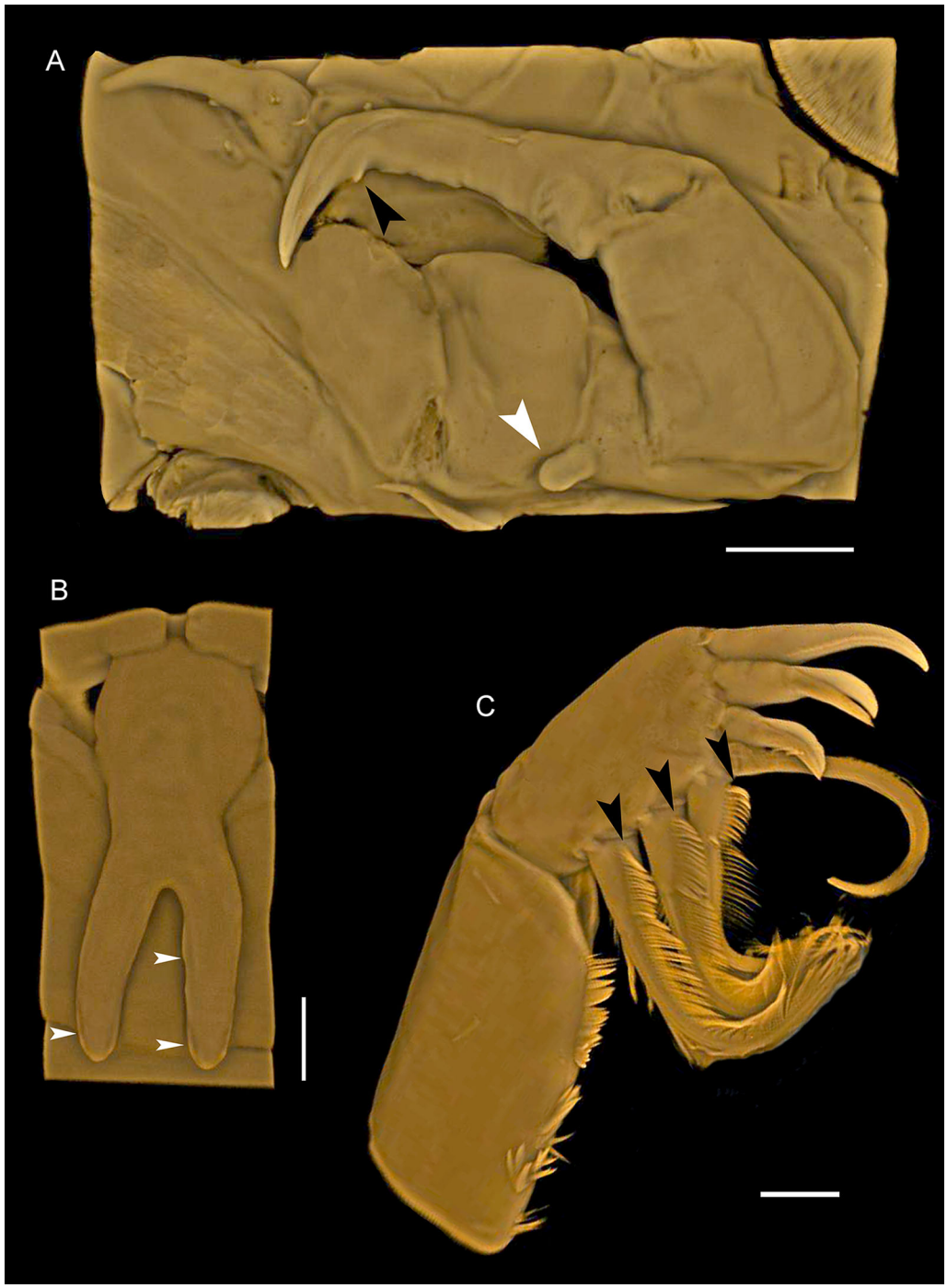

Fig. 2 *Caligus quadratus* Shiino, 1954, female. CLSM images with Drishti processing. A, Antenna with small cuticular knob (black arrowhead) on claw and rounded posterior process (white arrowhead) on proximal segment plus postantennal process; B, Tines of sternal furca with marginal flanges (arrowheads); C, Distal exopodal segment of leg 1 with four terminal elements and three posterior plumose setae bearing fine setules (arrowheads). *Scale-bars*: A, 100 μm; B, C, 50 μm

outer and inner margins and with pecten at base; middle 2 elements (spines 2 and 3) unequal, each with accessory process and ornamented with finely serrated distal flange along outer margin; innermost element (seta 4) apparently longer than other 3 spines, ornamented with fine setules along outer margin. Endopod of leg 2 (Figs. 3A, 4A, B) 3-segmented; first segment with short row of fine spinules (Fig. 4A, B

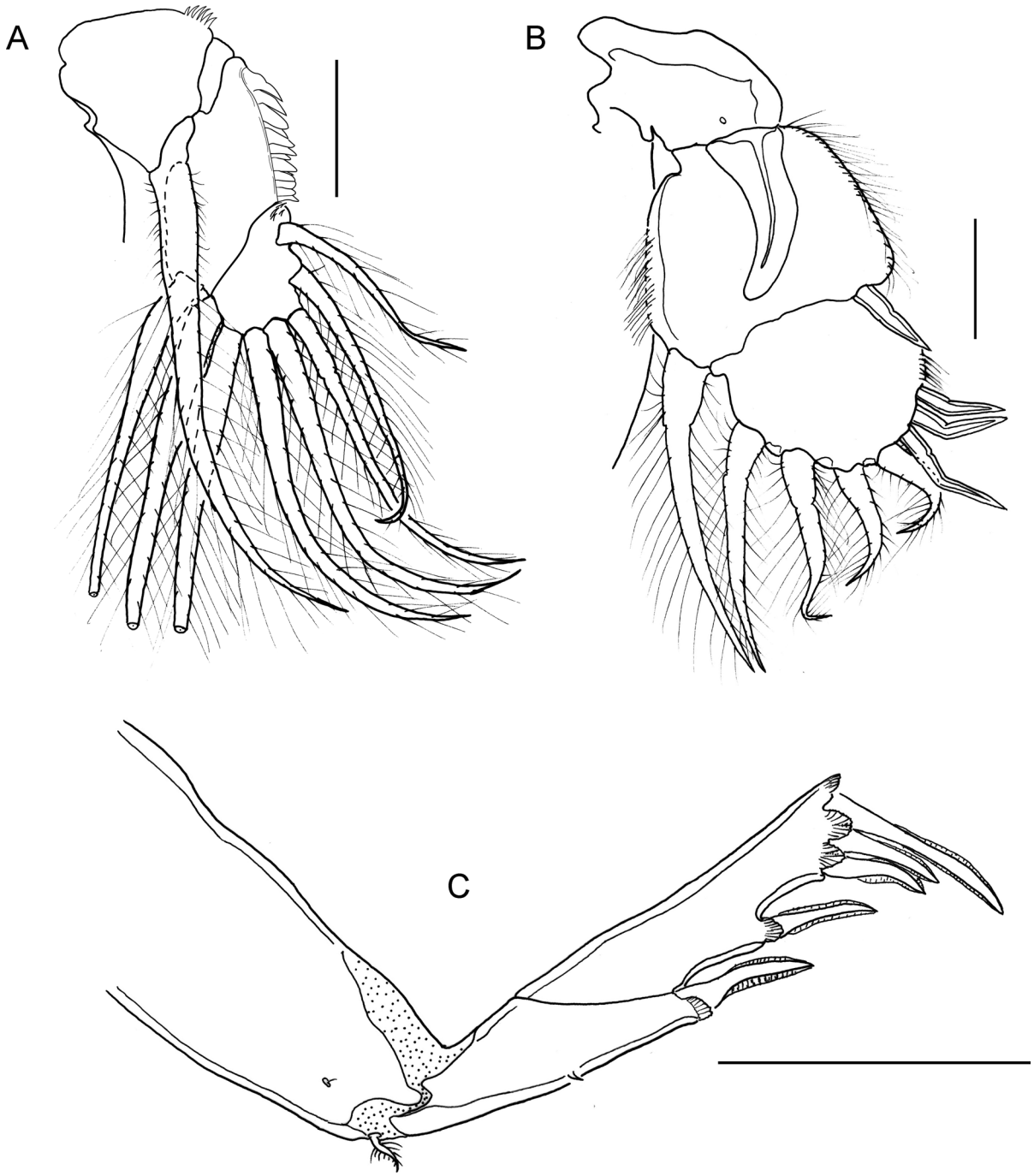

Fig. 3 *Caligus quadratus* Shiino, 1954, female. A, Leg 2 endopod; B, Leg 3 exopod; C, Leg 4 exopod. *Scale-bars*: A, B, 100 µm; C, 200 µm

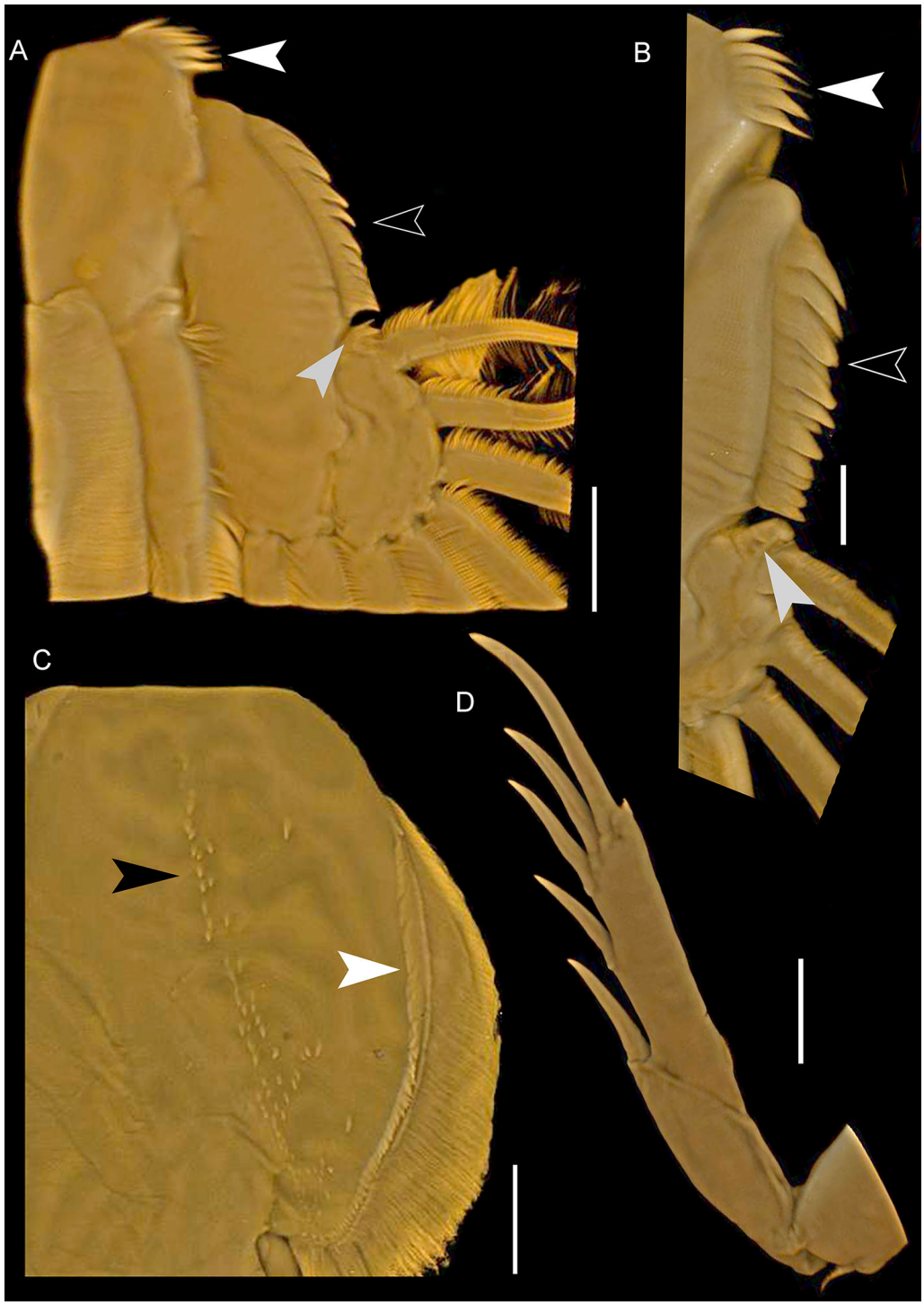

Fig. 4 *Caligus quadratus* Shiino, 1954, female. CLSM images with Drishti processing. A, Leg 2 endopod with spinules (white and gray arrowheads) on outer distal corner of the first and third segments and stout denticles (black arrowhead) along the outer margin of the second endopodal segment; B, The same at higher magnification; C, Outer ventral surface of leg 3 protopod ornamented with patch of spinules (black arrowhead) and large marginal membrane plus flange (white arrow) along outer margin; D, Leg 4 with 2-segmented exopod. *Scale-bars*: A, C, D, 100 μm; B, 50 μm

white arrowheads) at outer distal corner and carrying long inner plumose seta; second endopodal segment with rows of stout denticles (Fig. 4A, B, black arrowheads) along outer margin and carrying 2 inner plumose setae; third endopodal segment smallest, bearing small tuft of spinules on outer proximal corner (Fig. 4A, B, gray arrowheads), and with 6 plumose setae. Exopod of leg 3 (Fig. 3B) 3-segmented; first exopodal segment bearing curved spine extending slightly beyond middle of second exopodal segment; second exopodal segment with inner plumose seta and spine on outer distal corner, outer and inner margins both ornamented with fine setules; third exopodal segment of leg 3 with 3 outer spines, inner spine (third spine) longest, and with 4 plumose setae. Outer ventral surface of leg 3 protopod ornamented with patch of spinules (Fig. 4C, black arrowhead) and carrying large marginal membrane plus flange (Fig. 4C, white arrow) along outer margin. Leg 4 (Figs. 3C, 4D) uniramous with 2-segmented exopod; first segment with 1 distal spine about extending just over 60% of distance along margin of second exopodal segment; second segment with 1 lateral spine extending beyond base of outermost spine on distal margin plus 3 apical spines along oblique distal margin, inner spine longest, outer spine slightly shorter than middle spine, each spine ornamented with hyaline membrane, and with pecten at base. Spine (Roman numerals) and seta (Arabic numericals) formula of legs 1–4 as follows:

	Exopod	Endopod
L1	I-0; III, 1, 3	vestigial
L2	I-1; I-1; II, I, 5	0-1; 0-2; 6
L3	I-0; I-1; III, 4	0-1; 6
L4	I-0; I, III	absent

Leg 5 (not illustrated) represented by single papilla with 3 pinnate setae.

Adult male [Based on 1 specimen; Fig. 5] Total body length 3.7 mm (n = 1) excluding caudal setae. Dorsal cephalothoracic shield longer than wide, 1.89 × 1.82, suborbicular, with slightly convex lateral margins. Thoracic zone of shield slightly wider than long (1.00 × 1.17), length of thoracic zone about 53% of length of cephalotorax. Fourth pedigerous somite wider than long (0.17 × 0.42), indistinctly fused with genital complex posteriorly. Genital complex distinctly longer than wide, 0.75 × 0.46, elongate, with slightly convex lateral margins, anteriormost part of lateral margins folded. Abdomen 2-segmented; first abdominal somite, 0.28 × 0.23, shorter and slightly narrower than anal somite, 0.46 × 0.28. Length of entire abdomen about 98.6% of length of genital complex. Caudal ramus as long as wide, 0.11 × 0.11, armed with 6 plumose setae. Antenna (Fig. 5B) 3-segmented; proximal segment slender and unarmed; middle segment armed with 2 corrugated pads; terminal segment smallest, with overlapped 4 plates, 2 basal setae plus small lateral corrugated pad. Maxillule (Fig. 5C) with straight posterior dentiform process armed with minute medial denticle (Fig. 5D). Maxilliped (Fig. 5E) comprising robust proximal segment (corpus) bearing 4 processes on myxal surface; cuticular knob-like proximal and distal myxal processes distinctly smaller than other 2 adjacent conical myxal processes (Fig. 5F), each conical process with minute pore at apex. Distal subchela representing fused endopodal segments plus claw; subchela armed with small lateral outgrowth and seta at base of claw.

Remarks

Caligus quadratus was first described by Shiino (1954) based only on a female collected from the inner surface of the gill operculum of a yellowfin tuna *Neothynnus macropterus* (accepted as *Thunnus albacares* (Bonnaterre) purchased from a fish market in Shimakatsu (as Shimakatu), Mie Perfecture, Japan. Five years later the same author re-described *C. quadratus* based on both sexes, collected from a common dolphinfish *Coryphaena hippurus* Linnaeus purchased from the same locality (Shiino, 1959). Subsequently, *C. quadratus* has been reported many times on various fish species including the brick seabass *Acanthistius pictus* (Tschudi) (Serranidae), *C. hippurus* L. (Coryphaenidae), shiner perch *Cymatogaster aggregata* Gibbons (Embiotocidae), orange-spotted grouper *Epinephelus coioides* (Hamilton) (Serranidae), mangrove red snapper *Lutjanus argentimaculatus* (Forskål), Russellš snapper *L. russellii* (Bleeker) (Lutjanidae), Peruvian rock seabass *Paralabrax humeralis* (Valenciennes) (Serranidae), orange-spotted spinefoot *Siganus guttatus* (Bloch) (Siganidae), *T. albacares* (Scombridae), keel-jawed

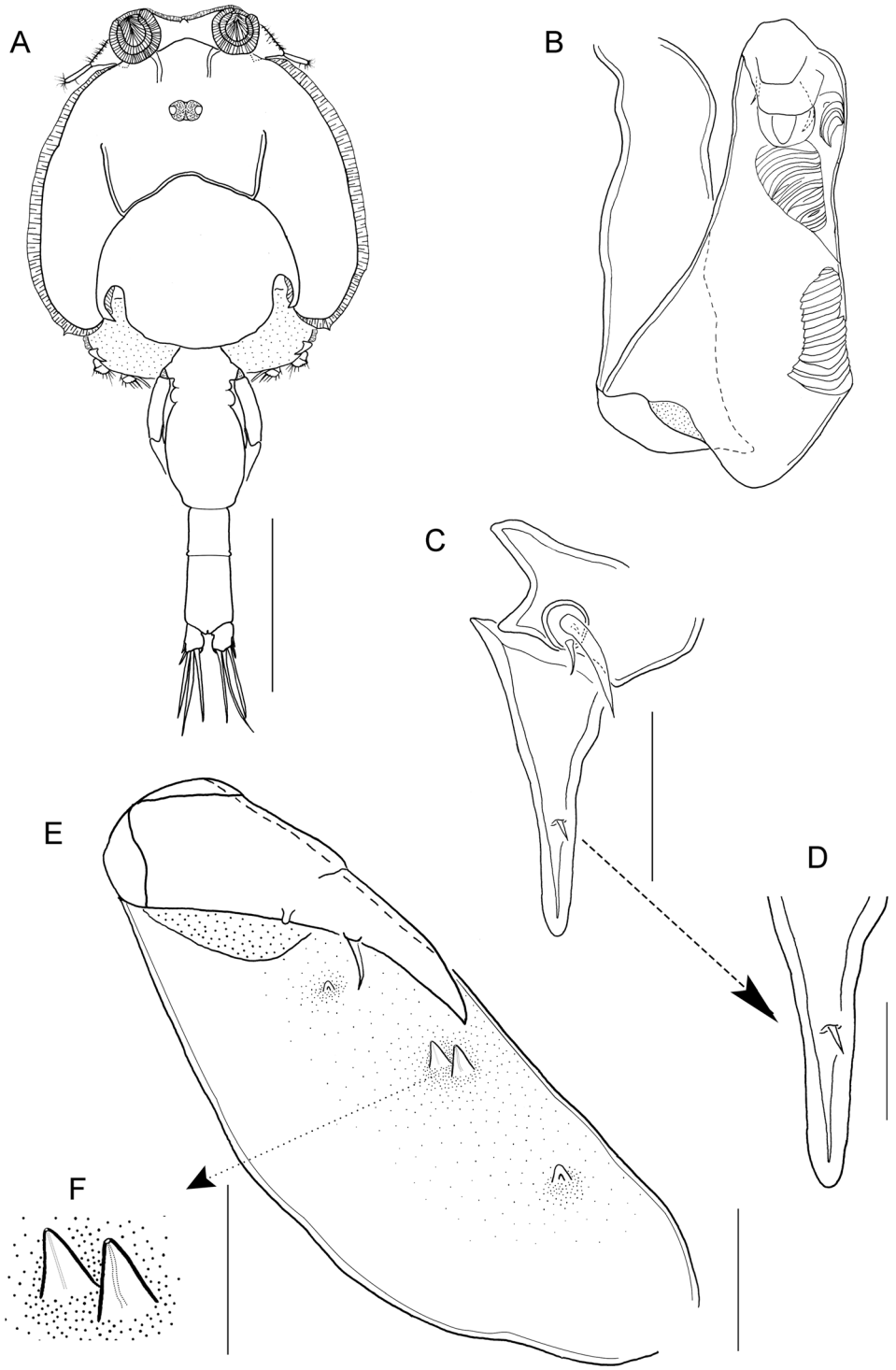

Fig. 5 *Caligus quadratus* Shiino, 1954, male. A, Habitus, dorsal view; B, Antenna, C, Maxillule; D, Dentiform process of maxillule armed with minute medial denticle; E, Maxilliped; F, Higher magnification of the middle 2 adjacent myxal processes on male maxilliped. *Scale-bars*: A, 1 mm; B, C, E, 100 μm; D, F, 50 μm

needle fish *Tylosurus acus malnotus* (Bleeker) (Belonidae) sampled from the western North Pacific (Kabata & Gusev, 1966; Kazachenko & Avdeev, 1977), Hawaii (Lewis, 1967), eastern South Pacific (Baeza & Castro, 1980; Fernandez & Villalba, 1986; Luque & Farfan, 1991), western North Atlantic (Burnett-Herkes, 1974), Indian Ocean (Pillai, 1964, 1985), and off Taiwan (Lin & Ho, 2001; Ho & Lin, 2004). To my knowledge, this is the first report of *C. quadratus* from the Mediterranean and from Turkish marine waters. Although *C. quadratus* was re-described in detail by Shiino (1950), it has been re-described twice to modern standards (Lin & Ho, 2001; Ho & Lin, 2004). The key similarities between the Mediterranean specimen of *C. quadratus* and the previously re-described Japanese and Taiwanese material are as follows: (i) the shape of the 1-segmented abdomen with indented lateral margins posteriorly; (ii) the slightly lobate posterolateral corners of the genital complex; (iii) the shape of the posterior process on the proximal segment of the female antenna; (iv) the weakly curved tine on the postantennal process; (v) the shape of the sternal furca with its slightly divergent, short rounded tines; (vi) the shape of the maxilliped in both sexes; (vii) the shape and relative lengths of the terminal elements and the posterior plumose setae on the free posterior margin of leg 1 distal exopod segment; (viii) the pattern of spinular ornamentation on the outer ventral surface of the apron of leg 3; (ix) the weakly curved shape of the first exopod spine on leg 3; (x) the 2-segmented exopod of leg 4 with I-0; I, III spine and setal formula.

The Mediterranean material differs from the Japanese and Taiwanese material in having: (i) a slightly longer female body (5.8–6.7 *vs* 4.82–6.00 mm); (ii) a female genital complex that is subrectangular with almost parallel lateral margins whereas it is subquadrangular with convex lateral margins in Lin & Ho (2001) and Ho & Lin (2004). However, the shape of the genital complex of *C. quadratus* examined here shows a close similarity to the genital complex illustrated in the re-description of Shiino (1959: Abb. 3A, p. 9). In addition, Shiino (1959) showed the variation in forms of the female genital complex that he observed in *C. quadratus* (cf. Abb. 5A-D, p. 13). When making comparisons of the shape of the female genital complex of *Caligus* species, it is necessary to allow for potential variability which may due to the reproductive state of the individual female (Parker, 1969; Boxshall, 1974, 2018). Therefore, this difference can be interpreted as a minor variation between the present material and the previously described material of *C. quadratus*. Besides the differences in shape discussed above, morphological differences in the spinular ornamentation along the outer margin of the first and second endopod segments of leg 2, were observed. Although Shiino (1954) described this ornamentation as "a row stiff cirri present along outer border of first 2 endopodite joints, though confined to a small terminal portion in first joint" (Shiino, 1954: p. 27), he illustrated these elements as if they were fine setules (cf. Shiino, 1954: Text-figure H, p. 28). In his re-description of *C. quadratus*, Shiino (1959) provided more detailed drawings of the ornamentations on the endopod segments of leg 2 (Shiino, 1959: Abb. 5F, p. 13) but, this time, he illustrated them as spinules and he also figured a small tuft of spinules on outer corner of the third endopodal segment. Lin & Ho (2001) and Ho & Lin (2004) also mentioned the existence of this spinular ornamentation only on the outer margins of the first and second endopodal segments of leg 2, and similar to Shiino (1954), they drew the spinules as fine setules and added a small tuft of spinules to the third endopodal segment though this was not mentioned in their text (Lin & Ho, 2001, figure 12C; Ho & Lin 2004, figure 140B). In contrast to the previous descriptions of *C. quadratus*, confocal laser scanning microscope (CLSM) images obtained in the present study (Fig. 4A, B) revealed that the first and third segments of leg 2 endopod are ornamented with spinules while the outer margin of the second segment of the same leg bears a row of large denticles instead of spinules as mentioned in Shiino (1954, 1959), Lin & Ho (2001), and Ho & Lin (2004). It is important to note here that *C. quadratus* was also re-described by Pillai (1985) based on material sampled from four different teleost hosts including *C. hippurus* and one elasmobranch, *Rhinobatos schlegelii* Müller & Henle. Although the material examined by Pillai (1985) also reveals close morphological similarities to the Mediterranean material of *C. quadratus*, it differs in having a subcircular genital complex and a 2-segmented (*vs* 1-segmented) abdomen.

Based on the recently published key to currently recognized species groups within the genus *Caligus* (Ohtsuka & Boxshall, 2019), *C. quadratus* falls into the *Caligus bonito*-group which was first established

Table 1 Species of *Caligus bonito*-group: characterised by a 3-segmented leg 4 armed with four spines on compound second exopodal segment; three plumose setae present on posterior margin of distal exopodal segment of leg 1; and ornamentation of large denticles present along outer margin of second endopodal segment of leg 2; antenna with process present on proximal segment but often small or weakly developed

Species	CL: CW	CL: GCL	GCL: GCW	GCL:ABL	ABL:ABW	Reference
C. quadratus Shiino, 1954	1.0:1	1.2:1	1.2:1	0.7:1	4.2:1	Present material
C. grandiabdominalis Yamaguti, 1954	1.0:1	1.1:1	0.6:1	0.8:1	1.0:1	Yamaguti (1954)
C. bonito C. B. Wilson, 1905	1.1:1	1.5:1	1.0:1	0.8:1	3.1:1	Turkish material (CUMAP-COP/2019-1,2) (CUMAP-COP/2019-1,2)
C. malabaricus Pillai, 1961	1.2:1	1.3:1	0.9:1	1.0:1	2.1:1	Pillai (1985)
C. tenuifurcatus C. B. Wilson, 1937	1.1:1	1.6:1	1.2:1	1.1:1	2.0:1	Wilson (1937)
C. biseriodentatus Shen, 1957	1.1:1	1.5:1	1.1:1	1.1:1	3.3:1	Boxshall (2018)
C. mutabilis C. B. Wilson, 1905	1.2:1	1.4:1	1.1:1	1.2:1	2.0:1	Cressey (1991)
C. triabdominalis T. Byrnes, 1987	1.1:1	1.8:1	1.2:1	1.2:1	2.3:1	Byrnes (1987)
C. asperimanus Pearse, 1951	1.1:1	1.6:1	1.2:1	1.2:1	3.3:1	Cressey (1991)
C. omissus Cressey & Cressey, 1980	1.2:1	1.5:1	1.1:1	1.3:1	3.0:1	Cressey & Cressey (1980)
C. phipsoni Bassett-Smith, 1898	1.1:1	1.6:1	1.0:1	1.7:1	1.7:1	Pillai (1985)
C. hoplognathi Yamaguti & Yamasu, 1959	1.0:1	1.4:1	1.0:1	1.7:1	1.9:1	Yamaguti & Yamasu (1959)
C. cossackii Basset-Smith, 1898	1.0:1	1.6:1	1.3:1	2.0:1	1.7:1	Pillai (1985)
C. asymmetricus Kabata, 1965	1.2:1	2.0:1	1.0:1	3.1:1	1.1:1	Ho & Lin (2004)

Abbreviations: ABL, abdomen length; ABW, abdomen width; CL, cephalothorax length; CW, cephalothorax width; GCL, genital complex length; GCW, genital complex width

by Boxshall (2018), because it possesses the following two distinctive characters: (i) Leg 1 has 3 well developed inner setae on the distal exopod segment (Figs. 1G, 2C), and (ii) the second endopod segment of leg 2 is ornamented with large denticles along the outer margin (Figs. 3A, 4A, B). In his paper, Boxshall (2018) included a total of 13 valid species within the *C. bonito*-group: *Caligus bonito* C. B. Wilson, 1905; *C. asperimanus* Pearse, 1951; *C. asymmetricus* Kabata, 1965; *C. biseriodentatus* Shen, 1957; *C. cossackii* Basset-Smith, 1898; *C. grandiabdominalis* Yamaguti, 1954; *C. hoplognathi* Yamaguti & Yamasu, 1959; *C. malabaricus* Pillai, 1961; *C. mutabilis* C. B. Wilson, 1905; *C. omissus* Cressey & Cressey, 1980; *C. phipsoni* Bassett-Smith, 1898; *C. tenuifurcatus* C. B. Wilson, 1937; and *C. triabdominalis* T, Byrnes, 1987; but *C. quadratus* was not listed. Presumably, illustrations depicting the presently observed large denticles along the outer margin of the second endopod segment of leg 2 (Fig. 4A, B) as "fine setules" in the previous descriptions of *C. quadratus* (Shiino, 1954, 1959; Lin & Ho, 2001; Ho & Lin, 2004), might be the reason that *C. quadratus* was omitted from the *Caligus bonito*-group. In addition to these two key characters presented for *C. bonito*-group (Ohtsuka & Boxshall, 2019), following two additional character states for the diagnosis of the *C. bonito*-group (Boxshall, 2018): (i) having a 3-segmented leg 4 armed with four spines on compound second exopod segment; (ii) antenna with process present on proximal segment but often small or weakly developed, are also present in the Mediterranean material of *C. quadratus* as well as in the Japanese and Taiwanese material. Therefore, *C. quadratus* is here included as a member of the *C. bonito*-group and is compared with its 13 congeners within the group.

Caligus quadratus has a genital complex that is shorter than the 1-segmented abdomen, with the ratio of length of genital complex to length of abdomen (GCL: ABL) = 0.7:1. In other words, the genital complex is only about 70% of length of the abdomen. Species exhibiting such proportions within the *C. bonito*-group are delimited in Table 1 showing a list of the species ordered from the "shortest" to "longest" genital complex in comparison to the length of the entire abdomen. With the exception of *C. quadratus*, there are only three species, *C. bonito*, *C. grandiabdominalis* and *C. malabaricus*, that share a genital complex with a GCL: ABL ratio between 0.7:1 and 1.0:1. The remaining ten species all have a genital complex that is longer than the abdomen. Therefore, the new material of *C. quadratus* was only compared with *C. bonito*, *C. grandiabdominalis* and *C. malabricus*. Among these three species, the morphology of *C. bonito* shows the closest similarity with *C. quadratus.* However, *C. bonito* differs from *C. quadratus* in having: (i) a female genital complex that has distinctly lobate (*vs* slightly lobate) postero-lateral corners; (ii) a postantennal process carrying 2 bisensillate papillae sensillae (*vs* trisensillate papillaee); (iii) a sternal furca with slender, diverging, tapering tines without a lateral flange (see figure 21E, p. 49 in Boxshall, 2018) (*vs* tines not tapering and with a lateral flange); (iv) the 3 plumose setae on the posterior margin of the distal exopodal segment of leg 1 are ornamented with unusually stout setules (*vs* fine setules) proximally on outer margin; (v) the third endopod segment of leg 2 has 3 small denticles (*vs* 4 small spinules) on outer proximal corner; (vi) leg 3 apron ornamented with dense spinules along inner and outer ventral surface (*vs* sparse spinules along inner ventral surface).

Caligus grandiabdominalis can easily distinguished from *C. quadratus* in having a genital complex that is distinctly wider than long (*vs* longer than wide) and an abdomen that is as long as wide (*vs* 4.2 times longer than wide in *C. quadratus*) (see Table 1). *Caligus malabricus* differs from *C. quadratus* in having a triangular (*vs* subrectangular) genital complex that is slightly wider than long (*vs* longer than wide), with distinctly lobate (*vs* slightly lobate) postero-lateral corners, and a 2-segmented female abdomen (*vs* 1-segmented).

With its long, subrectangular genital complex, and slender abdomen that is longer than the genital complex, *C. quadratus* also resembles *C. productus* Dana, 1852 which was also reported from the common dolphinfish *Coryphaena hippurus*. However, *C. quadratus* can be easily distinguished from *C. productus* in having: (i) a subrectangular genital complex with slightly lobate postero-lateral corners (*vs* distinctly lobate postero-lateral corners that extend slightly beyond the middle of the abdominal somite); (ii) having a 1-segmented abdomen (*vs* 2-segmented); (iii) a female maxilliped without a myxal process (*vs* with a small subtriangular myxal process); (iv) three plumose setae (*vs* none) on the free posterior margin of the distal exopodal segment of leg 1.

Caligus scribae Essafi, Cabral & Raibaut, 1984

Host: *Sparisoma cretense* (Linnaeus) (Perciformes: Scaridae) (n = 5; caught on 11.iii.2019).
Locality: North-eastern Mediterranean waters off Arsuz, in İskenderun Bay, Turkey.
Material examined: 3 females (CUMAP-COP/2019-5) and 2 males (CUMAP-COP/2019-6) deposited in the collections of the Aquatic Parasitology Museum of the Faculty of Fisheries in Cukurova University (CUMAP), Adana, Turkey.
Site on host: Ventral body surface, near ventral fins

Adult female [Based on 3 specimens; Figs. 6–8.] Body comprising caligiform cephalothorax incorporating first to third pedigerous somites, free fourth pedigerous somite, genital complex and subrectangular 1-segmented abdomen. Total body length 2.38–2.47 (2.42; n = 3) excluding caudal setae. Cephalothoracic shield slightly longer than wide, 1.47–1.57 × 1.37–1.48 (1.53 × 1.40) excluding marginal hyaline membranes. Frontal plates bearing paired lunules. Free thoracic zone of shield comprising about 57% of length of cephalothorax, slightly wider than long, 0.84–0.90 × 0.92–1.04 (0.87 × 0.95). Posterior margin of free thoracic zone extending beyond posterior ends of lateral zones. Trapezoidal fourth pedigerous somite 0.08–0.16 × 0.33–0.37 (0.10 × 0.35) distinctly separated from genital complex. Genital complex 0.42–0.51 × 0.62–0.71 (0.47 × 0.67), subtriangular, with slightly convex lateral sides and concave posterior margin. Posterolateral corners slightly lobate, extending posteriorly to middle of abdomen. Abdomen subquadrangular, 1-segmented, 0.22–0.25 × 0.22–0.25 (0.23 × 0.23), *c.*49% of length of genital complex, and fused with genital complex

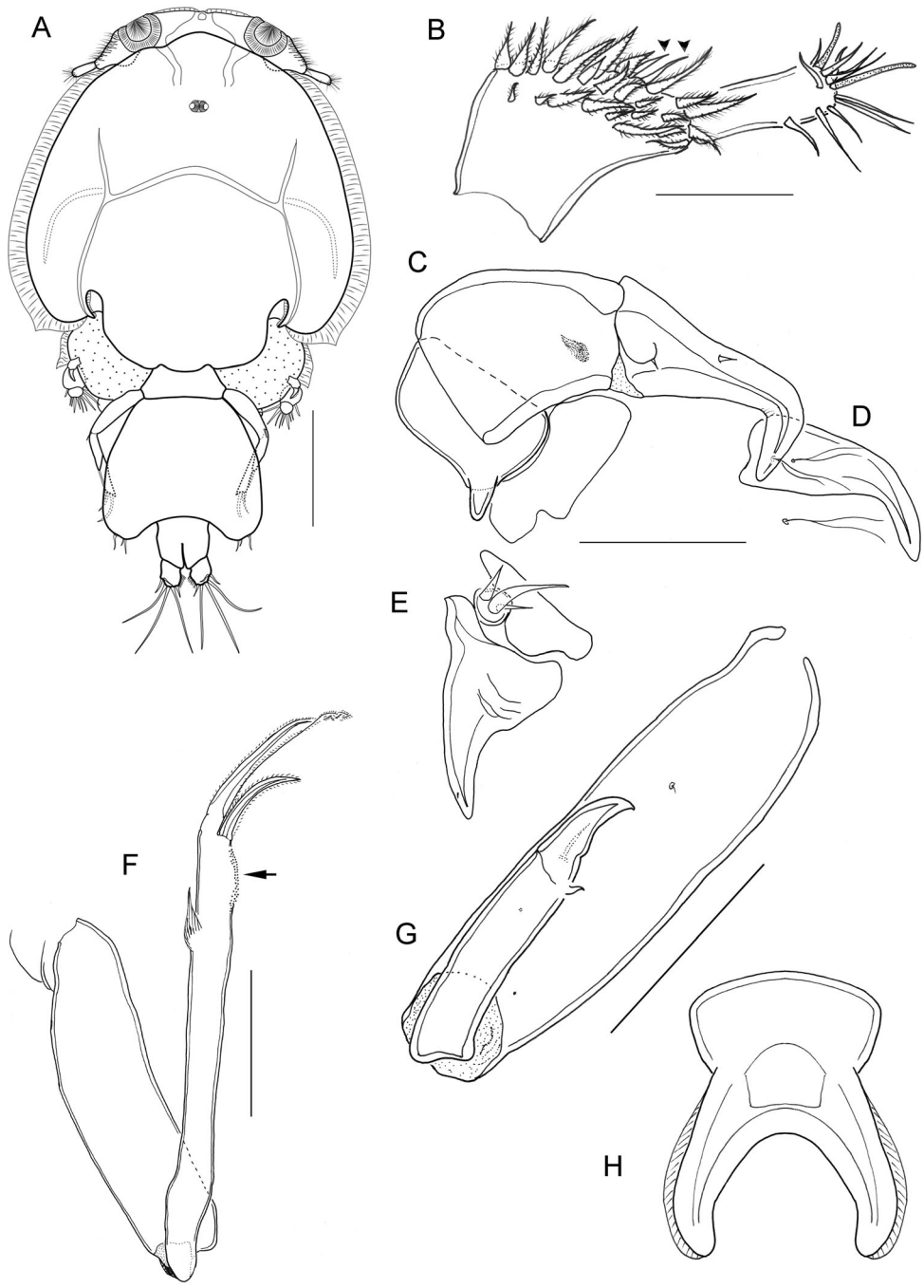

Fig. 6 *Caligus scribae* Essafi, Cabral & Raibaut, 1984, female. A, Habitus, dorsal view; B, Antennule; C, Antenna; D, Postantennal process; E, Maxillule; F, Maxilla, G, Maxilliped; H, Sternal furca. *Scale-bars*: A, 0.5 mm; B–G, 100 μm

with neck-like anterior part. Caudal ramus as long as wide, 0.08–0.12 × 0.08–0.13 (0.10 × 0.10), about 44% of length of abdomen, armed with 6 pinnate setae, ornamented with fine setules on inner margin. Combined length of genital complex, abdomen and caudal ramus *c*.52% of length of cephalothorax. Antennule (Fig. 6B) 2-segmented, proximal segment distinctly wider than distal, armed with 25 plumose

setae on anterior and antero-ventral surfaces plus 2 unarmed setae located dorsally (Fig. 6B, arrowheads); distal segment armed with 1 subterminal seta on posterior margin and 11 setae plus 2 aesthetascs on distal margin. Antenna (Fig. 6C) uniramous, 3-segmented; proximal segment with short, blunt, spinous posterior process; middle segment subrectangular with small corrugated pad on dorsal surface; distal segment forming sharply curved claw with spine-like seta proximally and small distal seta. Postantennal process (Fig. 6D) weakly curved, carrying 2 papillae each with 2 sensillae; similar papilla with 2 sensillae located on body surface adjacent to postantennal process. Maxillule (Fig. 6E) comprising weakly curved dentiform posterior process tapering towards tip with minute distal denticle on outer margin, proximal part of dentiform process with traces of weak cuticular corrugations; anterior papilla bearing 3 unequal setae. Maxilla (Fig. 6F) 2-segmented, brachiform; proximal segment (lacertus) large, unarmed; slender distal segment (brachium) bearing small subterminal hyaline membrane (flabellum) on outer margin and ornamented with minute denticles distally along posterior margin plus short canna and long calamus distally: canna ornamented with bilateral strips of serrated membrane, calamus ornamented with strips of serrated membrane twisted towards the tip. Maxilliped (Fig. 6G) comprising slender proximal segment (corpus) ornamented with pores and sensillae medially and slender distal subchela representing fused endopodal segments plus claw; subchela armed with 1 long and 1 short seta at base of claw. Sternal furca (Fig. 6H) with subrectangular box and bluntly-pointed, distally-curved divergent tines, outer margin of each tine carrying flange. Swimming leg 1 (Fig. 7A) biramous with 2-segmented exopod and reduced vestigial endopod (Fig. 7A, arrowed). Sympod armed with lateral plumose seta and inner seta plus bifid sensilla. First exopodal segment ornamented with row of setules along free posterior margin and bearing small spine at outer distal corner. Distal exopodal segment with 3 plumose setae posteriorly plus 4 terminal elements (Fig. 7B); outermost element (spine 1) simple, middle 2 elements (spines 2 and 3) each bearing single spiniform accessory process, innermost element (seta 4) about twice as long as spines. Leg 2 (Fig. 7C) biramous with 3-segmented rami. Coxa small, with large pinnate seta on posterior margin and sensillae on ventral surface. Basis with 1 small spine at outer distal angle plus membrane along free posterior margin and ventral surface ornamented with small sensilla near coxa; long naked seta present close to posterior margin. First exopodal segment *c*.2 times longer than second; both segments with pinnate seta on inner margin and long oblique spine at outer distal corner reflexed across surface of segment. Third exopodal segment with 3 outer spines; first spine smallest and simple, second spine with hyaline membrane along inner margin, third spine longest and bearing hyaline membrane along outer margin and fine setules along inner margin, and 5 pinnate setae. First endopodal segment with long inner pinnate seta; second endopodal segment with 2 inner pinnate setae; third segment with 6 pinnate setae; each endopodal segment ornamented with rows of fine setules on outer margin. Leg 3 (Fig. 8A) exopod 3-segmented with outer spine on first segment just extending beyond mid-length of second segment, first spine with hyaline membrane along outer margin. Second exopodal segment with outer spine and inner plumose seta plus prominent sensilla on medio-distal surface. Third exopodal segment with 3 outer spines increasing in length from outer to inner, and 4 short pinnate setae. Outer margin of last two segments with rows of fine setules. Endopod 2-segmented; first segment with long inner pinnate seta, second with 6 pinnate setae, ornamented with rows of long setules along outer margin. Leg 4 (Fig. 8B) uniramous. Protopodal segment with outer seta derived from basis and ornamented with 2 sensillae on outer margin. Exopod 2-segmented; first segment with 1 distal spine extending just beyond middle of margin of second exopodal segment and bilaterally serrated with hyaline membrane; second segment with 3 apical spines along oblique distal margin, inner spine longest and with serrated hyaline membrane along outer margin, middle spine about twice as long as shortest outer spine, each spine with pecten at base, outer two spines bilaterally serrated with hyaline membrane. Spine (Roman numerals) and seta (Arabic numerals) formula of legs 1–4 as follows:

	Exopod	Endopod
L1	I-0; III, 1, 3	vestigial
L2	I-1; I-1; II, I, 5	0-1; 0-2; 6
L3	I-0; I-1; III, 4	0-1; 6
L4	I-0; III	absent

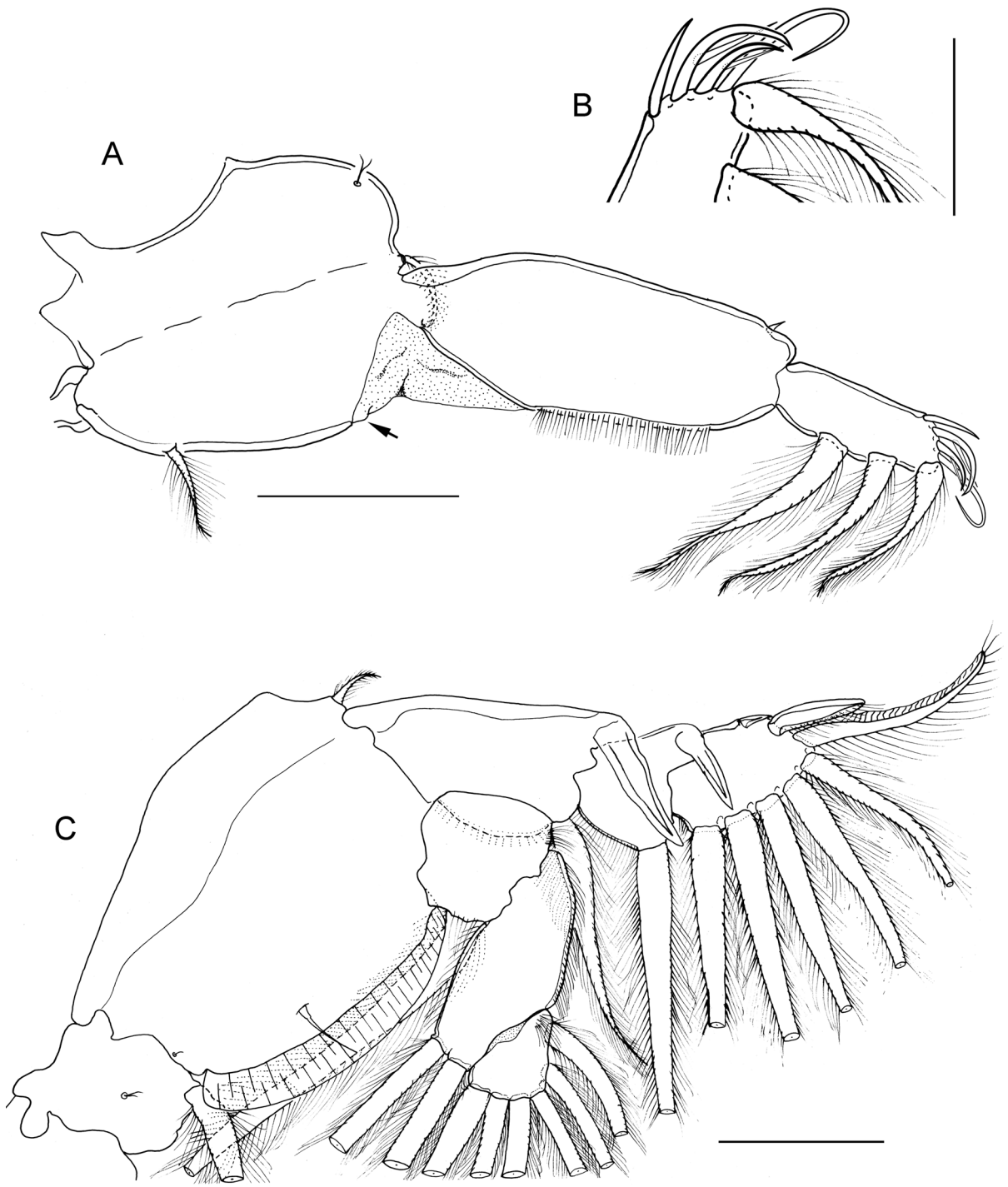

Fig. 7 *Caligus scribae* Essafi, Cabral & Raibaut, 1984, female. A, Swimming leg 1; B, Terminal elements on distal exopodal segment of leg 1; C, Leg 2. *Scale-bars*: A, C, 100 μm; B, 50 μm

Fig. 8 *Caligus scribae* Essafi, Cabral & Raibaut, 1984, female. A, Leg 3; B, Leg 4; C, Leg 5. *Scale-bars*: 100 μm

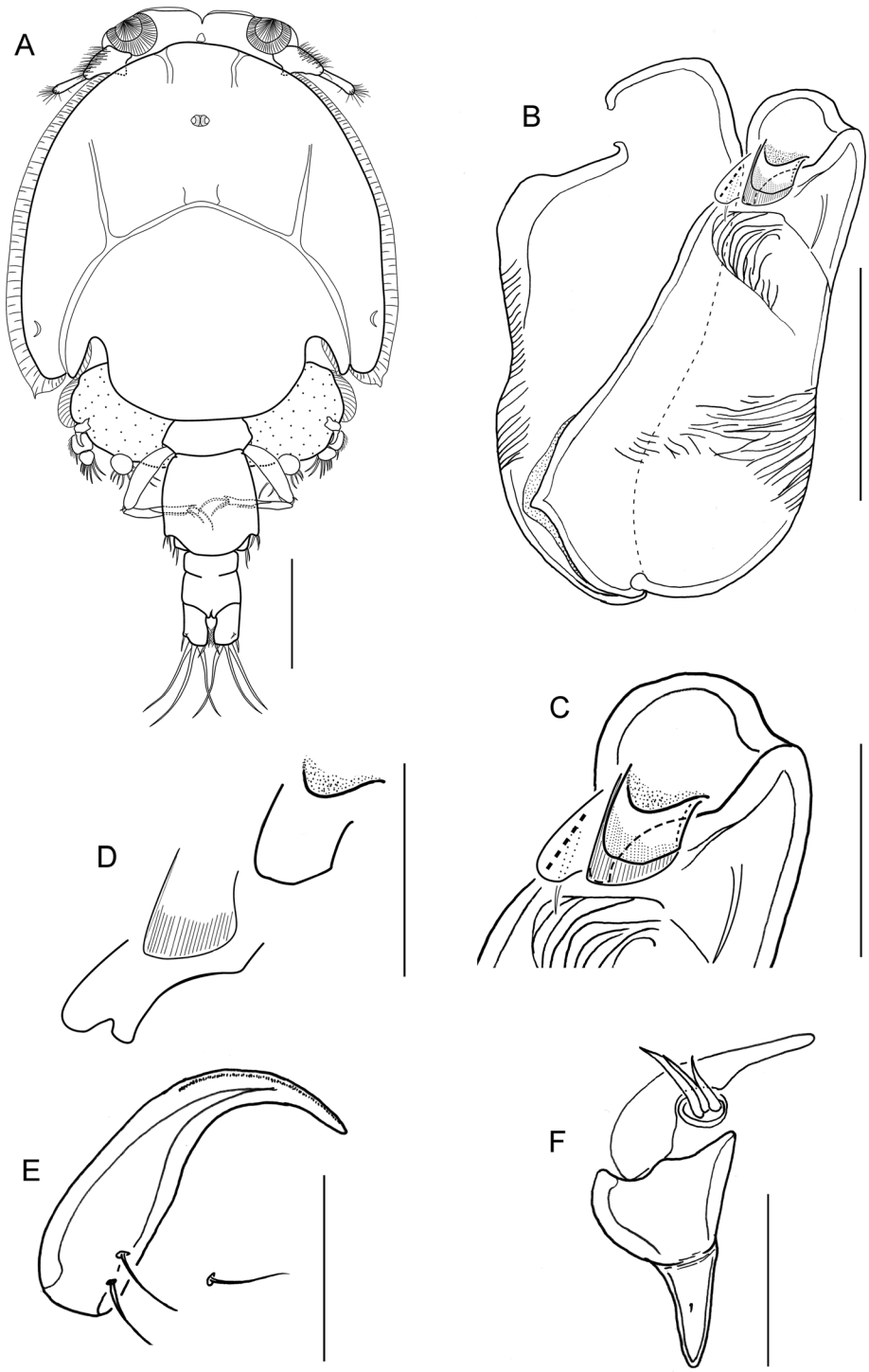

Fig. 9 *Caligus scribae* Essafi, Cabral & Raibaut, 1984, male. A, Habitus, dorsal view; B, Antenna; C, Terminal segment of antenna; D, Four plates on terminal segment of antenna; E, Postantennal process; F, Maxillule. *Scale-bars*: A, 0.5 mm; B, E, F, 100 μm; D, C, 50 μm

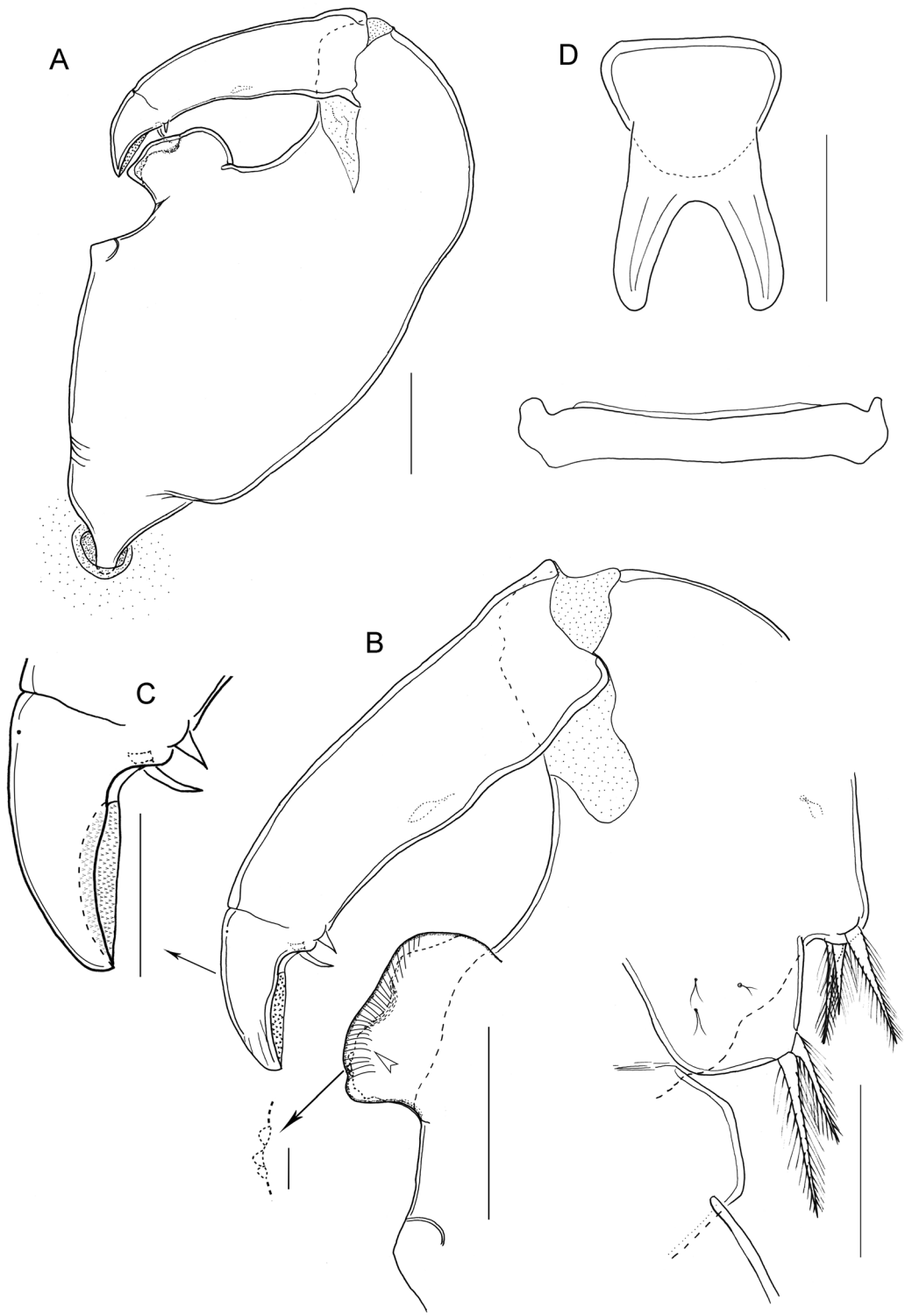

Fig. 10 *Caligus scribae* Essafi, Cabral & Raibaut, 1984, male. A, Maxilliped; B, Subrectangular myxal process and maxilliped claw (*inset*: three adjacent minute knobs on outer distal corner of the dorsal lobe of the myxal process); C, Details of maxilliped claw; D, Sternal furca and intercoxal sclerite of leg 1; E, Legs 5 and 6. *Scale-bars*: A, B, D, E, 100 μm; B (*inset*), 10 μm; C, 50 μm

Leg 5 (Fig. 8C) located at posterolateral corner of genital complex, represented by 2 papillae; outer papilla bearing single plumose seta; inner papilla bearing unequal 2 plumose setae.

Adult male [Based on 2 specimens; Figs. 9, 10.] Body 2.84–2.88 (2.86 mm) long, excluding caudal setae. Dorsal cephalothoracic shield longer than wide, 1.68–1.72 × 1.62–1.67 (1.70 × 1.64), excluding marginal hyaline membranes. Free thoracic zone of shield wider than long, 0.96–1.20 × 1.29–1.35 (1.08 × 1.32). Fourth pedigerous somite 0.28–0.33 × 0.40–0.44 (0.31 × 0.42), distinctly separated from genital complex. Genital complex subquadrangular, 0.42–0.46 × 0.41–0.45 (0.44 × 0.43), with parallel sides. Abdomen comprising 2 somites; first free abdominal somite 0.07–0.13 × 0.23–0.26 (0.10 × 0.25), shorter and slightly narrower than anal somite, 0.17–0.22 × 0.27–0.33 (0.20 × 0.30); combined length of genital complex and entire abdomen about 44% of length of cephalothorax. Caudal rami *c.*1.45 times longer than wide, bearing 6 pinnate setae. Antennule as in female. Antenna (Fig. 9B) 3-segmented; proximal segment long, with corrugated adhesion pad on outer surface; middle segment largest, with corrugated pads on medial and distal surfaces; terminal segment of antenna (Fig. 9C) comprising 4 overlapping plates (Fig. 9D); first three plates directed posteromedially and semi-bifid fourth plate directed laterally, from top to the bottom the third plate ornamented with fine cuticular ridges extending parallel along lateral sides, and armed with 2 slender basal setae. Postantennal process (Fig. 9E) strongly curved than that of female, carrying 2 papillae each with sensilla; similar papilla with sensilla located on body surface near postantennal process. Maxillule (Fig. 9F) with small dentiform knob located medially on posterior spinous process. Maxilla as in female. Maxilliped (Fig. 10A) with massive corpus carrying conspicuous conical process proximally and subrectangular, bilobate (dorsal and ventral lobes) myxal process on myxal region (Fig. 10B); dorsal lobe with 3 adjacent minute knobs on outer distal corner (Fig 10B, inset), ventral lobe ornamented with finely corrugated pad along anterior margin (Fig. 10B, white arrowhead); subchela armed with 2 small seta at base of claw; concave ventral surface of claw surrounded with cuticular flanges on either side, inner surface of each flange ornamented with minute spinules (Fig. 10C). Sternal furca (Fig. 10D) with short diverging tines and without flanges. Legs 1–4 as in female. Leg 5 (Fig. 10E) represented by 2 papillae located on posterolateral margins of genital complex, outer papilla with 1 and inner papilla with 2 plumose setae. Leg 6 (Fig. 10E) represented by single papilla bearing 2 unequal setae on posteroventral side of genital complex.

Remarks

In their original description, Essafi et al. (1984) presented a reasonably detailed description of both sexes of *C. scribae* which provided sufficient information to identify this copepod. However, the following key diagnostic characters were lacking in the description: (i) female and male maxilliped; (ii) the terminal segment of the male antenna; and (iii) details of legs 1–3. The strongest similarities between newly collected specimens of *C. scribae* described here, and the material of Essafi et al. (1984) are: (i) the shape of the short, 1-segmented female abdomen with lateral indentations on its anterodorsal margins which forms a neck-like transition between genital complex and abdomen; (ii) the shape of the female genital complex with rounded and slightly lobate posterolateral corners; (iii) the female antenna with a short posterior process on proximal segment and an acutely curved terminal claw; (iv) the curved tine on the postantennal process; (v) maxilla with serrations distally on the posterior margin of the brachium; (vi) a 3-segmented leg 4 with the first and second exopodal segments bearing 1 and 3 distal spines, respectively; (vii) a vestigial endopod on leg 1 that is highly reduced in size (almost not visible); and (viii) the male maxilliped has a massive subrectangular myxal process.

However, the Turkish female differs from Essafi et al. (1984) description of the type in having: (i) a shorter body (2.42 *vs* 4.30 mm); (ii) the female postantennal process bears 2 bisensillate papillae and an adjacent bisensillate papilla (*vs* papillae unisensillate); the maxillule has a tiny denticle (*vs* none) on outer distal margin of the slightly curved posterior process (*vs* straight); (iii) the male and female maxillipeds each carry 1 long and 1 short seta (*vs* only 1 seta) at base of the terminal claw; (iv) a bilobate myxal process ornamented with corrugated pad (*vs* without corrugated pad) is present in the male maxilliped; (v) the male leg 5 carries of 3 long setae

(*vs* 2 short setae) in comparison to the length of the 2 setae on leg 6. These differences may be due to intraspecific variation or misinterpretation. In addition, the differences in the male maxilliped claw and in the details of the bilobate myxal process with its corrugated surface on the male maxilliped corpus might have been overlooked by Essafi et al. (1984) as these structural details can only be seen at higher magnifications.

Within the genus there are seven species sharing the following character states: (i) the female genital complex is noticeably wider than long; (ii) the length of the abdomen is between 30 and 50% of the length of the genital complex; (iii) the abdomen is longer than wide; (iv) each of the middle 2 terminal elements on distal exopod segment of leg 1 carries a spiniform accessory process; (v) the exopod of leg 4 has I-0; III spine formula. These species are: *C. brevis* Shiino, 1954; *C. longipedis* Bassett-Smith, 1898; *C. orientalis* Gusev, 1951; *C. oviceps* Shiino, 1952; *C. patulus* Wilson, 1937; *C. punctatus* Shiino, 1955; and *C. stokesi* Byrnes, 1987. The characters distinguishing each of these species from *C. scribae* are as follows.

Caligus brevis differs from *C. scribae* in having: (i) the thoracic zone of the cephalothoracic shield has a posterior margin that extends slightly (*vs* distinctly) beyond the end of lateral zones; (ii) a bell-shaped (*vs* subtriangular) female genital complex with a wide (*vs* narrow) anterior part and without posterolateral lobes (*vs* with posterolateral lobes); (iii) the female postantennal process carries 2 unisensillate papillae and similar papilla on the adjacent ventral surface (*vs* bisensillate papillae); (iv) the male maxilliped has a massive subrectangular myxal process (*vs* 2 myxal processes (a massive subrectangular process on mid myxal area and a proximal subtriangular myxal processes); and (v) the maxilliped claw lacks ornamentation (*vs* ornamented with cuticular membrane).

Caligus longipedis can be distinguished from *C. scribae* in having: (i) a cephalothorax with indented (*vs* not indented) anterolateral margins; (ii) an antenna with a posterior process on basal segment and a terminal claw that are ornamented with longitudinal cuticular ridges; (iii) a female postantennal process carrying 2 unisensillate papillae and similar papilla on the adjacent ventral surface (*vs* bisensillate papillae); (iv) a maxillule with bluntly tipped, rounded apex on the posterior process (*vs* with subtriangular, inwardly curved, tapering posterior process); (iv) a sternal furca with short, thick, slightly diverging tines (*vs* long, tapering, markedly divergent tines); (v) the spine on first exopodal segment of leg 4 that is longer (*vs* shorter) than the outer margin of second exopodal segment; (vi) a male maxilliped with a prominent triangular myxal process (*vs* corpus with 2 myxal processes: a massive, subrectangular mid myxal process plus a proximal subtriangular myxal process); (vii) a 2-segmented male abdomen with an anal somite 2.8 times longer than abdominal somite (*vs* anal somite 2 times longer than abdominal somite).

Caligus orientalis differs from *C. scribae* in having: (i) a circular cephalothorax (*vs* subtriangular with narrow anterior part); (ii) a subrectangular female genital complex that is 1.68 times wider than long (*vs* a subtriangular genital complex that is 1.35 times wider than long); (iii) a female postantennal process carrying 2 basal papillae each with 4 sensillae (*vs* 2); (iv) the female maxilliped claw has only one seta (*vs* two); (v) the tines of the sternal furca are almost parallel (*vs* markedly divergent); (vi) the caudal ramus is wider than long (*vs* longer than wide); (vi) the spine on first exopodal segment of leg 4 does not reach midway along outer margin of second exopodal segment (*vs* extending beyond midway); (vii) the male genital complex has triangular posterolateral corners that extend to the middle of the free abdominal somite (*vs* without triangular posterolateral corners).

Among the congeners mentioned above, *C. oviceps* reveals the closest similarity to *C. scribae* in body proportions and in most of the appendages. However, *C. oviceps* can be differentiated from *C. scribae* in having: (i) a female postantennal process that is strongly (*vs* weakly) curved and carries unisensillate (*vs* bisensillate) papillae; (ii) a female maxilliped with a rounded process proximally on corpus (*vs* none); (iii) a female sternal furca with slightly divergent tines (*vs* strongly divergent) tines; (iv) a clearly noticeable vestige of the endopod on leg 1 (*vs* indistinctly noticeable); (v) a male genital complex with convex (*vs* parallel) lateral margins; (vi) a male antenna with 4 triangular cuticular plates (*vs* from top to bottom, 1 subtriangular and 3 subrectangular) plus 2 basal setae on the terminal segment; (vii) a male leg 5 with short setae (*vs* with long setae reaching beyond bases of leg 6 setae); (viii) a male maxilliped with a smooth myxal margin proximal to the myxal process (*vs* with slight prominence proximal to myxal process).

Table 2 List of caligid copepods parasitic on marine fishes off Turkey

Species	Host	Region	Source of Turkish record
Genus *Caligus* O.F. Müller, 1785			
Caligus adenensis Özak, Sakarya & Boxshall, 2019	*Belone belone* (L.)	Mediterranean Sea	Özak et al. (2019a)
Caligus apodus (Brian, 1924)	*Chelon labrosus* (Risso); *Chelon saliens* (Risso); *Chelon ramada* (Risso); *Mugil cephalus* L.; *Solea solea* (L.)	Sea of Marmara; Aegean Sea; Mediterranean Sea	Altunel (1983); Özak et al. (2013); Öktener et al. (2017c)
Caligus bonito C. B. Wilson, 1905	*Auxis rochei* (Risso); *Coryphaena hippurus* L.; *Sarda sarda* (Bloch); *Euthynnus alletteratus* (Rafinesque)	Aegean Sea; Sea of Marmara	Öktener & Trilles (2009); Öktener et al. (2017b)
Caligus brevicaudatus A. Scott, 1901	*Chelidonichtys lucerna* (L.); *Solea solea* (L.)	Mediterranean Sea	Özak et al. (2013); Demirkale et al. (2015a)
Caligus dakari van Beneden, 1892	*Argyrosomus regius* (Asso); *Dentex dentex* (L.)	Aegean Sea	Öktener (2009)
Caligus diaphanus von Nordmann, 1832	*Chelidonichtys lucerna* (L.); *Chelidonichthys lastoviza* (Bonnaterre)	Sea of Marmara; Aegean Sea	Öktener et al. (2016, 2018)
Caligus lagocephali Pillai, 1961	*Lagocephalus spadiceus* (Richardson); *Lagocephalus suezensis* Clark & Gohar	Mediterranean Sea	Özak et al. (2012)
Caligus lichiae Brian, 1906	*Lichia amia* (L.); *Seriola dumerili* (Risso, 1810)	Mediterranean Sea	Özak et al. (2019b)
Caligus ligusticus Brian, 1906	*Lithognathus mormyrus* (L.)	Mediterranean Sea	Demirkale et al. (2015b)
Caligus macrurus Heller, 1865	*Lobotes surinamensis* (Bloch)	Mediterranean Sea	Özak et al. (2017)
Caligus minimus Otto, 1821	*Dicentrarcus labrax* (L.); *Labrus merula* L.	Black Sea; Sea of Marmara; Aegean Sea; Mediterranean Sea	Tareen (1982); Tokşen (1999); Cengizler et al. (2001); Özak (2007); Uluköy & Kubilay (2007); Canlı (2010); Özer & Öztürk (2011); Tanrikul & Perçin (2012); Yalım et al. (2014); Er & Kayış (2015); Öktener et al. (2017c)
Caligus mulli Rodrigues, Özak, Silva & Boxshall, 2018	*Mullus barbatus* L.	Mediterranean Sea	Rodrigues et al. (2018)
Caligus pageti Russel, 1925	*Chelon labrosus* (Risso); *Chelon saliens* (Risso); *Chelon ramada* (Risso); *Mugil cephalus* L.	Aegean Sea	Altunel (1983)
Caligus pelamydis Krøyer, 1863	*Scomber scombrus* L.	Aegean Sea	Tareen (1982)
Caligus quadratus Shiino, 1954	*Coryphaena hippurus* L.	Mediterranean Sea	Present study
Caligus scribae Essafi, Cabral & Raibaut, 1984	*Sparisoma cretense* L.	Mediterranean Sea	Present study
Caligus solea Demirkale, Özak, Yanar & Boxshall, 2014	*Solea solea* (L.)	Mediterranean Sea	Demirkale et al. (2014); Sakarya (2017)
Caligus temnodontis Brian, 1924	*Pomatomus saltatrix* (L.)	Mediterranean Sea	Özak et al. (2010)

Table 2 continued

Species	Host	Region	Source of Turkish record
Caligus vexator Heller, 1865	*Dentex dentex* (L.)	Aegean Sea	Alaş & Öktener (2017b)
Caligus zei Norman & T. Scott, 1906	*Zeus faber* L.	Sea of Marmara	Öktener et al (2017b)
Genus *Euryphorus* H. Milne Edwards, 1840			
Euryphorus brachypterus (Gerstaecker, 1853)	*Thunnus thynnus* (L.)	Mediterranean Sea	Özak & Yanar (2016)
Genus *Lepeophtheirus* von Nordmann, 1832			
Lepeophtheirus acutus Heegaard, 1943	*Rhinobatos rhinobatos* (L.); *Aetomylaeus bovinus* (Geoffroy Saint-Hilaire)	Mediterranean Sea	Özak et al. (2018)
Lepeophtheirus europaensis Zeddam, Berrebi, Renaud, Raibaut & Gabrion, 1988	*Platichthys flesus* (L.)	Sea of Marmara	Oğuz & Öktener (2007); Alaş et al. (2017)
Lepeophtheirus lichiae Barnard, 1948	*Lichia amia* (L.)	Mediterranean Sea	Sakarya et al. (2019)

Caligus patulus differs from *C. scribae* in having: (i) a subrectangular (*vs* subtriangular) female genital complex with distinctly lobate (*vs* slightly lobate) posterolateral corners; (ii) a straight (*vs* curved) tine on postantennal process; (iii) seta 4 on the distal exopodal segment of leg 1 is as long as the third terminal spine (*vs* seta 4 distinctly longer than the 3 terminal spines); (iv) spines on first and second exopodal segments of leg 2 that are parallel to the axis of ramus (*vs* with spines extending obliquely over the surface of the segments).

Caligus punctatus can be distinguished from *C. scribae* in having: (i) a subrectangular female genital complex (*vs* subtriangular); (ii) a female maxilliped claw with one seta (*vs* two) at base of claw; (iii) a female sternal furca with more or less parallel (*vs* divergent) tines; (iv) a male genital complex with convex (*vs* parallel) lateral margins; (v) a 2-segmented male abdomen with a free abdominal somite that is distinctly wider than long (*vs* slightly wider than long); (vi) a male maxilliped corpus with two unequal subtriangular myxal processes (*vs* with a massive subrectangular and smaller subtriangular proximal myxal processes); (vi) a male maxillule with corrugated pad (*vs* none) on posterior process.

Caligus stokesi differs from *C. scribae* in having: (i) a female genital complex with a straight posterior margin (*vs* concave posterior margin); (ii) a female postantennal process with unisensillate papillae (*vs* two sensillae); (iii) a female sternal furca with slightly divergent, spatulate tines lacking flanges (*vs* distinctly diverging, tapering tines with flanges).

Discussion

In a recently published review about the parasitic copepod diversity of the Turkish fishes (Alaş et al., 2015), twelve species of caligid copepods, belonging to two genera, *Caligus* and *Lepeophtheirus*, were listed from 15 marine fish hosts. However, in their review, Alaş et al. (2015) overlooked *Caligus dakari* van Beneden, 1892 (syn. *Caligus mauritanicus* Brian, 1924) which was previously reported by Öktener (2009). Since the review of Alaş et al. (2015), the number of newly recorded species of caligid copepods has increased from 13 to 22 and the number of host fishes has increased from 15 to 26 in Turkish waters (Özak & Yanar, 2016; Öktener et al., 2016; Özak et al., 2017; Öktener et al., 2017a, b; Alaş & Öktener, 2017a,

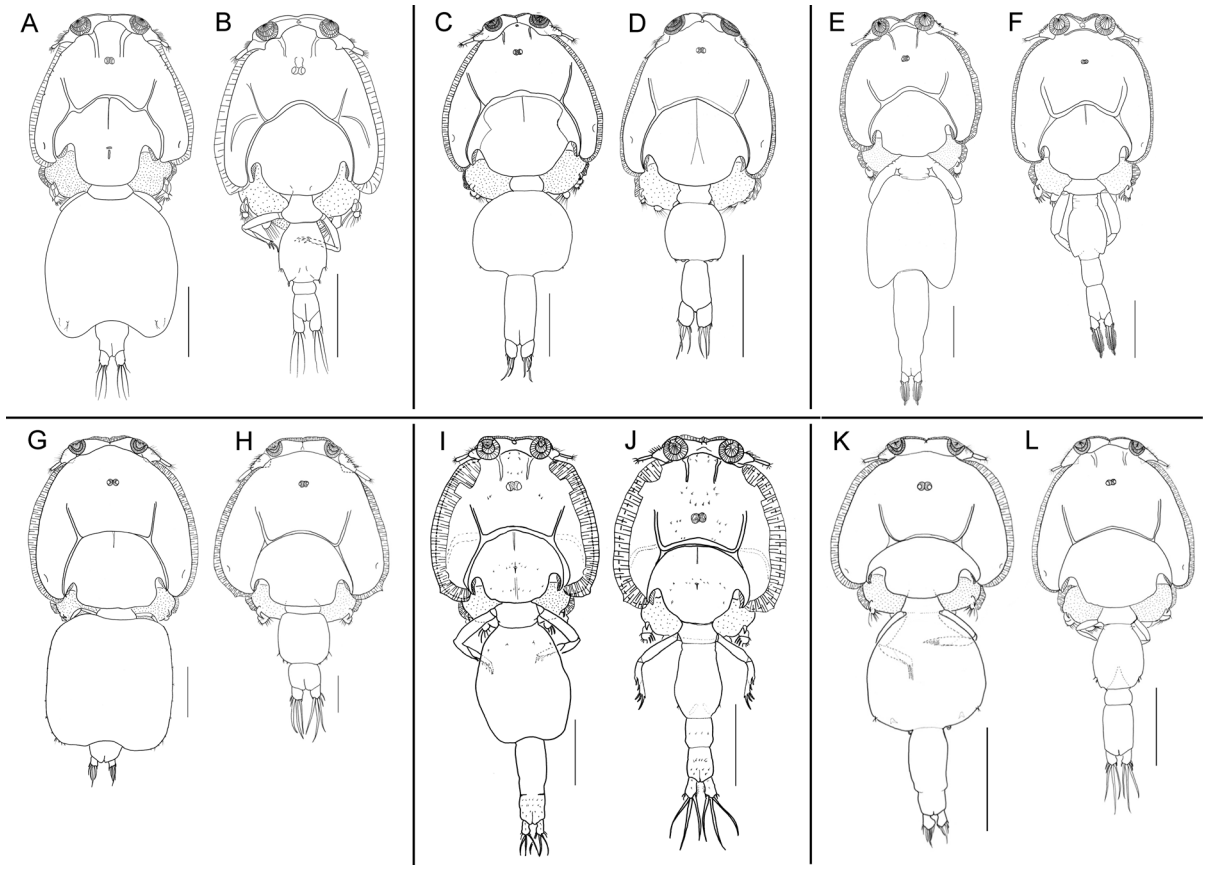

Fig. 11 Species of caligid copepods in marine fishes off Turkey. *Caligus adanensis* Özak, Sakarya & Boxshall, 2019 (A, female; B, male); *C. apodus* (Brian, 1924) (C, female; D, male); *C. bonito* C. B. Wilson, 1905 (E, female; F, male); *C. brevicaudatus* A. Scott, 1901 (G, female; H, male); *C. dakari* van Beneden, 1892 (I, female; J, male); *C. diaphanus* von Nordmann, 1832 (K, female; L, male). *Scale-bars*: A–G, I–L, 1 mm; H, 0.5 mm

b; Rodrigues et al., 2018; Özak et al., 2018, 2019a, b). However, of these new records, the report by Alaş & Öktener (2017a) of *Caligus mugilis* Brian, 1935 from the flathead grey mullet, *M. cephalus* caught in Bandırma Bay (Sea of Marmara) is erroneous, resulting from a misidentification: (i) the female specimen of *Caligus* rerported as *C. mugilis* in Alaş & Öktener (2017a: p.134, figure 1) (hereafter referred to as "*Caligus* sp."), has 1-segmented abdomen that is approximately as long as the genital complex whereas the abdomen length is distinctly less than the half of the length of the genital complex in *C. mugilis* (see p.165, figure V.1 in Brian, 1935); p. 85, figure 54 in Ben Hassine, 1983); (ii) the posterolateral corners of the genital complex in *Caligus* sp. are indistinctly lobate and do not extend beyond the posterior margin of the genital complex whereas in *C. mugilis* the genital complex has distinctly lobate posterolateral corners that extend slightly beyond the middle of the abdomen; (iii) the female maxilliped of *Caligus* sp. bears a distinct, subtriangular myxal process (Alaş & Öktener, 2017a: p.134, figure 2H), whereas *C. mugilis* lacks a myxal process on the maxilliped (Brian, 1935: p.166, figure VI). Due to the significant differences listed above, *C. mugilis* is not included in the Turkish caligid fauna.

The Turkish coastline stretches over 8,333 km bordering four major seas, the Black Sea, Sea of Marmara, Aegean Sea, and Mediterranean Sea (Levantine Sea coast of Turkey). Together with the presently reported two species of *Caligus*, these extensive marine ecosystems harbour a total of 24 species of caligid copepods utilizing 31 fish species as hosts (Table 2). These belong to 20 different families:

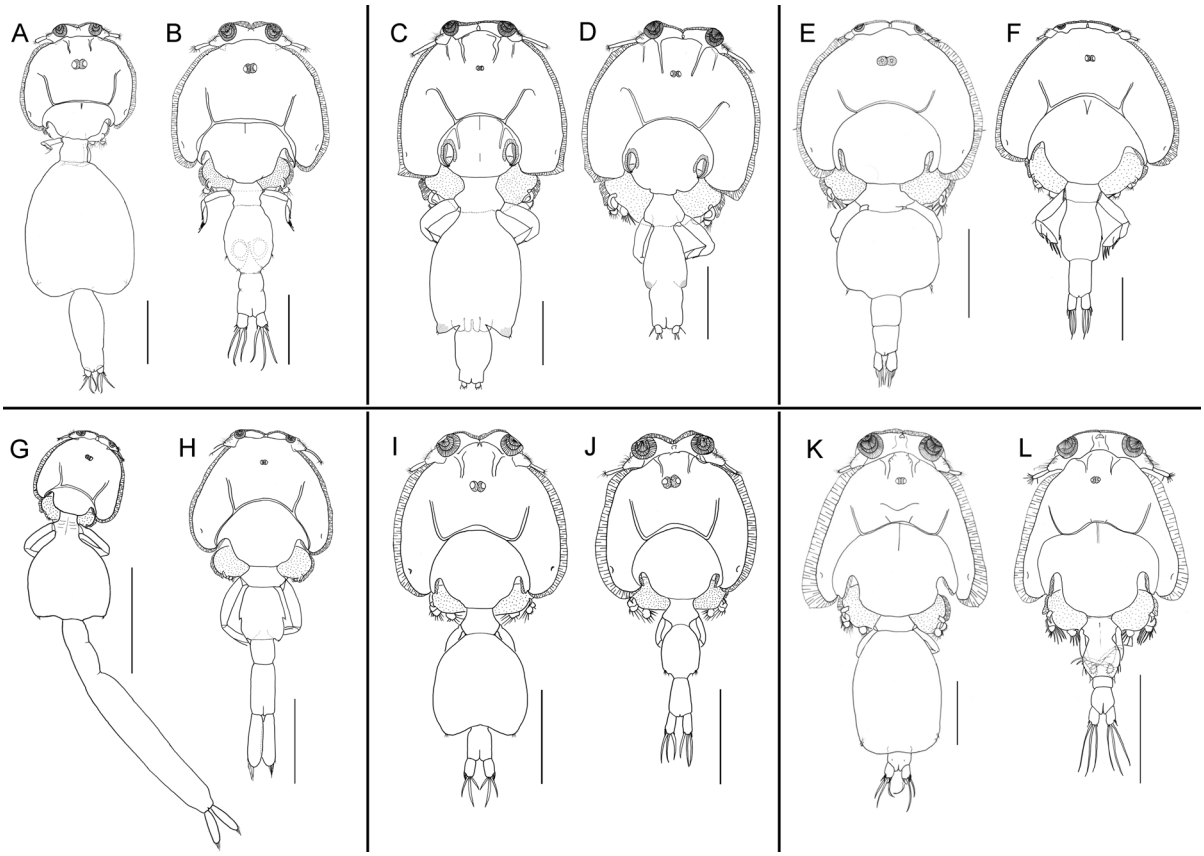

Fig. 12 Species of caligid copepods in marine fishes off Turkey. *Caligus lagocephali* Pillai, 1961 (A, female; B, male); *C. lichiae* Brian, 1906 (C, female; D, male); *C. ligusticus* Brian, 1906 (E, female; F, male); *C. macrurus* Heller, 1865 (G, female; H, male); *C. minimus* Otto, 1821 (I, female; J, male); *C. mulli* Rodrigues, Özak, Silva & Boxshall, 2018 (K, female; L, male). *Scale-bars*: A, B, F, K, L, 0.5 mm; C–E, J, H–I, 1 mm; G, 2 mm

Belonidae, Carangidae, Coryphaenidae, Labridae, Lobotidae, Moronidae, Mugilidae, Mullidae, Myliobatidae, Pleuronectide, Pomatomidae, Rhinobatidae, Scaridae, Sciaenidae, Scombridae, Soleidae, Sparidae, Tetraodontidae, Triglidae and Zeidae.

These 24 species of caligids (Figs. 11–14) belong to three genera, *Caligus*, *Euryphorus* H. Milne Edwards, 1840 and *Lepeophtheirus*. Of these, the genus *Euryphorus* is represented by a single species, *Euryphorus brachypterus* (Gerstaecker), which can be easily distinguished from the species in the genera *Caligus* and *Lepeophtheirus* in having a pair of subquadrangular dorsal plates on the fourth pedigerous somite (see p.164, figure 7E in Özak & Yanar (2016). These are absent in species of *Caligus* and *Lepeophtheirus*. The 20 species belonging to the genus *Caligus* can be distinguished from the three species of *Lepeophtheirus* by the possession of lunules (suction cups) on the paired frontal plates, near the antennules; *Lepeophtheirus* spp. lack lunules. The species of *Caligus* reported from the marine fishes off Turkey can be identified with the aid of the following key.

Key to the species of *Caligus* (females only) parasitic on marine fishes off Turkey

1a Leg 4 absent ..... …. *C. apodus* (Fig. 11C)
1b Leg 4 present ..... … 2
2a Leg 4 with 2-segmented exopod ..... … 3
2b Leg 4 with 3-segmented exopod with setal formula I;I;III ..... …. 5
3a Leg 4 with 2-segmented exopod with setal formula I; II ..... …. *C. pageti* (Fig. 13A)
3b Leg 4 with 2-segmented exopod with setal formula I; III or I; IV ..... … 4
4a Leg 4 with 2-segmented exopod with setal formula I; III ..... … 6

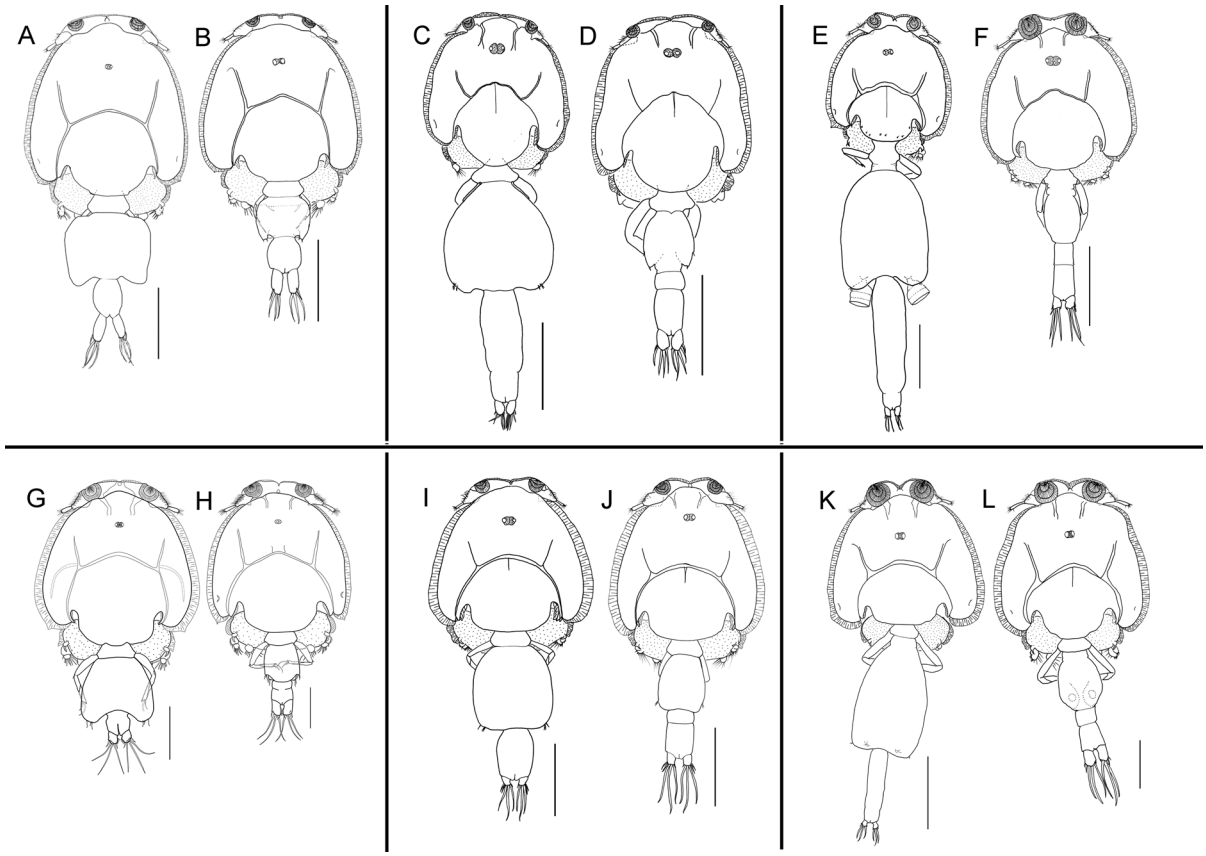

Fig. 13 Species of caligid copepods in marine fishes off Turkey. *Caligus pageti* Russel, 1925, (A, female; B, male); *C. pelamydis* Krøyer, 1863, (C, female; D, male); *C.quadratus* Shiino, 1954 (E, female; F, male); *C. scribae* Essafi, Cabral & Raibaut, 1984 (G, female; H, male); *C. solea* Demirkale, Özak, Yanar & Boxshall, 2014 (I, female; J, male); *C. temnodontis* Brian, 1924 (K, female; L, male). *Scale-bars*: A–F, I–K, 1 mm; G, H, L, 0.5 mm

4b Leg 4 with 2-segmented exopod with setal formula I; IV 10
5a Abdomen 1-segmented 16
5b Abdomen 2-segmented 18
6a Middle spine on distal exopodal segment of leg 4: short (less than the half the length of the inner spine .... *C. minimus* ..... (Fig. 12I)
6b Middle spine on distal exopodal segment of leg 4: long (at least half the length of the inner spine 7
7a Spine on first exopodal segment of leg 3: shorter than the length of second segment 8
7b Spine on first exopodal segment of leg 3: as long as or longer than the length of second segment 9
8a Genital complex subtriangular, with lobate posterolateral corners and concave posterior margin ..... *C. scribae* (Fig. 13G)
8b Genital complex quadrangular, with rounded posterolateral corners and linear posterior margin ..... *C. solea* (Fig. 13I)
9a Inner apical seta (seta 4) on distal exopodal segment of leg 1 distinctly longer than other 3 spines ..... *C. adanensis* (Fig. 11A)
9b Inner apical seta (seta 4) on distal exopodal segment of leg 1 shorter than other 3 spines ..... *C. brevicaudatus* (Fig. 11G)
10a Distal exopodal segment of leg 1 with 3 plumose setae on free posterior margin 11
10b Distal exopodal segment of leg 1 lacking 3 plumose setae on free posterior margin 14
11a Abdomen length distinctly more than the half the length of the genital complex 12
11b Abdomen length distinctly less than the half the length of the genital complex 13

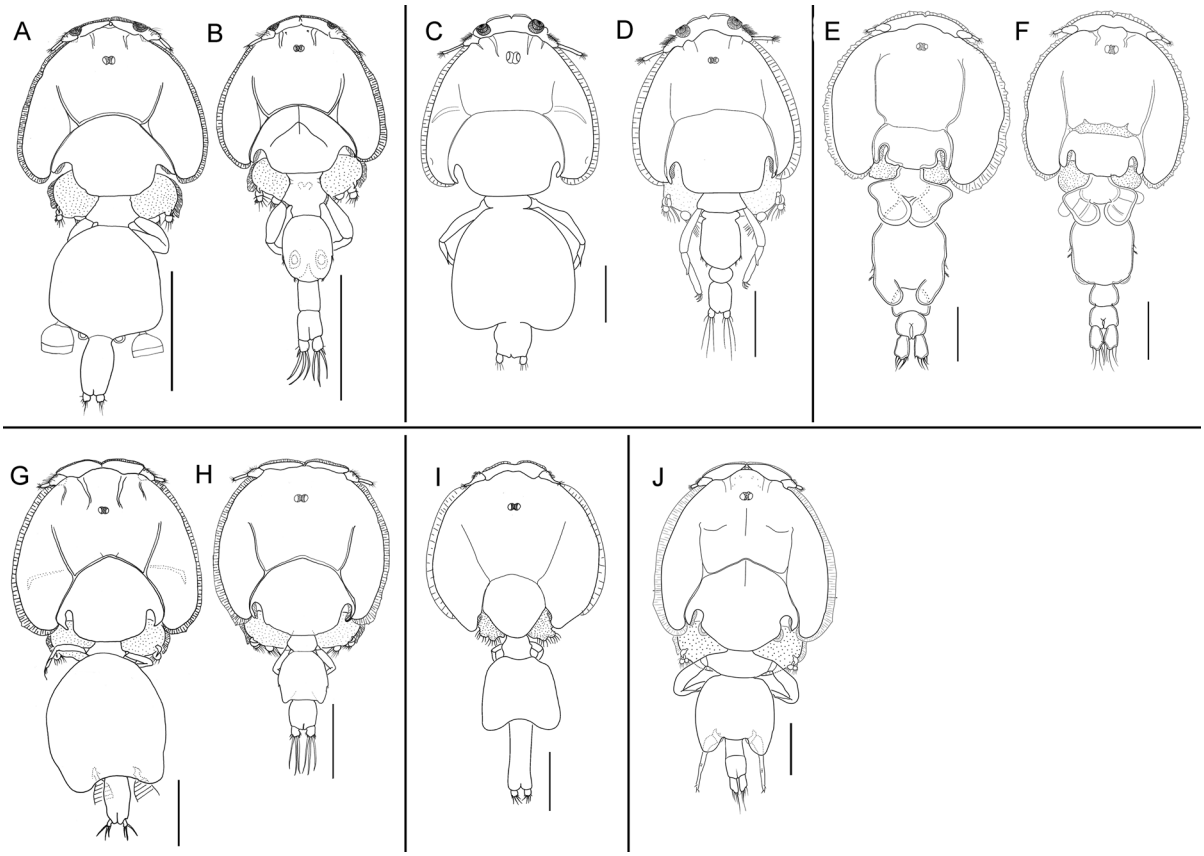

Fig. 14 Species of of caligid copepods in marine fishes off Turkey. *Caligus vexator* Heller, 1865, (A, female; B, male); *C. zei* Norman & T. Scott, 1906 (C, female; D, male); *Euryphorus brachypterus* (Gerstaecker, 1853) (E, female; F, male); *Lepeophtheirus acutus* Heegaard, 1943 (G, female; H, male); *L. europaensis* Zeddam, Berrebi, Renaud, Raibaut & Gabrion, 1988 (I, female); *L. lichiae* Barnard, 1948 (J, female). *Scale-bars*: A–G, I, J, 1 mm; H, 0.5 mm

12a Distal exopodal segment of leg 1 with 3 plumose setae on posterior margin each with fine setules proximally on outer margin ..... *C. quadratus* (Fig. 13E)

12b Distal exopodal segment of leg 1 with 3 plumose setae on posterior margin each with unusually stout basal setules proximally on outer margin …..... *C. bonito* (Fig. 11E)

13a Outer proximal corner of maxilliped corpus with laterally directed, subtriangular projection …..... *C. mulli* (Fig. 12K)

13b Outer proximal corner of maxilliped corpus without laterally directed, subtriangular projection ..... … *C. zei* (Fig. 14C)

14a Outer margin of the second endopodal segment of leg 2 with dense, rows of large dentiform setules ..... *C. dakari* (Fig. 11I)

14b Outer margin of the second endopodal segment of leg 2 with rows of fine setules 15

15a Maxilliped corpus with robust triangular myxal process ..... *C. lagocephali* (Fig. 12A)

15b Maxilliped corpus without a myxal process ..... *C. temnodontis* (Fig. 13K)

16a Abdomen length extremely longer than the length of genital complex .... *C. macrurus* (Fig. 12G)

16b Abdomen length about as long as the half-length of genital complex 17

17a Leg 3 with patch of large sclerotised knobs on inner ventral surface … *C. lichiae* ..(Fig. 12C)

17b Leg 3 without large sclerotised knobs on inner ventral surface ..... *C. vexator* (Fig. 14A)

18a Postantennal process present 19

18b Postantennal process absent .... *C. ligusticus* (Fig. 12E)

19a Maxilliped corpus with robust triangular myxal process ..... *C. diaphanus* (Fig. 11K)
19b Maxilliped corpus without a myxal process ..... *C. pelamydis* (Fig. 13C)

A second key to identify the species of the genus *Lepeophtheirus* reported off Turkey is presented below.

Key to the species of *Lepeophtheirus* (females only) parasitic on marine fishes off Turkey

1a Fifth leg comprising setiferous papillae 2
1b Fifth leg comprising spiniform process ..... *L. lichiae* (Fig. 14J)
2a Abdomen slender and longer than the subquadrangular gential complex ..... *L. europaensis* (Fig. 14I)
2b Abdomen elongate and less than the half the length of the subcircular genital complex ..... *L. acutus* (Fig. 14G)

Of the seas off Turkey, the Mediterranean Sea had the highest diversity of caligid copepods (17 spp.), followed by Aegean Sea (8 spp.), Sea of Marmara (6 spp.) and Black Sea (1 sp.). According to Bilecenoğlu et al. (2014), these extensive marine ecosystems host 512 marine fish species. Considering this rich diversity of marine fishes in the seas off Turkey, it seems that the caligid fauna of Turkey is relatively poorly known since only 6% of the marine fishes have been found to be infested with caligid copepods. In addition, 93.5% of the fish species reported with caligid copepods in Turkish waters were teleost hosts whereas only 6.5% were elasmobranchs. It is important to note that of the 31 fish hosts reported in the present study, only four species, *Aetomylaeus bovinus* (Geoffroy Saint-Hilaire), *Lagocephalus spadiceus* (Richardson), *L. suezensis* Clark & Gohar, and *Sparisoma cretense* (Linnaeus), have no economic importance either for Turkish fisheries or for aquaculture in Turkey whereas the other species (27 spp.) listed have high economic value in Turkey.

Two of these four fish species, *L. spadiceus* and *L. suezensis*, are Red Sea immigrants which constitute a serious threat for the Turkish marine ecosystems in particular in the eastern Mediterranean region. The caligid copepod *Caligus lagocephali* Pillai, 1960, previously reported as *Caligus fugu* Yamaguti & Yamasu, 1959 by Özak et al. (2012), from these two tetrodontid fish species captured in İskenderun Bay, Turkey, constitutes the first and only alien caligid copepod report in Turkish waters. Considering the 101 non-indigenous fish records in Turkish marine waters (Turan et al., 2018), it seems possible that more alien caligid copepod species may have been carried into Turkish seas by these immigrant fish species. Consequently, it can be concluded that there are probably more caligid copepods waiting to be discovered on marine fishes off Turkey.

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving animals were in accordance with the ethical standards of the University of Çukurova in Adana, Turkey. All applicable international, national and/or institutional guidelines for the use and care of animals were followed. Fish samples studied in Turkey were maintained according to the guidelines of the animal facility at Faculty of Fisheries of the Çukurova University in Turkey. Specimens of the two caligid copepods re-described herein, were collected from purchased dead fish samples caught by the local fishermen. Previously fixed specimens of the other caligid copepods stored in the collections of the Aquatic Parasitology Museum of the Faculty of Fisheries in Cukurova University (CUMAP) were used for the habitus drawings. Therefore, this study was granted exemption from requiring ethics approval.

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