

資料 Data

# *Caligus epidemicus* (Copepoda: Caligidae), a Pathogenic Sea Louse of Wild and Captive Fish in Indo-West Pacific Region: a Review

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**Abstract:** This paper compiles information on various aspects of the biology (i.e., taxonomy and morphology, geographical distribution and occurrence in relation to salinity, hosts, attachment sites, occurrence on wild and captive hosts, occurrence in plankton samples, life cycle, pathogenicity, and treatment and control) of the caligid copepod *Caligus epidemicus* based on the literature published in 1971–2013. The species attaches to the body surface of fish; it exhibits very low host specificity and has been found from 36 teleost species in 17 families and 5 orders and even from cultured shrimps. It is the most pathogenic parasite among the known caligid copepods from the Indo-West Pacific region, causing mortalities in captive fish as well as disease problems in wild and captive fish. Its infection level remains low in wild fish populations, but fish in captivity usually have higher levels of infection than those caught in the wild. Its life cycle was reported to comprise 10 stages (two naupliar, one copepodid, six chalimus stages, and adult) although *Caligus* spp. have typically eight stages in their life cycles. A rearing period of 17 days at 24–25°C is necessary for the species to develop to an ovigerous female after hatching from the egg.

**Keywords:** *Caligus epidemicus*, sea louse, fish parasite, biology, aquaculture, pathogenicity

## I. Introduction

Copepods of the siphonostomatoid family Caligidae, commonly called sea lice, often cause various problems, such as skin lesions, growth retardation, and mortalities, in farmed fish (Pike and Wadsworth, 1999; Johnson et al., 2004). *Lepeophtheirus salmonis*, *Caligus elongatus*, and *C. rogercresseyi* are such typical examples in salmon aquaculture conducted at higher latitudes in the Northern and Southern hemispheres. Since the salmon aquaculture supports a big industry and those caligids give a great economic loss to the industry (Costello, 2009), numerous basic and applied studies have been conducted to prevent their infection (Boxshall and Defaye, 1993; Costello, 2006; Boxaspen, 2006; Mordue (Luntz) and Birkett, 2008; Wagner et al., 2008; Jones and Beamish, 2011; Hayward et al., 2011).

Caligid copepods also are problematic in finfish culture in East Asia and Australasia. For example, *Caligus orientalis* has been pathogenic to farmed fish in Japan, Taiwan, and China (Nagasawa, 2004). *Caligus chiastos* and *C. amblygenitalis* have become the pathogenic species in the southern bluefin tuna (*Thunnus maccoyii*) farming in South Australia (Hayward et al.,

2008, 2009).

*Caligus epidemicus* has been regarded as the most dangerous parasite among the known caligid copepods in Asia (Ho, 2000). This species causes poor conditions in wild fish (Hewitt, 1971) and mortalities in captive fish (Lin and Ho, 1993; Lin et al., 1996). When Ho (2000) wrote a review on the sea lice related to cage aquaculture in Asia, the species was recorded only from Australia, New Zealand, Thailand, Philippines, and Taiwan. Its distribution, however, has since been confirmed in other countries of the Indo-West Pacific region, including India (Santhosh and Radhakrishnan, 2009; Vinoth et al., 2010; Rameshkumar et al., 2013), Malaysia (Venmathi Maran et al., 2009; Muhd-Faizul et al., 2012), Vietnam (Vo et al., 2008, 2012), and Indonesia (Yuniar et al., 2007). In Vietnam and Malaysia, the species was found infecting cultured marine fish (Vo et al., 2008, 2012; Venmathi Maran et al., 2009; Muhd-Faizul et al., 2012). Also, in the Philippines, more than 5,000 individuals of *C. epidemicus* were found on a single captive fish (elongate surgeonfish *Acanthurus mata*) (Ho et al., 2004). Therefore, recently, the significance of the species as a pathogenic parasite in finfish aquaculture in the

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Indo-West Pacific region has been increasing more than before.

This paper compiles information on various aspects of the biology of *C. epidemicus* based on the literature published from 1971–2013. It represents the second attempt of serial reviews on the biology of caligid copepods, especially those inducing economic losses in aquaculture and fisheries, in the Indo-West Pacific region (Nagasawa, 2004). In the present review, the scientific and common names of fish follow Froese and Pauly (2013). Terms used to show the occurrence of the parasite in the host population are prevalence (percentage of fish infected), mean intensity (average number of parasites per infected host) and mean abundance (average number of parasites per host regardless of whether the host is infected or not), as defined by Bush et al. (1997). For this paper, *C. epidemicus* were observed and newly illustrated (Figs. 1–3) using the specimens from the Philippines, because the same specimens had been reported but not described by Ho et al. (2004).

## II. Taxonomy and morphology

*Caligus epidemicus* was originally described by Hewitt (1971) based on adult female and male specimens as well as copepodid and chalimus specimens from southern black bream (*Acanthopagrus butcheri*) (as bream *Mylio butcheri*) and four species of the family Mugilidae (as mullet), i.e., flathead grey mullet (*Mugil cephalus*), yellow-eye mullet (*Aldichetta forsteri*, as *Alorichetta forsteri*), flat-tail mullet (*Liza argentea*), and sand grey mullet (*Myxus elongatus*, as *M. elongans*), caught in the lower Mitchell River, Victoria, Australia. Subsequently, Roubal (1981) and Byrnes (1987) briefly described this caligid species from surf bream (*Acanthopagrus australis*) and four species of seabreams (*Acanthopagrus* spp.), respectively, taken in the coastal waters of Australia. In their book, Ho and Lin (2004) reported the detailed morphology of female and male adults of *C. epidemicus* from Taiwan. Venmathi Maran et al. (2009) also briefly described the morphology of the species from Malaysia. In addition to these works, Lin and Ho (1998) studied the structure of legs 1 and 4 and the male antenna of *C. epidemicus* and five other species (*C. acanthopagri*, *C. orientalis*, *C. oviceps*, *C. punctatus*, and *C. rotundigenitalis* [as *C. multispinosus*]) from

Taiwan.

There are records of “*Caligus* sp.” in the Philippines (Lio-Po and Barry, 1988) and Thailand (Chinabut, 1996). This unspecified caligid in both countries is herein regarded as *C. epidemicus* based on the photographed morphology of an ovigerous female. The illustrated morphology of Thai specimens also shows that they are identical to *C. epidemicus*.

*Caligus epidemicus* is a small species among caligid copepods. Adult females do not exceed 3 mm in body length (BL) (excluding the setae on the caudal rami): 2.46–2.85 (mean 2.66,  $n = 10$ ) or 2.362–2.649 (2.529,  $n = 15$ ) mm BL from Australia (Hewitt, 1971; Roubal, 1981) and 2.23–2.33 (2.28,  $n = 10$ ) mm BL from Malaysia (Venmathi Maran et al., 2009). Adult females from Taiwan are slightly smaller than Australian and Malaysian ones, being 1.97 mm BL (no data available for size variation) (Ho and Lin, 2004). Adult males do not exceed 2 mm BL: 1.52–1.72 (mean 1.59,  $n = 10$ ) or 1.539–1.665 (1.562,  $n = 15$ ) mm BL from Australia (Hewitt, 1971; Roubal, 1981), 1.58–1.65 (1.62,  $n = 8$ ) mm BL from Malaysia (Venmathi Maran et al., 2009), and 1.51 mm BL from Taiwan (Ho and Lin, 2004).

Byrnes (1987) collected many specimens of *C. epidemicus* from four species of seabreams (*Acanthopagrus* spp.) in the coastal waters of Australia and presented the measurement data of these specimens by host species and sampling locality. While no particular comments were made by this author, the female specimens from southern black bream (*A. butcheri*) caught along the south coast of Australia were largest (2.442–2.480 mm in mean BL), followed by those specimens from surf bream (*A. australis*) from the southeast coast of Australia (2.030–2.309 mm in mean BL). In contrast, the female specimens from goldsilke seabream (*A. berda*) and yellowfin seabream (*A. latus*) collected along the north and northwest coasts of Australia were smaller, being 1.870–2.144 and 1.998–2.291 mm in mean BL, respectively. These data suggest that individuals of *C. epidemicus* can become larger or smaller at higher or lower latitudes, respectively, which may be due to the effect of water temperature on the growth rate of the parasite. The possibility that the host species affects the growth rate of *C. epidemicus* may be negligible in this case because Byrnes (1987) examined the four species of seabreams which are very closely

related.

The best description of *C. epidemicus* was made by Ho and Lin (2004) using material from Taiwan. The following description of adult females and males is mostly based on it but is supplemented by the observation in this study using material from the Philippines. The female and male specimens illustrated in Figs. 1A and 3A were 2.04 and 1.44 mm BL, respectively,

Female (Figs. 1–2): Cephalothoracic shield (1A) subcircular with well-developed frontal plate and medium-sized lunules. Fourth pediger (Fig. 1A) 2.78 times wider than long (3.27 times in the Philippine specimen). Genital complex (Fig. 1B) subrectangular with broadly rounded corners. Abdomen (Fig. 1B) short, subquadrate, and 1-segmented. Caudal ramus (Fig. 1C) short, about as long as wide, armed with 3 short, subterminal and 3 long, terminal setae. Egg sac about 2/3 length of body (about 1/2 length in the Philippine specimen). Antennule (Fig. 1D) 2-segmented; proximal segment with 25 setae on anterodistal surface; distal segment with 1 subterminal seta on posterior margin and 11 setae plus 2 aesthetascs on distal margin. Antenna (Fig. 1E) 3-segmented; proximal segment (coxa) with blunt posteromedial process; middle segment (basis) subrectangular and unarmed; distal segment (endopod) sharply pointed claw with one and another setae each in proximal and middle regions. Postantennal process (Fig. 1E) bluntly pointed, bearing 2 basal papillae with each carrying 4 setules (3 or 4 setules in the Philippine specimen), another similar papilla nearby on sternum carrying 4 setules (3 setules). Maxillule (Fig. 1E) consisting of straight dentiform process and basal papilla with 3 small setae. Maxilla (Fig. 1F) 2-segmented; proximal segment (lacertus) large and unarmed; distal segment (brachium) slender, carrying small, subterminal, hyaline membrane (flabellum) on outer edge and two spinulated elements, a short subterminal canna and a long terminal calamus. Maxilliped (Fig. 1G) 3-segmented; proximal segment (corpus) largest, with a basal rounded protrusion (such protrusion not distinguished but a small swelling in myxal area in the Philippine specimen), middle (shaft) and distal (claw) segments fused to form subchela, claw with long barbell at base. Sternal furca (Fig. 2A) with subquadrate box, bearing short tines. Armature on rami of legs 1–4 are as

follows (Roman numerals indicating spines and Arabic numerals, setae): 1-0; III,I,3 and vestigial for the exopod and endopod of leg 1; I-1, I-1; II,I,5 and 0-1; 0-2; 6 for those of leg 2; I-0, I-1; III,4 and 0-1; 6 for those of leg 3; and I-0; II and absent for those of leg 4. Leg 1 (Fig. 2B) protopod with long, plumose outer seta and another small, plumose inner seta, in addition to a papilla bearing 1 setule on outer margin of coxa; vestigial endopod a small process tipped with 1 setule; first segment of exopod with row of spinules on posterior edge and small spiniform seta at outer distal corner; middle 2 of 4 terminal elements (Fig. 2C) on last segment of exopod with accessory process, element 1 pinnate in distal half and element 4 naked and shorter than element 1. Leg 2 (Fig. 2D) coxa small, with setule-bearing papilla on ventral surface and large, plumose, inner seta on posterior edge; basis large, with small seta on outer edge; posterior margin of basis with long, narrow membrane and small marginal setule near midway of this membrane; outer edges of both basis and first segment of exopod fringed with large marginal membrane; Proximal 1 outer spine on terminal segment of exopod (Fig. 2E) naked. Leg 3 (Fig. 2F) protopod with small, plumose, outer seta and long, plumose inner seta, in addition to an outer and a posterior marginal membrane; ventral surface of protopod with setule-bearing papilla at both ends of latter membrane, outer margin corrugated anterior to former membrane; velum well developed and fringed with setules; proximal segment of exopod (Fig. 2G) with membrane on lateral margin and its spine also bearing lateral membrane. Leg 4 (Fig. 2H) protopod with plumose seta at outer distal corner; terminal segment of exopod with pecten at base of inner spine (pecten invisible in the Philippine specimen). Leg 5 (Fig. 1B) represented by 2 small, isolated papillae on posterolateral corner of genital complex, 1 tipped with small plumose seta and other with 3 similar setae.

Male (Fig. 3): Cephalothoracic shield (Fig. 3A) suborbicular, with well-developed frontal plate and medium-sized lunules. Fourth pediger (Fig. 3B) 3.03 times wider than long (2.63 times in the Philippine specimen). Genital complex (3B) subrectangular, with posteriorly protruded posterolateral process. Abdomen (Fig. 3B) small and subquadrate. Caudal ramus (Fig. 3B) slightly wider than long and armed as in female. Antenna (Fig. 3C) 3-segmented; proximal segment slender and

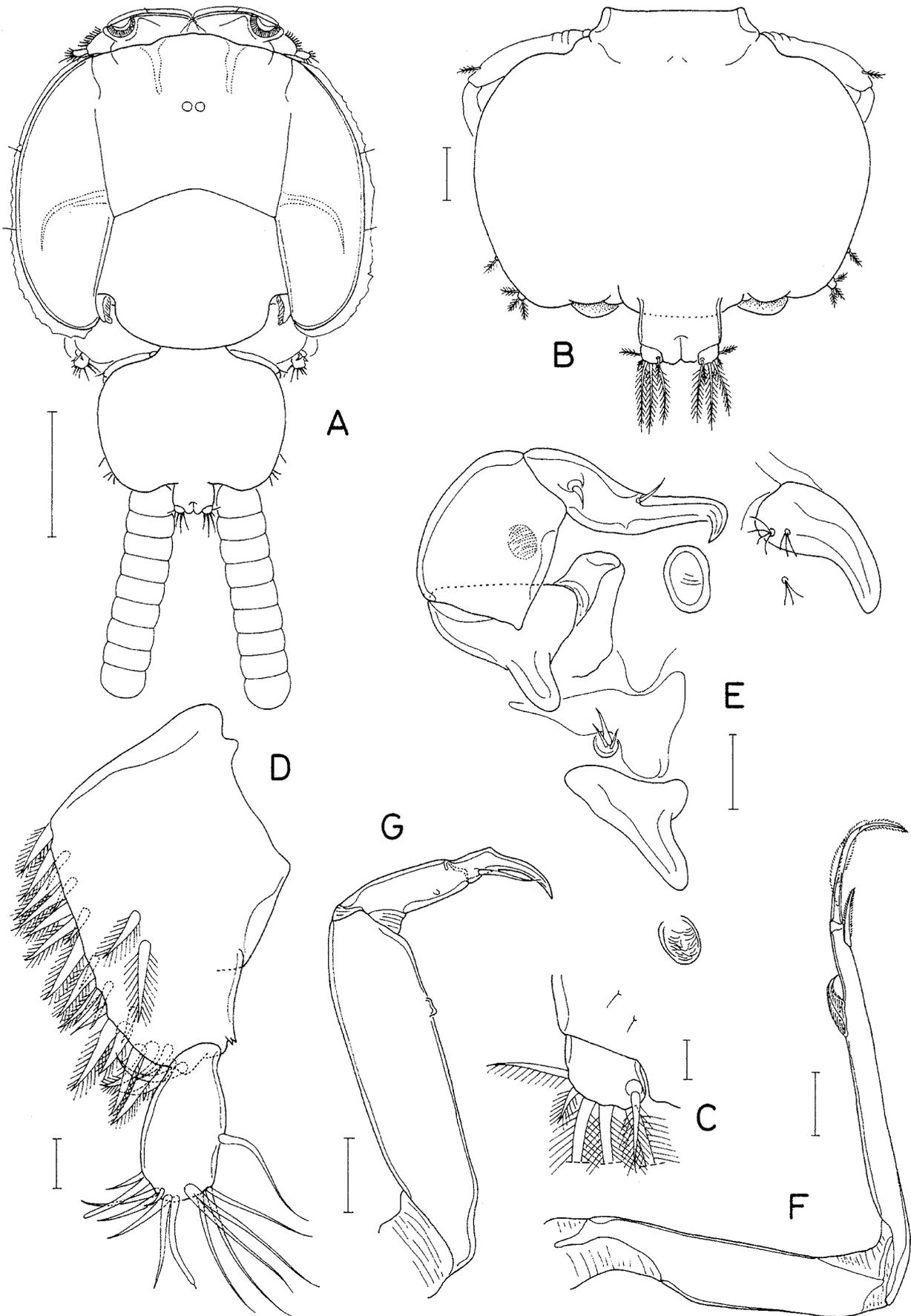


Fig. 1 *Caligus epidemicus*, female. A, habitus, dorsal; B, genital complex and abdomen, dorsal; C, caudal ramus, dorsal; D, antennule; E, antenna, postantennary process and maxillule; F, maxilla; G, maxilliped. Scale bars (mm): 0.5 in A; 0.1 in B; 0.02 in C-D; 0.05 in E-G.

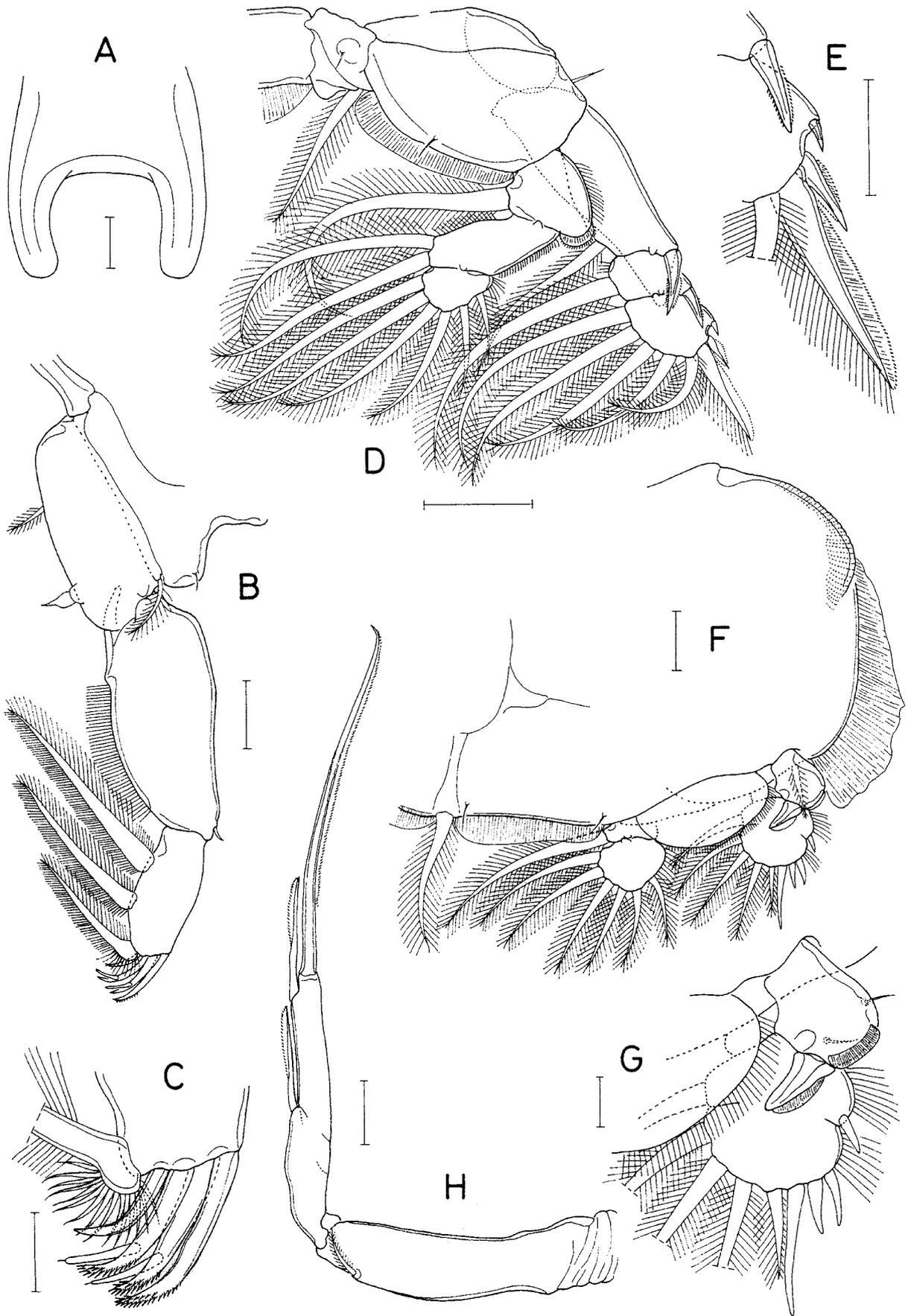


Fig. 2 *Caligus epidemicus*, female. A, sternal furca; B, leg 1; C, tip of leg 1 exopod; D, leg 2; E, outer distal part of leg 2 exopod; F, leg 3; G, rami of leg 3; H, leg 4. Scale bars (mm): 0.02 in A, C, G; 0.05 in B, E, F, H; 0.1 in D.

armed with long corrugated adhesive pad; middle segment largest, armed with 3 (1 large and 2 small) corrugated adhesion pads in central and distal regions; terminal segment (Fig. 3D) smallest, with 2 medial setae and a corrugated adhesion pad in basal region and a large tooth-like projection in middle region. Maxilliped (Fig. 3E) 3-segmented, bearing a spine in myxal area. Leg 5

(Fig. 3B) represented by 2 papillae on posterolateral side of genital complex, 1 tipped with seta and other with 3 setae. Leg 6 (Fig. 3B) represented by 2 short setae (3 setae in the Philippine specimen) on ventral surface at base of posterolateral process on genital complex. Sternal furca (Fig. 3F) with subquadrate box, bearing short tines.

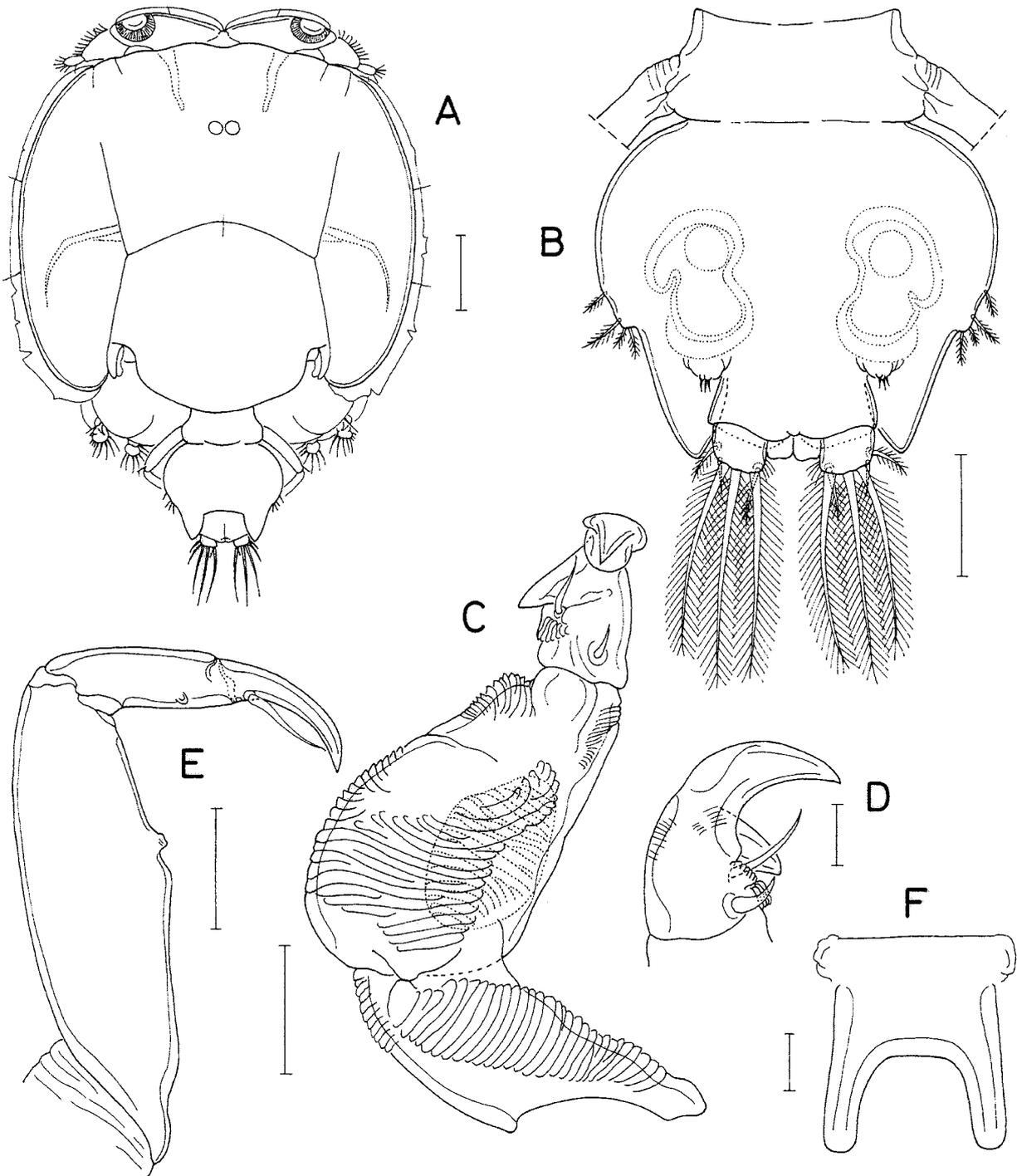


Fig. 3 *Caligus epidemicus*, male. A, habitus, dorsal; B, genital complex, abdomen and caudal rami, ventral; C, antenna; D, terminal part of antenna; E, maxilliped; F, sternal furca. Scale bars (mm): 0.2 in A; 0.1 in B; 0.05 in C, E; 0.02 in D, F.

### III. Geographical distribution and occurrence in relation to salinity

*Caligus epidemicus* is widely distributed in the Indo-West Pacific region (Fig. 4) and has been reported so far from Australia, New Zealand, India, Indonesia, Malaysia, Thailand, Vietnam, Philippines, and Taiwan (see Table 1 for the literature). The known distribution of the species covers the tropical, subtropical, and temperate waters in the Southern and Northern hemispheres, ranging from Lakes Entrance (37° 53' S), Victoria, southern Australia (Byrnes 1987; Byrnes and Rohde 1992) in south to Bei-men (23° 17' N), Tainan, Taiwan (Ho and Lin, 2004) in north. The species may be found in other Asian countries, where no systematic investigations on caligid copepods have so far been conducted.

The distribution of *C. epidemicus* in the coastal waters of Australia was reported by Byrnes and Rhode (1992) as divided into five zoogeographical regions (Banksian, Peronian, Maugean, Flindersian, and

Dampierian). The species occurs in all of these regions but it is abundant in two regions (Peronian and Maugean) located in southeast Australia, where surf bream (*A. australis*) and southern black bream (*A. butcheri*) serve as hosts, respectively.

*Caligus epidemicus* is a brackish-water or coastal marine species found on fish in the lower reaches of rivers and the inshore and estuarine environments. As stated below (see the Treatment and control section), adults of *C. epidemicus* can tolerate a wide range of salinity (Roubal, 1997). In the lower Mitchell River, Australia (a type locality of the species), the salinity fluctuated between 4.5 and 28 ppt (Hewitt, 1971). The species was also recorded at different salinity levels ranging from 2–30 ppt (Regidor and Arthur, 1986), 12–28 ppt (Ruangpan and Kabata, 1984), 19.7–31.2 ppt (Yurinar et al., 2007), 30–32 ppt (Cruz-Lacierda et al., 2011) to 35–50 ppt (Lio-Po and Barry, 1988). Its life cycle also can be completed at 20 ppt in the laboratory (Lin and Ho, 1993).

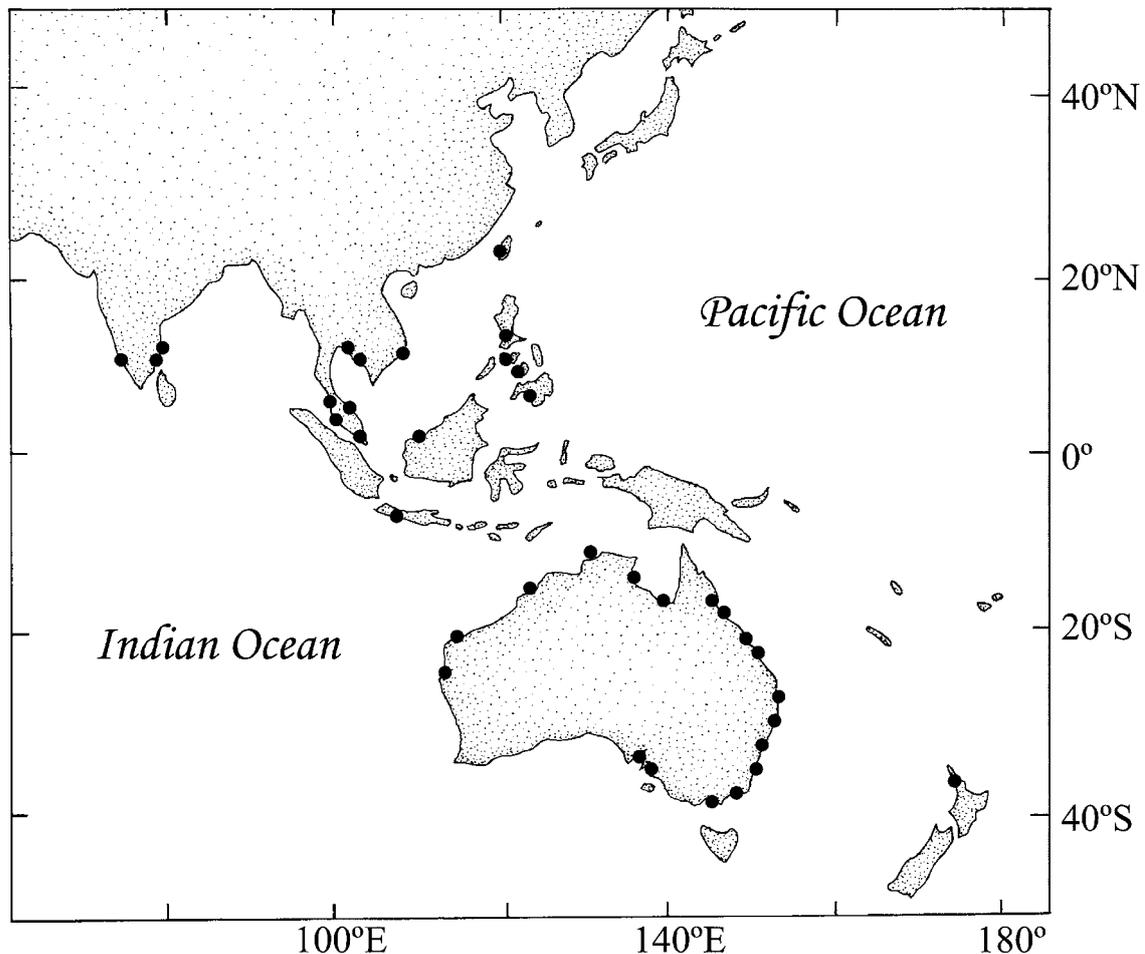


Fig. 4 A map of the Indo-West Pacific region, showing the localities (closed circles) where *Caligus epidemicus* was collected.

#### IV. Hosts

Since its original description in 1971, *C. epidemicus* has been reported from 36 teleost species, a tilapia hybrid, and unspecified and unidentified mugilids during the last four decades (Table 1). These fish hosts belong to 17 families (Chanidae, Mugilidae, Acanthuridae, Ambassidae, Carangidae, Cichlidae, Gobiidae, Latidae, Lutjanidae, Monodactylidae, Rachcentridae, Scatophagidae, Serranidae, Siganidae, Sparidae, Teraponidae, and Pleuronectidae) in four orders (Gonorhynchiformes, Mugiliformes, Perciformes, and Pleuronectiformes). Most of these fish are coastal marine and brackish-water species. Interestingly, the species was accidentally found on tiger shrimps (*Penaeus monodon*) cultured in Thailand (Ruangpan and Kabata, 1984). Accordingly, it is evident that *C.*

*epidemicus* exhibits very low host specificity and can utilize a wide variety of finfish. Nonetheless, elasmobranchs are not listed as the hosts of the species. Also, it has not been reported from offshore migratory fish, except for yellowtail amberjack (*Seriola lalandi*) from Australia (Hutson et al., 2007).

The fact that some euryhaline fish species, such as mugilids and sparids of *Acanthopagrus*, are included in the list of the known hosts (Table 1) is one of the features in host utilization of *C. epidemicus*. Such euryhaline fish can move and carry the copepod between the lower reaches of rivers and the coastal sea area. In Far East Asia, *Caligus orientalis* also uses both brackish-water and coastal marine fish as hosts (Nagasawa, 2004), and these *Caligus* species are different from most of their congeners which infect only marine fish.

Table 1 Fish hosts of *Caligus epidemicus* reported between 1971 and 2013. The copepod was recorded from cultured individuals of the species with an asterisk (\*). The classification and scientific and common names of fish are adopted from Froese and Pauly (2013).

Scientific name	Common name	Country or region	Reference
Gonorhynchiformes: Chanidae			
<i>Chanos chanos</i> *	milkfish	Philippines Taiwan	Regidor and Arthur 1986 Lin and Ho 1998; Ho and Lin 2004
Mugiliformes: Mugilidae			
<i>Aldrichetta forsteri</i>	yellow-eye mullet	Australia	Hewitt 1971 (as <i>Alorichetta forsteri</i> )
<i>Liza argentea</i>	flat-tail mullet	Australia	Hewitt 1971
<i>Liza macrolepis</i> *	largescale mullet	Taiwan	Lin and Ho 1998; Ho and Lin 2004
<i>Mugil cephalus</i> *	flathead grey mullet	Taiwan Australia	Lin et al., 1993; Lin and Ho 1998; Ho and Lin 2004 Hewitt 1971
<i>Myxus elongatus</i>	sand grey mullet	Australia	Hewitt 1971 (as <i>Myxus elongans</i> )
<i>Paramugil parmatus</i>	broad-mouthed mullet	Philippines	Ho et al. 2004 (as <i>Liza parmata</i> )
Unspecified species		India	Santhosh and Radhakrishnan 2009
Unidentified species		Thailand	Chinabut 1996 (as mullet. The parasite was reported as <i>Caligus</i> sp.)
Perciformes: Acanthuridae			
<i>Acanthurus mata</i>	elongate surgeonfish	Philippines	Ho et al. 2004
Perciformes: Ambassidae			
<i>Ambassis marianus</i>	estuary perchlet	Australia	Hallett and Roubal 1995
Perciformes: Carangidae			
<i>Carangoides malabaricus</i>	Malabar trevally	India	Rameshkumar et al. 2013
<i>Parastromateus niger</i>	black pomfret	India	Rameshkumar et al. 2013
<i>Seriola lalandi</i>	yellowtail amberjack	Australia	Hutson et al. 2007
<i>Trachinotus blochii</i> *	snubnose pompano	Philippines Taiwan	Cruz-Lacierda et al. 2011 Lin and Ho 1998; Ho and Lin 2004
Perciformes: Cichlidae			
<i>Oreochromis aureus</i> *	blue tilapia	Taiwan	Lin and Ho 1998; Ho and Lin 2004
<i>Oreochromis mossambicus</i> *	Mozambique tilapia	Taiwan	Lin and Ho 1993, 1998; Lin et al. 1996; Ho and Lin 2004
<i>Oreochromis niloticus niloticus</i> *	Nile tilapia	Philippines Philippines	Ho et al. 2004 Natividad et al. 1986 (as <i>Oreochromis niloticus</i> ); Bondad-Reantaso and Arthur 1990 (as <i>O. niloticus</i> )
<i>Oreochromis urolepis hornorum</i> *	Wami tilapia	Philippines	Ho et al. 2004
<i>Oreochromis hybrid</i> *		Taiwan	Lin and Ho 1998; Ho and Lin 2004

Table 1 continued.

Perciformes: Gobiidae			
<i>Glossogobius celebius</i>	Celebes goby	Philippines	Ho et al. 2004
Perciformes: Latidae			
<i>Lates calcarifer</i> *	barramundi	Philippines Vietnam Taiwan Malaysia Thailand	Cruz-Lacierda et al. 2011 Vo et al. 2011 Lin and Ho 1998 (as <i>Lates calcifer</i> ); Ho and Lin 2004 Venmathi Maran et al. 2009; Muhd-Faizul et al. 2012 Chinabut 1996 (the parasite was reported as <i>Caligus</i> sp.)
Perciformes: Lutjanidae			
<i>Lutjanus argentimaculatus</i> *	mangrove red snapper	Philippines	Ho et al. 2004
Perciformes: Monodactylidae			
<i>Monodactylus argenteus</i>	silver moony	Philippines	Ho et al. 2004
Perciformes: Rachycentridae			
<i>Rachycentron canadum</i> *	cobia	Philippines	Ho et al. 2004
Perciformes: Scatophagidae			
<i>Scatophagus argus</i>	spotted scat	Philippines  Taiwan Indonesia	Lio-Po and Barry 1988 (the parasite was reported as <i>Caligus</i> sp.)  Lin and Ho 1998 Yurinar et al. 2007
Perciformes: Serranidae			
<i>Epinephelus bleekeri</i> *	duskytail grouper	Vietnam India	Vo et al. 2008, 2011 Vinoth et al. 2010
<i>Epinephelus coioides</i> *	orange-spotted grouper	Philippines Vietnam Malaysia	Ho et al. 2004 Vo et al. 2008, 2011 Venmathi Maran et al. 2009
<i>Epinephelus malabaricus</i> *	Malabar grouper	Taiwan	Lin and Ho 1998; Ho and Lin 2004
<i>Epinephelus tauvina</i>	greasy grouper	Vietnam	Vo et al. 2011
Perciformes: Siganidae			
<i>Siganus guttatus</i> *	goldlined spinefoot	Philippines	Ho et al. 2004
<i>Siganus javus</i>	streaked spinefoot	Indonesia	Yurinar et al. 2007
Perciformes: Sparidae			
<i>Acanthopagrus australis</i>	surf bream	Australia	Roubal 1981, 1990a, 1990b, 1994, 1995, 1997; Byrnes 1987; Byrnes and Rohde 1992; Aken'Ova and Lester 1996
<i>Acanthopagrus berda</i>	goldsilk seabream	Australia	Byrnes 1987; Byrnes and Rohde 1992
<i>Acanthopagrus butcheri</i>	southern black bream	Australia	Hewit 1971 (as <i>Mylio butcheri</i> ); Byrnes 1987; Byrnes and Rohde 1992
<i>Acanthopagrus latus</i>	yellowfin seabream	Australia	Byrnes 1987; Byrnes and Rohde 1992
<i>Acanthopagrus schlegelii schlegelii</i> *	blackhead bream	Taiwan	Lin and Ho 1998 (as <i>Acanthopagrus schlegeli</i> ); Ho and Lin 2004 (as <i>A. schlegeli</i> )
Perciformes: Terapontidae			
<i>Terapon jarbua</i> *	Jarbua terapon	Taiwan	Lin and Ho 1998
Pleuronectiformes: Pleuronectidae			
<i>Rhombosolea leporina</i>	yellowbelly flounder	New Zealand	Hine et al. 2000

## V. Attachment sites

The principal attachment site of adult *C. epidemicus* is the fish's body surface. There are, however, controversial observations regarding other attachment sites. Roubal (1994) reports that the species was never collected from the gill filaments, gill arch, buccal (=mouth) or opercular (=gill) cavities, while Byrnes (1987) and Ho and Lin (2004) stated that adults occur on the gills and in the mouth or oral cavity. Moreover, the fins and gill cavities were reported as additional attachment sites by Bondad-Reantaso and Arthur (1990)

and by Ho et al. (2004) and Venmathi Maran et al. (2009), respectively.

Copepodids and chalimi of *C. epidemicus* were mainly found on the anterodorsal and anteroventral flanks, the dorsal and lateral sides of the head and the pectoral fins of experimentally infected surf bream (*A. australis*) (Roubal, 1994). Only a few individuals at these stages were found on the posterior fins and the posterior flank of the body. Based on these observations, Roubal (1994) suggested that protection from water flow is not a major factor to determine the spatial distribution

of the copepod of these stages.

In the experimental infection with *C. epidemicus* using estuary perchlet (*Ambassis marinus*), a small coastal fish (1–4 cm long), most parasites of the copepodid and early chalimus stages attached to the pectoral fins but did not settle on other parts of the host (Hallett and Roubal, 1995).

## VI. Occurrence on wild and captive hosts

Infection level of *C. epidemicus* remains low in wild fish populations, but fish in captivity usually have higher levels of infection than those caught in the wild. Since this species of sea louse has a one-host life cycle, it can easily develop a large population at fish farms, where fish are held at high density in a limited water body. This section deals with the occurrence of *C. epidemicus* on various wild and captive fish by country and region (Australia, New Zealand, India, Indonesia, Malaysia, Thailand, Vietnam, Philippines, and Taiwan).

Several investigations were conducted to determine the infection with *C. epidemicus* on four species of seabreams (*A. butcheri*, *A. australis*, *A. berda*, and *A. latus*) in Australia. Mean abundances of the parasite on these hosts from the coastal waters of this country were 0.13–2.3, 0.3–3.6, 0.18–7.8, and 0.38–1.9, respectively (Byrnes, 1987). In a population of surf bream (*A. australis*) from a small estuary in New South Wales, the species of caligid was rare: prevalence and mean intensity being only 3% and 1.0 and 1% and 1.0 for adult female and male copepods, respectively (Roubal, 1990a). On the other hand, when surf bream caught in a coastal pond, Queensland, were held in an experimental sea cage for up to six weeks, there was a marked increase in mean abundance (51.4) of the parasite, compared to wild fish (4.2) and pond fish (9.3) (Roubal, 1995). Udonellids (*Udonella myliobati*) are known to occur on *C. epidemicus* infecting surf bream from eastern Australia (Aken'Ova and Lester, 1996).

In New Zealand, *C. epidemicus* was recorded from yellowbelly flounder (*Rhombosolea leporina*) in Manukau Harbour (Hine et al., 2000). No infection data were reported.

In India, Santhosh and Radhakrishnan (2009) reported *C. epidemicus* for the first time and found it on three species of mullets in the estuarine habitats of Kerala. This parasite was also found on duskytail

grouper (*Epinephelus bleekeri*) from Vellar Estuary (Vinoth et al., 2010) and two species of carangids (Malabar trevally *Caragoides malabaricus* and black pomfret *Parastromateus niger*) from Parangipettai (Rameshkumar et al., 2013).

Through a survey on the crustacean parasite fauna of coastal fish from Segara Anakan Lagoon, central Java, Indonesia, *C. epidemicus* was found on streaked spinefoot (*Siganus javus*) and spotted scat (*Scatophagus argus*) (Yurinar et al., 2007). Prevalence and mean intensity of the parasite on these fish species were 20% and 1.00 and 4.3% and 1.33, respectively.

Two species of cage-cultured marine fish, barramundi (*Lates calcarifer*) and orange-spotted grouper (*Epinephelus coioides*), from Penang, Malaysia, were found to harbor *C. epidemicus* (Venmathi Maran et al., 2009). Barramundi harbored another caligid species, *Caligus punctatus*. Recently, five species of sea lice, *C. chistos*, *C. epidemicus*, *C. rotundigenitalis*, *C. punctatus*, and *Caligus* sp., were found infecting barramundi cultured in Malaysia, but *C. epidemicus* constantly predominated among these species and at different sites (Muhd-Faizul et al., 2012).

In Thailand, *C. epidemicus* was found to heavily infect tiger prawns (*P. monodon*) cultured at a farm in Chantaburi Province in 1977 (Ruangpan and Kabata, 1984). Despite the fact that this was a very unusual infection of the crustacean decapod by the fish-parasitizing *C. epidemicus*, when discovered, its infection level was high with prevalence and mean intensity of 72% and 19, respectively. Copepods were attached mainly to the telsons and legs of the prawns. While the authors could not assess whether *C. epidemicus* infection continued at the prawn farm, Chinabut (1996) later reported that fingerling of mullet (species unidentified) from prawn ponds in Rayong Province were heavily infected with *C. epidemicus* (as *Caligus* sp., see the Taxonomy and morphology section), which herein suggests that such fish serve as the reservoir hosts for the copepod in the ponds. Chinabut (1996) also found *C. epidemicus* on cage-cultured barramundi (*L. calcarifer*) from southern Thailand.

Vietnam was recently added to the countries where *C. epidemicus* occurs. Vo et al. (2008) found this caligid on wild orange-spotted grouper (*E. coioides*) and duskytail grouper (*E. bleekeri*) caught in brackish waters

in Nha Trang. They also collected specimens of *C. epidemicus* from orange-spotted grouper cultured in brackish-water ponds. Prevalence and mean intensity of the parasite on these groupers were low, ranging from 6.3–11.1% and 1.9–2.5, respectively. The groupers were concurrently infected with another species of sea louse, *Caligus multispinosus*. Interestingly, no infection was observed on the groupers cultured in sea waters. Currently, Vo et al. (2012) listed four species of marine fish (*E. coioides*, *E. bleekeri*, Malabar grouper *E. malabaricus*, greasy grouper *E. tauvina*, and *L. calcarifer*) as the hosts of *C. epidemicus*.

In the Philippines, *C. epidemicus* occurs on commercially important fish reared in brackish waters. The species infected Nile tilapia (*Oreochromis niloticus niloticus*, as *O. niloticus*) cultured in Leganes, Iloilo Province (Natividad et al., 1986; Bondad-Reantaso and Arthur, 1990). Up to 548 copepods were found on a single fish (Natividad et al. 1986). Prevalence and mean intensity of the parasite irregularly fluctuated at monthly intervals but reached up to 100% and 47.8, respectively. Infection level also increased with an increase in fish age (Bondad-Reantaso and Arthur, 1990). Juvenile milkfish (*Chanos chanos*) from brackish-water ponds in Pagbilao, Quezon Province and Molo, Iloilo Province, had infection with *C. epidemicus* (Regidor and Arthur, 1986). Prevalence and mean intensity ranged from 4.0–36.0% and 1.0–8.8, respectively.

Recently, *C. epidemicus* was found infecting marine fish cultured in the coastal ponds, cages and tanks or occurring in the sea-water supply canals in various localities of the Philippines (Ho et al., 2004). The infected fish are orange-spotted grouper (*E. coioides*), mangrove red snapper (*Lutjanus argentimaculatus*), Mozambique tilapia (*Oreochromis mossambicus*), Wami tilapia (*O. urolepis hornorum*), cobia (*Rachycentron canadum*), goldlined spinefoot (*Siganus guttatus*), elongate surgeonfish (*A. mata*), Celebes goby (*Glossogobius celebius*), broad-mouthed mullet (*Paramugil parmatus*, as *Liza parmata*), and silver moony (*Monodactylus argenteus*). Prevalence of infection was usually high, often up to 100%. Over 5,000 individuals of *C. epidemicus* were found on a single elongate surgeonfish. The cultured fish often had infections with other species of sea lice, *Caligus quadratus*, *Lepeophtheirus sigani* and *Pseudocaligus*

*uniartus*, in addition to *C. epidemicus*. Furthermore, *C. epidemicus* caused disease problems in goldlined spinefoot (*S. guttatus*) and barramundi (*L. calcarifer*) experimentally reared at the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC-AQD) in Iloilo Province (Cruz-Lacierda et al., 2011). While two other caligids, *P. uniartus* and *L. sigani*, also parasitized goldlined spinefoot, *C. epidemicus* was the most predominant: up to 660 individuals of the species were found on a single fish. Prevalence and mean intensity on barramundi were 100% and 12.7, respectively.

In Taiwan, *C. epidemicus* has been reported from 11 species and tilapia hybrid cultured in brackish and/or salt waters (Lin and Ho, 1998). These fish are milkfish (*C. chanos*), barramundi (*L. calcarifer*), Malabar grouper (*E. malabaricus*), Jarbua terapon (*Terapon jarbua*), snubnose pompano (*Trachinotus blochii*), blackhead seabream (*Acanthopagrus schlegelii schlegelii*, as *A. schlegeli*), spotted scat (*S. argus*), blue tilapia (*Oreochromis aureus*, as *O. aurea*), tilapia hybrid (*Oreochromis* sp.), Mozambique tilapia (*O. mossambicus*), largescale mullet (*Liza macrolepis*), and flathead grey mullet (*M. cephalus*). Later, however, Ho and Lin (2004: 174) did not list two species (*T. jarbua* and *S. argus*) as the Taiwanese hosts of *C. epidemicus*. Despite the great efforts of work on the caligid copepods of Taiwan, there is yet no record of *C. epidemicus* from wild fish. For this, Ho and Lin (2004: 61, 337) suspect that the species was introduced into Taiwan by means of human activities. No data on prevalence and intensity of the parasite on cultured fish from Taiwan are available.

## VII. Occurrence in plankton samples

When the population of *C. epidemicus* exploded in the lower Mitchell River, the species was found in plankton samples as well (Hewitt, 1971). While there was no record about the stage of individuals collected, it is most likely that adults detached from the fish host were sampled. Ho (2000) suggested that planktonic individuals of *C. epidemicus* are capable to disperse without “hitch hiking” on the wild fish.

## VIII. Life cycle

Hewitt (1971) was the first to describe the life history of *C. epidemicus* using specimens from the fish

in the lower Mitchell River, Australia. He recognized five instars in his specimens, which were called Stage A, B, C, D, and E, and gave descriptions for each of the stages. He regarded Stage A as “copepodite” and the remaining stages as “chalimus.” Subsequently, the species was reported to have 11 stages: two naupliar, one copepodid, six chalimus, one young adult, and adult stages (Lin and Ho, 1993; Lin et al., 1996; Ho and Lin, 2004). For the use of “young adult”, Ho and Lin (2004) recommended to use it rather than the “preadult” which had been used by Lin and Ho (1993) and Lin et al. (1996) for the species. The number of stages in the life history of *C. epidemicus* is very unusual among its congeners because most species of the genus have only four chalimus stages. Lin et al. (1996) explained that the delay in the development of legs 3 and 4 causes the addition of the fifth and sixth chalimus stages in this species. Moreover, these authors stressed that no moult was observed between the young adult and the adult, which indicates that both stages are identical, i.e., the adult. In other words, *C. epidemicus* has 10 stages in its life cycle. On the other hand, through a study on the life cycle of *Lepephtheirus elegans* and a review of the life cycles of caligid copepods, Venmathi Maran et al. (2013) concluded that the caligids have typically have eight stages (two naupliar, one copepodid, and four chalimus stages, and the adult). As stated above, the fifth and sixth chalimus stages were recognized in *C. epidemicus*.

The life cycle of *C. epidemicus* was studied by Lin and Ho (1993) and Lin et al. (1996) at 24–25°C in the laboratory. It takes approximately 28 h to hatch as nauplii after the appearance of eggs in the newly formed egg sac. It also needs a period of 17 days to develop to an ovigerous female after hatching. The duration for each of the 10 stages excluding the adult in the life cycle is 6 and 14.5 h each for the first and second nauplius stages, two days for the copepodid stage, 12 h for the first chalimus stage, one day each for the second to sixth chalimus stages and 5 days for the young adult stage.

An ovigerous female of *C. epidemicus* has about 21 eggs in each of its egg sacs (Lin and Ho, 1993). The hatching in this species involves a two-step process: breaking of the chamber wall following swelling of the egg and rupture of the egg membrane. The newly hatched, first nauplius is motionless and weakly phototactic. After moulting, the second nauplius

gradually becomes less active and sinks to the bottom. The copepodid is initially very active, moves swiftly in the water but later spends much time on the bottom. However, when a fish is introduced in the water, the copepodid suddenly becomes active and attaches to the fish using the antennae. A frontal organ (including the frontal filament) later appears between the bases of the antennae. The attached copepodid moults into the first chalimus, which attaches to the fish by the frontal filament produced by the copepodid. Passing six moults, the chalimus develops into the young adult. The parasite of the latter stage uses the frontal filament to attach to the host but is easily detached.

As mentioned above, copepodids of *C. epidemicus* are infective to fish hosts. They survived for up to 7, 8, and 5 days at 19, 22, and 26°C, respectively, without food (Hallett and Roubal, 1995). Three- or 4-day-old copepodids were more infective than younger ones.

## IX. Pathogenicity

An epizootic of *C. epidemicus* occurred in the wild populations of southern black bream (*A. butcheri*), flathead grey mullet (*M. cephalus*), yellow-eye mullet (*A. forsteri*), flat-tail mullet (*L. argentea*), and sand grey mullet (*M. elongatus*) from January to March 1968 in the lower Mitchell River, Australia (Hewitt, 1971). In February, fish were found in highly poor condition, and prevalence was very high. Since the epizootic was associated with high water temperature and salinity during a period of severe drought, such environmental factors are considered to have contributed to the development of a large population of the species. While some authors (e.g., Roubal, 1994: 631, 1995: 423; Ho and Lin, 2004: 335) state that *C. epidemicus* killed many fish in this locality, no description is present in Hewitt (1971) about whether the infected fish were dead or not. No similar case of epizootic has happened since Hewitt's (1971) paper.

*Caligus epidemicus* is known to cause mortalities in captive fish. For example, Mozambique tilapia (*O. mossambicus*) were killed by the heavy infection with the parasite in the experimental ponds at the Tainan Branch of the Fisheries Research Institute of Taiwan (Lin and Ho, 1993; Lin et al., 1996). This species of sea louse also killed ten other fish species, blackhead seabream (*A. schlegelii schlegelii*), milkfish (*C. chanos*), Malabar

grouper (*E. malabaricus*), barramundi (*L. calcarifer*), largescale mullet (*L. macrolepis*), flathead grey mullet (*M. cephalus*), spotted scat (*S. argus*), blue tilapia (*O. aureus*), Jarbua terapon (*T. jarbua*), and snubnose pompano (*T. blochii*), cultured in the coastal brackish-water ponds in Taiwan (Ho, 2000).

At the SEAFDEC-AQD in the Philippines, infection with numerous *C. epidemicus* and a few individuals of two other caligids caused a 10% mortality in broodstocks of goldlined spinefoot (*S. guttatus*). The fish showed severe erosion and haemorrhaging of the body surface, fins, and eyes. Barramundi (*L. calcarifer*) infected with *C. epidemicus* also showed disease signs, such as loss of appetite and lethargy with reduced growth rate (Cruz-Lacierda et al., 2011).

The mortality of fish infected with *C. epidemicus* depends on their size (Ho, 2000). In the infection experiment, larval Malabar grouper (*E. malabaricus*) (2–3 cm long) were killed within three minutes after attack by a single parasite, while young fish of the same species (20 cm long) did not die until four or five days later after attack by almost 100 parasites.

When various numbers (one to 100) of either copepodids or adults of *C. epidemicus* were introduced into aquaria in which estuary perchlet (*A. marinus*) of two size groups (1 or 2–4 cm long) were kept, all of 2–4 cm long fish were killed within two days when exposed to 10 or more adults (Hallett and Roubal, 1995). However, fish of 2–4 cm and 1 cm long exposed to 25 or fewer copepodids and to five or fewer copepodids, respectively, were not killed during the five-day period of the experiment. Also, no 1-cm long fish exposed to five or fewer adult parasites were dead. These data indicate that heavy infection with adult *C. epidemicus* causes the mortality in small fish like estuary perchlet. It has been well documented that the feeding activity of adults of caligid copepods, such as the salmon louse *Lepeophtheirus salmonis*, causes severe damages (e.g. extensive epidermal and submucosal erosion, scale loss, and haemorrhage) in infected fish (Wooten et al., 1982; Pike and Wadsworth, 1999).

Based on histopathological observations of the tissues affected by *C. epidemicus* from captive surf bream (*A. australis*), Roubal (1994) stated that no significant pathology could be attributed to either preadult or adult copepods, which is quite different from

the results (mentioned above) obtained by the experimental infection. The author observed that the impact associated with adult copepods were restricted to an imprint of the cephalothrax on the host's epidermis. As one reason for the lack of pathology, he explained that the thick scales of the host may prevent deep wounds. Moreover, he noted that copepodids eroded the host's epidermis and the most extensive tissue response was associated with the redundant frontal filament.

Recently, udonellids have been reported not to take their nutrition from caligids but to feed directly on fish mucus and epithelium (Freeman, 2005). *Udonella myliobati* infecting *C. epidemicus* (Aken'Ova and Lester, 1996) may affect the health of surf bream surf bream (*A. australis*) in Australia.

No work has been done to estimate an economic loss, due to, for example, mortalities and growth retardation caused by *C. epidemicus*, in the farming industry in Asia. Such estimation may be difficult in countries of Southeast Asia, where extensive fish culture using open, earthen ponds dug on the coast is commonly conducted. Moreover, since farmed fish often are not well managed even in the intensive culture cages in those countries, it may be very hard to estimate the loss.

## X. Treatment and control

Freshwater treatment may be used for infection with *C. epidemicus* in the intensive fish culture. At the SEAFDEC-AQD in the Philippines, no infection of the species was observed after a broodstock of goldlined spinefoot (*S. guttatus*) was subjected to flow-through fresh water for 4 h (Cruz-Lacierda et al., 2011).

Roubal (1997) investigated the salinity tolerance *in vitro* of adults and free-living nauplii of the species. Adults can revive in normal salinity after short (15 min) exposure to fresh water but die in longer exposure. They also can survive in salinity from 10 to 50 ppt for at least 40 h. Eggs can develop at >5 ppt but no embryos develop in fresh water. No nauplii hatch or moult at <10 ppt. The author recommended that freshwater treatment is done repeatedly for extended periods.

There is a short note (Chinabut, 1996) reporting that various types of insecticides have been used in the treatment of *C. epidemicus* (as *Caligus* sp., see the Taxonomy and morphology section) in both closed and open water system in Thailand. However, no detailed

information was published about this chemical treatment. In the same note (Chinabut, 1996), use of cleaner fish has been recommended as biological control to remove the parasite from farmed fish, but there has been no trial or practice at fish farms.

## XI. Conclusions and future research

*Caligus epidemicus* is a pathogenic parasite of wild and captive fish. In addition to its wide distribution in the tropical, subtropical and temperate waters of the Indo-West Pacific region in the Southern and Northern hemispheres, the species exhibits very low host specificity. It is very likely that the number of fish species as hosts of *C. epidemicus* increases through the faunal surveys on the parasitic copepods in the countries of the Indo-West Pacific region.

Much remains unknown about the ecology of *C. epidemicus* at fish farms. In Southeast Asia, two types of culture methods are conducted: intensive culture using floating cages in coastal waters and extensive culture using wide earthen ponds on the coast. As fish density in intensive culture is much higher than that in extensive culture, the parasite may propagate easily in the former culture. Moreover, water temperatures in tropical countries of Southeast Asia are stably high, which may allow the parasite to proliferate throughout the year. We need investigations on the population dynamics of the parasite in different culture systems and the occurrence of the parasite on wild fish near culture sites. We also need experimental work in the laboratory to study the impact of different water temperatures on the growth and reproduction of the parasite.

Little work has been done on the pathology of infection with *C. epidemicus*. To date, only Roubal (1994) reported on the histopathology of infection of fish with *C. epidemicus*. The pathology caused by this parasite should be studied using different techniques. Furthermore, as there is no specificity of the parasite to particular fish species, juveniles of many species of marine fish produced at hatcheries and those of saline-tolerant tilapias can be used as hosts for experimental infection in the laboratory, which may enable us to assess quantitatively the impact of the parasite of different developmental stages and intensities of infection on the fish host.

While it was mentioned that various insecticides

have been used for control of *C. epidemicus* (as *Caligus* sp., see the Taxonomy and morphology section) in Thailand (Chinabut, 1996), nothing is known about the efficiency of such chemical treatment and sensibility of the parasite to the chemicals used. It is desirable to reduce the frequent use of chemicals for the sake of the conservation of aquatic environments and the safety of food fish produced at fish farms. We need much work to establish efficient measures of control and treatment against infection with *C. epidemicus*.

Since farmed produced fish, such as groupers, are commonly transported alive between countries in Southeast Asia, it is highly plausible that *C. epidemicus* has been introduced into various parts of this region. Parasitological examination of those internationally transported fish is needed from a quarantine viewpoint.

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