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Occurrence of *Caligus lalandei* Barnard, 1948 (Copepoda, Siphonostomatoida) on Amberjacks (*Seriola* spp.) in the Western North Pacific

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ABSTRACT—*Caligus lalandei* Barnard, 1948 (Caligidae, Siphonostomatoida) is redescribed based on the materials occurring in the waters of East Asia. This parasitic copepod is so far known only from the amberjacks (*Seriola* spp.) outside of the western North Pacific. However, in 1989 it was discovered on "mojako" (juveniles) of *Seriola quinqueradiata* collected off Azuma-cho and Yamakawa-cho in Kogoshima Prefecture, Japan. In 1998 it appeared on *Seriola lalandi* caught in a set net installed off the coast near Kangreung, Korea and in the following year it was found parasitic on *S. lalandi* cultured in Tsukumi of Oita Prefecture, Japan. The possible origin of the occurrence of *C. lalandei* in Japan and Korea is discussed; but, due to several unknown factors, it is inconclusive at this point of time whether the occurrence of *C. lalandei* in Japan and Korea is due to the "natural" or "artificial" process. However, the parasite has well established in its new habitat - the northern region of the western North Pacific.

INTRODUCTION

Four species of amberjacks (*Seriola*) are known from the western North Pacific, they are: Japanese amberjack (*Seriola quinqueradiata* Temminck & Schlegel), yellowtail amberjack (*Seriola lalandi* Valenciennes), greater amberjack [*Seriola dumerili* (Risso)], and almaco jack (*Seriola rivoliana* Valenciennes) (Forese and Pauly, 2000). Of these four species *S. quinqueradiata* is economically most important in Japan and Korea. It is commonly called "yellowtail" and has been cultured in a large scale since the 50's. The seeds for this culture, commonly called "mojako" in Japan, are gathered from the sea off Kyushu, Shikoku, and central Honshu (Fig. 1) for the culture in Japan and from the Tsushima Strait for the culture in Korea. Due to its commercial importance, the parasites occurring on *S. quinqueradiata* have been well studied in Japan in the past.

So far, only two species of sea lice (Caligidae, Siphonostomatoida, Copepoda), *Caligus seriolae* Yamaguti, 1936 and *Caligus spinosus* Yamaguti, 1939, are known parasitic on both wild and cultured *S. quinqueradiata*. However, in 1989 the juveniles of *S. quinqueradiata* collected off Azuma-cho and Yamakawa-cho in Kagoshima Prefecture, Japan (Fig. 1) for seeds to be used in the local yellowtail culture were found carrying a species of *Caligus* new to East Asia. In 1998 the same species of sealouse was noticed parasitic on *S. lalandi* caught in a set net installed off the central east coast of Korea (about 60 km north of Kangreung) and a year later it was found on *S. lalandi* cultured at Tsukumi in Oita Prefecture, Japan (Fig. 1). Studies of the sealice obtained from these four locations revealed that they are not only conspecific but also identifiable with *Caligus lalandei* Barnard, 1948.

Caligus lalandei was first reported from *S. lalandi* caught in Kalk Bay of South Africa (Barnard, 1948). Subsequently, it was reported from the same species of fish taken in Chile (Baeza and Castro, 1980) and New Zealand (Jones, 1988), and also from New Zealand on another species of amberjack, Samson fish *Seriola hippos* Günther. *Caligus tenuicaudatus* Shiino, 1959, parasitic on "*Seriola dorsalis* (Gill)" (= *S. lalandi*) in Baja California, Mexico was considered by Baeza and Castro (1980) to be a junior synonym of *C. lalandei*. If the synonymization is correct, then, our discovery is the first record of *C. lalandei* in the western North Pacific. Since the original description of *C. lalandei* is inadequate, lacking the details of the fine structure of the appendages that are indispensable in the modern taxonomy of Copepoda, the type specimens kept at South African Museum in Cape Town, South Africa were restudied. Also, in order to confirm Baeza and Castro's (1980) relegation of *C. tenuicaudatus* to the synonym of *C. lalandei*,

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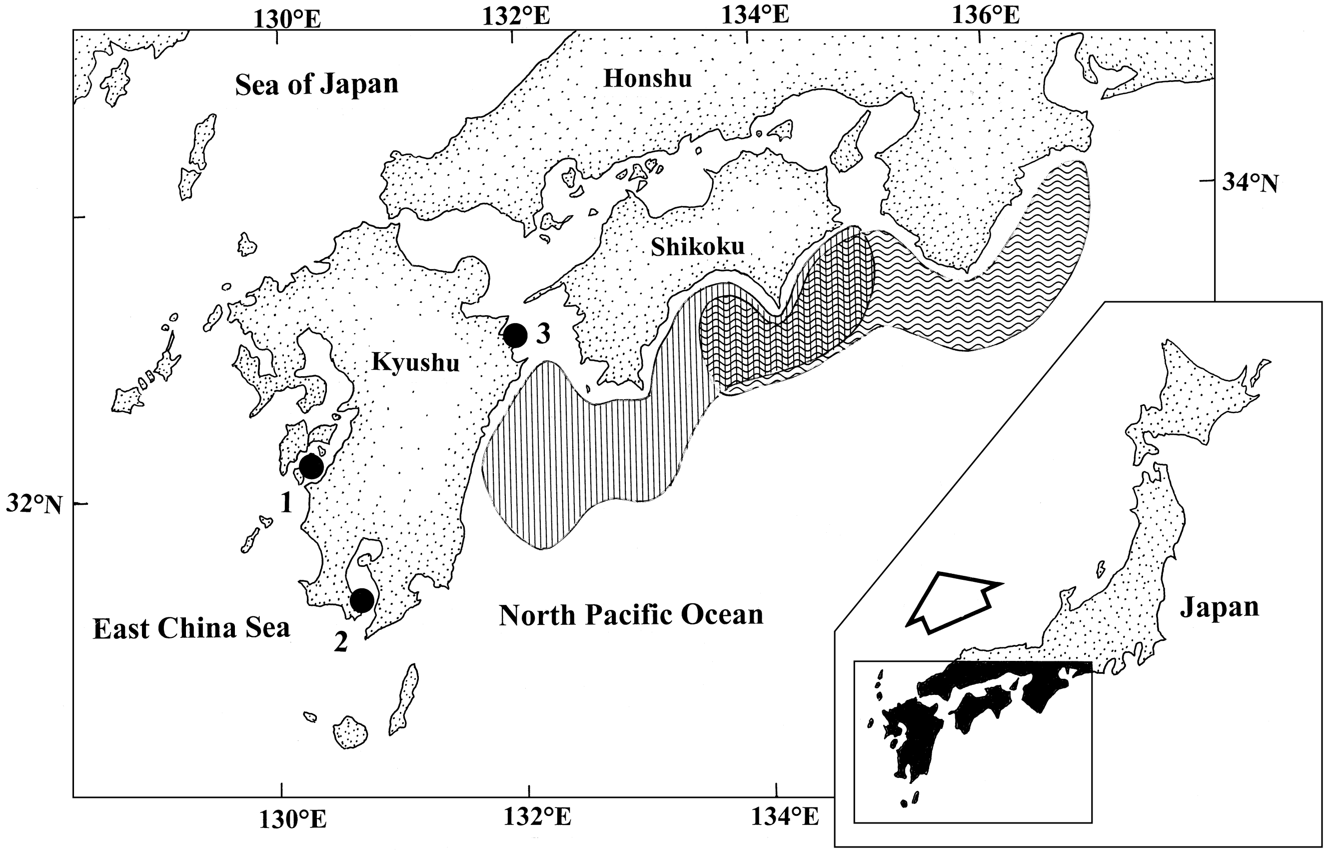

Fig. 1. Map showing the places in Japan where the materials studied in the present study were obtained. Area of the North Pacific Ocean shown in vertical lines indicates the collection site of Cruise Waka 1 and that in wavy lines, of Cruise Waka 2. Arabic numerals in Kyushu indicate the site where *Caligus lalandei* was found: 1=Azuma-cho, 2 =Yamakawa-cho, and 3=Tsukumi.

the type specimens of *C. tenuicaudatus* kept in the Faculty of Aquatic Bioresources at Mie University in Tsu, Japan were also reexamined.

In this paper, in addition to redescribe *C. lalandei*, the possible origin of this parasite in the western North Pacific as well as its current status of parasitism in the region are discussed.

MATERIALS AND METHODS

Materials used in the present study were taken from the following four collections: 10♀♀ and 1♂ collected from the juveniles of *S. quinqueradiata* gathered for culture off Azuma-cho in Kagoshima, Japan on 15 May, 1989; 2♀♀ and 1♂ collected from the juveniles of *S. quinquerqdiata* gathered for culture off Yamagawa-cho in Kagoshima, Japan on 17 May, 1989; 6♀♀ and 1♂ on *S. lalandi* collected on 2 July, 1998 near Kangreung, Korea; and 4♀♀ and 8♂♂ collected from "*Seriola aureovittata* Temminck & Schlegel" (= *S. lalandi* according to Froese and Pauly, 2000) cultured at Tsukumi in Oita, Japan on 25 June, 1999. In order to assess the status of *C. lalandei* parasitism in Japan, the "mojako" (juveniles) of *S. quinqueradiata* collected off Kyushu, Shikoku, and central Honshu (Fig. 1) by R/V *Wakashio maru* during her Waka Cruise in April and June 1996 were also examined.

The juveniles of *S. quinqueradiata* preserved in formaldehyde were examined in water under the dissection microscope. The copepod parasites were removed from their hosts and preserved in 70% alcohol. The preserved specimens of *Caligus* were dissected in a drop of lactic acid and the removed body parts and appendages were studied under a dissection microscope by employing the hanging-drop method devised by Humes & Gooding (1964). The type specimens of *C. lalandei* (A8517, containing 4♀♀ and 1♂ all partially dissected or damaged) kept in the collections of the South African Museum and that of *C. tenuicaudatus* (S399, containing 2♀♀) kept in the Faculty of Bioresources at Mie University were examined in a drop of lactic acid without dissection. Drawings were made with the aid of a camera lucida.

RESULTS

Redescription of *C. lalandei*

The following redescription is based on the observations of adult specimens collected from Korea and Japan. Inasmuch as the sealouse is new to this area, part of the adult specimens examined in this study have been deposited in the National Science Museum in Tokyo, Japan. Below are their catalogue numbers: NSMT-Cr 13937 (6♀♀ and 2♂♂ from Azuma-cho, Kagoshima, Japan), NSMT-Cr 13938 (4♀♀ and 4♂♂ from Tsukumi, Oita, Japan), and NSMT-Cr 13939 (4♀♀ from Kangreung, Korea).

FEMALE. Body (Fig. 2A) 7.85 (7.57–8.63, n=10) mm long, excluding setae on caudal rami. Cephalothoracic shield longer than wide, 3.28×2.88 μm. Genital complex also longer than

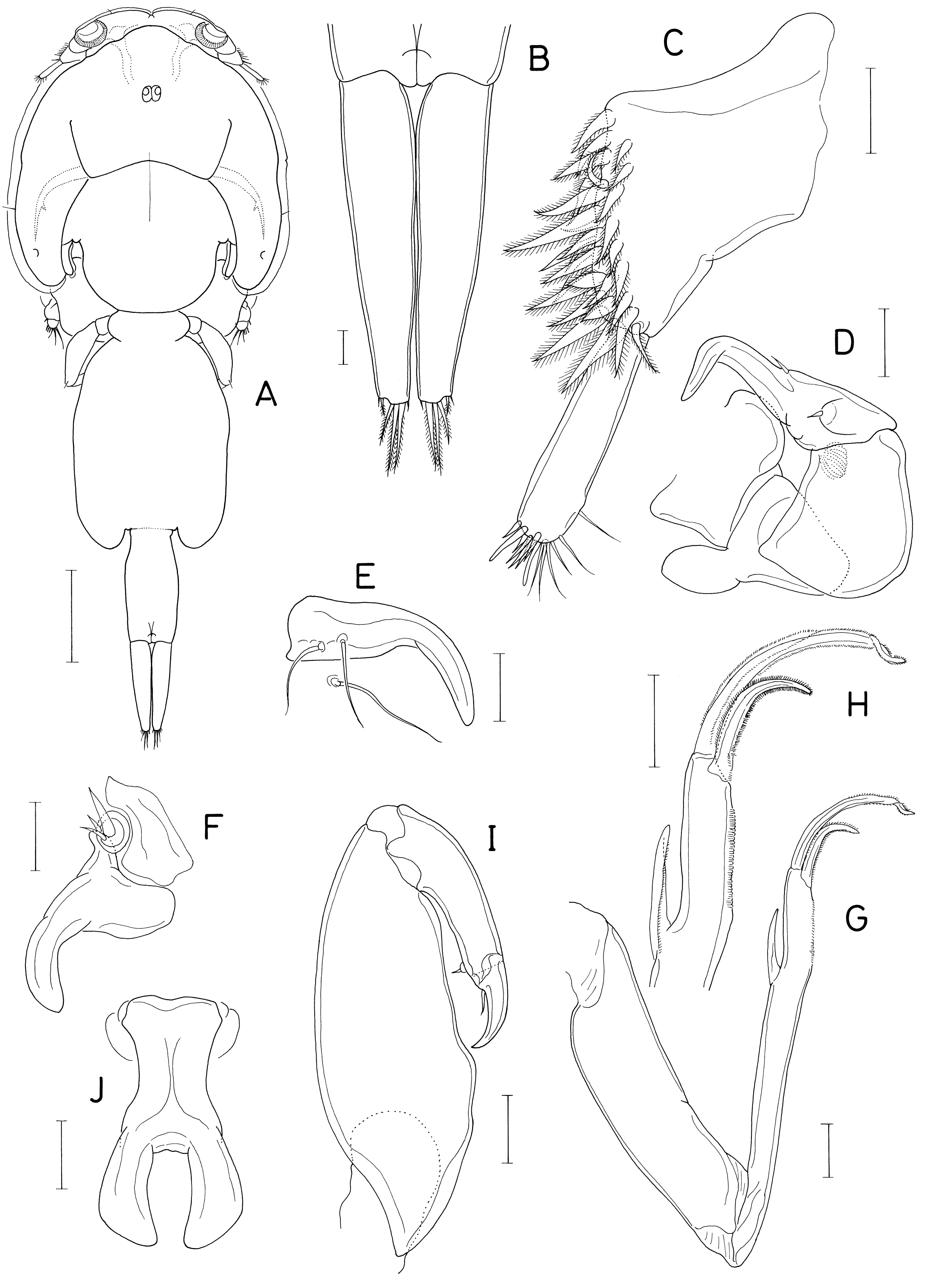

Fig. 2. *Caligus lalandei* Barnard, female. A, habitus, dorsal. B, caudal rami, dorsal. C, antennule, dorsal. D, antenna, ventral. E, postantennal process, ventral. F, maxillule, ventral. G, maxilla, ventral. H, terminal part of maxilla, ventral. I, maxilliped, medial. J, sternal furca, ventral. Scale bars: A=1 mm, B–J=0.1 mm.

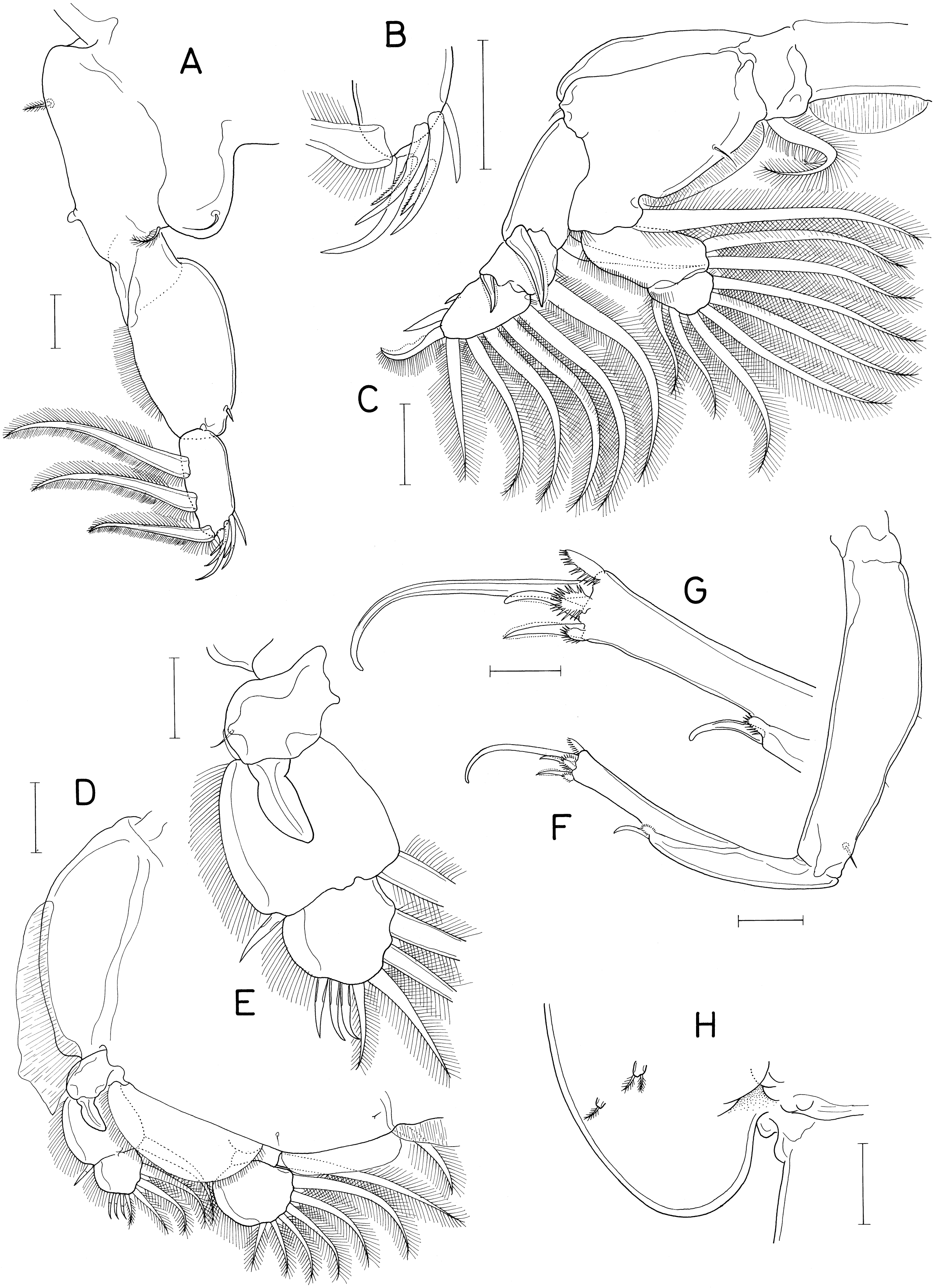

Fig. 3. *Caligus lalandei* Barnard, female. A, leg 1, anterior. B, terminal end of leg 1 exopod, anterior. C, leg 2, anterior. D, leg 3, anterior. E, exopod of leg 3, anterior. F, leg 4, anterior. G, terminal part of leg 4 exopod, anterior. H, posterolateral portion of genital complex, ventral. Scale bars: A, B, E, G, H=0.1 mm; C, D, F=0.2 mm.

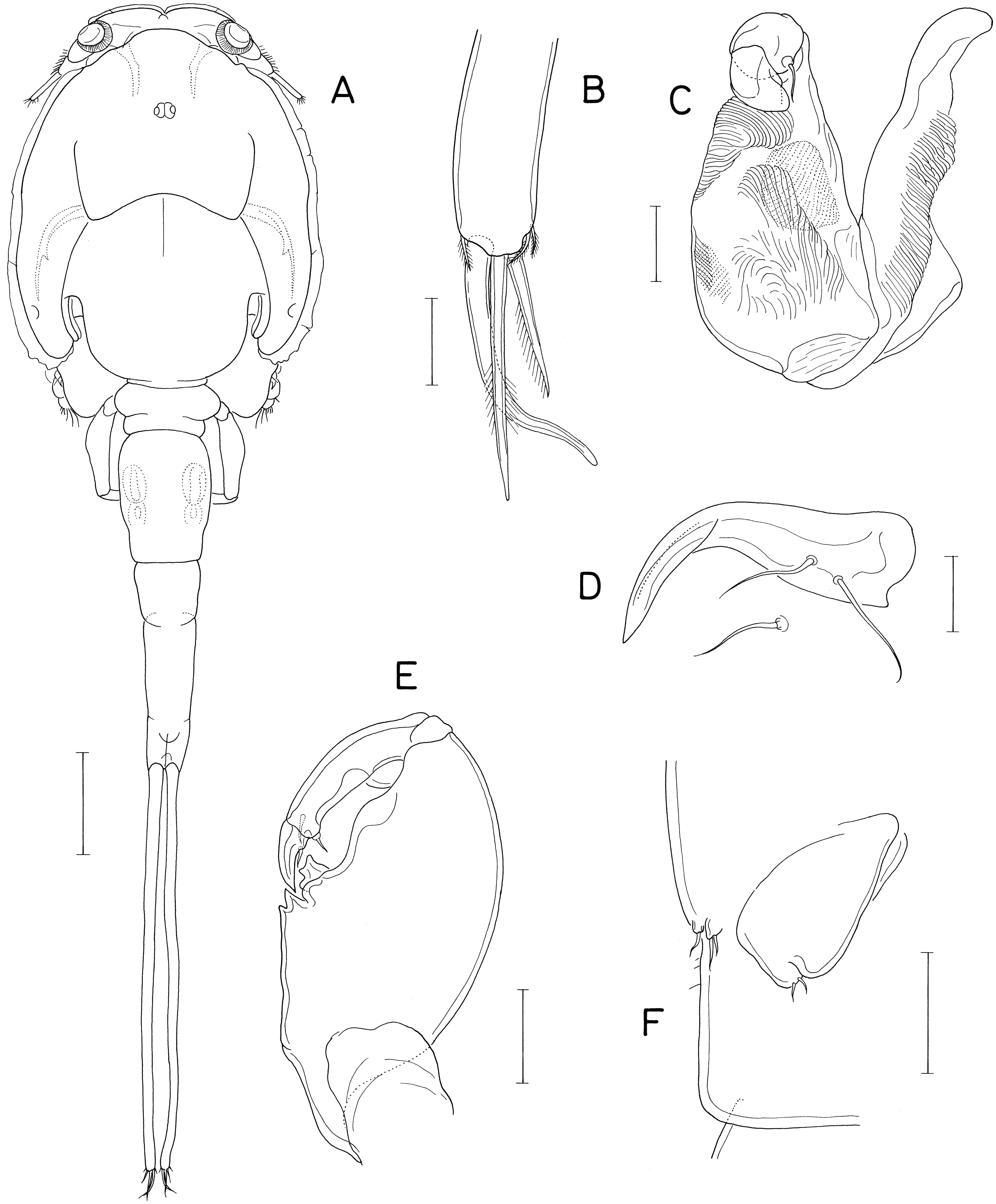

Fig. 4. *Caligus lalandei* Barnard, male. A, habitus, dorsal. B, tip of caudal ramus, dorsal. C, antenna, ventral. D, postantennal process, ventral. E, maxilliped, medial. F, posterolateral portion of genital complex, ventral. Scale bars: A=1 mm; B, C, D=0.1 mm; E, F=0.2 mm.

wide, with bluntly protruded posterior corners. Abdomen 1-segmented, with slightly constricted anterior region and measuring 1.25×0.58 mm. Caudal ramus (Fig. 2B) 4.45 (980×220 µm) times longer than wide and tipped with 6 unequal setae of which the 4 central ones are pinnate.

Antennule (Fig. 2C) 2-segmented; proximal segment with

28 plumose setae on anterodistal surface; distal segment slender, about 4 times longer than wide and armed with a subterminal seta on posterior margin and 11 setae plus 2 aesthetascs on distal margin. Antenna (Fig. 2D) 3-segmented; proximal segment smallest, with blunt process at posteromedial corner; second segment rectangular and unarmed; distal segment a sharply pointed, curved claw bearing 2 setae, one in proximal region and other one in middle region. Postantennal process (Fig. 2E) large, bearing 2 small papillae with each carrying a simple seta. Another similar papilla located nearby on sternum. Mandible of usual form in *Caligus*. Maxillule (Fig. 2F) comprising bluntly pointed, bent process and papilla with 3 setae. Maxilla (Fig. 2G) 2-segmented; proximal segment (lacertus) unarmed; slender distal segment (brachium) carrying subterminal hyaline membrane (Fig. 2H, with rolled edge and assuming spiniform) on outer edge and 2 unequal elements (calamus and canna) terminally. Distal margin of brachium on medial surface finely serrated (Fig. 2H). Maxilliped (Fig. 2I) 3-segmented; proximal segment (corpus) largest and unarmed; middle and distal segments fused to form strong claw, carrying medial papilla tipped with small seta and another medial seta at base of terminal hook (distal segment). Sternal furca (Fig. 2J) with spatula-like tines.

Armature on rami of legs 1–4 as follows (Roman numerals indicating spines and Arabic numerals, setae):

	Exopod	Endopod
Leg	11-0; IV,3	(vestigial)
Leg 2	I-1; I-1; II,I,5	0-1; 0-2; 6
Leg 3	I-0; 1-1; 3,4	0-1; 6
Leg 4	I-0; III	(missing)

Leg 1 (Fig. 3A) protopod with naked outer seta on coxa and short, plumose, outer and inner seta on basis; vestigial endopod small and unarmed; first segment of exopod with row of long spinules on posterior edge; middle 2 of 4 terminal elements on last segment of exopod (Fig. 3B) with accessory process. Leg 2 (Fig. 3C) coxa small, with large plumose seta on posterior edge; basis with small naked outer seta and medial seta just dorsal to marginal membrane. Leg 3 (Fig. 3D) protopod (apron) with outer, marginal membrane; first segment of exopod with outer setule and its large, outer spine with constricted base (Fig. 3E). Leg 4 (Fig. 3F) protopod with short, simple outer seta in addition to 2 setules in middle region of outer margin; pectens on exopod segments at insertion of each of 4 spines (Fig. 3G). Leg 5 represented by 2 small papillae on ventral side of posterolateral lobe of genital complex (Fig. 3H), 1 tipped with small plumose seta, other with 2 similar setae.

Table 1. Sealice (*Caligus*) recovered from the "mojako" of Japanese amberjack (*Seriola quinqueradiata*) collected in western North Pacific off Kyushu, Shikoku, and central Honshu in 1996 during Cruise Waka 1 (in April) and Waka 2 (in June) of R/V *Wakashio maru* Abbreviations: AD = adult, CH1= first chalimus, CH2 = second chalimus, CH3=third chalimus, OV=ovigerous, and PA=preadult.

Coll. Date	Cruise	Station	Fish	Parasite		
				Name	Stage	Number
96-04-19	Waka 1	2-10	No. 01	*C. lalandei*	CH 1	1
96-04-21	"	4-28	No. 02	"	CH 1	1
96-04-22	"	5-01	No. 33	"	CH 3	1
	"	5-02	No. 21	"	CH 2	1
			No. 37	"	CH 2	1
	"	5-03	No. 05	"	CH 2	1
96-04-23	"	6-04	No. 07	"	CH 2	1
	"	6-11	No. 04	"	CH 2	1
	"	6-19	No. 33	"	CH 2	1
	"	6-22	No. 01	"	CH 3	1
			No. 04	"	CH 1	1
			No. 05	"	CH 2	1
96-04-25	"	8-06	No. 12	"	CH 3	1
			No. 13	"	CH 2	1
					CH 3	1
96-06-13	Waka 2	2-05	No. 01	"	CH 1	1
96-06-14	"	3-08	No. 04	*C. spinosus*	OV♀	1
96-06-15	"	4-18	No. 03	*C. lalandei*	CH 2	1
		4-19	No. 03	*C. spinosus*	CH 2	1
96-06-16	"	5-01	No. 18	"	AD♂	1
		5-02	No. 06	"	PA♀	1
		5-10	No. 18	*C. lalandei*	CH 2	2
96-06-19	"	6-07	No. 01	*C. spinosus*	CH 2	1
				"	CH 3	1
		6-15	No. 08	"	CH 2	1
				"	OV♀	1
		6-17	No. 01	"	CH 3	1

MALE. Body (Fig. 4A) 13.48 (10.96–18.84, n=10) mm long, excluding setae on caudal rami. Cephalothoracic shield longer than wide, 3.70×2.93 mm. Genital complex also longer than wide, 1.27×. 0.93 mm. Abdomen indistinctly 3-segmented, with middle segment twice longer than each of other segments. Caudal ramus extremely slender, nearly 32 times longer than wide (4,000×125 µm), tipped with 3 small plumose setae and another 3 unequal elements (Fig. 4B). Antenna (Fig. 4C) 3-segmented; proximal segment slender with corrugated medial surface; middle segment largest, armed with 6 corrugated pads; terminal segment smallest, with medial seta in basal region and indistinctly triple-lamellate cuticular flap at distal end. Postantennal process (Fig. 4D) generally as in female, but slightly sharper. Maxilliped (Fig. 4E) different from female in bearing 2 bifid medial processes on corpus and small terminal seta on middle segment in addition to distomedial papilla tipped with seta. Both legs 5 and 6 (Fig. 4F) present; while leg 5 appearing as in female, leg 6 represented by 2 setae at tip of ventrolateral ridge.

Chalimus larvae on the juveniles of *S. quinqueradiata*

Two species of *Caligus* were recovered from the juveniles of *S. quinqueradiata* collected in the western North Pacific off Kyushu, Shikoku, and central Honshu in 1996 (Table 1). They are *C. spinosus* Yamaguti, 1939 in addition to *C. lalandei*. These two species of sea lice can be easily distinguished by the structure of their caudal rami, it is long (at least 4 times as long as wide) in *C. lalandei* and short (less than 1.5 times as long as wide) in *C. spinosus*. Although this difference in size is not so great during the chalimus stages, it is still detectable, with more than twice as long as wide in *C. lalandei*. This size discrepancy is also applicable in distinguishing between *C. lalandei* and *C. seriolae*.

The results of examinations of 646 juveniles of *S. quinqueradiata* (measuring 17–83 mm in fork length) collected in April 1996 and another 295 juveniles of the same species (measuring 20–127 mm in fork length) collected in June 1996 were summarized in Table 1. While the juveniles collected in April were infected with only the chalimus stages of *C. lalandei*, those collected in June were largely infected by *C. spinosus* with both adult and larval stages. The prevalence of sea lice infection on the juveniles collected in April was 2.17% (14/646) and for those collected in June was slightly higher, 3.39 (10/295)%. The mean intensity of infection for *C. lalandei* in April was 1.00 (1–2) and went up slightly in June, with 1.33 (1–2) parasites for each infected fish.

DISCUSSION

Identity and distribution of *C. lalandei*

Inasmuch as the type specimens of *C. lalandei* deposited in the South African Museum (A8517) are not intact (damaged or partially dissected) and the specimens collected from the amberjacks (*Seriola* spp.) of Japan and Korea bear a close resemblance with the South African specimens, the above redescription of *C. lalandei* was decided to be made based on the newly collected materials. As far as reexamination of the type specimens of *C. lalandei* is concerned, no appreciable morphological discrepancy was detected except for the size difference. According to Barnard (1948), the length of the female *C. lalandei* from South Africa is 10.5 mm and that of the male, 16 mm. A close comparison of our specimens with the type specimens of *C. tenuicaudatus* (S 399) deposited in the Faculty of Bioresources at Mie University also shows that they are identical, even the size is comparable between them. *C. tenuicaudatus* is only known of the female and according to Shiino (1959) its body length is 8.32 mm, within the range of our specimens. Therefore, Baeza and Castro's (1980) proposal to relegate *C. tenuicaudatus* Shiino, 1959 to the junior synonym of *C. lalandei* Banard, 1948 is supported.

The most outstanding characteristic of *C. lalandei* is exhibited in its caudal ramus. It is long, so unusually long in particular in the male (see Fig. 4A) that makes one wonder how does "he" maneuver in moving on the fish body. *Caligus* is the largest genus of parasitic copepods containing more than 250 species and a great majority of them are known only for the female. However, among so many congeners, only one other species, *C. bennetti* Causey, 1953, has a pair of long caudal rami in the female comparable to *C. lalandei*, with its length greater than 4 times of the width. All of the rest have, at most, a caudal ramus about twice as long as the width. Nevertheless, *C. bennetti* differs greatly from *C. lalandei*. It has in the female a greatly elongated abdomen, lacking the sternal furca, and bearing a pair of leg 4 with 3-segmented (instead of 2-segmented) exopod armed with 5 (instead of 4) spines. *Caligus bennetti* is so far known only from the Atlantic tripletail *Lobotes surinamensis* (Bloch) occurring in the Gulf of Mexico (Causey, 1953) and Caribbean Sea (Ho and Bashirullah, 1977).

Caligus lalandei is host specific to *Seriola*. So far it is known parasitic on three species of this genus, namely on yellowtail amberjack (*S. lalandei*) from South Africa (Barnard, 1948), Mexico (Shiino, 1959; called "*Seriola dorsalis*"), Chile (Baeza and Castro, 1980; called "*Seriola mazatlana* Steindachner"), New Zealand (Jones, 1988; called "*Seriola grandis*"), Korea and Japan (present report); on Samson fish (*S. hippos*) from New Zealand (Jones, 1988); and on Japanese amberjack (*S. quinqueradiata*) from Japan (present report). It is, however, still unknown from the amberjacks of the Atlantic Ocean.

Origin of *C. lalandei* in Japan

Although the culture of yellowtail (*S. quinqueradiata*) began in Japan in 1927, it did not become a major aquafarming industry until 1950 when the Inland Sea became the center of the yellowtail culture. Since then the production of cultured amberjacks (largely *S. quinqueradiata* with small amount of *S. dumerili* and *S. lalandi*) grew rapidly and steadily and went from less than 100 mt/yr in the 70's to 160,000 mt/yr in the 90's (Anonym, 1997). During this growing period of yellowtail culture, no sea louse other than *C. spinosus* was recorded from Japan plaguing occasionally the yellowtail farm (Fujita *et al.*, 1968; Izawa, 1969). Before then, *C. spinosus* was already known from the amberjacks caught in the wild. It was reported by Yamaguti (1939) on *S. quinqueradiata* and by Shiino (1960) on "*Seriola aureovittata*" (=*S. lalandi*). In 1978 when one of the co-author (JSH) studied for four months (from August to November) the copepod parasite fauna of Sado Island (in the Sea of Japan), he had an opportunity to examine daily the amberjacks (*S. quinqueradiata* and *S. lalandi*) caught in a set net installed off Tassha where the Sado Marine Biological Station of Niigata University was located. At that time only *C. spinosus* was found. Therefore, it is reasonably certain to say that *C. lalandei* is not a parasite in the western North Pacific. However, curiously, 20 years later the parasite was discovered by one of us (IHK) from *S. lalandi* caught off the east coast of Korea (facing the Sea of Japan) in the vicinity of Kangreung.

Owing to the rapid expansion of the yellowtail culture industry coupled with occasional shortage of juveniles gathered from the sea off Kyushu, Shikoku, and central Honshu, the yellowtail farmers in Japan started in the late 80's to import the seeds of greater amberjack (*S. dumerili*) from Hainan, China for culture (Anonym, 1997). With the sudden appearance of *C. lalandei* on the amberjacks in Japan and Korea, naturally, the imported juveniles were suspected first to be the carrier of this exotic sealouse, because it has been established that the occurrence of an exotic species of Monogenea, *Neobenedenia girellae* (Hargis, 1955), on the cultured marine fishes in Japan in the 90's was due to the importation of juvenile *S. dumerili* from Hainan for culture (Ogawa *et al.*, 1995). However, there is no direct evidence to support this speculation, for *C. lalandei* is yet to be reported from the imported juveniles of *S. dumerili* (personal communication with Mr. T. Yamashita and Mr. M. Fukudome).

As noted above, *C. lalandei* is unknown from the amberjacks of the western North Pacific including those occurring in the South China Sea where Hainan is located. However, since the copepod parasite fauna of the South China Sea is very poorly known, we cannot consider at this point of time that *C. lalandei* is not present on the amberjacks of *S. dumerili* and/or *S. lalandi* occurring in the southern part of the western North Pacific.

If *C. lalandei* is a parasite on the amberjacks in the South China Sea and the juveniles of *S. dumerili* imported into Japan for culture did not carry *C. lalandei*, the sealouse in question still can appear on *S. lalandi* in the waters of Japan and Korea if there is migration of amberjacks into the northern waters from the south that happen to carry *C. lalandei*. However, since we know nothing about the migration of *S. lalandi* and *S. dumerili* in the western North Pacific, this speculation is also inconclusive. Therefore, at this point of time, it is impossible to state with certainty whether the occurrence of *C. lalandei* in Japan and Korea is due to the "natural phenomenon" (recent immigration of the infected amberjacks) or "artificial activity" (importation of infected juvenile amberjacks for culture).

Current status of *C. lalandei* parasitism in Japan

It is also impossible to determine when *C. lalandei* was introduced either artificially or naturally into the waters of Japan and Korea. But, nevertheless, it is certain that the parasite has well established in its new habitat in the western North Pacific. The discovery of both adults and chalimus larvae on the juveniles of *S. quinqueradiata* is the proof, because this species of amberjack is not the original host and it is restricted in the Northwest Pacific ranging from Japan and the eastern Korean Peninsula to the Hawaiian Islands (Anonym, 1997; Froese and Pauly, 2000).

As far as we are aware, *C. lalandei* has not yet caused serious problem to yellowtail culture in Japan like *C. spinosus* did in the past. However, this is not to say that it will not (Ho, 2000). On the contrary, we believe it will cause more serious problem if there is an outbreak of this parasite, because it is larger than *C. spinosus*. While on the average *C. spinosus* is 5 mm long, *C. lalandei* is nearly twice that size. The larger the parasite the more damage it can cause to the host. For example, in the farming of Atlantic salmon (*Salmo salar* L.) in Europe, the damages caused by the larger parasitic copepod, *Lepeophtheirus salmonis* (Krøyer), are far greater than the smaller confamilial species, *Caligus elongatus* Edwards (Boxshall and Defaye, 1993; Pike and Wadsworth, 1999).

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