

A New Asymmetrical Near-bottom Calanoid Copepod, *Paramisophria platysoma*, with Observations of Its Integumental Organs, Behavior and In-situ Feeding Habit^{1), 2)}

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Abstract

A new hyperbenthic calanoid copepod, *Paramisophria platysoma* collected from the littoral and sublittoral zones on the Pacific coast of Japan is described. The new species has a remarkably asymmetrical body with the left lateral side compressed. However, a SEM examination revealed that the integumental organs of the female cephalothorax are nearly symmetrically distributed. Three different patterns of behavior of living copepods were observed using a VHS tape recorder system: (1) usual, continuous swimming with the compressed left lateral side parallel to the bottom, using antennae 2, mandibular palps and maxillae 1; (2) fast "jumping" possibly with flaps of swimming legs; and (3) resting with the left lateral side just on the bottom. The gut content analysis of adult females showed that they fed carnivorously on benthic harpacticoid nauplii and copepodids. Their asymmetrical bodies, peculiar swimming behavior and feeding habit dependent on benthic organisms seem to be adaptations to a hyperbenthic life in shallow waters.

Near-bottom calanoid copepods have been collected from shallow waters to deep waters of over 1000 m deep (cf. BOWMAN & GONZÁLEZ 1961, BRADFORD 1969, CAMPANER 1977, FOSSHAGEN 1968a, b, 1970a, b, GRICE 1972, OHTSUKA 1984, 1985, OHTSUKA & HIROMI 1987). During the course of investigations of near-bottom plankton in South Japan a new species of *Paramisophria* (Copepoda: Calanoida) was found in the littoral and sublittoral zones on the Pacific coast. The present paper deals with the description of the new species with discussions of its integumental organs, behavior, in-situ feeding habit, and zonation of 2 species of *Paramisophria* in the same locality.

Materials and Methods

The specimens of this species were collected in lower littoral and upper sublittoral zones (less than about 1m deep) on the northern and southern beaches of the Seto Marine Biological Laboratory (Tanabe and Kanayama Bays) during low tides from 1985 to 1989 using weighted conical nets or hand-nets by skin diving. The

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²⁾ 非対称の体を持つ近底層カラヌス目カイアシ類の新種 *Paramisophria platysoma* の記載及びその皮殻器官、行動、天然餌料

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bottom sediment was composed of pebbly coarse sand. The specimens were fixed in 10 % neutralized formalin/seawater immediately after capture for examinations of body, integumental organs and gut contents. The integumental organs of cephalothoraxes of 6 females were examined with a SEM (Joel JSM-T20). Swimming behavior was recorded by a VHS tape recorder system (Hitachi KP-C210; Victor BR-S610) for living copepods sorted from samples and transferred into small petri-dishes (7cm in diameter, 3.5 cm in depth) containing filtered seawater under a dissecting microscope with a transmitted light source. At least 10 living individuals were observed for this purpose. For gut content analysis, 10 intact adult females were dissected, and the guts taken from the cephalothoraxes were mounted on glass slides. The contents were examined by a differential interference microscope ($\times 400$). Percentage of occurrence of a certain food item in guts is shown as follows: (Percentage of occurrence of a certain food item) = (Number of individuals feeding on a certain food item)/10 $\times 100$.

Description

Paramisophria platysoma, n. sp.

(Figs. 1-4)

Materials examined. All specimens were taken from the northern (Tanabe Bay) and southern (Kanayama Bay) beaches of the Seto Marine Biological Laboratory. Holotype: adult female, dissected and mounted on glass slides (18 II 1985, Tanabe Bay). Allotype: adult male, dissected and mounted on glass slides (12 V 1987, Kanayama Bay). Paratypes: 2 adult females, dissected and mounted on glass slides (18 II 1985, Tanabe Bay); 2 adult females, whole specimens (18 II 1985, Tanabe Bay); adult male, dissected and mounted on glass slides (14 V 1987, Kanayama Bay). The types are deposited at the Seto Marine Biological Laboratory.

Female. Body (Fig. 1A) 1.08 mm long; prosome considerably asymmetrical with left side compressed and right one smoothly curved in dorsal view; rostrum (Fig. 1B) pointed downward with a pair of rostral filaments; cephalosome separated from pediger 1; pedigers 4 and 5 fused; posterior corner of pediger 5 (Fig. 1C, D) with dorso-lateral process and round lateral lobe. Urosome (Fig. 1A, D, E, F) 4-segmented; genital segment asymmetrical, with right ventro-lateral and left ventral oviduct openings; copulatory pore located on left ventro-lateral side; segment 2 as long as segment 3; anal segment short, half length of preceding segment; furcal ramus somewhat depressed with 4 terminal plumose setae, postero-dorsal setule and subterminal outer seta. Left antenna 1 (Fig. 1G) longer than right (Fig. 1H); both 21-segmented. Antennae 2 (Fig. 1I, J) asymmetrical, 2nd segment of right endopod about 1.4 times as long as that of left, and 1st segment of right endopod and 3 proximal segments of right exopod also slightly longer than those of left. Mandible (Fig. 2A) symmetrical; gnathobase with 4 teeth; rounded protuberance present at base of outermost tooth; basipod bearing 2 terminal setae of unequal lengths; endopod absent; exopod 4-segmented. Maxilla 1 (Fig. 2B)

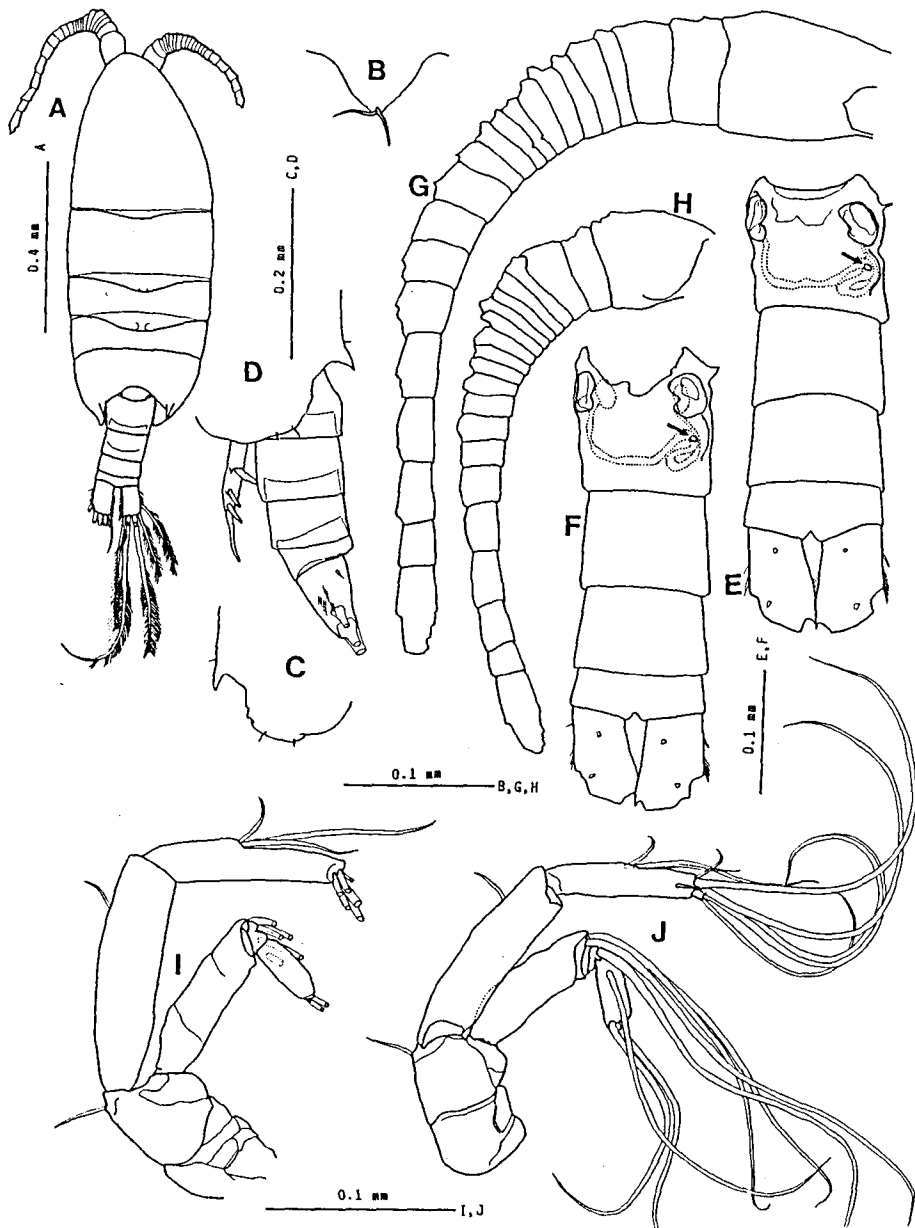


Fig. 1. *Paramisophria platysoma*, n. sp. Female (A-E, G-J: holotype; F: paratype). A. Habitus, dorsal view; B. Rostrum, ventral view; C. Pediger 5, right lateral side; D. Pediger 5 and urosome, left lateral side; E, F. Urosome, ventral view, copulatory pores indicated by arrows; G. Left antenna 1, all setae, hairs and aesthetascs omitted; H. Right antenna 1, all setae, hairs and aesthetascs omitted; I. Right antenna 2; J. Left antenna 2.

symmetrical; gnathobase with 4 teeth and short pointed process; 1st outer lobe bearing 8 setae; endopod bulbous, bearing 2 small setae of unequal lengths; exopod fused with basipod 2, bearing 3 plumose setae. Maxilla 2 (Fig. 2C) symmetrical, similar in armature to that of *P. itoi*; 5th inner lobe having a strong spine. Maxilliped (Fig. 2D) symmetrical, similar in structure to that of *P. itoi*; proximal row of teeth of basipod 2 finer than that of *P. itoi*. Legs 1-4 symmetrical, with 3-segmented endopod and exopod. Setation and spinulation as in those of *P. itoi*. Leg 1 (Fig. 3A): basipod 2 with outer medial seta and inner distal seta; exopod segment 1 furnished with large serrated outer spine reaching middle of exopod segment 3. Legs 2 (Fig. 3B) and 3 (Fig. 3C) similar in setation and spinulation, but inner terminal corner of basipod 2 rounded in former and bifurcated in latter. Leg 4 (Fig. 3D): basipod 2 with inner corner bifurcated terminally and 1 thick seta near base of exopod on posterior surface. Leg 5 (Fig. 3E, F) 3-segmented; endopod completely fused with basipod 2, with 1 or 2 pointed tips; exopod bearing 3 lateral and 2 terminal spines, outer terminal spine twice as long as inner.

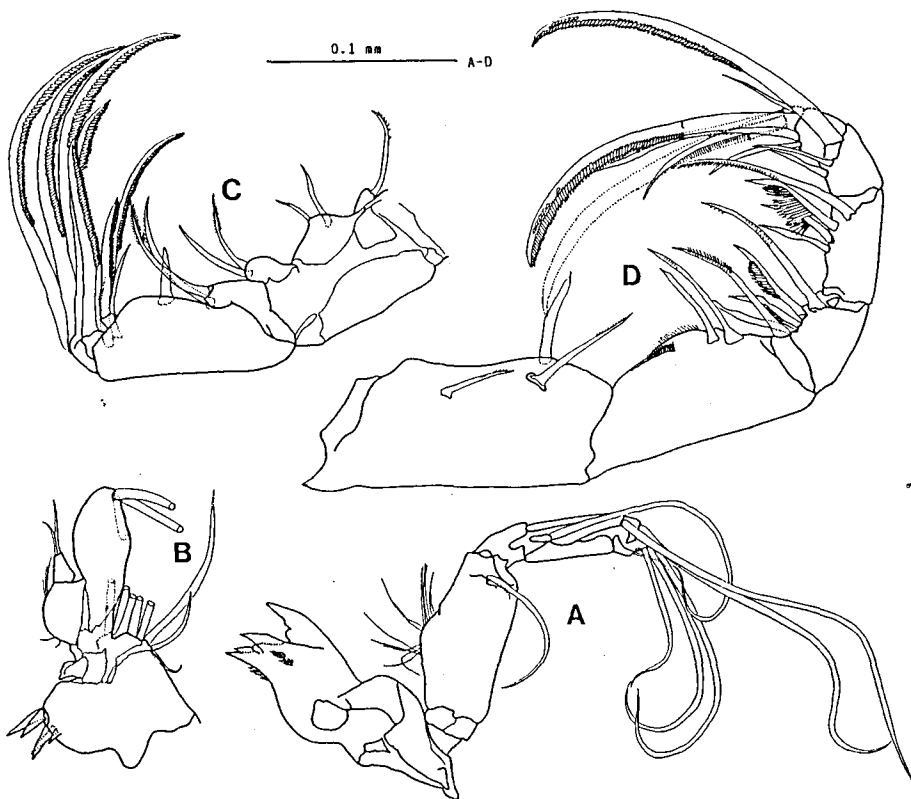


Fig. 2. *Paramisophria platysoma*, n. sp. Female (holotype). A. Mandible; B. Maxilla 1; C. Maxilla 2; D. Maxilliped.

Male. Body (Fig. 4A, B) 1.03 mm long; prosome asymmetrical as in female; urosome 5-segmented. Left antenna 1 (Fig. 4C) geniculate, 20-segmented; segments 16 and 17 bearing low lamella along anterior margin; segment 18 with 2 low lamellae anteriorly; terminal 2 segments incompletely fused; articulation present between segments 17 and 18. Right antenna 1 (Fig. 4D) 21-segmented, shorter than left one as in female. Antenna 2: right endopod and exopod longer than left ones as well as in female. Leg 5 (Fig. 4E, F): right exopod 3-segmented; seg-

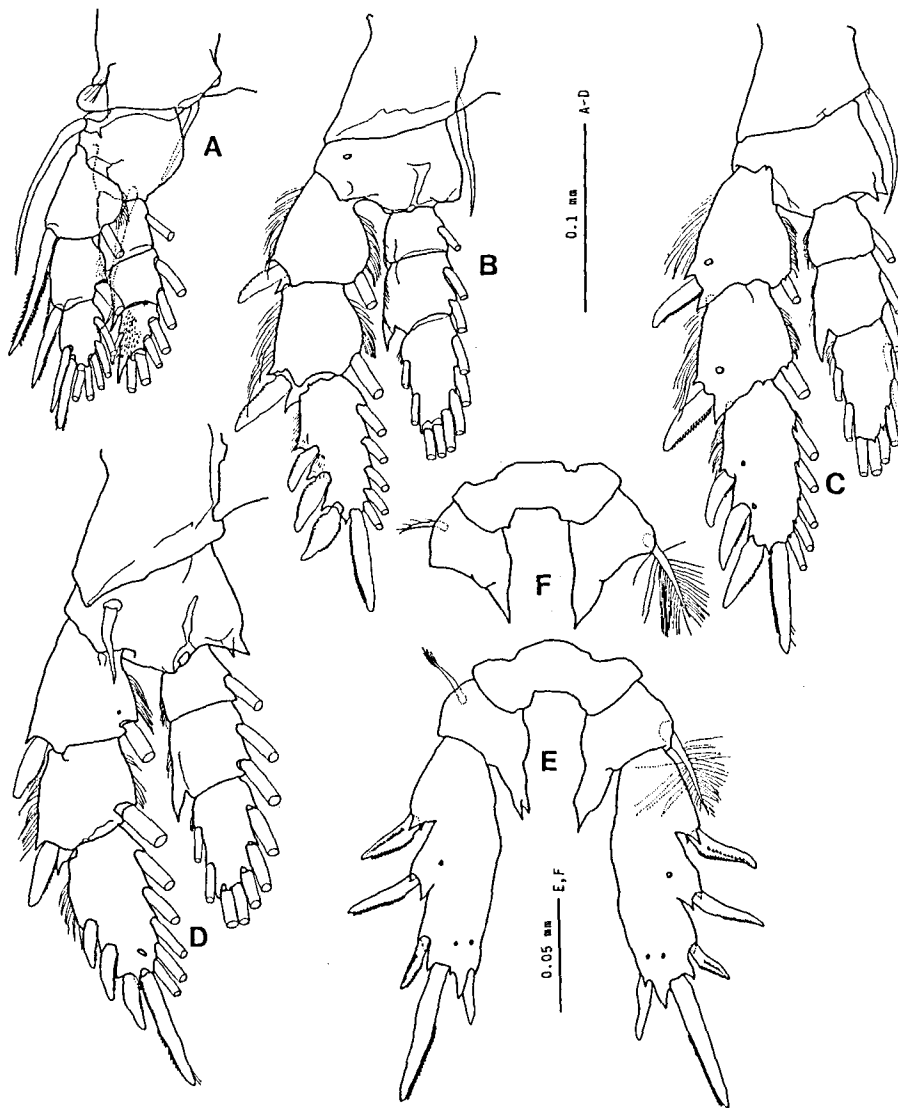


Fig. 3. *Paramisophria platysoma*, n. sp. Female (A-E: holotype; F: paratype) A. Leg 1, posterior view; B. Leg 2, posterior view; C. Leg 3, anterior view; D. Leg 4, posterior view; E. Leg 5, anterior view; F. Basipods of leg 5.

ment 2 bearing outer middle seta and inner terminal patch of hairs; segment 3 incompletely fused with preceding segment, bearing 4 terminal processes increasing in size inward, innermost one with middle part serrated; left leg with 1-segmented rudimentary bulbous endopod; exopod segments 1 and 2 bearing outer seta, respectively; exopod segment 3 small, bearing a large terminal process, 2 lateral setules and short outer medial process.

Variation. Legs 5 of both sexes vary morphologically. The inner projection of basipod 2 of the female right leg 5 is produced distally into 1 or 2 tips (Fig. 3E, F). The endopod of the male left 5 is variable in shape (Fig. 4E, F): the endopod of

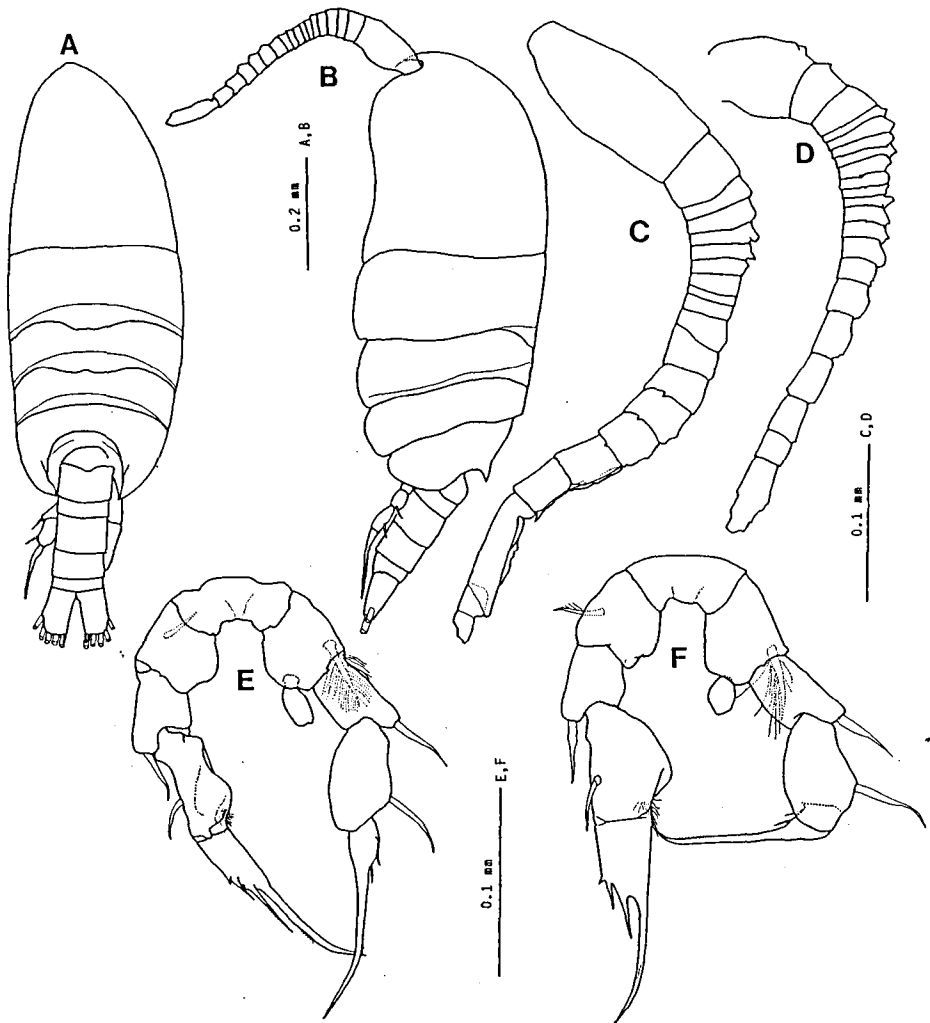


Fig. 4. *Paramisophria platysoma*, n. sp. Male (A, B, F: allotype; C, D, E: paratype). A. Habitus, dorsal view; B. Habitus, left lateral view; C. Left antenna 1; D. Right antenna 1; E, F. Leg 5, anterior view.

the allotypic male is bulbous and short while that of the paratypic male is more elongated than the former. Similar variations of legs 5 of both sexes are found in a congeneric species, *Paramisophria variabilis* MCKINNON & KIMMERER, whose specific name is derived from the variety of shapes of legs 5 of both sexes (MCKINNON & KIMMERER 1985).

Remarks. The new species is easily distinguished from other species of *Paramisophria* by its asymmetrical body. The female is unique in that leg 5 lacks an inner plumose seta on the endopod which is present in females of 6 other species: *P. ammophila* FOSSHAGEN, 1968, *P. cluthae* SCOTT, 1897, (in SARS 1903), *P. itoi* OHTSUKA, 1985, *P. spooneri* KRISHNASWAMY, 1959, *P. variabilis* MCKINNON & KIMMERER, 1985, and *P. cluthae* sensu TANAKA (TANAKA 1966).

Etymology. The specific name "*platysoma*" is derived from the asymmetrical bodies of both sexes with the left sides compressed.

Integumental Organs of the Female Cephalothorax

Integumental organs are functionally chemoreceptors, mechanoreceptors and gland openings (VAUPEL KLEIN 1982), and used as important taxonomic characteristics of pelagic copepods (cf. FLEMINGER 1973, FLEMINGER & HULSEMAN 1987, MAUCLINE 1987). Integumental organs of hyperbenthic calanoid copepods have hardly been studied except for CAMPANER (1984) and MAUCLINE (1987). Integumental organs of *Paramisophria platysoma* were observed here to answer the following questions. (1) Are there differences of distributional patterns of integumental organs on the right and left sides? (2) Is the integumental pore pattern of the new species different from those of other species of the family Arietellidae? (3) Does the new hyperbenthic calanoid copepod have any integumental organs which are not observed in pelagic ones, and vice versa? Before answering these questions, integumental organs of the cephalothorax of *P. platysoma* are described.

Four morphologically different types of integumental organs were found on the prosome of the female. (1) Divergent-hair sensillum (Plate I, A, B): hair branching off near the base into 2-6 fine hairs tapering distally; hair around 10-20 μm long; shallow circular depression around the base of the hair, 2-4 μm in diameter. (2) Single-hair sensillum (Plate I, C, D): hair not branching, gradually tapering, whose tip is blunt without pores; hair 5-15 μm long; shallow circular depression around the base of hair, about 2 μm in diameter. (3) Circular pore, large type (Plate I, D): pore circular or elliptic, 2.0-3.5 μm in diameter; several pores with valve-like structures inside the pores. (4) Circular pore, small type (Plate I, D): pore very small, 0.3-0.6 μm in diameter; shallow circular depression around the pore, about 1.0 μm in diameter.

As shown in Figs 5 and 6, 4 types of integumental organs of the prosome are not uniformly distributed. Circular pores have a wide distribution over the cephalothorax while hair sensilla are unevenly distributed: the single-hair sensilla are mainly distributed on the cephalosome; the divergent-hair sensilla have a restricted distribution on the pedigers and the posterior end of the cephalon. A single-hair sensillum is often accompanied by one or more small circular pores near it

(Plate I, D). Most of the integumental organs on the right and left sides are distributed symmetrically except for several small circular pores and hair sensilla. No integumental organs are present on the dorsal median line except for large circular pores on the cephalosome and pediger 1. Articulated parts among somites have no integumental organs. This seems to mean that the integumental organs are perforations but not superficial modifications of the integuments.

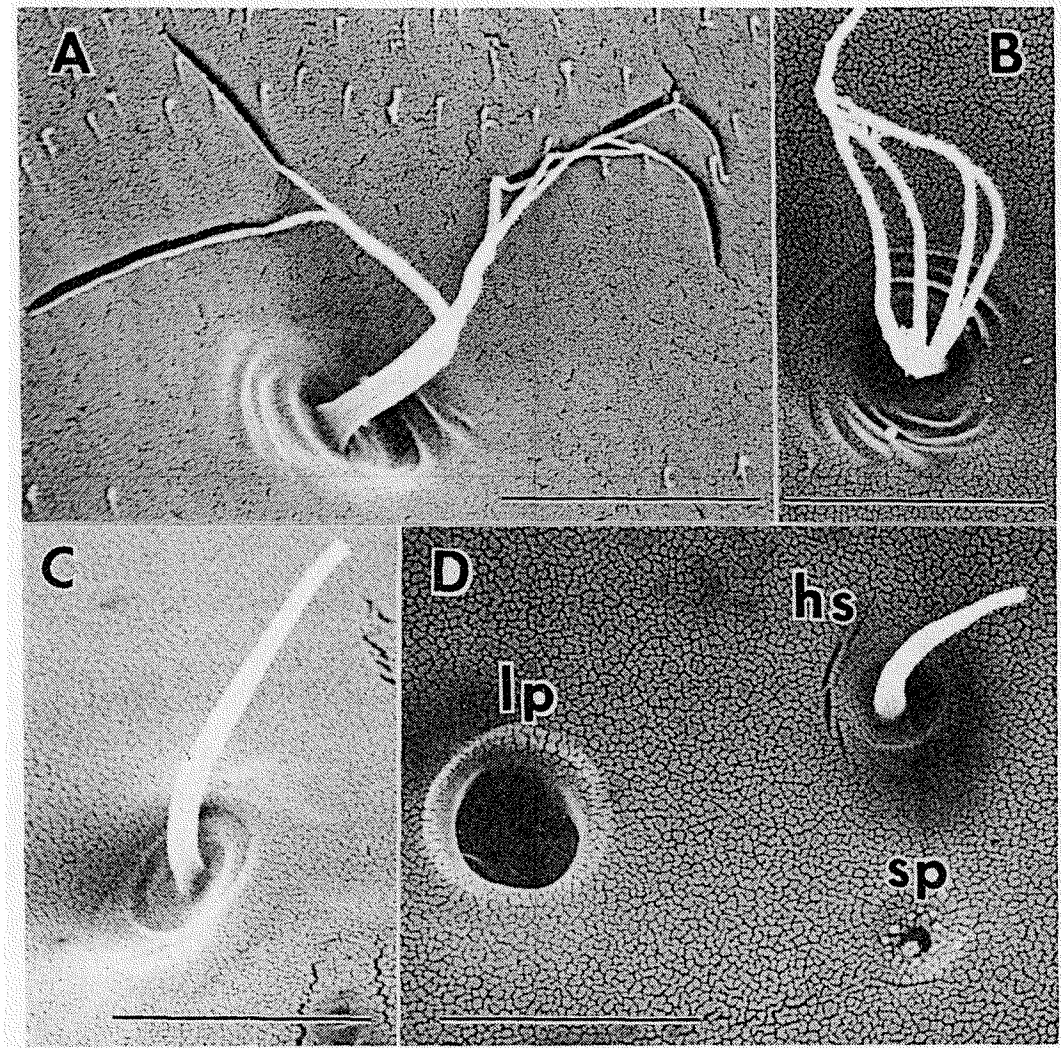


Plate I

Four types of integumental organs of the cephalothorax of *Paramisophria platysoma*, n. sp. (Scale bar = 5 μm)

A, B: Divergent-hair sensillum.

C: Single-hair sensillum.

D: Three types of integumental organs: lp: circular pore, large type; sp: circular pore, small type; hs: single-hair sensillum.

The distribution patterns of integumental organs are slightly different among individuals in: (1) presence and absence of single-hair sensillum and both types of pores, (2) number of integumental organs, particularly, small circular pores, and (3) relative sites of integumental organs.

Hair sensilla are presumed to be mechanoreceptors detecting currents and/or direct touch stimuli (MAUCHLINE 1977; VAUPEL KLEIN 1982). Two types of hair sensilla of *P. platysoma* may be functionally different. The divergent-hair sensillum may detect currents because the divergent hairs are fine and flexible. On the contrary, the single-hair sensillum is rigid and not so fine as the former so that the single-hair sensillum may be a mechanoreceptor of direct touch stimuli. Circular pores may be secretory or chemosensory organs or osmoreceptors (VAUPEL KLEIN 1982). Transverse walls of large circular pores are morphologically similar to valves of luminous glands observed in *Metridia princeps* (HERRING 1988: Plate I, C, D), but the luminescence has not been confirmed in the family Arietellidae (see HERRING 1988: Table 1).

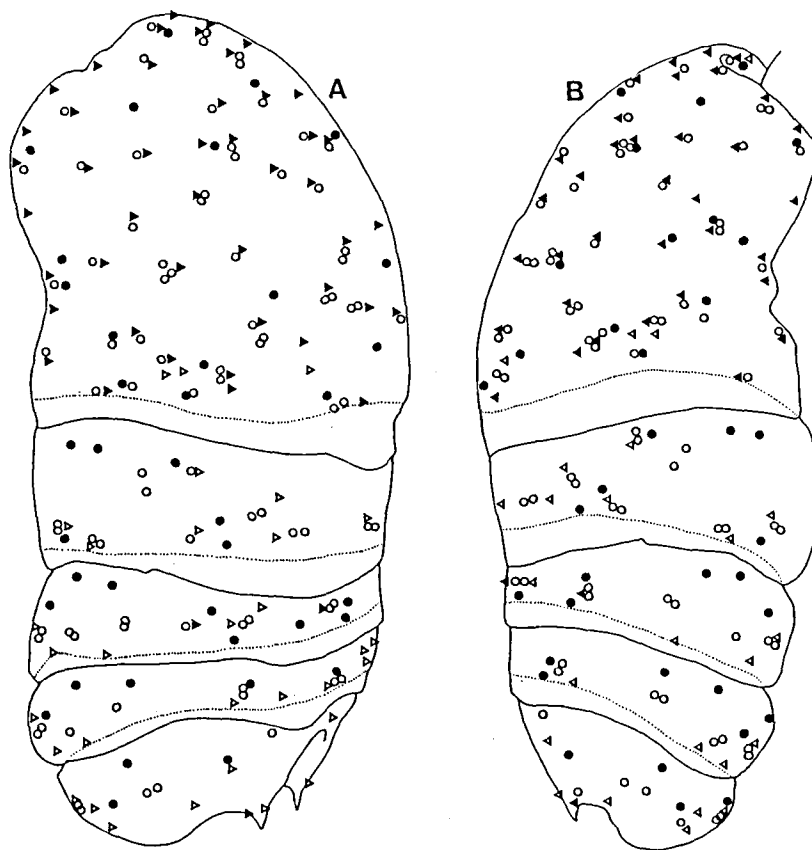


Fig. 5. *Paramisophria platysoma*, n. sp. Female. Schematic illustration of the location of 4 types of integumental organs on cephalothorax, lateral views. A. Left side; B. Right side. ○: Circular pore, small type; ●: Circular pore, large type; △: Divergent-hair sensillum; ▲: Single-hair sensillum.

As the copepod is laterally asymmetrical and swims in a very peculiar manner described below, any integumental organs were expected to be asymmetrically distributed, and it might be possible to surmise the functions of the integumental organs such as statoreceptors and mechanoreceptors. However, observations of the integumental organs revealed that basically they have a symmetrical distribution on the cephalothorax. Then it was impossible to find integumental organs which exist on only one side and appear to be functionally statoreceptors or mechanoreceptors to maintain their peculiar swimming manner.

In the family Arietellidae, 3 species of *Arietellus* and 2 of *Metacalanus* have already been examined to clarify pore patterns on their bodies or thoracic segments (CAMPANER 1984; MAUCLINE 1977, 1987). Because these studies deal with pores which are left after digestion of integumental organs in hot alkali, they appear to include 'artificial' (pores which resulted from integumental organs such as hairs after digestion) and 'real' pores, and it is difficult to directly compare the circular pores of *P. platysoma* with pores in these studies. According to MAUCLINE (1987), the familial pore signature for the family Arietellidae is the dorsal mid-

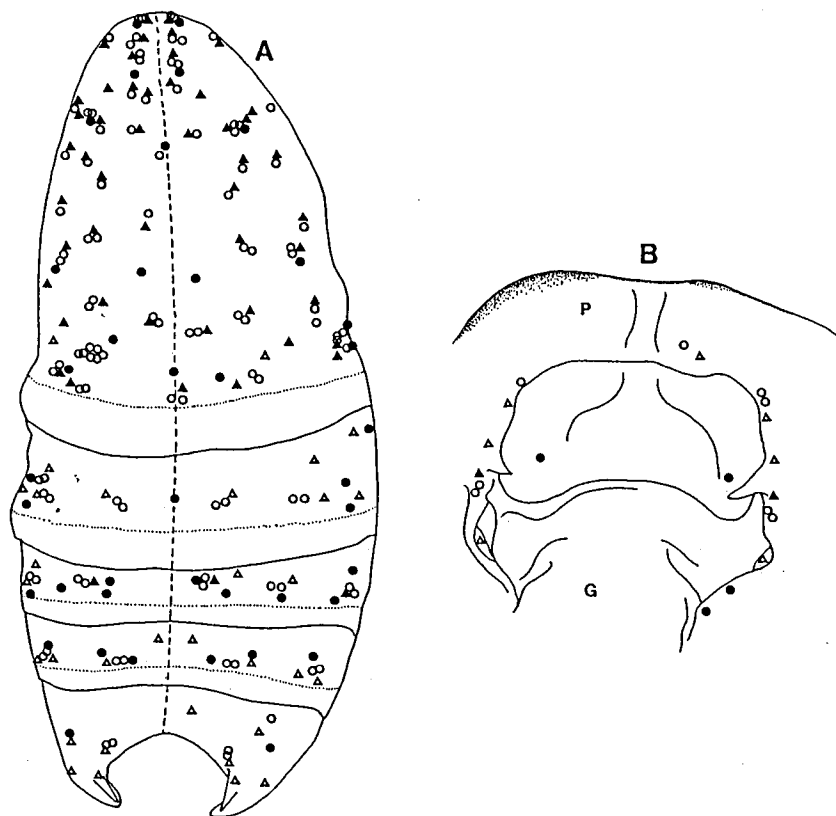


Fig. 6. *Paramisophria platysoma*, n. sp. Female. Schematic illustration of the location of 4 types of integumental organs on cephalothorax, dorsal view. A. Dorsal view, median line indicated by broken line; B. Postero-dorsal view of Pediger 5. G: Genital segment; P: Pedigers 4 and 5. Symbols the same as in Fig. 5.

line pore in pediger 1 and the configuration of dorsal median complex in pediger 2. *P. platysoma* has a large circular pore on the dorsal mid-line of pediger 1 and 2 pairs of large and small pores near the dorsal medial line (Fig. 6A), which possibly correspond to the familial pore signature of MAUCLINE (1987). *P. platysoma* has no patch of small pores of 5 μm in diameter on thoracic segments as well as in *Metacalanus*, which are found on pedigers 2-5 in *Arietellus*, and is basically more similar to *Metacalanus* in dorsal and lateral pore patterns than to *Arietellus* (see MAUCLINE 1987: Fig. 3).

Based on the morphological similarities of legs 5 of both sexes and habitats, CAMPANER (1984) divided 7 genera of the Arietellidae into 2 groups: the genus *Paramisophria* belongs to the 2nd group together with the relatively shallow water planktobenthic or epipelagic genera, *Metacalanus*, *Parapseudocyclops*, *Rhaphidophorus*, and *Sarsarietellus* while the 1st group consists of bathypelagic or deep water planktobenthic genera, *Arietellus*, *Paraugaptilus* and *Scutogerulus*. Also in the pattern of integumental organs, *Paramisophria* is more closely related to *Metacalanus* than to *Arietellus*.

Integumental organs which are morphologically similar in SEM view to those of *P. platysoma* are also found in pelagic calanoid copepods. The divergent-hair sensillum of *P. platysoma* is referred to as a "compound seta" found in the Megacalanidae and other families (MAUCLINE 1977). The single-hair sensillum of *P. platysoma* is commonly observed as hair- and peg-sensilla in many species of pelagic calanoids, and pores of a wide variety of sizes and shapes are distributed on their bodies and appendages (FLEMINGER 1973; HERRING 1988; MAUCLINE 1977; VAUPEL KLEIN 1982). On the other hand, the cephalothorax of *P. platysoma* lacks such integumental organs as the "slit-shaped glandular pores", "tubular glandular pore" and "pit-sensillum" which VAUPEL KLEIN (1982) described in *Euchirella messinensis*. Although the comparison of integumental organs of *P. platysoma* with those of pelagic calanoids depends only on observations by SEM, even integumental organs similar in SEM view to each other are considered to have different functions so that the correct inference of functions of integumental organs needs both SEM and TEM examinations (cf. GILL 1986).

Behavior and Asymmetrical Parts of the Body

Observations of living copepods, including early stages, revealed that the copepods swam continuously just above the bottom with the left lateral side parallel to the bottom (Fig. 7). The copepods swam freely along the bottom and sometimes rose up to near the surface along the inner wall of a dish with the left lateral side directed toward it. During the peculiar continuous swimming, the antennae 2, mandibular palps and maxillae 1 continued to move rhythmically, and other appendages usually remained stationary in the position illustrated in Fig. 7. The copepods rarely stopped swimming and lay on its left lateral side just on the bottom. While lying on the bottom, the copepods continued to move slowly the antennae 2, with the urosome bending dorsally (Fig. 7). The copepods were observed to make a "jumping" possibly with flaps of legs 1-4 when they approached other individuals or organisms. The copepods had the same swimming position near the bottom immediately after water disturbance as that before disturbance. These behaviors

did not change at all when such conditions as light intensity, size and depth of the dish for observation, and density of copepods were different. Therefore it is certain that these behaviors are natural but not artificial in a laboratory.

FOSSHAGEN (1968b) observed *P. cluthae* swimming in the same manner as *P. platysoma* although the body of the former is symmetrical (see SARS 1903). According to OHTSUKA & HIROMI (1987), a shallow water hyperbenthic calanoid, *Stephos pacificus* (Family Stephidae) also swims describing a circle near the bottom with the left lateral side parallel to the bottom although the copepod has a symmetrical body. Other shallow water hyperbenthic calanoids, *Pseudocyclops* (Family Pseudocyclopidae) and *Pseudocyclopiia* (Family Pseudocyclopiidae) have symmetrical bodies, and have not so far been observed swimming with their left sides parallel to the bottom (OHTSUKA unpublished). Hence a hyperbenthic calanoid copepod appears to have swimming behavior peculiar to the family or genus it belongs to.

The asymmetrical parts of the copepod body seem to be adapted for the behavior in its habitat. The compressed left lateral side of the cephalothorax appears to be suitable for swimming parallel to the flat bottom and lying on it in the lower littoral and upper sublittoral zones. Because the lower littoral and upper sublittoral zones seem to be more exposed to wave actions than in deeper waters, the compressed left lateral side of *P. platysoma* may protect it from strong wave actions in the zones. The asymmetry of the body is found in several species of *Paramisophria* which are distributed in deeper waters, but the asymmetry is not as strong as in *P. platysoma* (OHTSUKA unpublished). The shortened exopod segments of the left antenna 2, compared with those of the right, might prevent the fine setae of the appendage from being damaged by touching the bottom. The

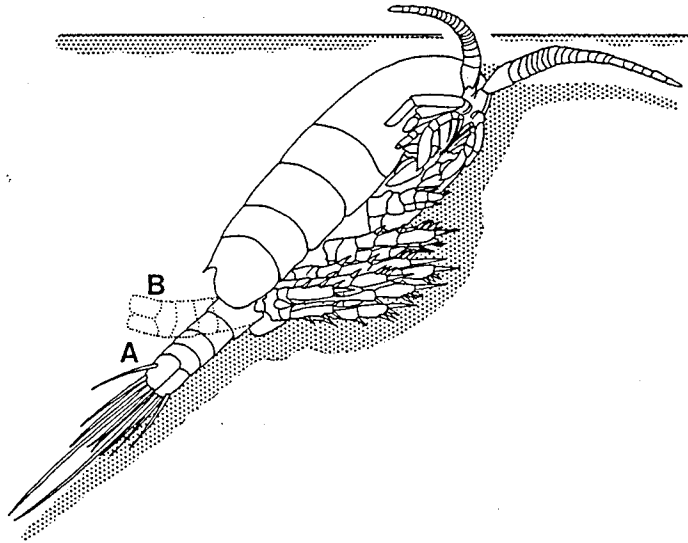


Fig. 7. *Paramisophria platysoma*, n. sp. Schematic illustration of the swimming position with the compressed left lateral side parallel to the bottom. A, B. Position of the urosome in swimming and resting, respectively.

asymmetry of antennae 2 has not so far been reported in other congeneric species, and then this characteristic may have evolved with the strongly compressed left lateral side of the cephalothorax to adapt in the lower littoral and upper sublittoral zones. The left antenna 1 is, however, longer than the right, which is characteristic of the family Arietellidae, particularly, the genus *Paramisophria* (CAMPANER 1977, SARS 1903) but not of only *P. platysoma*. Antenna 1 is considered to be both mechanoreceptor and chemoreceptor (GILL 1986) but has no function as a swimming appendage while antenna 2 plays a main role in swimming. Detection of uneven currents around both antennae 1 may make the copepod swim with the left lateral side parallel to the bottom. In addition to the unequal lengths of both antennae 1, the position of antennae 1 of the swimming copepod is asymmetrical with the longer left extending anteriorly and the shorter right stretching slightly posteriorly (see Fig. 7). The similar position of antennae 1 of the swimming copepod is also observed in the symmetrical *P. cluthae* which swims like *P. platysoma* (FOSSHAGEN 1968b). This observation confirms that the asymmetrical antennae 1 have a close relationship to the peculiar swimming behavior.

The left oviduct opening of the adult female is located near the ventral median line but not as ventro-laterally as the right one. The copepods belonging to the family Arietellidae are known to carry egg-sacs but not release eggs freely (SEKIGUCHI 1974, OHTSUKA unpublished). However, the egg-sac carrying females were not observed in the present study. Considering the 2 oviduct openings on the genital segment of the female, *P. platysoma* may carry 2 egg-sacs. The location of the left oviduct opening might serve to prevent the left egg-sac from being disconnected. The similar asymmetrical location of both oviduct openings is also found in *P. itoi* and a closely related genus *Parapseudocyclops* with the symmetrical cephalothoraxes although their swimming behaviors have not been observed yet (OHTSUKA unpublished). On the other hand, the location of copulatory pores is different from those of 2 taxa: in *P. platysoma*, both copulatory pores open into a common opening near the left oviduct opening (Fig. 1E, F, indicated by arrows) while the common openings of 2 taxa are located nearly on the middle ventral lines; although the spermatophore of *Parapseudocyclops* is sausage-like in shape, that of *P. platysoma* has not so far been observed (OHTSUKA unpublished). The migration of the copulatory pores from the middle line to the left ventro-lateral side may easily enable the male to attach a spermatophore on the copulatory opening of the female, and/or prevent the spermatophore attaching on the urosome from being disconnected.

In-situ Feeding Habit of Adult Females

The copepods fed mainly on benthic harpacticoid nauplii (50%) and copepodids (30%). Unidentified copepodids were frequently found (40%). Diatoms were also frequently detected (50%). Because of their small sizes, the diatoms might be derived from the gut contents of prey copepod nauplii and copepodids. Unidentified remains, consisting of small particles and sticky translucent materials, were found in all guts. These remains seem to be originated from sediment particles and tissues of prey organisms. The gut content analysis revealed that the copepods fed carnivorously on epibenthic harpacticoids.

Zonation of Two Species of *Paramisophria*

The above-mentioned unique morphological and behavioral characteristics of the new species might have resulted from the adaptation of the copepod in its habitat, lower littoral and upper sublittoral zones of about 1m deep. *Paramisophria itoi* collected from the same locality has a symmetrical body, and is mainly distributed in waters deeper than 5 m (OHTSUKA unpublished). No specimens of *P. platysoma* have been collected from waters of around 5 m deep during the period from 1983 to 1989 in Tanabe Bay (OHTSUKA unpublished). There are no other records of the precise collection depths except for FOSSHAGEN's (1968b) report of *P. am-mophila* (1-9 m in depth) and *P. cluthae* (10-240 m in depth).

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