

Redescriptions of the Closely Related Calanoid Copepods *Acartia japonica* and *A. australis* with Remarks on Their Zoogeography^{1), 2)}

HIROSHI UEDA³⁾

College of Science, University of the Ryukyus, Nishihara-cho, Okinawa 903-01

Abstract

The neritic calanoid copepods *Acartia* (*Odontacartia*) *japonica* and *A. australis* are redescribed by examining specimens from Japanese and New Caledonian waters, respectively, and type specimens of the latter species. *A. japonica* previously may have been confused with a co-occurring, morphologically similar common species, *A. erythraea*, whose distinctive characters, including those of immature copepodite stages, are illustrated. Within the subgenus *Odontacartia*, *A. australis* and *A. japonica* are placed in STEUER's *A. erythraea* species group; they are much more similar to each other than to other species of the group. The former two species are assumed to have diverged relatively recently and the speciation may be explained by FLEMINGER's hypothesis concerning a cool-water barrier in Wallacea during Pleistocene glacial periods. *A. japonica* has been recorded only from the Japan Sea coast, but the geographical range may extend more equatorward because it is a typical warm-water species occurring only in summer periods.

The calanoid copepod *Acartia japonica* Mori was first described by MORI (1940) from Katae Bay, a small inlet on the Japan Sea coast of Shimane Prefecture, middle Japan; subsequently it was not recorded until 1983. TANAKA (1965, p. 387) considered it to be identical with *A. amboinensis* Carl. However, during the course of a study on the ecology of planktonic copepods in Japanese inlet waters (UEDA et al. 1983), a copepod identified as *A. japonica* was encountered in Uchiura Bay, an inlet of Wakasa Bay on the Japan Sea coast, Fukui Prefecture. In addition, I obtained this copepod from other inlets of Wakasa Bay and from Wadani Bay, a small inlet near the type locality of *A. japonica*. Here I compare these specimens with the previous descriptions and specimens of related species, including paratypes of *A. australis* Farran, and conclude that *A. japonica* can be distinguished from the related species but is very closely similar to *A. australis*. Since the original descriptions of both *A. japonica* and *A. australis* are insufficient for comparison with each other and with related species, I redescribe the two species here and discuss their geographical distribution and speciation.

Specimens were examined usually in 70 % lactic acid or 50 % glycerin under a microscope and measured with an ocular micrometer. Detailed examination and illustration were made with a differential interference microscope and a drawing tube attachment.

¹⁾ Accepted 23 May 1986

²⁾ カラス目橈脚類の近縁種 *Acartia japonica* と *A. australis* の再記載とその地理的分布

³⁾ 上田拓史, 琉球大学理学部

Acartia japonica MORI, 1940

(Figs. 1A-H, 2A-G, 3A-E)

Acartia japonica MORI, 1940, p. 328, figs. 1-5.

Material examined: Twenty-five females and 85 males, Uchiura Bay (35°29'N, 135°29'E), Aug.-Oct. 1978; 7 females and 5 males, Tsuruga Bay (35°44'N, 136°02'E), 29 Aug. 1978; 7 females and 1 male, Iné Fisheries Harbor (35°40'N, 135°17'E), 12 Sept. 1978; 7 females and 3 males, Wadani Bay (35°32'N, 133°00'E; 18 km west of the type locality), 17 Sept. 1979. All samples were taken at night except for those from Uchiura Bay collected in the daytime. Twenty females and 10 males from Uchiura Bay are deposited in the National Science Museum, Tokyo (NSMT-Cr 8957).

Measurements: Uchiura Bay (7 Sept. 1978) females 1.35-1.41 mm (av. 1.38 mm, $N=10$), males 1.19-1.24 mm (av. 1.22 mm, $N=10$).

Description:

Female: Prosome (excluding posterolateral spine) 3.3-3.5 times as long as wide (Fig. 1A). Proportional lengths of prosome to urosome (including rami) 82:18. In lateral view head indented at midpoint of dorsal margin (Fig. 1B). Last metasomal segment with a large posterolateral spine and a smaller dorsal spine on each side (Fig. 1C, D); the latter spine doubled in some specimens.

First urosomal (genital) segment as long as wide; with 2 posterodorsal spines, several irregular rows of very minute hair-like spinules on lateral surface and numerous fine hairs on posteroventral margin. One specimen from Uchiura Bay with both posterodorsal spines doubled on this segment. Second segment with 8-12 posterodorsal spinules. Third (anal) segment without spinules or hairs. Caudal rami ca. 1.2 times as long as wide; almost symmetrical but dorsal seta of right ramus is slightly more distally inserted than that of left; each ramus with 4-6 rows of very minute hair-like spinules on dorsal surface, several hairs on lateral margin, and 1 row of fine hairs and 1-3 spinules on ventral surface (Fig. 1E).

First antenna 19-segmented, but 2nd and 3rd segments are fused posterodorsally (Fig. 1F); when reflexed, extending almost to posterior border of genital segment (Fig. 1B). First segment with 1 large stout spine and usually 1 spinule on ventrodistal surface (Fig. 1G). The stout spine slightly curved, placed near posterior margin of ventral side and directed anterodistally, and therefore, generally not seen in dorsal view. Second segment with 0-3 (usually 3) spines on posterior margin and a few spinules on ventrodistal region. Other segments of 1st antenna without spines or spinules except for claw-like spine at anterodistal corner of 4th segment.

First segments of 5th leg fused medially (Fig. 1H); 2nd segment, ca. 55 μm long, 2 times as long as wide; terminal spine gently curved, ca. 3 times as long as 2nd segment, slightly thickened basally; lateral plumose seta shorter than terminal spine.

Male: Prosome (excluding posterolateral spine) 3.1 times as long as wide (Fig. 2A). Proportional lengths of prosome to urosome (including rami) 80:20. Head slightly indented at midpoint of dorsal margin (Fig. 2B). Last metasomal segment with 1-5 (usually 3) postero-

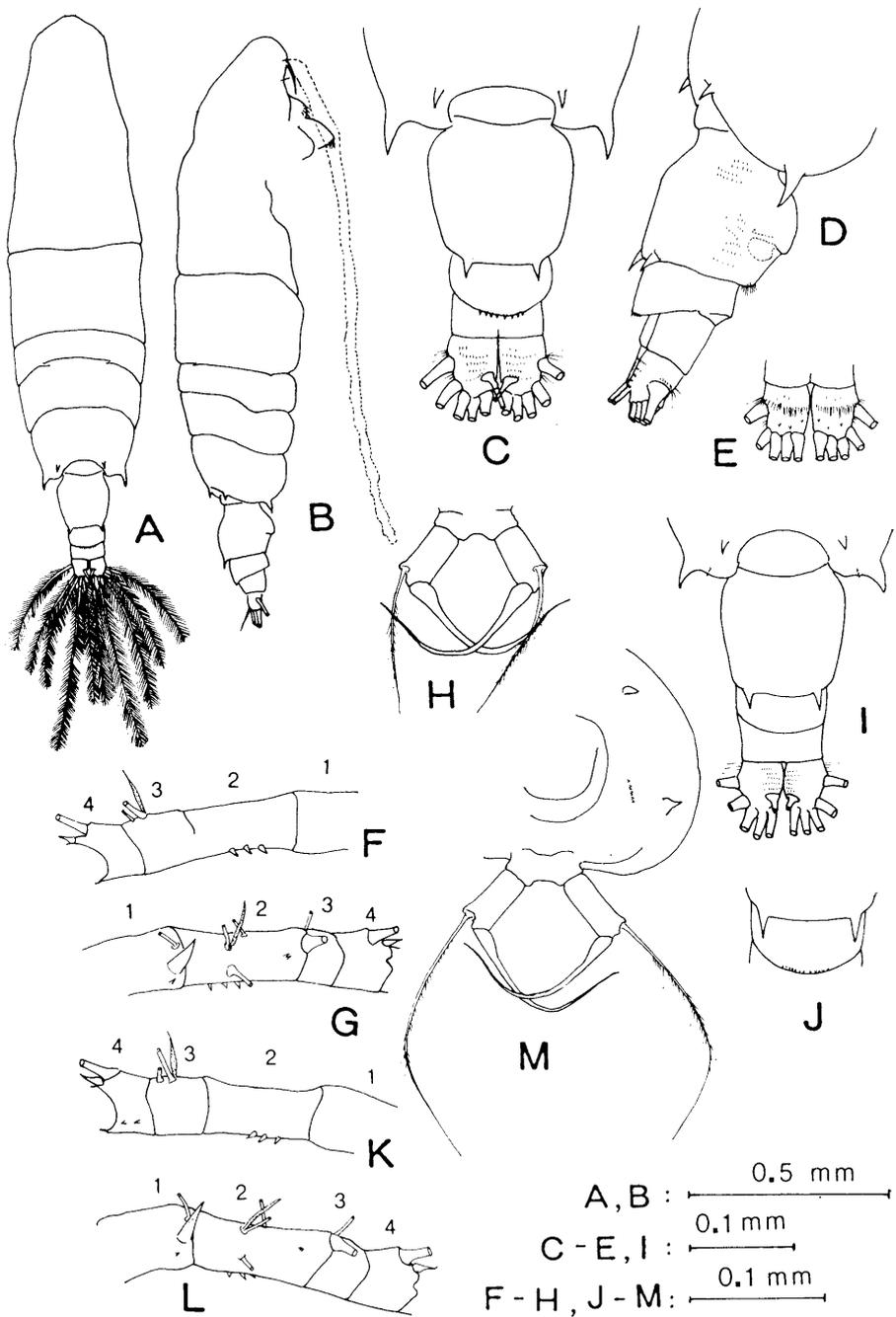


Fig. 1. A-H, *Acartia japonica*, adult female, from Uchiura Bay: A, B, dorsal and lateral views; C, D, posterior metasome and urosome, dorsal and lateral views; E, caudal rami, ventral view; F, G, 1st to 4th segments of 1st antenna, dorsal and ventral views; H, 5th leg, posterior view. I-M, *A. australis*, adult female, from New Caledonia: I, posterior metasome and urosome, dorsal view; J, 2nd urosomal segment with posterodorsal spinules; K, L, 1st to 4th segments of 1st antenna, dorsal and ventral views; M, posterior metasome and 5th leg, posterior view.

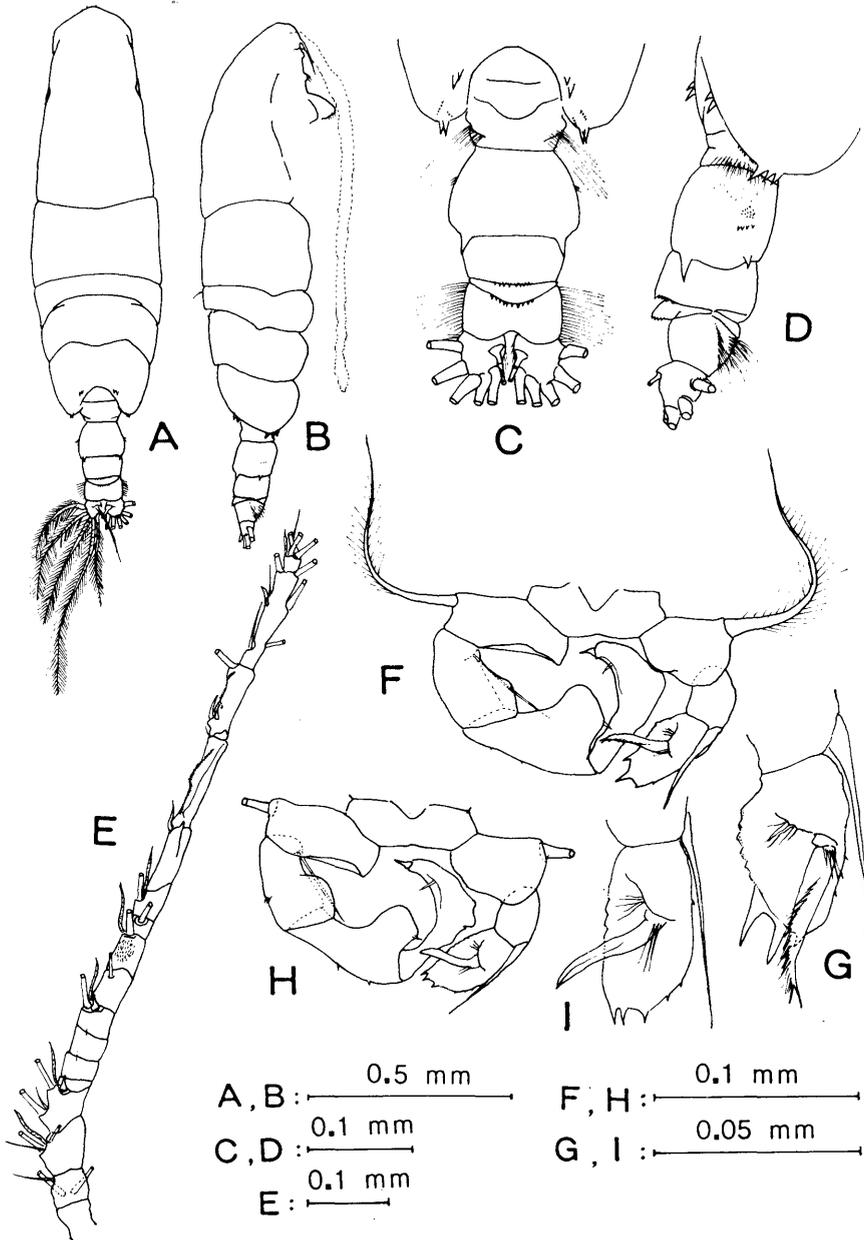


Fig. 2. A-G, *Acartia japonica*, adult male, from Uchiura Bay: A, B, dorsal and lateral views; C, D, posterior metasome and urosome, dorsal and lateral views; E, right 1st antenna, dorsal view; F, 5th leg, anterior view; G, 3rd segment of left 5th leg. H, I, *A. australis*, adult male, from New Caledonia: H, 5th leg, anterior view; I, 3rd segment of left 5th leg.

lateral spines, 1-3 (usually 2) posterodorsal spines and 2 rows of minute spinules on dorsal side of posterolateral spines on each side (Fig. 2C, D).

First urosomal segment with numerous long lateral hairs. Second segment shorter than wide; posterior margin with 2 larger dorsolateral spines and 2 smaller ventrolateral spines (the latter sometimes doubled); mid-lateral surface with numerous, very minute spinules and 1 row of 3-5 larger spinules. Third and 4th segments each with 8-12 posterodorsal spinules. Fifth (anal) segment with numerous long hairs on ventral and lateral sides; those on lateral side lined diagonally. Caudal rami almost as long as wide and symmetrical, fringed with lateral and medial hairs but without hairs or spinules on dorsal and ventral surfaces.

First antenna extending slightly beyond posterolateral border of 3rd metasomal segment (Fig. 2B). Right antenna 17-segmented (Fig. 2E); geniculation between 14th and 15th segments; 10th segment with numerous minute spinules on dorsal surface. Left antenna 21-segmented, without spines or spinules except for claw-like spines on 4th and 8th segments.

First segment of right 5th leg ca. 60 μm long, 2 times as long as wide, with long plumose seta on distolateral corner (Fig. 2F). Second segment as long as 1st segment, with short seta on inner proximal corner; anterodistal corner roundly projecting inward. Third segment longer (ca. 70 μm) than 1st segment, with 2-3 minute spinules on lateral margin and distally with truncate, large inner projection; distal margin of this projection with small conical spine. Fourth segment curved at mid-point, with small spine at four-fifths distance along inner margin and slightly larger terminal spine.

Segments of left 5th leg much shorter than those of right. First segment with long plumose lateral seta. Second segment with basally thickened long spine on distolateral corner. Third segment longer than 2nd segment and greatest width at one-third of length from proximal end (Fig. 2G); medial one-third of inner margin serrate; more distal inner margin with 2 spines, and with much smaller spine terminally; outer margin usually with 2-3 minute spinules; mid-anterior surface with large blade-like spine and tuft of very fine hairs. This blade-like spine nearly as long as the segment and slightly recurved distally; inner margin fringed with numerous short hairs; with small basal barb bearing some fine hairs.

Remarks: (also see Discussion section) In MORI's (1940) original description of *Acartia japonica*, the seta on the first segment of the right fifth leg of the male is much shorter than that of the left. I also observed one specimen with such a short seta among 94 males examined and consider that this short seta is due to aberrant development. The lateral setae on the first segments of the right and left fifth legs of most males are equal in length.

In his remarks on the genus *Acartia*, TANAKA (1965) stated that *A. japonica* appeared to be identical with *A. amboinensis*, but in the specific remarks on *A. amboinensis* in the same paper, he distinguished it from *A. japonica* by several characters. These accounts concerning the relationship between the two species are contradictory. As noted below, *A. amboinensis* and *A. japonica* are not conspecific, and *A. amboinensis* described by him from the Izu region is certainly distinct from *A. japonica*, judging from the characters of the first antenna of the female.

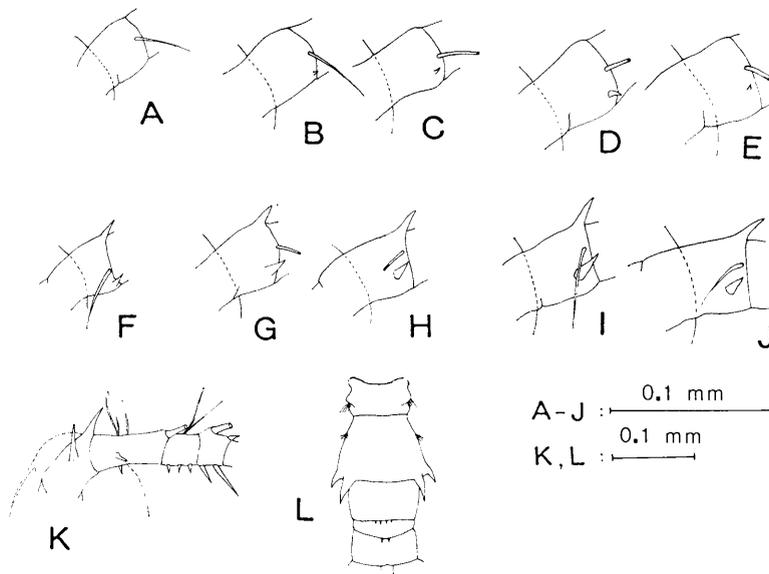


Fig. 3. A-E, *Acartia japonica*, 1st segment of left 1st antenna of immature copepodite CIII, CIV female, CIV male, CV female and CV male, respectively. F-J, *A. erythraea*, same. K, L, *A. erythraea*, adult female and male: K, 1st to 4th segments of left 1st antenna of female; L, urosome of male, dorsal view. (All figures were based on specimens from Uchiura Bay.)

Daylight swarming activity near the bottom of inshore water (UEDA et al. 1983) may be responsible for the lack of records of *Acartia japonica*, because plankton in such waters are not easily collected by ordinary daytime plankton samplings; the specimens of the present study were collected by night samplings except for those from daytime swarms. It is also possibly considered that the absence of records is due to the confusion of this species with the closely allied *A. erythraea* Giesbrecht. *A. japonica* and *A. erythraea* co-occurred in all the samples examined here. The latter species is commonly distributed in inlet waters of the middle and southern Japan from summer to fall (e.g., HIROTA 1962, ITOH & IZUKA 1979). *A. japonica* is distinguished from *A. erythraea* by the spines on the first antenna in the female (*A. erythraea* has two large spines on the first segment and one, three and two spines on posterior margins of the second to fourth segments, respectively—Fig. 3K) and by the ventral spines on the second urosomal segment in the male, which are well-developed and visible from dorsal side in *A. erythraea* (Fig. 3L). These two species can be distinguished even in the immature copepodite stages older than CII by the spines on the first segment of the first antenna; *A. japonica* has no or only a single small spine (Fig. 3A-E) instead of two spines of *A. erythraea* (Fig. 3F-J). However, CI and CII stages with spines on the first antenna were not found in any samples of the present study, suggesting that in both species the spines on the first antenna are not developed during these earlier stages; it may be impossible to separate these species in early copepodids.

In Uchiura Bay *Acartia japonica* was observed restrictedly in shallow water of the innermost part from August to October 1978. During this period, the surface water temperature and salinity of this site were measured 25.8–30.9°C and 33.0–33.4‰, respectively.

Acartia australis FARRAN, 1936

(Figs. 1I–M, 2H–I)

Acartia australis FARRAN, 1936, pp. 120–122, fig. 23.

Material examined: Two female and 1 male paratypes loaned by the British Museum (Natural History) (No. 1948. 4. 28. 116); 20 females and 7 males, Prony Bay, south of New Caledonia (22°23'S, 166°52'E), 11 Dec. 1978.

Measurements: New Caledonia female 1.29–1.40 mm (av. 1.34 mm, $N=6$), male 1.17–1.23 mm (av. 1.21 mm, $N=6$).

Description: Morphological features of the body and appendages very similar to those of *A. japonica* but differing in the following respects.

Female: Last metasomal segment with 1 row of minute spinules on inner side of posterolateral spine on each side (Fig. 1I, M). Second urosomal segment usually without spinules on posterodorsal margin, but rarely with several very minute spinules on this position (Fig. 1J), which are less conspicuous than those of *A. japonica*. Second and 3rd segments of 1st antenna completely separate (Fig. 1K, L); 4th segment with 2 small spines on posterodorsal surface. Lateral plumose seta of 5th leg longer than terminal spine (Fig. 1M).

Male: Second segment of right 5th leg with a few minute spinules at ca. 0.6 distance of lateral margin (Fig. 2H). Third segment of left 5th leg with greatest width at two-thirds of length from proximal end (Fig. 2I); marginal spines located almost at distal end and relatively small as compared with those on distomedial margin of *A. japonica*; large blade-like spine on mid-anterior surface without hairs on medial margin.

Remarks: (also see Discussion section) In FARRAN's (1936) original description of this species, the stout spine on the first segment of the first antenna of the female is located "nearer the upper than the lower margin." In the paratypes and New Caledonian specimens, this spine is nearer the posterior (lower) margin of the segment as in *A. japonica*. However, the apparent position of the spine depends on the angle the antenna is mounted on a glass slide; this difference may explain the apparent differences in the two accounts. In the original description the fourth segment of the first antenna of the female and the third and fourth urosomal segments of the male are naked. However, armature on these segments as described here is found on both the paratypes and New Caledonian specimens without exception.

Discussion

Acartia japonica and *A. australis* are referable to STEUER's subgenus *Odontacartia*. STEUER (1923) divided the subgenus into two species group, i.e., the *erythraea* group (*A. erythraea*, *A. amboinensis* and *A. bispinosa* Carl) and the *centrura* group (*A. centrura* Giesbrecht, *A. spinicauda* Giesbrecht and *A. pacifica* Steuer), and an intermediate species, *A. lilljeborgi*

TABLE 1. COMPARATIVE LIST OF SPINES ON THE FIRST TO FOURTH SEGMENTS OF THE FEMALE FIRST ANTENNA OF STEUER'S *Acartia erythraea* GROUP

Segment No.	<i>A. erythraea</i>	<i>A. amboinensis</i> *	<i>A. bispinosa</i> *	<i>A. australis</i>	<i>A. japonica</i>
1	2 stout spines	2 stout spines	2 stout and 2 small spines	1 stout spine	1 stout spine
2	1 small spine	1 small spine	1 curved stout spine	usu. 3 small spines	usu. 3 small spines
3	3 small spines	1 small spine	no spine	no spine	no spine
4**	2 larger spines	1 small spine	2 small spines	2 small spines	no spine

* according to STEUER (1923)

** The claw-like spine on the anterodistal corner, which is common to the subgenus *Odontacartia*, is omitted.

Giesbrecht. The characters differentiating the *erythraea* group from the *centrura* group are: in the female, the first segment of the first antenna with large spines, the second urosomal segment without large spine, short caudal rami and the terminal spine of the fifth leg without peculiar swelling or process; in the male, the third and fourth urosomal segments without large spines and the second segment of the left fifth leg with a long, distolateral spine. *A. australis* and *A. japonica* belong to the *erythraea* group. The five species of this group are very similar to each other, but have diverged most distinctly in the spines on the first antenna of the female (Table 1). These spines apparently indicate that *A. australis* and *A. japonica* are much more similar to each other than to the other three species; the former two species are readily distinguished from the latter by having a single large spine on the first segment instead of two large spines.

The close morphological similarity between *Acartia australis* and *A. japonica* suggests that they may have undergone speciation relatively recently. Biantitropical speciation of neritic copepods has been explained in relation to temperature increase of the tropical water from the Oligocene to the mid-Miocene (BRADFORD 1980). However, because both *A. australis* and *A. japonica* are warm-water species that can occur even in waters with temperatures higher than 30°C (FARRAN 1949), high temperature in equatorial ranges cannot be considered as a causal factor isolating them. FLEMINGER (in press) hypothesizes that during Pleistocene glacial periods coastal upwelling system in the eastern Indonesian sea, which extensively cooled surface waters probably to 20–21°C, may have constituted a barrier for pelagic, warm-stenothermal species, and that this barrier in the equatorial seaway connecting the Indian and Pacific Oceans and dividing the Asian and Australian/New Guinean coasts resulted in divergence of the coastal-zone calanoids *Labidocera* and *Undinula*. His "Wallacea barrier hypothesis" also may explain the primary geographical isolation and speciation between *A. australis* and *A. japonica*. Because both species are warm-stenothermal like equatorial species, occurring only during periods of temperatures higher than 25°C (FARRAN 1949), their ancestral population would have been distributed continuously in equatorial ranges which connect the ranges of the present species. It is considered likely that the extensive cool-water barrier due to upwelling between the Asian and Australian/New Guinean coasts during glaciation may have broken up

the continuity of their ancestral populations and this separation resulted in the divergence of the present two species.

Acartia australis and *A. japonica* also are behaviorally similar, i.e., both species form monospecific swarms in shallow waters during the daytime (HAMNER & CARLETON 1979, UEDA et al. 1983). However, the conditions of their habitats and their ecological roles greatly differ. *A. australis* is a dominant copepod in subtropical coral reef areas of the Southwest Pacific (SALE et al. 1978, BINET 1984), while *A. japonica* has been found in small, temperate embayments on the Japan Sea coast and is not a common species. Neither species has been recorded from tropical and subtropical waters of the Northwest Pacific. However, considering that *A. japonica* is not readily collected by usual sampling methods, the possibility that the species is distributed in tropical and subtropical Asian coasts cannot yet be discounted. As discussed above, this species is warm-stenothermal like other summer species in the warm-temperate latitudes, such as *A. erythraea*, whose geographic ranges generally extend more equatorward.

Acknowledgements

I wish to thank Dr. G. A. BOXSHALL of the British Museum (Natural History) for loaning paratypes of *A. australis*, H. SEMURA and H. KITAZAWA of the Shimane Prefectural Fisheries Experimental Station for specimens from Wadani Bay, and Drs. D. BINET and P. MOLL of the Antenne ORSTOM for New Caledonian specimens. Thanks are also due to Dr. S. NISHIDA of the Ocean Research Institute, University of Tokyo, Dr. M. TAKEDA of the National Science Museum, Tokyo, and Dr. and Mrs. E. H. WILLIAMS of the University of Puerto Rico for their critical reading of early drafts of the manuscript. I am grateful to Dr. F. D. FERRARI of the Smithsonian Institution for his reviewing of the manuscript and useful suggestions and to Dr. A. FLEMINGER of the Scripps Institution of Oceanography for kindly sending me a preprint of his unpublished paper and critical comments.

Literature Cited

- BINET, D., 1984. Copépodes planctoniques du lagon de Nouvelle-Calédonie: facteurs écologiques et associations d'espèces. *Mar. Biol.*, **82**: 143-156.
- BRADFORD, J.M., 1980. Zoogeography of some New Zealand neritic pelagic crustacea and their close relatives. *Inf. Ser. N.Z. Dep. scient. ind. Res.*, **137**: 593-612.
- FARRAN, G.P., 1936. Copepoda. *Sci. Rep., Great Barrier Reef Exped.*, **5**: 73-142.
- FARRAN, G.P., 1949. The seasonal and vertical distribution of the Copepoda. *Sci. Rep., Great Barrier Reef Exped.*, **2**: 291-312.
- FLEMINGER, A., in press. The Pleistocene equatorial barrier between the Indian and Pacific Oceans and a likely cause for Wallace's Line. In *Proceedings of the First International Conference on Pelagic Biogeography*. UNESCO.
- HAMNER, W.M. & J.H. CARLETON, 1979. Copepod swarms: attributes and role in coral reef ecosystems. *Limnol. Oceanogr.*, **24**: 1-14.
- HIROTA, R., 1962. Species composition and seasonal changes of copepod fauna in the vicinity of Mukaishima. *J. oceanogr. Soc. Japan*, **18**: 35-40.
- ITOH, H. & S. IIZUKA, 1979. Studies on the zooplankton in Omura Bay—I. Seasonal occurrences of copepods. *Bull. Fac. Fish., Nagasaki Univ.*, No. 47: 5-14. (In Japanese with English

abstract)

- MORI, T., 1940. Two new copepods from Japanese waters. *Zool. Mag., Tokyo*, **52**: 328-330.
- SALE, P.F., P.S. MCWILLIAM & D.T. ANDERSON, 1978. Faunal relationships among the near-reef zooplankton at three localities on Heron Reef, Great Barrier Reef, and seasonal changes in this fauna. *Mar. Biol.*, **49**: 133-145.
- STEUER, A., 1923. Bausteine zu einer Monographie der Copepodengattung *Acartia*. *Arb. zool. Inst. Univ. Innsbruck*, **1**: 91-144, pls. 1-11.
- TANAKA, O., 1965. The pelagic copepods of the Izu region, middle Japan. Systematic account XIII. Parapontellidae, Acartiidae and Tortanidae. *Publ. Seto mar. biol. Lab.*, **12**: 379-408.
- UEDA, H., A. KUWAHARA, M. AZETA & M. TANAKA, 1983. Underwater observations on copepod swarms in temperate and subtropical waters. *Mar. Ecol. Prog. Ser.*, **11**: 165-171.