JOURNAL OF CRUSTACEAN BIOLOGY, 1(4): 545–557, 1981

RECENT INTRODUCTION OF THE CIROLANID ISOPOD CRUSTACEAN *CIROLANA ARCUATA* INTO SAN FRANCISCO BAY

Thomas E. Bowman, Niel L. Bruce, and Jon D. Standing

ABSTRACT

Evidence is presented for the recent introduction of *Cirolana arcuata*, previously known from Australia and New Zealand, into San Francisco Bay, where it appears to be established. Thus far it has been found only at the Oleum Power Plant on San Pablo Bay near Rodeo. *C. robusta* Menzies, from Chile, and Chilean specimens identified as *C. concinna* by Menzies are shown to belong to *C. arcuata*. The species is redescribed and illustrated in detail.

San Francisco Bay, formed in the late Pleistocene (Atwater, *et al.*, 1977), is geologically young. If we accept the view that the time required for speciation is greater, in most cases, than the age of the Bay, it is unlikely that a semienclosed basin of this age will contain endemic species. Therefore the estuarine habitats of the Bay have been available for occupation by non-endemic species, and between 75 and 100 species of invertebrates have been introduced since the middle of the 19th century (Carlton, 1975, 1979a, 1979b). Six of the introduced species are isopods. Here we record the apparent recent introduction of a seventh isopod, *Cirolana arcuata* Hale. The taxonomy of the species is complex and we will review it before we consider the evidence for its introduction into San Francisco Bay.

Cirolana arcuata Hale, 1925
Figs. 1–9

Cirolana arcuata Hale, 1925: 133–134, fig. 2a–k.—Naylor, 1961: 11, 13–14, fig. 4a–h.—Hurley, 1961: 267, 284, 293.—Morton and Miller, 1968: 454, 481, fig. 167-3.
Cirolana concinna Hale.—Menzies, 1962: 123, fig. 40A–E [misidentification].
Cirolana robusta Menzies, 1962: 123, 126, fig. 41D–E.—Ramirez, 1974: 417–418, fig. 8.—Carvacho, 1977: 32, 34, 35, fig. 4a–e [new synonymy].

Distribution.—(Fig. 1). AUSTRALIA.—New South Wales: Little Sirius Cove, Port Jackson (Hale, 1925); Broughton Island ("paratypes" in Australian Museum). South Australia: Port Willunga, found among "paratypes" of *Cirolana corpulenta* Hale in South Australian Museum. NEW ZEALAND.—Cook Strait; Red Bluff, Chatham Island (Naylor, 1961). CHILE.—Antofagasta Province: Mejillones, near Antofagasta (Carvacho, 1977); Concepción Province: Bahía Concepción (Ramirez, 1974); Bahía San Vicente (Menzies, 1962); Llanquihua Province: Isla Tenglo, near Puerto Montt (Menzies, 1962). UNITED STATES.—California: San Francisco Bay: San Pablo Bay, eastern shore, near Rodeo, Contra Costa County (new record) (Fig. 2).

Description.—Length up to 19 mm: 12 and 12.5 mm (Hale); 10.5–14.5 mm (Naylor); 16 mm (holotype of *C. robusta*, not 27 mm as stated by Menzies); 15–19 mm (Ramirez); 13.5 mm (Carvacho); largest California specimen 16 mm. Body length 2.2–2.8 times greatest width. Eyes well-developed. Antenna 1 reaching about midlength of pereonite 1; antenna 2 reaching from midlength of pereonite 2 to posterior margin of pereonite 3. Frontal lamina longer than wide, expanded anteriorly, sides slightly converging posteriorly. Clypeus projecting anteroventrally, in lateral view pointed, with concave anterior margin and convex posterior

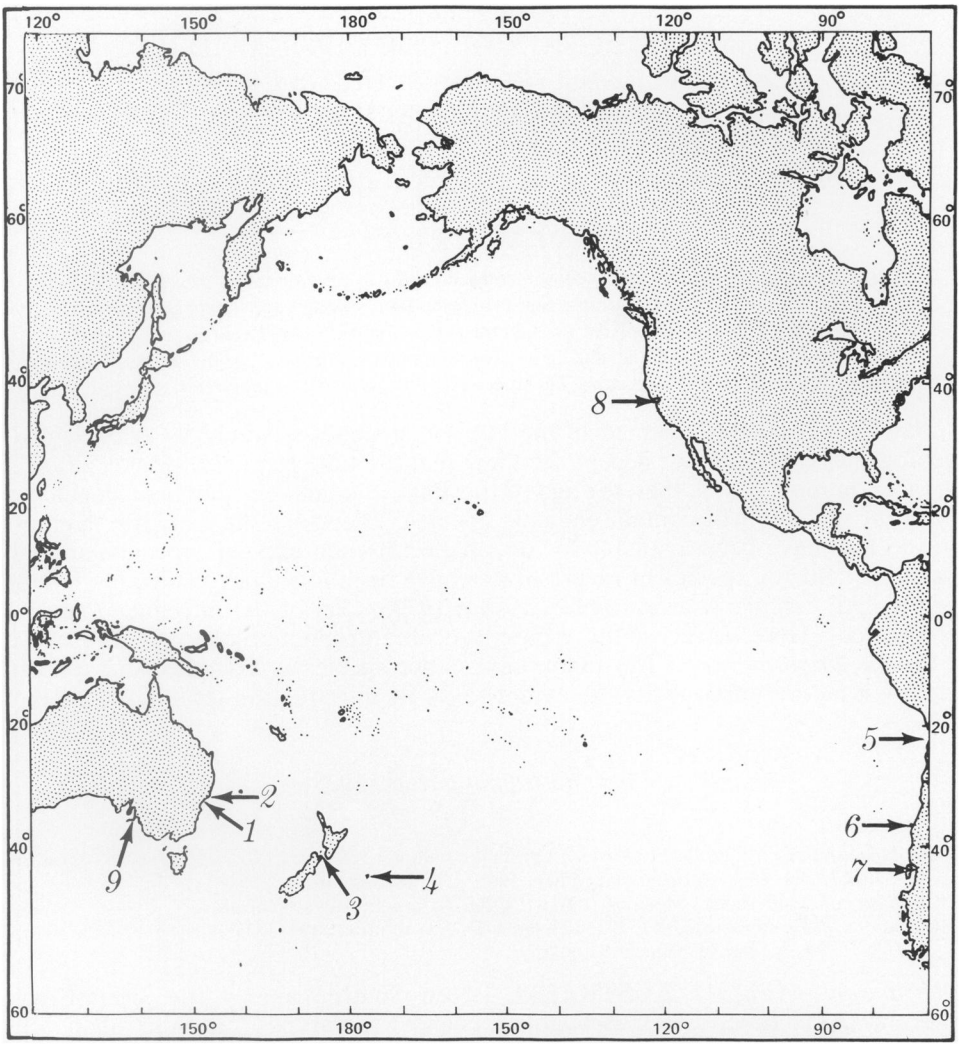

Fig. 1. Known distribution of *Cirolana arcuata*. 1, Port Jackson; 2, Broughton Island; 3, Cook Strait; 4, Chatham Island; 5, Mejillones; 6, Bahía Concepción and Bahía San Vicente; 7, Isla Tenglo; 8, San Francisco Bay; 9, Port Willunga.

margin. Left mandible incisor tricuspate, right incisor quadricuspate. Maxilla 1, exopod with 11 apical spines and 1 seta; endopod with 3 circumplumose setae. Maxilliped slender; endite with 1 retinaculum. Pereopods stout, armed with robust spines and rows of long setae. Coxae increasing in size posteriorly; coxa 7 overlapping pleonites 1–3 laterally. Pleonites all reaching lateral margin, but pleonite 5 almost completely overlapped laterally by pleonite 4. Pleopods all undivided, but exopods of pleopods 3–5 with small partial suture; exopods of pleopods 1–5 and endopods of pleopods 1–2 with marginal setae, endopods of pleopods 3–5 glabrous; protopods of all pleopods with lateral lobes. Appendix masculina arising at about ⅓ distance along medial margin of pleopod 2 endopod. Pleotelson about 0.6 times as long as width at base, linguiform, broadly rounded

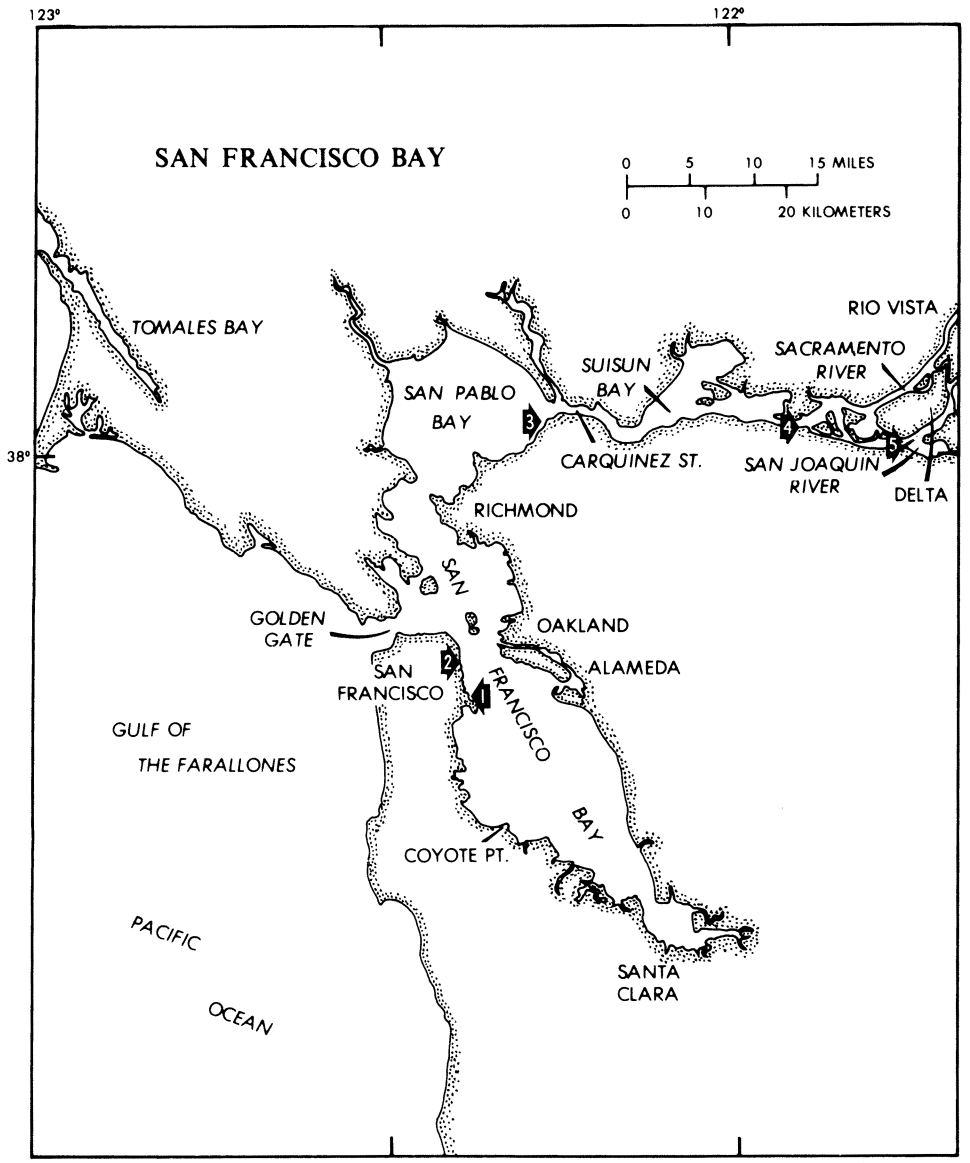

Fig. 2. San Francisco Bay, showing localities of power plants where collections were made. 1, Hunter's Point; 2, Potrero; 3, Oleum; 4, Pittsburg; 5, Contra Costa. *Cirolana arcuata* was found only at the Oleum Power Plant.

posterior margin with about 34 plumose setae and 5–9 short spines. Uropod protopod produced medially into triangular process, distal margin with 2 ventromedial spines; exopod shorter than and about ½ width of endopod, each armed with plumose setae and about 7 short spines inserted in notches.

Remarks.—The decision to place both *C. robusta* Menzies and *C. concinna* of Menzies in synonymy with *C. arcuata* is based upon examination of 8 "paratypes" of *C. arcuata* from Broughton I. and 3 from Little Sirius Cove (Australian

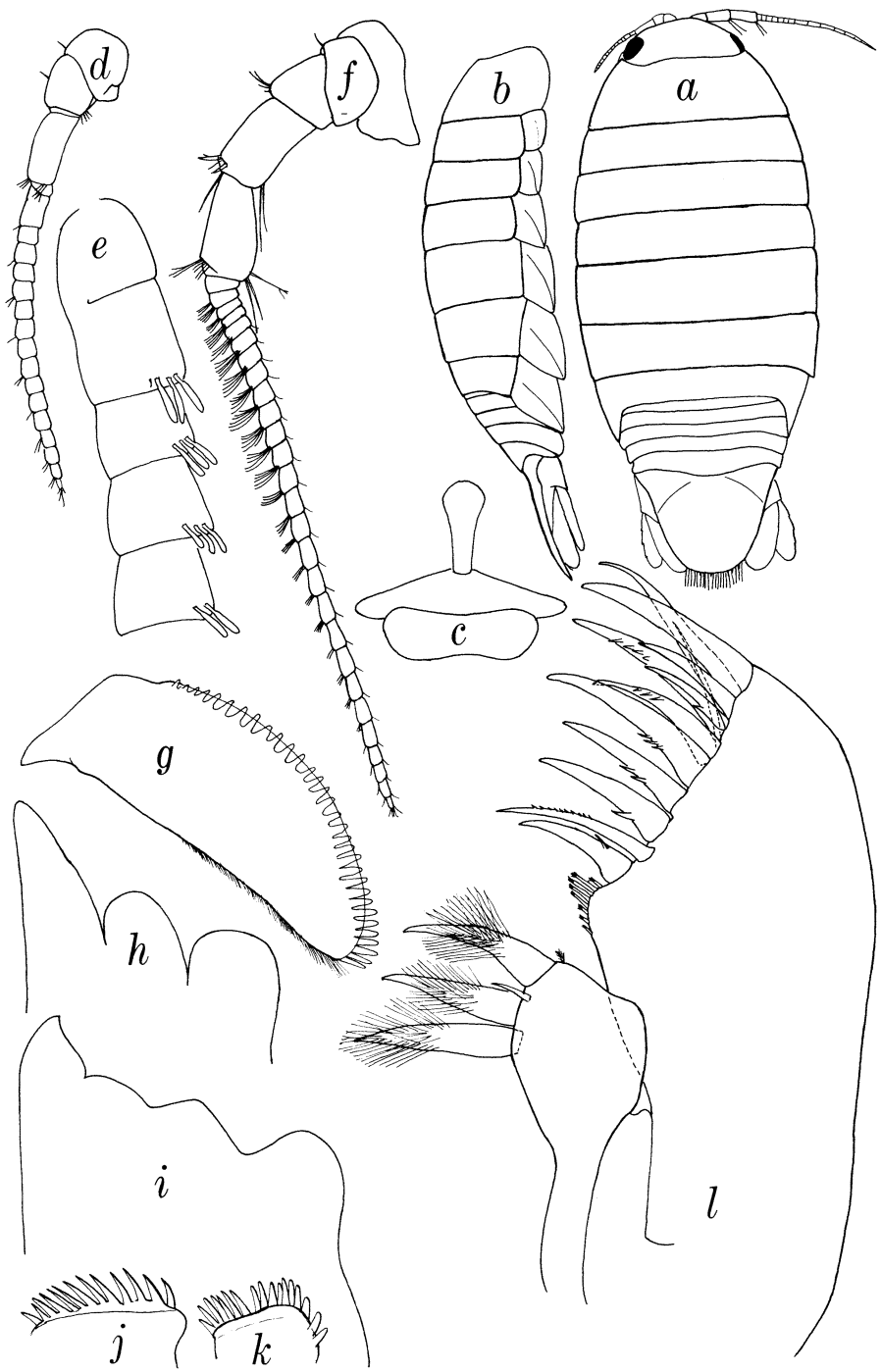

Fig. 3. *Cirolana arcuata* from San Francisco Bay, ♀: a, Habitus, dorsal; b, Same, lateral (head not shown); c, Labrum, clypeus, and frontal lamina; d, Left antenna 1, dorsal; e, Part of left antenna 1 flagellum, ventral; f, Left antenna 2, dorsal; g, Molar of left mandible; h, Incisor of left mandible; i, Incisor of right mandible; j, Lacinia of left mandible; k, Lacinia of right mandible; l, Maxilla 1.

Fig. 4. *Cirolana arcuata* from San Francisco Bay, ♀: a, Left maxilla 2; b, Same, detail of endopod; c, Left maxilliped; d, Left pereopod 1. *C. arcuata,* "paratype" from Little Sirius Cove, P9628: e, First segment of palp of maxilliped.

Fig. 5. *Cirolana arcuata* from San Francisco Bay, ♀: a, Left pereopod 2; b, Left pereopod 3; c, Right pereopod 4.

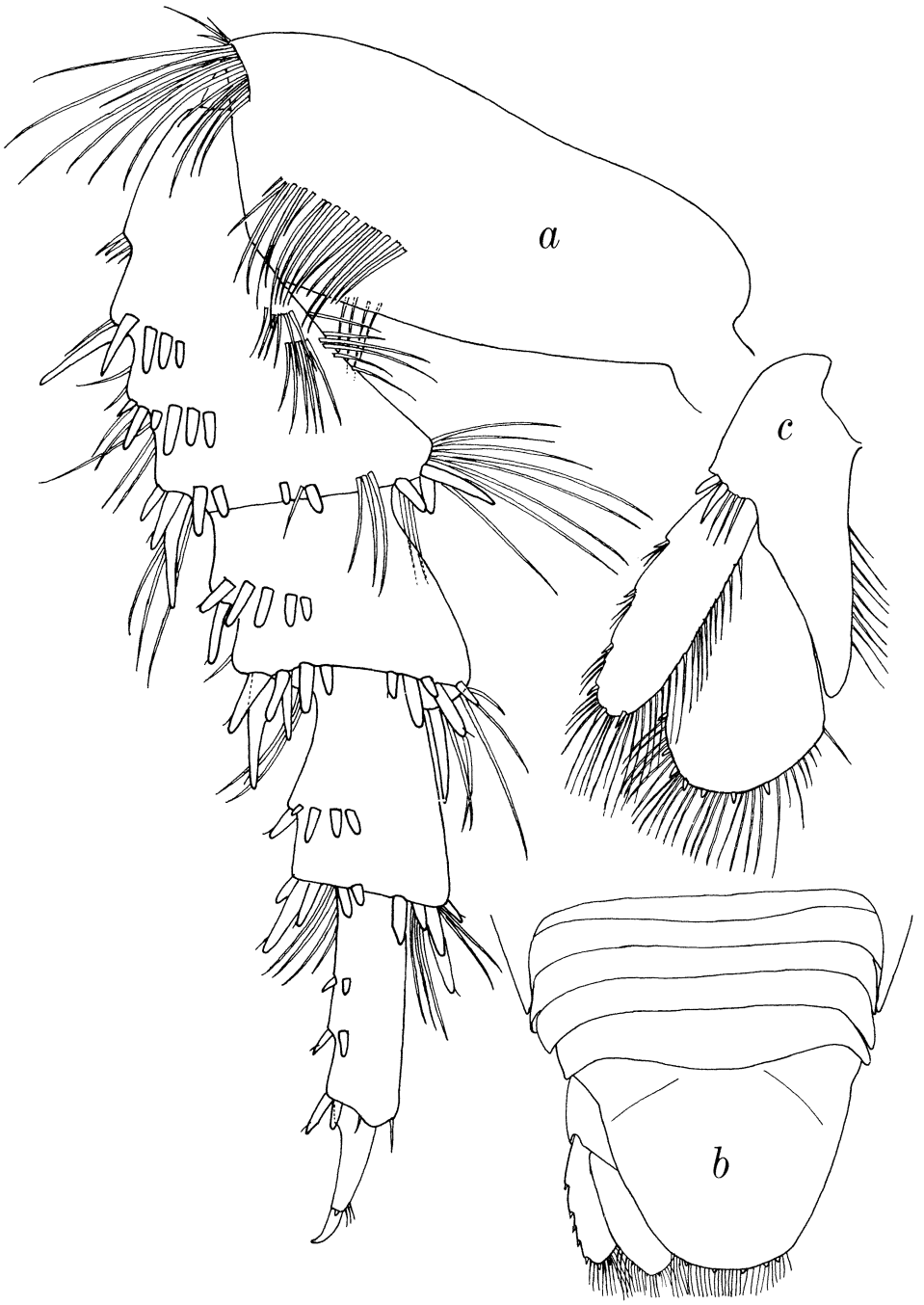

Fig. 6. *Cirolana arcuata* from San Francisco Bay, ♀: a, Left pereopod 5; b, Pleon and pleotelson, dorsal; c, Right uropod, ventral.

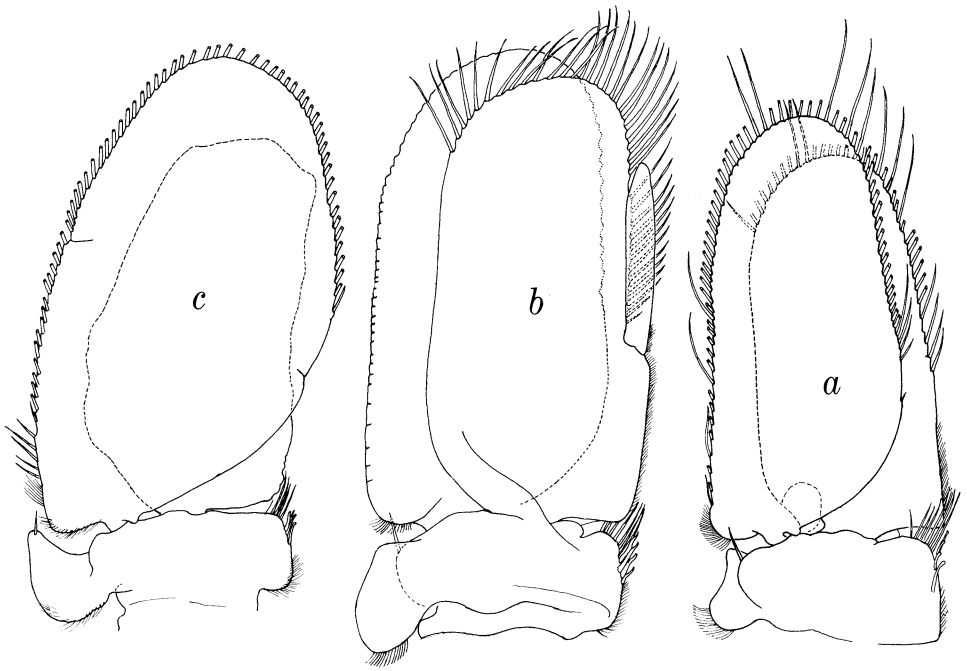

Fig. 7. *Cirolana arcuata* from San Francisco Bay: a, Left pleopod 2, ♀; b, Left pleopod 2, ♂; c, Left pleopod 4, ♀.

Museum, Sydney), the holotype and both paratypes of *C. robusta* (Riksmuseet, Stockholm), and specimens from Chile identified as *C. concinna* by Menzies (Riksmuseet, Stockholm). The "paratypes" of *C. arcuata* are probably not paratypes. Hale lists only a ♀ type and a ♂ allotype from Little Sirius Cove, although he mentions that "several specimens were taken in company with *Sphaeroma quoyana*." No mention is made of Broughton I., and the catalog number of the 3 "paratypes" from the type-locality, P9628, is much higher than those given by Hale for the holotype (P8200) and allotype (P8201).

As shown in Figs. 8–9, there are only minor differences among the above specimens, such as the length of the appendix masculina and the setae of the 1st segment of the maxillipedal palp. The length of the appendix masculina varies with maturity, and the differences observed do not appear to be significant. An oblique row of setae is present on the posterior surface of the 1st maxillipedal palp segment near the distolateral corner in *C. concinna* of Menzies and in the San Francisco Bay *C. arcuata*. Hale (1925) does not show it in any cirolanid, nor does Carvacho (1977) in his *C. robusta*. In a "paratype" of *C. arcuata* from Little Sirius Cove the lateral row is absent, but a medial row, not shown by Hale, is present. Carvacho's *C. robusta* and the San Pablo specimens also have a medial row. Evaluation of the taxonomic significance of this variation requires study of more material than is now available to us.

Natural History

The distribution of *C. arcuata* shows that it is a cold temperate to warm temperate species. Depths at collection localities are not given by Hale or Naylor; other authors report intertidal depth. The type of substrate is not indicated by

Hale, Naylor, Ramirez, or Carvacho, but Menzies recorded sand, sand and gravel with mud and small stones, and hard rocks and boulders with coarse sand between the boulders. Morton and Miller state that *C. arcuata* occurs on the coarser shell sand of middle intertidal levels of protected sandy beaches, "half-swimming and half sand-ploughing," and "coming to the surface as scavengers by night, or at full tide." Menzies reports both exposed and very sheltered habitats for *C. arcuata,* but Morton and Miller list it only from sheltered localities.

C. arcuata appears to tolerate a wide range of salinities. Hale gives no salinity data, but reports that "several specimens were taken in company with *Sphaeroma quoyana,*" an isopod characteristically found in brackish water, which has also been introduced into San Francisco Bay (Rotramel, 1972). Salinities are not available for the Chilean localities except Puerto Montt, where the salinity in the harbor at 1 m ranged between 18.2 and 28.4‰ (Brattström and Dahl, 1951).

Occurrence of *Cirolana arcuata* in San Francisco Bay

Invertebrate samples taken from the filter screens of cooling water intake systems at 5 San Francisco Bay power plants were searched for *C. arcuata.* These samples, of 24 hours duration each, were gathered weekly from each power plant for a year and were representative of the larger invertebrates occurring in the immediate vicinity of the plants.

Cirolana arcuata were collected at only 1 locality in San Francisco Bay, the Oleum Power Plant of the Pacific Gas and Electric Company, near the town of Rodeo, Contra Costa County, in the northern expanse of San Francisco Bay known as San Pablo Bay. We searched for, but did not find this isopod, in equal numbers of samples from the 4 other power plants in San Francisco Bay: the Pittsburg and Contra Costa Power Plants in the western Delta, to the east of Rodeo, where salinities are very low; the Potrero and Hunter's Point Power Plants in San Francisco, south of Rodeo, where salinities are high (Fig. 2).

Even at the Oleum Power Plant, *C. arcuata* appeared to be uncommon, occurring in only 8 of 52 samples. The collection dates of these 8 samples, with recorded salinities and temperatures, are listed below.

Collection date	Salinity (‰)	Temperature (°C)
11 May 1978	6.8–18.0	16.0–18.5
18 May 1978	15.0–18.6	16.8–18.4
29 June 1978	17.2–24.0	18.0–20.1
8 August 1978	21.0–25.0	19.5–22.3
24 August 1978	20.8–26.2	19.6–21.2
21 December 1978	17.2–21.0	7.9–10.6
8 March 1979	11.2	8.9
5 April 1979	8.7–12.2	15.0–17.4

These collections have been deposited in the National Museum of Natural History, Smithsonian Institution.

Isopods that were more abundant than *C. arcuata* at the Oleum locality included *Gnorimosphaeroma oregonensis, Iais californica, Lironeca vulgaris, Lironeca californica, Sphaeroma quoyanum,* and especially *Synidotea laticauda.*

Although the known distribution of *C. arcuata* in San Francisco Bay (and in North America) is limited to a single locality, the presence of brooding females and juveniles in our collections suggests that the population is now established

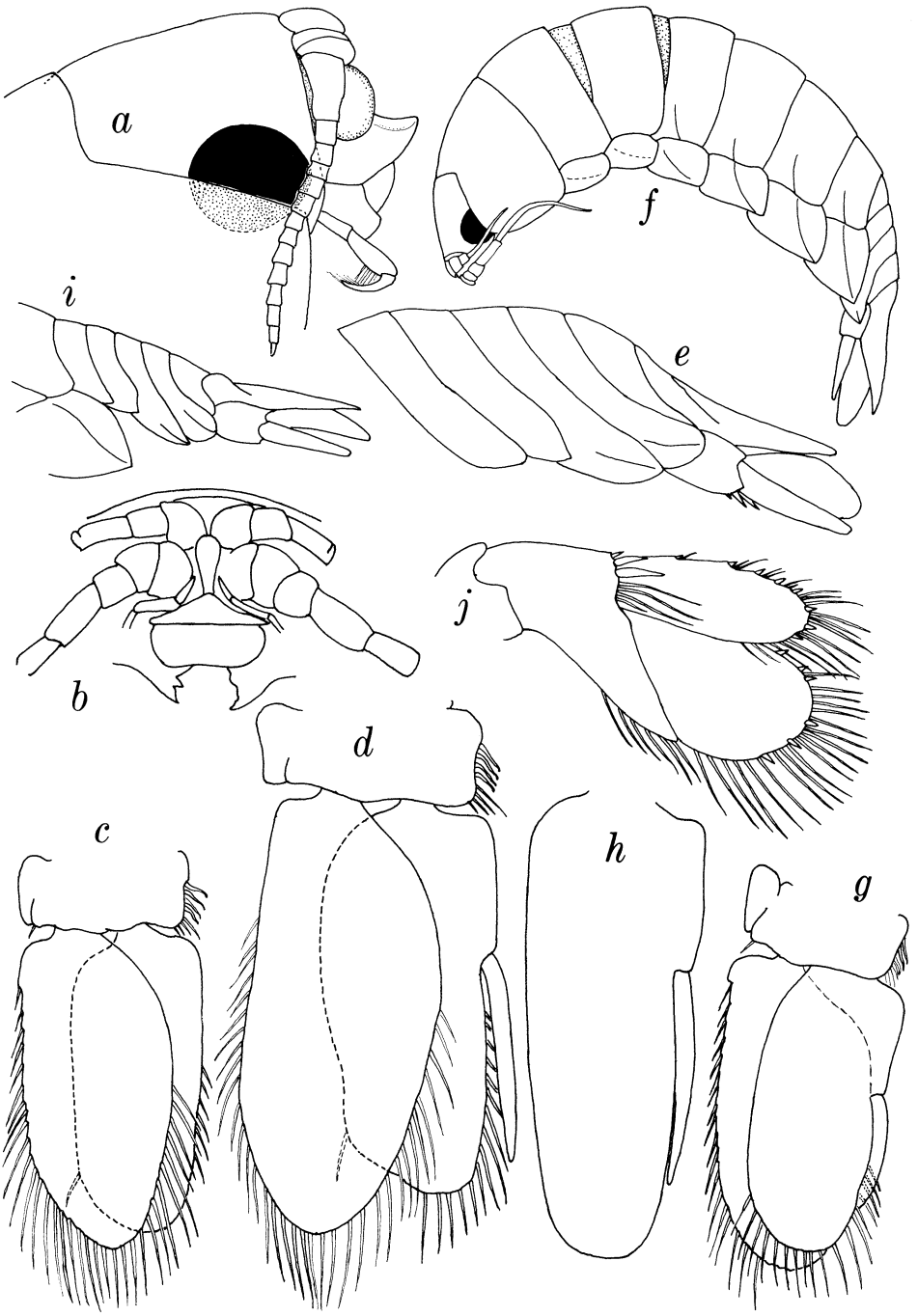

Fig. 8. *Cirolana arcuata*: a, San Francisco Bay ♀, head, lateral, showing pointed clypeus (antenna 2 removed); b–e, "Paratypes" from Broughton I.: b, Head, ventral; c, Pleopod 2, ♀; d, Pleopod 2, ♂; e, Pleon, lateral; f–g, *C. concinna* of Menzies: f, Habitus, lateral; g, Pleopod 2, ♂; h–j, *C. robusta*, paratype: h, Pleopod 2, endopod, ♂ (setae omitted); i, Pleon, lateral; j, Uropod, ventral.

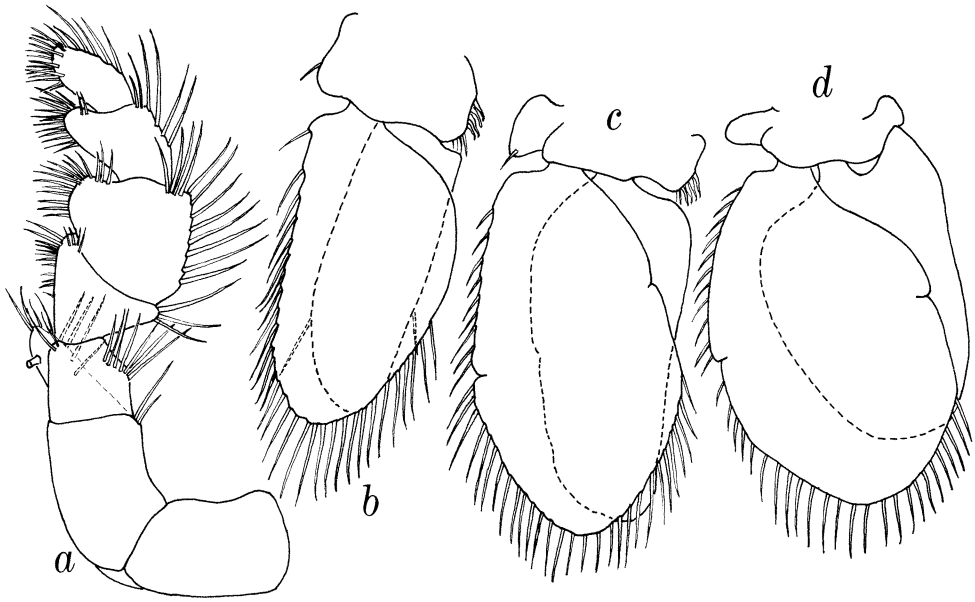

Fig. 9. *Cirolana arcuata*: a, *C. concinna* of Menzies, maxilliped; b–d, "Paratype" ♀ from Broughton I.: b, Pleopod 1; c, Pleopod 3; d, Pleopod 5.

there. It is likely that *C. arcuata* will be found in other brackish localities in San Francisco Bay in the future.

Evidence that *Cirolana arcuata* Is Introduced and Timing of Introduction

That the cirolanid isopod reported here is an exotic rather than a native California species, recently introduced (perhaps in or since the 1960's or 1970's), is clear from the following:

1. The specimens from San Francisco Bay are conspecific with a species, *Cirolana arcuata*, previously known only from the Southern Hemisphere. *C. arcuata* is widespread, abundant, and well-known in New Zealand and Chile, regions where it has evidently been present for many years, yet numerous studies since the 19th century on the isopods of the Pacific coast of North America have failed to report it. Active work on the cirolanid isopods of California continues by a number of investigators (e.g., Brusca and Ninos, 1978), yet *C. arcuata* remains known only from San Francisco Bay.

2. Introduced species of marine and estuarine invertebrates are numerous and well-documented in San Francisco Bay (Carlton, 1975, 1979b), and include a number of species from the southern hemisphere, including Australasia and Chile, such as the serpulid polychaete *Ficopomatus enigmaticus*, the amphipod *Orchestia chiliensis*, the isopods *Sphaeroma quoyanum* and *Iais californica*, the barnacle *Balanus amphitrite amphitrite*, and others (Carlton, 1979b, and J. T. Carlton, personal communication).

3. *C. arcuata* is highly localized within San Francisco Bay; its distribution elsewhere is much broader. No native isopod in San Francisco Bay is so restricted (J. T. Carlton, personal communication).

4. Considerable collecting has been done in San Pablo Bay and elsewhere in

San Francisco Bay, since the *Albatross* surveys of 1912–1913, but we are aware of no records of *C. arcuata* or an unidentified *Cirolana*. The following works contain records of isopods from San Pablo Bay: Filice, 1959 [*Gnorimosphaeroma oregonensis* (Dana), *Synidotea laticauda* Benedict]; Storrs, Selleck, and Pearson, 1964 (*S. laticauda*); Painter, 1966 (*S. laticauda*); Miller, 1968 (*G. oregonensis, S. laticauda*); Liu, 1973 (*S. laticauda*); Anderlini *et al.*, 1974 (*S. laticauda, Sphaeroma quoyanum* Milne Edwards).

Mode and Source of Introduction

C. arcuata was probably introduced to San Francisco Bay by a ship either in fouling such as that found on propeller shaft housings (J. T. Carlton, personal communication), or possibly in water ballast. All known introductions of invertebrates from Australia and Chile to San Francisco Bay are thought to have arrived by ships (Carlton, 1979a, 1979b).

The source could have been Australia, New Zealand, or Chile. Although *C. arcuata* was originally described from Australia, it appears to be quite rare there, if not altogether absent. It has not been reported from Australia since Hale's (1925) original description, and the 2 "new" localities reported herein, Broughton I. and Port Willunga, are from collections made more than 55 years ago. No more recently collected specimens have been found in any Australian museums. Comprehensive collections from the following Australian localities have been examined by one of us (NLB) without finding *C. arcuata*: Port Phillip Bay, Western Port, Crib Point, and Bass Strait, Victoria; Botany Bay, New South Wales; Moreton Bay, Queensland. At least some of these collections were made from habitats similar to those in which *C. arcuata* lives in New Zealand. It is possible that *C. arcuata* was introduced into Australia and subsequently died out there.

Cirolana arcuata is widespread and common in New Zealand (Morton and Miller, 1968; K. P. Jansen, personal communication). It is also widespread in Chile, but no information is available on its abundance there. Both Chile and New Zealand appear to be more likely sources than Australia, but no evidence favors one country over the other.

Acknowledgements

We are grateful to Dr. R. Olerod, Naturhistoriska Riksmuseet, Stockholm, and to Dr. J. L. Lowry, Australian Museum, Sydney, for the loan of specimens, and to Dr. J. T. Carlton, Woods Hole Oceanographic Institution, for reviewing the manuscript.

Literature Cited

Anderlini, V. C., J. W. Chapman, D. C. Girvin, A. S. Newton, and R. W. Risebrough. 1974. Dredging impact—heavy metals uptake study.—U.S. Army Corps of Engineers, San Francisco, 42 pp.

Atwater, B. F., C. W. Hedel, and E. J. Helley. 1977. Late Quaternary deposition history, Holocene sea-level changes, and vertical crustal movement, Southern San Francisco Bay, California.—United States Geological Survey Professional Paper 1014, 15 pp.

Brattström, H., and E. Dahl. 1951. General account, lists of stations, hydrography. Reports of the Lund Chile Expedition 1948–49: 1.—Lunds Universitets Årsskrift, N.F. Avd. 2, 46(8): 1–88.

Brusca, R. C., and M. Ninos. 1978. The status of *Cirolana californiensis* Schultz and *C. deminuta* Menzies and George, with a key to the California species of *Cirolana* (Isopoda: Cirolanidae).—Proceedings of the Biological Society of Washington 91(2): 379–385.

Carlton, J. T. 1975. Introduced intertidal invertebrates.—*In:* R. I. Smith and J. T. Carlton, eds., Light's Manual, Intertidal Invertebrates of the Central California Coast, 3rd edition, University of California Press, Berkeley, pp. 17–25.

———. 1979a. History, biogeography, and ecology of the introduced marine and estuarine invertebrates of the Pacific coast of North America.—Ph.D. Dissertation, Ecology, University of California, Davis, 904 pp.

———. 1979b. Introduced invertebrates of San Francisco Bay.—*In:* T. J. Conomos, ed., San Francisco Bay: The Urbanized Estuary. AAAS, San Francisco, pp. 427–444.

Carvacho, A. 1977. Isopodes intertidaux des côtes du centre et du nord du Chili.—Crustaceana 32(1): 27–44.

Filice, F. P. 1959. Invertebrates from the estuarine portion of San Francisco Bay and some factors influencing their distributions.—Wasmann Journal of Biology 16(2): 159–211.

Hale, H. M. 1925. Review of Australian isopods of the cymothoid group. Part I.—Transactions of the Royal Society of South Australia 49: 128–185.

Hurley, D. E. 1961. A checklist and key to the Crustacea Isopoda of New Zealand and the Subantarctic Islands.—Transactions of the Royal Society of New Zealand, Zoology 1(20): 259–292.

Liu, D. H. W. 1973. A preliminary survey of benthic communities in selected areas in San Francisco Bay.—United States Army Corps of Engineers, San Francisco, 122 pp.

Menzies, R. J. 1962. The zoogeography, ecology, and systematics of the Chilean marine isopods. Reports of the Lund University Chile Expedition, 1945–49: 42.—Lunds Universitets Årsskrift, N.F. Avd. 2, 57(11): 1–162.

Miller, M. A. 1968. Isopoda and Tanaidacea from buoys in coastal waters of the continental United States, Hawaii, and the Bahamas (Crustacea).—Proceedings of the United States National Museum 125(3652): 1–53.

Morton, J., and M. Miller. 1968. The New Zealand sea shore.—Collins, London, 638 pp.

Naylor, E. 1961. Some isopods from the Chatham Islands, including two species of *Cirolana* new to New Zealand waters.—Transactions of the Royal Society of New Zealand, Zoology 1(2): 7–17.

Painter, R. E. 1966. Zoobenthos of San Pablo and Suisun Bays.—California Department of Fish and Game, Fish Bulletin 133: 40–56.

Ramirez, Amalia M. 1974. Isópodos litorales y marinos de la Bahía de Concepción. (Crustacea—Isopoda).—Boletin de la Sociedad de Biología de Concepción, Chile 48: 409–421.

Rotramel, G. 1972. *Iais californica* and *Sphaeroma quoyanum*, two symbiotic isopods introduced to California (Isopoda, Janiridae and Sphaeromatidae).—Crustaceana, Supplement 3: 193–197.

Storrs, P. N., R. E. Selleck, and E. A. Pearson. 1964. A comprehensive study of San Francisco Bay, 1961–62.—Sanitary Engineering Research Laboratory, University of California, Berkeley, pp. I-1 to IX-9.

RECEIVED: 6 March 1981.
ACCEPTED: 23 April 1981.

Addresses: (TEB) Department of Invertebrate Zoology (Crustacea), Smithsonian Institution, Washington, D.C. 20560; (NLB) Department of Zoology, University of Queensland, St. Lucia, Brisbane, Australia 4067; (JDS) Duke University Marine Laboratory, Beaufort, North Carolina 28516. (Coauthors are listed alphabetically.)