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

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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].


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 anteroven-trally, 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 tricuspat e, right incisor quadricuspat e. 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 1/3 distance along medial margin of pleopod 2 endopod. Pleotelson about 0.6 times as long as width at base, linguiform, broadly rounded
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 arculata* 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.
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.

<table>
<thead>
<tr>
<th>Collection date</th>
<th>Salinity (%)</th>
<th>Temperature (°C)</th>
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<tbody>
<tr>
<td>11 May 1978</td>
<td>6.8–18.0</td>
<td>16.0–18.5</td>
</tr>
<tr>
<td>18 May 1978</td>
<td>15.0–18.6</td>
<td>16.8–18.4</td>
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<tr>
<td>29 June 1978</td>
<td>17.2–24.0</td>
<td>18.0–20.1</td>
</tr>
<tr>
<td>8 August 1978</td>
<td>21.0–25.0</td>
<td>19.5–22.3</td>
</tr>
<tr>
<td>24 August 1978</td>
<td>20.8–26.2</td>
<td>19.6–21.2</td>
</tr>
<tr>
<td>21 December 1978</td>
<td>17.2–21.0</td>
<td>7.9–10.6</td>
</tr>
<tr>
<td>8 March 1979</td>
<td>11.2</td>
<td>8.9</td>
</tr>
<tr>
<td>5 April 1979</td>
<td>8.7–12.2</td>
<td>15.0–17.4</td>
</tr>
</tbody>
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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 1.: 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.
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 chilensis*, 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...

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.

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