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OITHONA DAVISAE, NEW SPECIES, AND *LIMNOITHONA SINENSIS* (BURCKHARDT, 1912) (COPEPODA: OITHONIDAE) FROM THE SACRAMENTO-SAN JOAQUIN ESTUARY, CALIFORNIA

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ABSTRACT

Zooplankton samples from the Sacramento-San Joaquin Estuary collected by the California Department of Fish and Game and the United States Geological Survey were examined for cyclopoid copepods of the family Oithonidae. Of the three species found, *Limnoithona sinensis, Oithona davisae,* new species, and *O. similis,* the first two are described here. *Limnoithona sinensis,* like its congener *L. tetraspina,* has been previously reported from delta localities in the Yangtze River, China. In general morphology *O. davisae* is similar to many estuarine/lagoonal oithonids of temperate and tropical American coastal waters. Two characters, an elongate ventrally pointed rostrum and/or a long distal spine on the inner lobe of the first maxilla, suggest affinities to the Indo-West Pacific estuarine species *O. brevicornis, O. aruensis,* and *O. wellershausi.* In the northern hemisphere *O. similis* is a common subarctic oceanic species. Specimens have also been reported from estuarine areas. Zooplankton samples taken in coastal estuarine localities from Humboldt Bay south to Baja California were examined to determine the distribution of these three species. *O. similis* was the only species found.

Cyclopoid copepods of the family Oithonidae are cyclically abundant members of the planktonic fauna of many American temperate, subtropical, and tropical estuaries and embayments (Deevey, 1948, 1960; Fish, 1936; Fonseca and Prado, 1979; González and Bowman, 1965; Hopkins, 1966, 1977; Lonsdale, 1981; and Lonsdale and Coull, 1977). Despite their importance in plankton communities, geographical distributions of many American estuarine oithonids are incompletely known. Collecting them requires a fine-mesh plankton net, and their small size and thin exoskeleton complicate dissection, making correct identification difficult.

Oithonids collected in bays and estuaries generally fall into two groups: a morphologically heterogeneous group whose distributions center on the continental shelf or beyond, in the epipelagic oceanic region, e.g., *Oithona nana, O. similis, O. plumifera,* and *O. simplex*; and a morphologically similar group whose members are associated with lower salinity waters of most estuaries. In well-studied American estuaries of the Atlantic coast usually a single species of the second group has been reported, e.g., *O. colcarva* in Chesapeake Bay (Lonsdale, 1981), North Inlet Estuary, South Carolina (Lonsdale and Coull, 1977), and Tampa Bay, Florida (Hopkins, 1977), or *O. hebes* in Bahia Fosforescente, Puerto Rico (González and Bowman, 1965). In Cananeia, Brazil, two species of the second group, *O. oligohalina* (? *neotropica,* see Ferrari and Bowman, 1980, for comments) and *O. ovalis,* have been reported, associated with separate salinity zones (Fonseca and Prado, 1979).

In most coastal areas oithonids are replaced by cyclopids in fresh waters. There are reports of oithonids associated with riverine fresh waters of estuaries, e.g., *Limnoithona sinensis* in the Yangtze River by Burckhardt (1913) and Shen and Tai (1962), and in the Amazon River, *O. amazonica* by Lindberg (1954) and *O. amazonica* and *O. bjornbergae* by Ferrari and Bowman (1980).

No comparable reports have been published for oithonids from American estuaries of the Pacific coast. Although historical studies of the Sacramento-San

Joaquin Estuary began over fifty years ago (Allen, 1920), we are unaware of any comprehensive treatment of oithonids.

In a recent survey of oithonids of the Sacramento-San Joaquin Estuary, we identified three species. *Limnoithona sinensis* is reported for the first time from fresh waters of the estuary and for only the third time worldwide. *Oithona davisae*, new species, is found in waters of salinities down to 12‰, and is morphologically similar to other estuarine species found in similar zones. Immature and mature males and females, the latter often with egg sacs, of both species are identified. These species are described here, their distributions in the estuary outlined, and the question of their introduction discussed.

The third species, *O. similis*, is commonly reported in subarctic oceanic waters of the northern hemisphere; its oceanic distribution in the Pacific extends southward with the California Current (Nishida, 1981). Sars (1918), who referred to the animals as *O. helgolandica*, first reported specimens in "fjords and shallow creeks" of Norway. Immature females and males, and a few mature females, were found in the Sacramento-San Joaquin Estuary, primarily in areas such as North San Francisco Bay, which is influenced by water of higher salinity entering the estuary from the Golden Gate and San Pablo Bay.

The Sacramento-San Joaquin Estuary

The estuary (Fig. 1) is formed by the Sacramento and San Joaquin Rivers. It consists of three interconnected bays (San Francisco Bay, often divided into North and South Bays by the Golden Gate, San Pablo Bay, and Suisun Bay) and the delta, a maze of river channels, sloughs, and flooded islands upstream from Suisun Bay.

The estuary's salinity is affected by both river runoff and tidal exchange between San Francisco Bay and the Pacific Ocean (Conomos, 1979). Annual runoff averages 20.9×10^9 m^3/yr, 91% of which comes from the Sacramento and San Joaquin rivers. The Napa River, which empties into San Pablo Bay, and Coyote Creek, draining into South San Francisco Bay, are the most important of the minor streams.

A salinity gradient exists between the Golden Gate, where salinity ranges from 30.6 to 32.9‰ between winter and summer of typical years, and the western tip of the delta, 72 km upstream, where summer salinities commonly peak at about 2‰. Western Suisun Bay salinities may reach 13‰ in summer and drop below 1‰ during high spring flows. Vertical salinity stratification in the gradient ranges from 3‰ in summer to between 5 and 10‰ during winter (Conomos, 1979). South San Francisco Bay salinity is close to that of the Pacific Ocean, since Coyote Creek provides only a small quantity of fresh water. High winter river runoff during wet years flushes the South Bay and lowers salinity there.

An entrapment zone of long water residence times, high turbidity, and high concentrations of suspended material, phytoplankton, and zooplankton occurs between 1.2 and 5.6‰ surface salinity (Arthur and Ball, 1979). River runoff controls its location, moving it from Suisun Bay and the western delta during summer and fall to Carquinez Strait and eastern San Pablo Bay during winter and spring.

The typical temperature range from winter to summer at the Golden Gate is 10°–16°C. At Alameda in North San Francisco Bay the range is 10°–20°C, and in the delta 6°–26°C.

Summer and fall flow patterns in the delta are greatly affected by water exports from the south delta by state and federal water projects, which remove 200–300

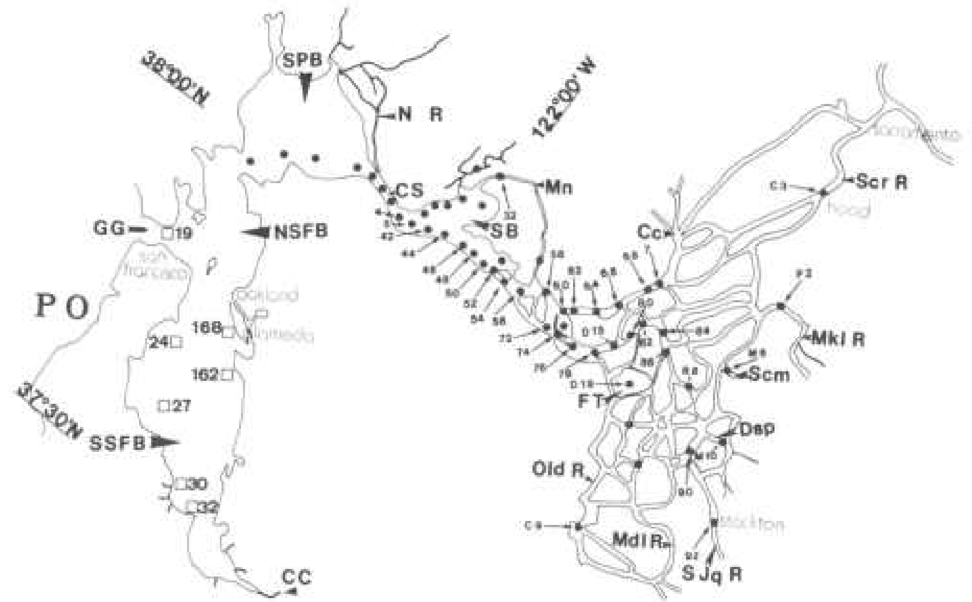

Fig. 1. Sacramento-San Joaquin Estuary. Location of stations (numbered): open squares, USGS; closed circles, California Department of Fish and Game. Cc = Cache Slough, CS = Carquinez Strait, CC = Coyote Creek, Dsp = Disappointment Slough, FT = Frank's Tract, GG = Golden Gate, Mdl R = Middle River, Mkl R = Mokelumne River, Mn = Montezuma Slough, Np R = Napa River, NSFB = North San Francisco Bay, Old R = Old River, PO = Pacific Ocean, Scr R = Sacramento River, S Jq R = San Joaquin River, SPB = San Pablo Bay, SSFB = South San Francisco Bay, SB = Suisun Bay, Scm = Sycamore Slough.

m^3/s from Old River and create a cross-delta flow of water from the Sacramento River through the Delta Cross-Channel and down the Mokelumne River and up Old and Middle Rivers. During summer the pumping often causes the San Joaquin River to flow upstream from its confluence with the Sacramento River to the mouth of Old River.

Materials and Methods

Sampling Program

The California Department of Fish and Game began taking zooplankton samples in the estuary in March 1971 at 43 stations throughout Suisun Bay and the delta to Rio Vista on the Sacramento River, and to Stockton on the San Joaquin. Samples were taken with an open conical net 12.7 cm in diameter with 154-μm mesh, or with a small pump. Samples were taken twice monthly from April to October and once a month during the rest of the year. Stations have been added over the years and presently a varying number of samples are taken from the city of Hood on the Sacramento, 114 km upstream from the Golden Gate, and Stockton on the San Joaquin, 124 km from the Golden Gate, to Point San Pablo in San Pablo Bay.

The United States Geological Survey collected zooplankton samples between February 1978 and December 1980 throughout San Francisco, San Pablo, and Suisun bays, and into the delta as far up the Sacramento River as its junction with Cache Slough, and the San Joaquin River as far as Three Mile Slough. Planktonic organisms were collected bimonthly at three depths in the ship channel by pumping water through 64- or 80-μm screens. Eleven of these samples from seven stations in South San Francisco Bay (see Fig. 1) were available for examination during this study.

Abbreviations Used

The following abbreviations are used in the descriptive text and in the legends for the figures:

Body Segments.—Pr = prosome, Cph = cephalosome, Pg = pediger, Ur = urosome, CR = caudal ramus.

Appendages.—A1 = first antenna, A2 = second antenna, Mn = mandible, Mx1 = first maxilla, Mx2 = second maxilla, Mxp = maxilliped, P = swimming legs.

Appendage Elements.—Bspd = basipodal segment, Re = exopodal segment, Ri = endopodal segment, Li = inner lobe.

Appendages.—A1 = first antenna, A2 = second antenna, Mn = mandible, Mx1 = first maxilla, Mx2 = second maxilla, Mxp = maxilliped, P = swimming legs.

In appendages with repeated elements, or elements with repeated armature, abbreviations may be combined as follows: Mx1Li1 = first lobe of first maxilla, P1Ri2 = second endopodal segment of first swimming leg, and P4Re3Se1 = first external spine on third exopodal segment of fourth swimming leg.

Descriptions

Limnoithona sinensis (Burckhardt, 1912)
Figs. 2–5

Oithona (*Limnoithona*) *sinensis* Burckhardt, 1912: 726; 1913: 343–344, 421, Figs. 15O(P) 1–5, 15P(Q) 1 and 7–9, 16Q(R) 1, 5–6, 10, 13, 16R(S) 2 and 9–16.

Limnoithona sinensis. Rosendorn, 1927: 48; Kiefer, 1928: 222; 1929: 11–12, Fig. 4; Shen and Tai, 1962: 225–226, Figs. 1–6.

Female.—Length range 0.47–0.55 mm (30 specimens); Pr/Ur = 1.1. Rostrum absent (Fig. 2A); forehead rounded dorsally (Fig. 3A). Knob near genital opening with 1 long and 1 short seta. CR length 6× width, armed as in Fig. 2C. A1 (Fig. 3B) with 9 free segments. A2 (Fig. 5A) with 2 segments; with 2 other incomplete articulation lines. Mn gnathobase simple; Bspd2 (Fig. 5B) with 3 simple setae medially; Re1 fused to Bspd2, Re4 and 5 fused, Re with 5 setae; Ri fused to Bspd2, with 5 setae. Mx1 (Fig. 5D) Li1 with 9 spines; Bspd2 with 2 small knobs medially with 2 spines each; Re with 1 segment, fused to Bspd2, with 4 setae; Ri with 1 segment, fused to Bspd2, with 4 setae. Mx2 with 4 segments armed as in Fig. 4A. Mxp with 4 segments armed as in Fig. 4B. P1–4 (Figs. 3C, D, 4C, D), each Bspd2 with 3 or 4 hairs on distomedial corner; Re1–3Se 1-1-3, 1-1-3, 1-1-3, 1-1-3; Si 1-1-4, 1-1-5, 1-1-5, 1-1-5; Ri1–3Si 1-1-6, 1-2-6, 1-1-6, 1-1-5; all setae simple. P5 (Fig. 2B) an unarticulated dorsolateral knob with 1 seta, and an articulated, simple, cylindrical segment ventrolaterally, with 1 thick external seta, longer terminal seta, and thinner, shorter internal seta.

Male.—Length range 0.41–0.51 mm (22 specimens); Pr/Ur = 1.1. Rostrum absent (Fig. 2D); forehead rounded dorsally (Fig. 3E). Genital flap with 3 setae, ventralmost small. CR length 5× width, armed (Fig. 2F) like female's. A1 (Fig. 3F) digeniculate, no aesthete distinguished. A2, Mn, Mx1, Mx2, Mxp, P1–5 (Figs. 2E, 3G, H, 4E–H, 5E–G) similar to female's, although slightly reduced in size, with P3 and P4 exhibiting least sexual dimorphism in size. Sexual dimorphism pronounced in length of terminal spine on P2Re3, and best illustrated by ratios of respective lengths of Re and Re3Se3 to length of this spine. For 5 females these ratios averaging 0.66 and 0.51; for 5 males 0.83 and 0.70.

Remarks.—*Limnoithona sinensis,* reported by Burckhardt in 1912, was described and illustrated by Burckhardt (1913) as a new subgenus, *Limnoithona,* of the genus *Oithona.* Rosendorn (1927) placed the species in the present genus, and Kiefer (1928) in the subfamily Limnoithoninae. Burckhardt's specimens were collected from three localities in China: Sutschau (Suzhou) Canal, through the Wangpu River (Huangpujiang) and Jangtsekjang (Yangtze River or Changjiang)

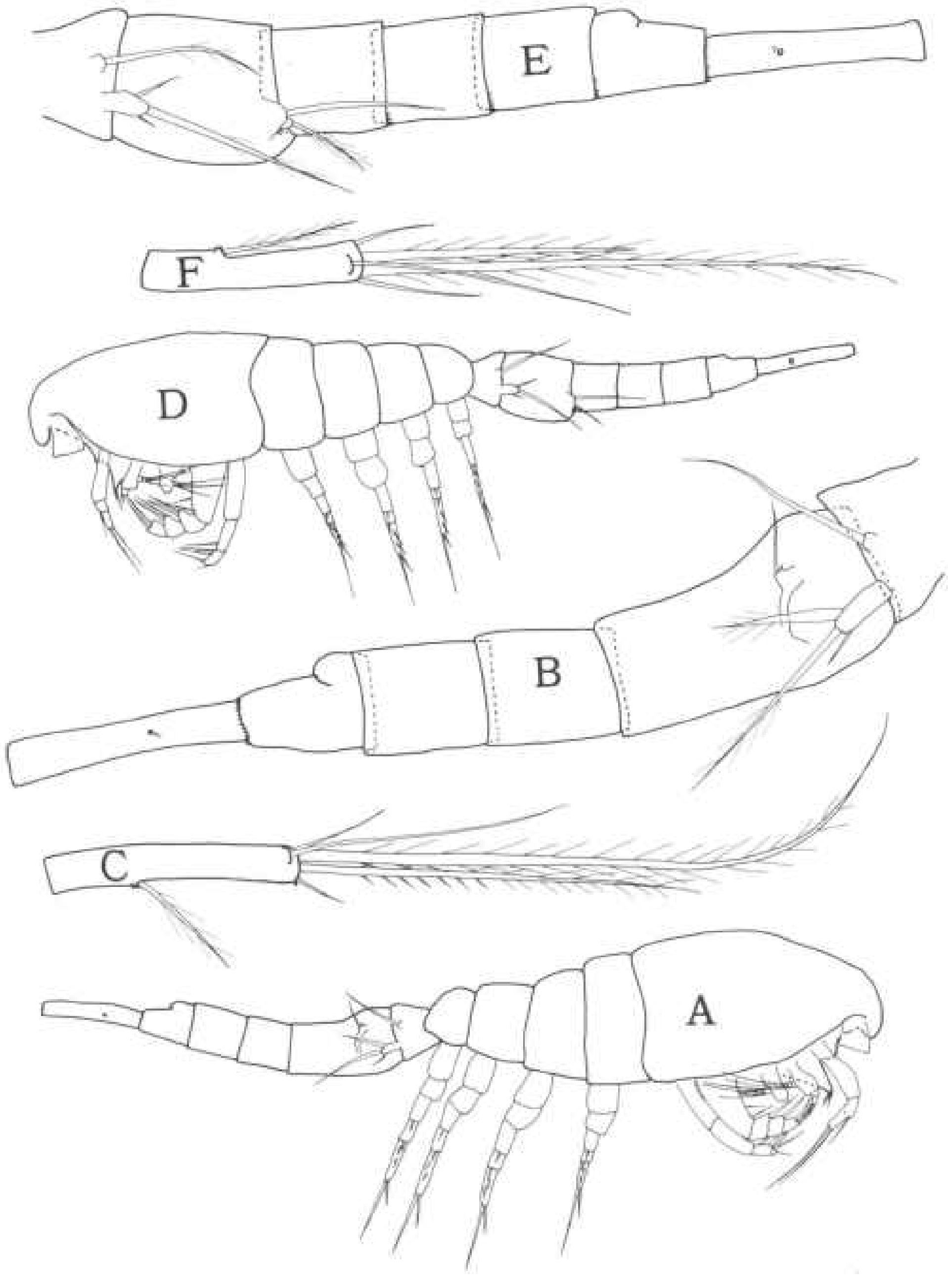

Fig. 2. *Limnoithona sinensis.* Female. A, habitus, lateral; B, Ur, lateral; C, CR, dorsal. Male. D, habitus, lateral; E, Ur, lateral; F, CR, dorsal.

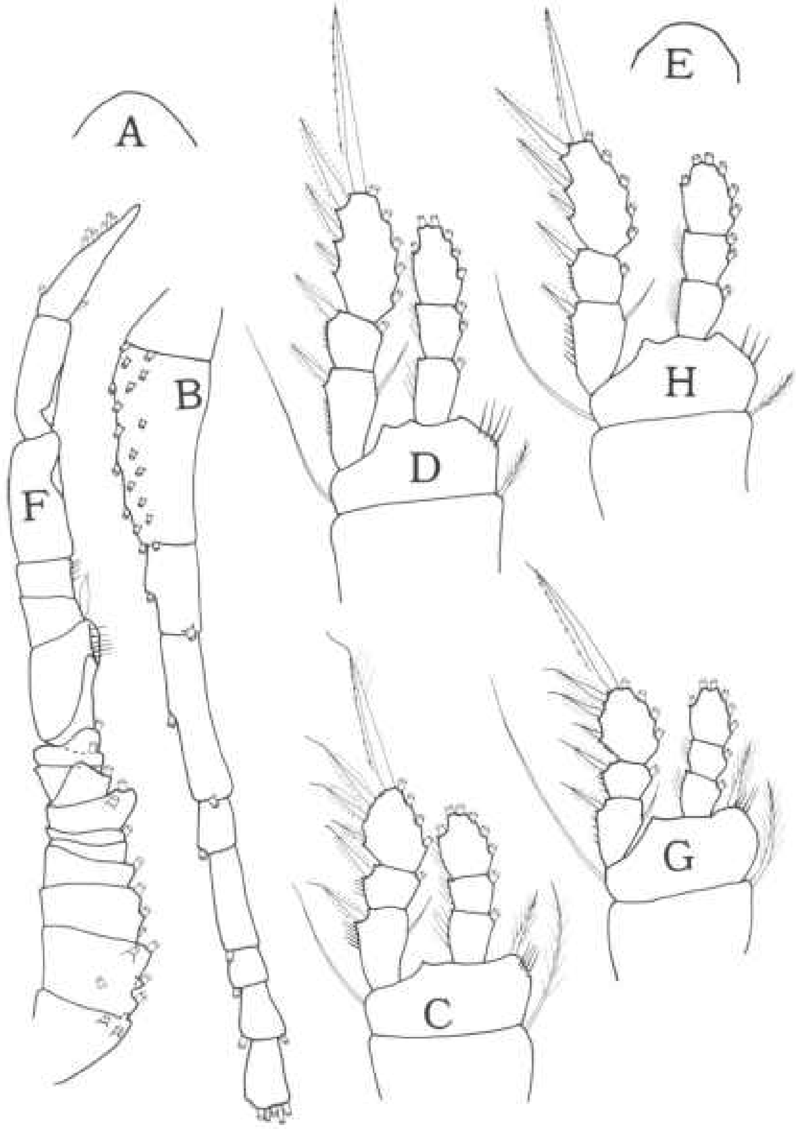

Fig. 3. *Limnoithona sinensis.* Female. A, forehead, dorsal; B, A1; C, P1; D, P2. Male. E, forehead, dorsal; F, A1; G, P1; H, P2.

60 km from the sea, 31°14′N, 121°26′E on 10 November 1898; Tahu or Tai-hu Lake, 31°15′N, 120°10′E, 0–4 m, 11 November 1898; Jangtsejang (Yangtze River or Changjiang) lower course between Kiukjang (Jiujuang) 29°12′N, 116°10′E and Tschinkjang (Zenjiang) 32°12′N, 119°25′E, 31 March–12 April 1906. The species has recently been reported from Wu Li Lake near the city of Wu-Sih (Wu Hsi, Wuxi) north of Tai-Hu Lake in the Yangtze River delta by Shen and Tai (1962).

From this information it seems that *Limnoithona sinensis* inhabits the brackish and fresh waters of the Yangtze River delta and inland to at least 300 km. A

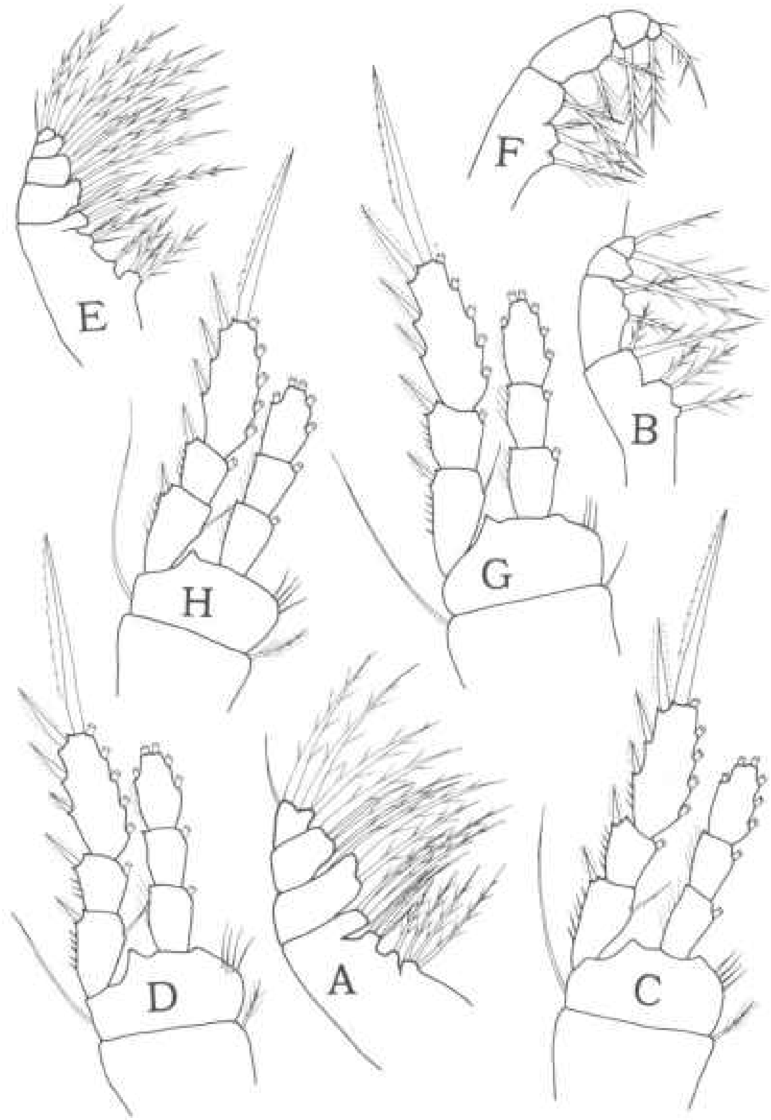

Fig. 4. *Limnoithona sinensis*. Female. A, Mx2; B, Mxp; C, P3; D, P4. Male. E, Mx2; F, Mxp; G, P3; H, P4.

congener, *Limnoithona tetraspina*, differing in the shape of the forehead and armature of P3 and 4Ri2 and P5, has recently been described from Tsungming Island (Chongmingdao) in the mouth of the Yangtze (Zhang and Li, 1976).

Specimens of *L. sinensis* from the Sacramento-San Joaquin Estuary are similar to descriptions and illustrations of Burckhardt (1913). The males are slightly smaller than females; Burckhardt mentions the sexes as similar in size. The genital flap of the males is armed with 2 long and 1 short setae; Burckhardt notes only 1 seta. The ratio of St2 (second from the medial edge) to St3 of CR is 2× in males and 1.5× in females; Burckhardt lists ratios of 2× for both sexes.

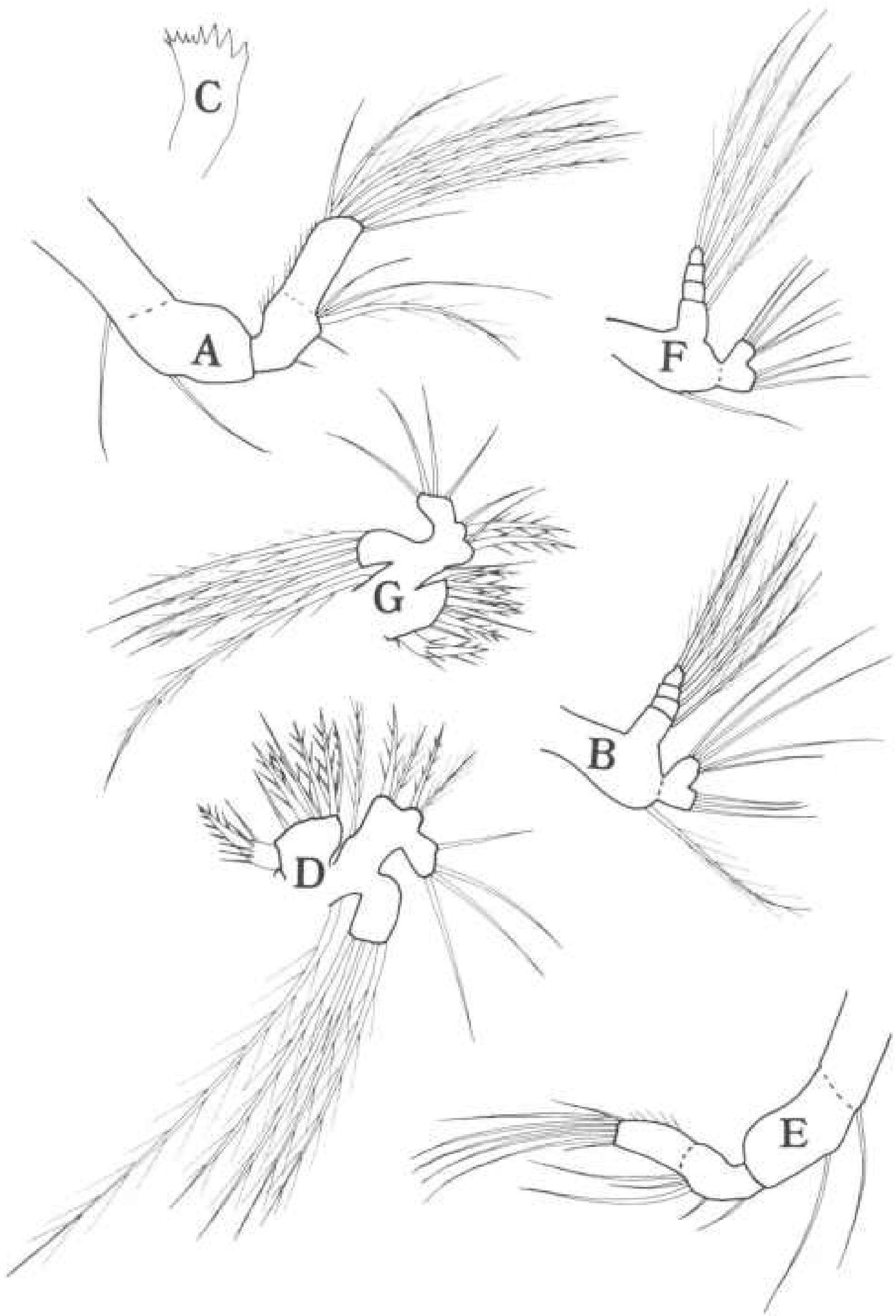

Fig. 5. *Limnoithona sinensis*. Female. A, A2; B, Mn; C, Mn, blade; D, Mx1. Male. E, A2; F, Mn; G, Mx1.

No attached spermatophores were noticed, but several females carried 1–6 eggs each (0.05 mm in diameter) in 1 or 2 sacs.

In our synonomy above, two letters, one in parentheses, are listed in Burckhardt's 1913 citation. The first is the letter from the figure caption, that in parentheses from the list of figures. Unfortunately these two sets are mismatched in our copy of the publication.

Oithona davisae, new species
Figs. 6–9

Type Specimens.—Female holotype USNM No. 195083, 30 female and 30 male paratypes USNM No. 195084 from USGS station 168 (37°43.4′N, 122°15.5′W) off the eastern shore of South San Francisco Bay collected on 12 November 1980 have been deposited in the National Museum of Natural History, Smithsonian Institution. Additional specimens from USGS station 162 (37°41.0′N, 122°14.0′W) augmented descriptions of the species.

Female.—Length range 0.54–0.62 mm (30 specimens); Pr/Ur = 1.2. Rostrum present (Fig. 6A), pointed ventrally; forehead rounded dorsally (Fig. 7A). Knob near genital opening with 2 setae, ventral small. CR length 3× width, armed as in Fig. 6C. A1 (Fig. 7B) with 13 segments. A2 (Fig. 8A) with 3 segments. Mn blade (Fig. 9C) simple; Bspd2 (Fig. 9A) with 2 thick, slightly curved spines with marginal spinules; Re with 4 segments, an incomplete articulation between 1 and 2, 4 and 5 fused, with 5 setae; Ri with 1 segment, 4 setae, lateralmost plumose. Mx1 (Fig. 9B) with Li1 having 9 spines distal elongate; Bspd2 with 3 thin setae; Re with 1 segment, fused to Bspd2, with 4 setae, proximal thickest and longest; Ri with 1 segment, fused to Bspd2, with 1 short seta. Mx2 (Fig. 8B) with incomplete articulation proximal to distal 2 lobes of 1st segment. Mxp as in Fig. 8C. P1Bspd2 (Fig. 7C) with 4 small hairs in addition to larger spine on distomedial corner. P4Bspd1 (Fig. 8E) with thicker spinules scattered on posterior face, and pronounced set on proximolateral corner; Bspd2 with scattered hairs on posterior face. P1–4 (Figs. 7C, D, 8D, E) Re1–3Se 1-1-3, 1-1-3, 1-1-3, 1-1-2; all Re1's with medial hairs; Re1–3Si 0-1-4, 0-1-5, 0-1-5, 0-1-5; Ri1–3Si 1-1-6, 1-2-6, 1-2-6, 1-2-5. P4Ri1 hairs on posterior face; Ri2 proximal seta simple, distal straight with thin flange on distal two-thirds; Ri3 proximal seta thick, straight, with thick flange on distal half. P5 (Fig. 6B) unarticulated knob dorsolaterally with 1 seta; ventrolaterally simple cylindrical segment with 1 terminal seta and hairs medially.

Male.—Length range 0.47–0.53 mm (30 specimens); Pr/Ur = 1.5. Rostrum absent; forehead quadrate dorsally. Cph flap (Figs. 6D, 9F) digitiform, reaching beyond Pg1 and 2 articulation. Pore signature "*hebes*" type (see remarks below); anterodorsal cluster 2 parallel lines of 11–14 organs, slope of these lines usually breaking ventrad at midlength; single anteroventral organ completing this section. Horizontal row anteriorly a broken pattern of 8–12 organs resolving into single line extending onto flap. Twelve distinct columns of 5–11 organs; 1st column ventral and posterior to anterodorsal cluster, with 2–4 organs scattered anteriorly. Horizontal series generally well-defined double line of organs ventral to columns, and single line on posterior and posterolateral edge of flap. Genital flap with 2 setae, ventral smaller. CR (Fig. 6E) length 2× width. A1 (Fig. 7F) digeniculate, with subterminal aesthete on terminal segment. A2 (Fig. 8F) with 2 free segments, terminal elongate. Mn blade similar to female; Bspd2 (Fig. 9D) with 2 thin spines, medial with spinules; Re with 4 articulated segments, 4 and 5 fused, with 5 setae, terminal brushlike; Ri1 with segment fused to Bspd2 with 4 setae. Mx1, Mx2, Mxp (Figs. 8G, H, 9E) similar to female but slightly reduced in size. P1–4 (Figs. 7G,H, 8I,J) similar to female but variously reduced with P4 exhibiting least

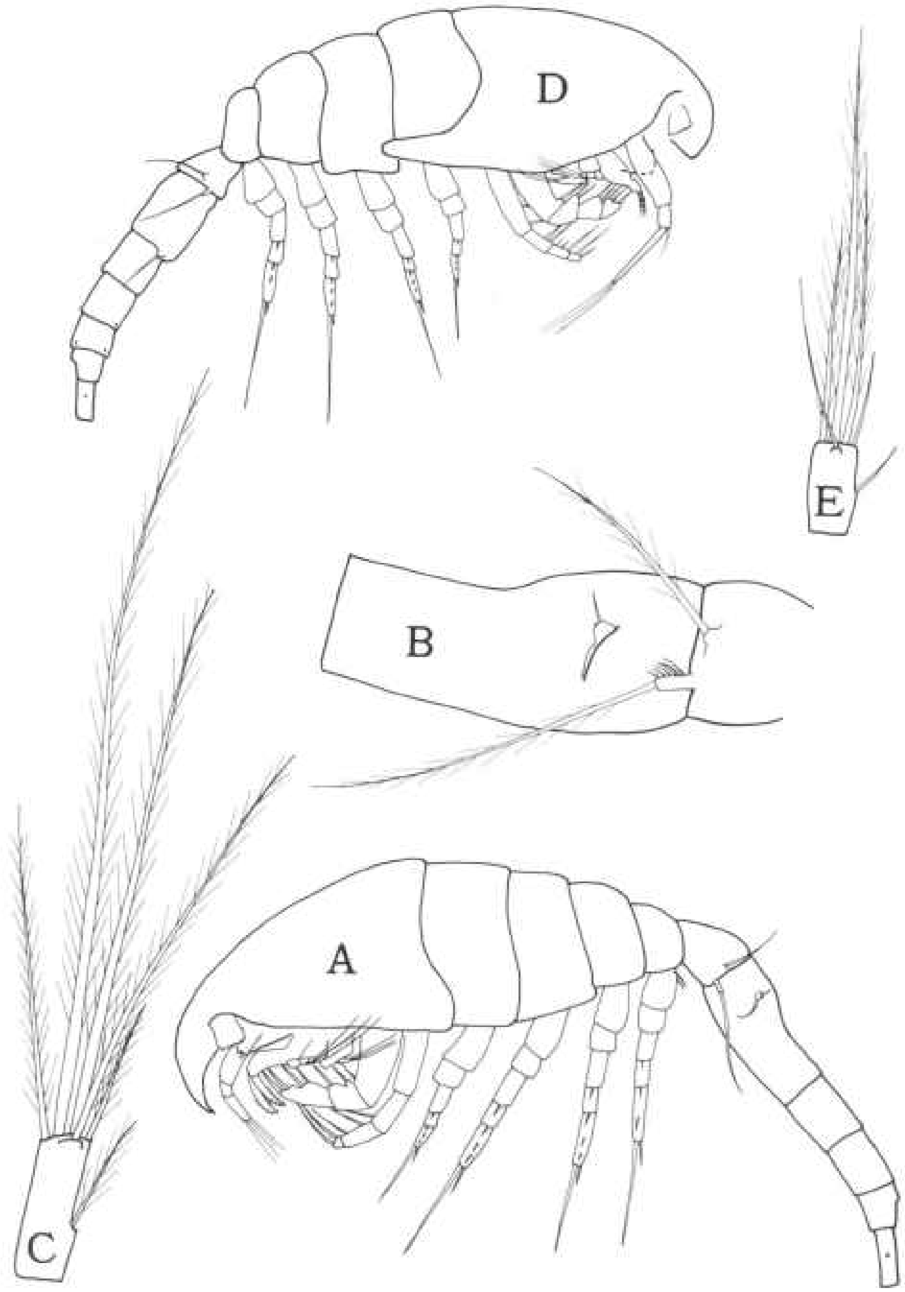

Fig. 6. *Oithona davisae.* Female. A, habitus, lateral; B, Ur1 and 2, lateral; C, CR, dorsal. Male. D, habitus, lateral; E, CR, dorsal.

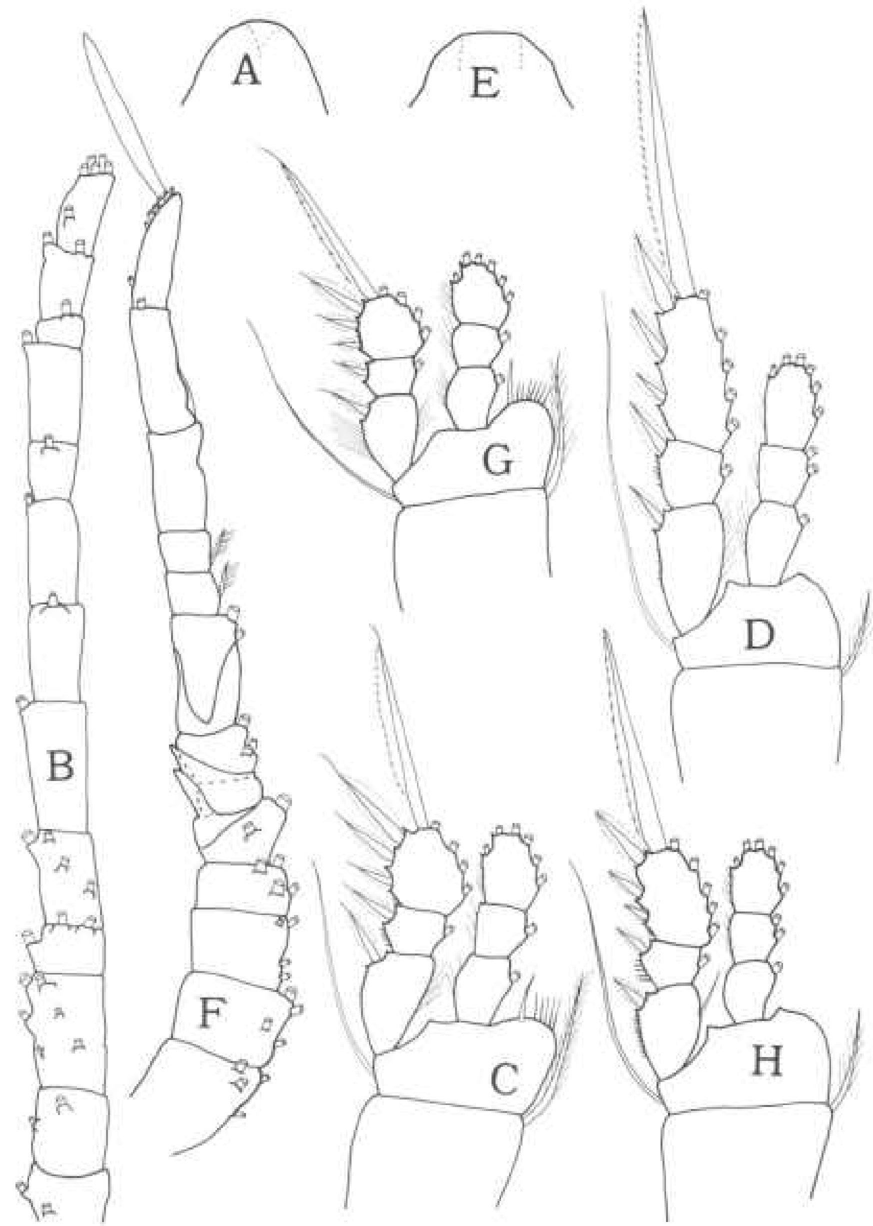

Fig. 7. *Oithona davisae.* Female. A, forehead, dorsal; B, A1; C, P1; D, P2. Male. E, forehead, dorsal; F, A1; G, P1; H, P2.

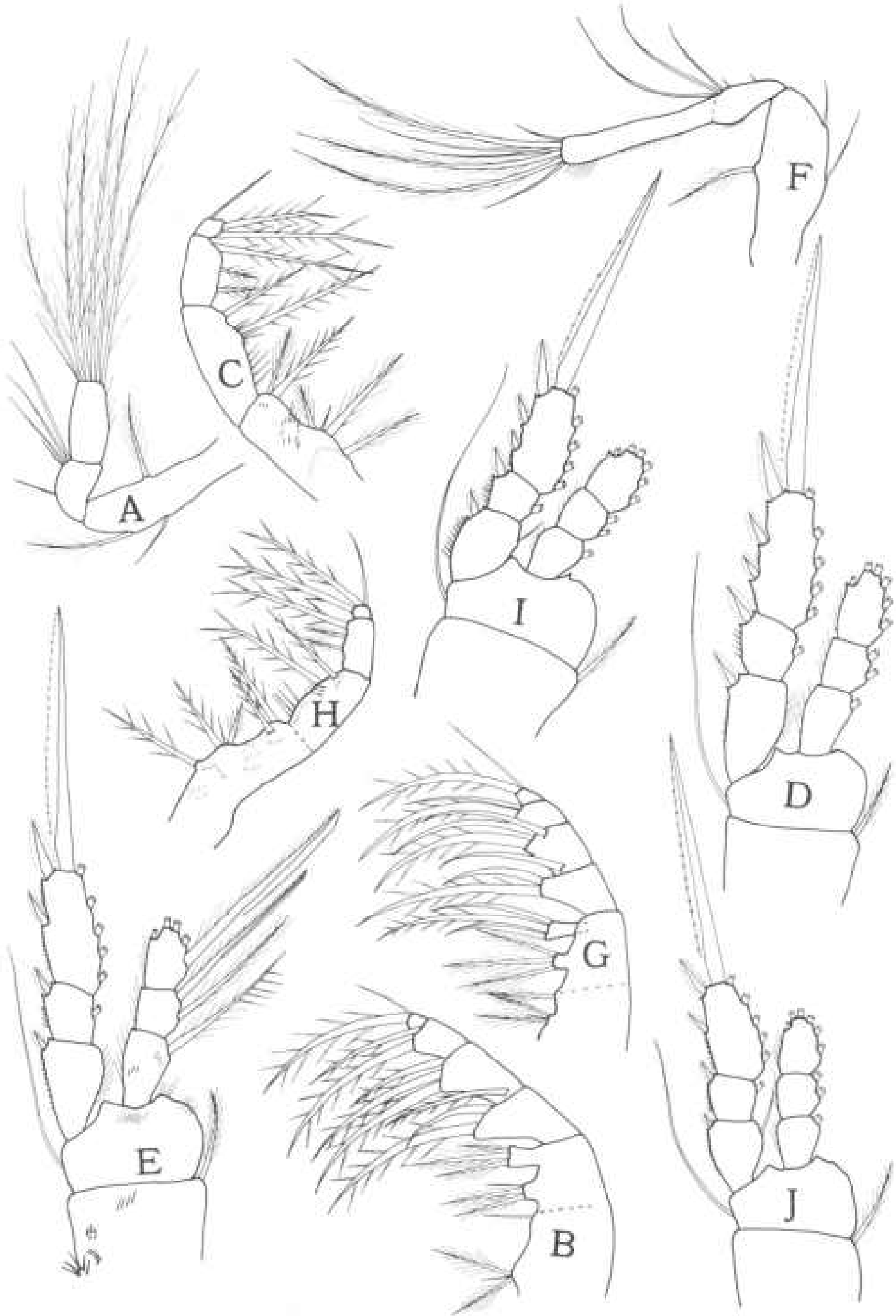

Fig. 8. *Oithona davisae*. Female. A, A2; B, Mx2; C, Mxp; D, P3; E, P4. Male. F, A2; G, Mx2; H, Mxp; I, P3; J, P4.

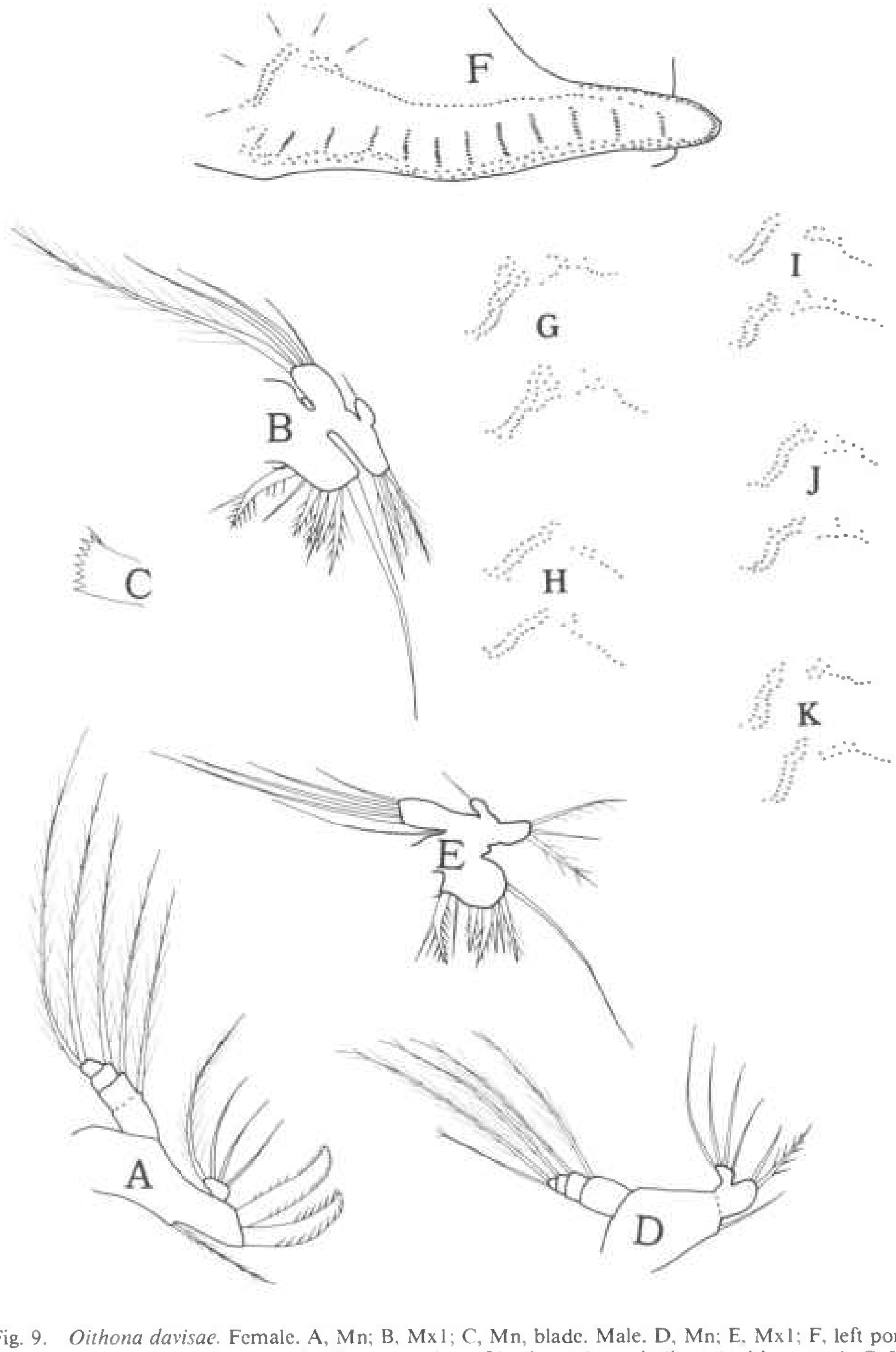

Fig. 9. *Oithona davisae.* Female. A, Mn; B, Mx1; C, Mn, blade. Male. D, Mn; E, Mx1; F, left pore signature (anterodorsal cluster and adjacent section of horizontal row indicated with arrows); G–K, left (top) and right (bottom, transposed 180°) anterodorsal cluster and adjacent section of horizontal row of male pore signature; G and H, 2 males from USGS station 27; I–K, 3 males from USGS station 32.

reduction; each Re1 with 1 internal seta, without hairs; P4Ri3 with 6 setae. P1–4 with all articles unadorned; all setae simple. P5 similar to female but without medial hairs.

Remarks.—Only 4 other oithonids with P1-4Re1-3Se of 1-1-3, 1-1-3, 1-1-3, 1-1-2, in both sexes have females with an elongate, ventrally pointed rostrum: *O. robusta, O. brevicornis, O. aruensis,* and *O. wellershausi* (see Nishida and Ferrari, in press, for remarks on the latter three). The distribution of *O. robusta* is oceanic, and it differs morphologically from *O. davisae* in the number and shape of the setae on MnRi and Mx1Ri. The other species are Indo-West Pacific, estuarine/lagoonal. *O. brevicornis* possesses a distinctive set of hairs on the genital segment. *O. aruensis* and *O. wellershausi* share exclusively with *O. davisae* an elongate distal spine on Mx1Li1 in both sexes. *O. aruensis* and *O. wellershausi* can be distinguished from *O. davisae* by the number of setae on Mx1Ri (3 or 1) in both sexes, and the relative length of CR, 2× versus 3× width for females, 1.5× versus 2× for males. In addition, *O. wellershausi* has 3 setae on Mx1Re, *O. davisae* has 4. Of the two modified setae on P4, distal on Ri2 and proximal on Ri3, females of *O. wellershausi* have a flange on the distal one-fifth and distal half of those setae, *O. aruensis* distal two-thirds and distal three-fourths, and *O. davisae* distal two-thirds and distal half.

In Figs. 9G–K intraspecific variation is shown for a part of the pore signature of 5 males (3 from USGS station 32 and 2 from USGS station 27). For each male, organs on the left side of the body are above the letter; those on the right side, transposed 180° through a vertical axis for easier comparison, are below the letter. Organs of the anterodorsal cluster comprise the left part of each signature, and the adjacent area of the horizontal row comprises the right. The numbers of organs associated with each area, and their positions relative to one another, vary in the five individuals. Further, variation in the left and right pattern of the same animal imparts a bilateral asymmetry to the animals.

Etymology.—*Oithona davisae* is named for Ms. Sally Davis of the California Department of Fish and Game, who first brought these animals to our attention.

DISTRIBUTIONS OF *LIMNOITHONA SINENSIS* AND *OITHONA DAVISAE* IN THE SACRAMENTO-SAN JOAQUIN ESTUARY
Figs. 10–14

Limnoithona sinensis was first found in samples taken by the California Department of Fish and Game during August 1979, at station 90 in the San Joaquin River near Stockton, California. Subsequently it was collected in Disappointment Slough, later Sycamore Slough, and eventually throughout the delta by October 1979. It remained more abundant in the San Joaquin River than in the Sacramento; specimens were not collected at Hood, near the most upstream station on the Sacramento, until October 1981 (Fig. 10). The species was more abundant in Suisun Bay in 1980 than in 1981. In the San Joaquin River it was more abundant in 1981. Its maximum abundance, 71,176/m^3, was recorded in August 1981 near Stockton (station 92). *L. sinensis* is now found throughout the fresh waters of the delta. It is most abundant from October through November and scarcest in March and April (Figs. 11–14).

Oithona davisae was first taken by the California Department of Fish and Game at station 56 in eastern Suisun Bay during December 1979. It was not found again upstream from San Pablo Bay until October 1980 at station 32 in Montezuma Slough. It was present in December 1980 in western Suisun Bay as far upstream

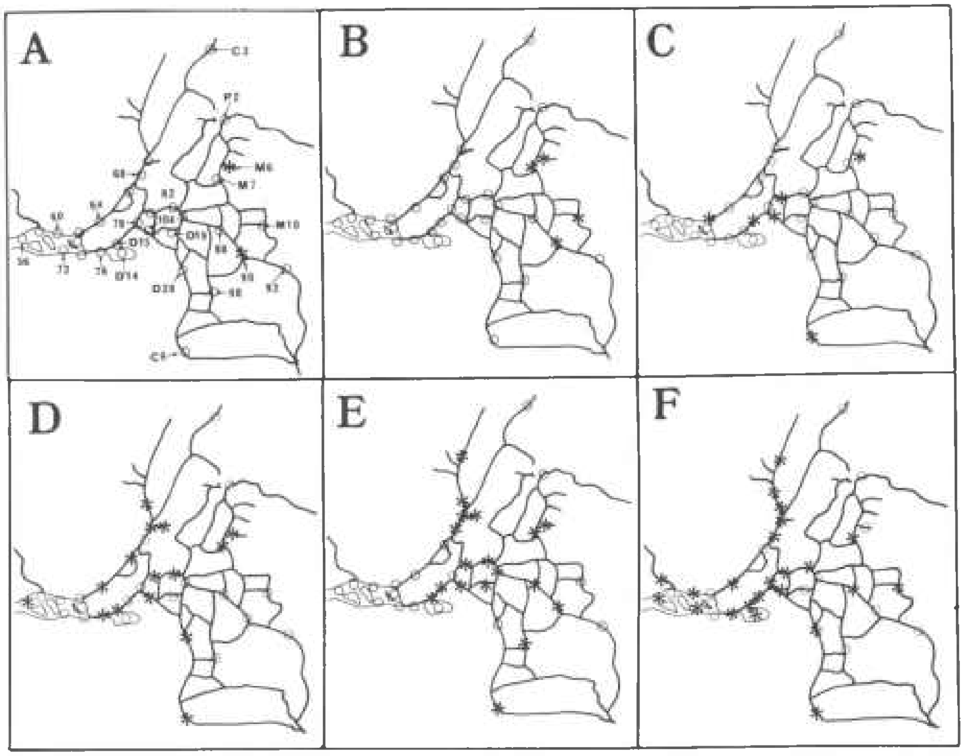

Fig. 10. Presence (stars) or absence (open circles) of *Limnoithona sinensis* from stations in the Sacramento-San Joaquin Estuary delta collected by the California Department of Fish and Game in 1979. A, August 1st week; B, September 1st week; C, September 3rd week; D, October 1st week; E, October 3rd week; F, November 1st week.

as Chipps Island, and became widespread in Suisun Bay in January and February 1981. Salinity of the water there was greater than 11.8‰. *Oithona davisae* was also present throughout San Pablo Bay in those months. The species then disappeared from Suisun Bay. With the exception of isolated occurrences in April and July it was not taken until August 1981 when it was found throughout Suisun Bay. It remained widespread until March 1982 with population densities almost always less than 1,000/m^3. *Oithona davisae* was not noted in samples collected in Suisun Bay from 1971 to 1978, even though 1976 and 1977 were marked by significant salinity intrusions into the bay.

The United States Geological Survey reported two oithonids, *Oithona* sp. and *O. spinirostris* (a synonym of *O. similis*) in San Francisco and San Pablo bays (Hutchinson, 1981, and unpublished data). We have examined some of these samples collected in South San Francisco Bay. A series of stations, 19, 24, 27, 30, and 32, begins at the Golden Gate and progresses sequentially southward off the western shore of South San Francisco Bay; stations 162 and 168 are located off the eastern shore. Plankton samples from stations 24, 27, 30, and 32 taken on 16 December 1980 and stations 162 and 168 on 12 November 1980 contained large numbers of immature and mature females and males of *O. davisae*. Samples taken on 16 September 1980 at station 19 near the Golden Gate in the mouth of the estuary contained a few immature specimens of *O. similis*.

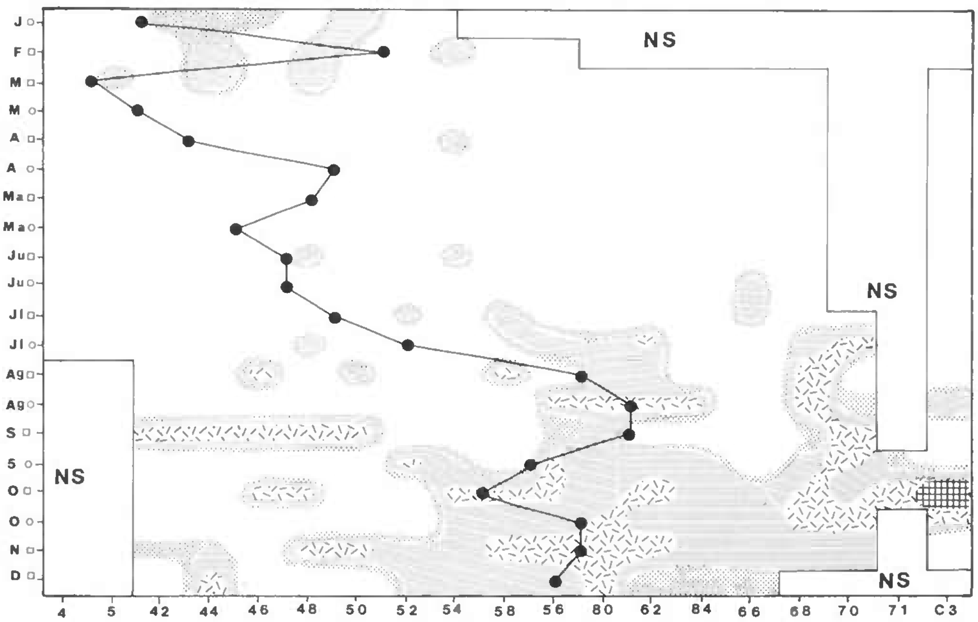

Fig. 11. Abundance of *Limnoithona sinensis* during 1980 from the Carquinez Strait (stations 4 and 5), through Suisun Bay (stations 42–58), and into the Sacramento River (stations 60–C3). Animals per m^3 of water: 10^0–10^1 dots, 10^1–10^2 horizontal lines, 10^2–10^3 broken pattern, 10^3–10^4 crosshatch. NS = not sampled. Area to left of line of circles with salinities greater than 1.2‰. Open square next to month symbol indicating samples were taken in first 15 days of month; open circle, last 15 days.

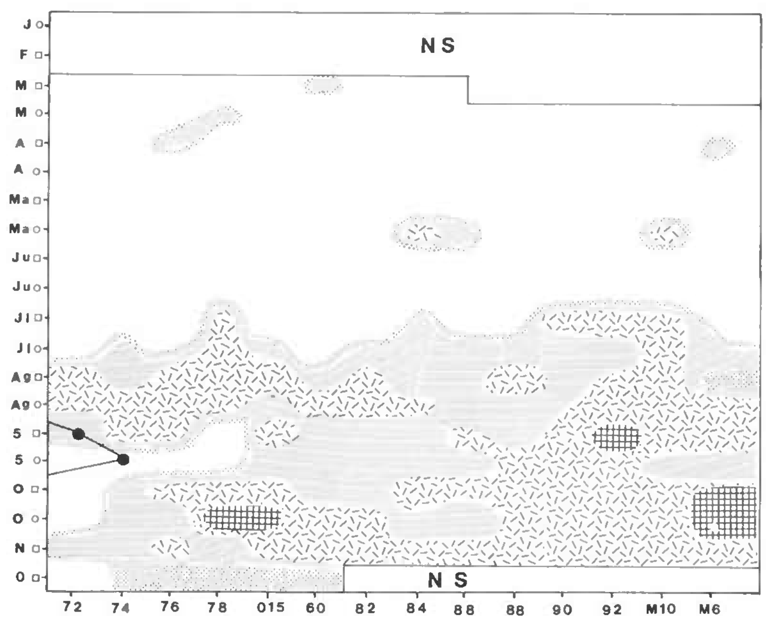

Fig. 12. Abundance of *Limnoithona sinensis* during 1980 in the San Joaquin River (stations 72–84), Old River (station 86), Stockton (station 92), Disappointment Slough (station M10), and Sycamore Slough (station M6). Symbols and abbreviations as for Fig. 11.

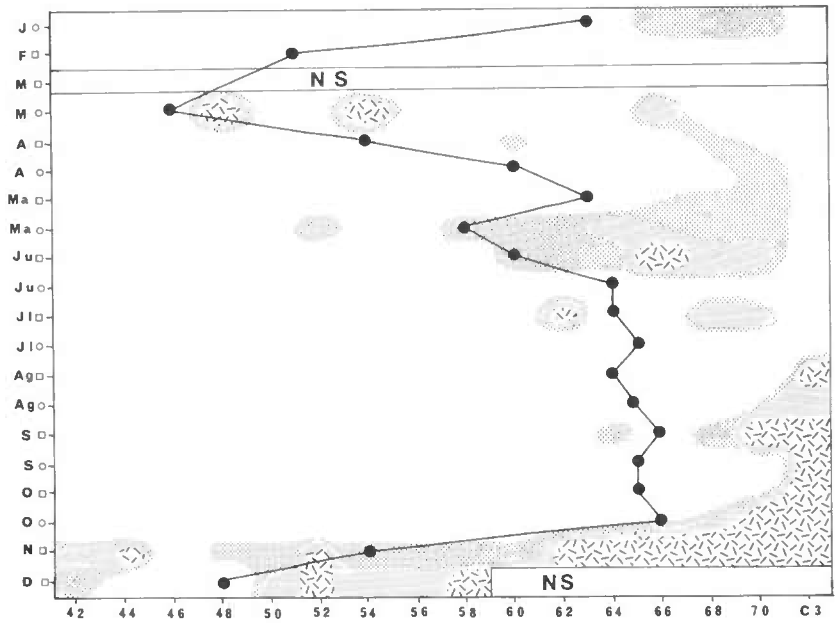

Fig. 13. Abundance of *Limnoithona sinensis* during 1981 from Suisun Bay (stations 42–58) into the Sacramento River (stations 60–C3). Symbols and abbreviations as for Fig. 11.

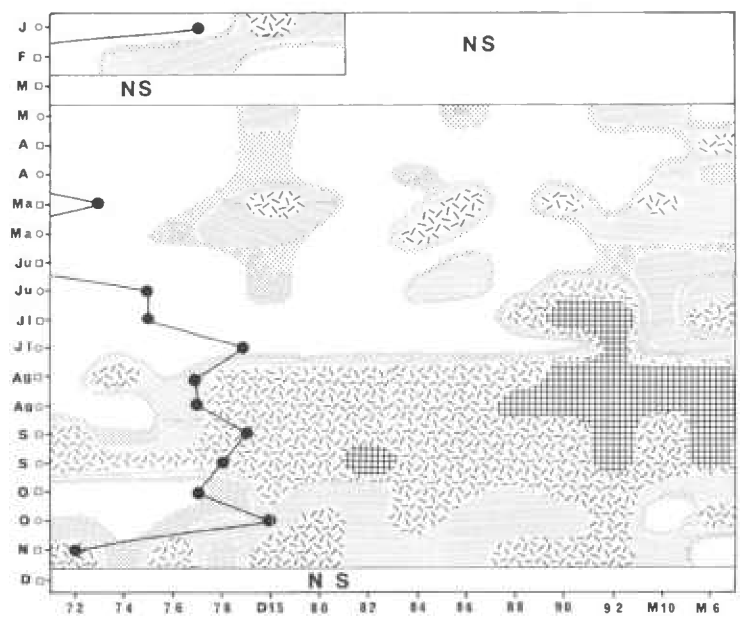

Fig. 14. Abundance of *Limnoithona sinensis* during 1981 in the San Joaquin River (stations 72–84), Old River (station 86), Stockton (station 92), Disappointment Slough (station M10), and Sycamore Slough (station M6). Symbols and abbreviations as for Fig. 11.

SYNANTHROPIC INTRODUCTION OF *LIMNOITHONA SINENSIS* AND *OITHONA DAVISAE* IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

The case for introductions of *L. sinensis* and *O. davisae* into the estuary rests on these facts. *Limnoithona sinensis* and its only congener, *L. tetraspina,* have previously been reported only from the Yangtze River delta. The occurrence of *L. sinensis* in the Sacramento-San Joaquin Estuary is established for three years beginning in August 1979. In the eight previous years samples taken in the same area and at similar times of the year failed to contain the species. *Oithona davisae* shares two distinctive morphological characters with Indo-West Pacific oithonids: a ventrally pointed rostrum with *O. brevicornis, O. aruensis,* and *O. wellershausi,* and an elongate distal spine on the inner lobe of maxilla 1 with the latter two species.

There is a comparatively well-documented history (Carlton, 1979) of introductions of marine invertebrates into the estuary, including an Asian continental planktonic calanoid, *Sinocalanus doerrii* (Orsi *et al.*, in press). A mechanism for introductions of planktonic copepods by ship ballast water has been suggested (Jones, 1966; Grindley and Grice, 1969; Carlton, 1979), and is presently being investigated (Carlton, personal communication).

Due to lack of adequate surveys, questions about the distribution of *L. sinensis* remain unanswered. This species may be: A) endemic to the Yangtze River; B) Asian continental riverine tropical to subtropical, or temperate to boreal; C) Indo-West Pacific continental and insular riverine. Plankton samples taken with a fine-mesh net (less than 100 μm) from the Mekong, Irrawaddy, Ganges, and Indus, the Huang, Amur, and Anadyr', or the Musi, Kapuas, Fly, Sepik, and Mamberamo would help to clarify this question. The discovery of representatives of *Limnoithona* in American rivers (Yukon, Kuskokwim, Susitna, and Columbia) would lend support to an alternate hypothesis: the populations in the Sacramento-San Joaquin Estuary and these other American rivers may have had a tenuous contact with similarly distributed Asian populations during the Pleistocene when the two continents were connected. Any such contact would have been broken with the post-Wisconsin rise in sea level about 2×10^4 yrs ago. A synanthropic introduction would imply the Sacramento-San Joaquin animals were separated from those of the Yangtze for no more than 2×10^2 yrs, with the beginning of trans-Pacific shipping.

Oithona davisae is similar morphologically to a number of congeners exclusively occupying estuarine and lagoonal habitats along the world's temperate and tropical coasts. Adequately described species include *O. brevicornis, O. dissimilis, O. aruensis, O. wellershausi, O. colcarva, O. fonsecae, O. hebes,* and *O. neotropica* (? *oligohalina*). In addition to habitat preference they share these morphological characteristics: female total length 0.5–0.6 mm, males slightly smaller; males and females with identical external spine count on swimming leg exopods, 1-1-3, 1-1-3, 1-1-3, 1-1-2; sexual dimorphism in basipod 2 of mandible expressed in females as 2 well-developed curved spines, variously armed, males exhibiting some reduction in size and changes in shape of these elements; cephalosome flap of males digitiform and reaching beyond posterior articulation of first pediger; male pore signature of "*hebes*" type with 11–12 columns, a dorsal horizontal row, and anterodorsal cluster of two approximately dorsoventral parallel lines of organs.

As yet no endemic estuarine representative of this group has been described from the Sacramento-San Joaquin Estuary. It seems reasonable that *O. davisae* should be so assigned. However, as noted above, this species possesses a ventrally pointed rostrum and elongate spine on the inner lobe of maxilla 1. These characters are shared exclusively with Indo-West Pacific members and may indicate a synanthropic introduction of this species, again by ship ballast water, possibly from estuaries of the Asian continent.

Evidence for a more extensive American distribution of *L. sinensis* and *O. davisae* was sought from plankton samples held at the Marine Invertebrate Collections of the Scripps Institution of Oceanography and the California Department of Fish and Game. Localities available included: Humboldt Bay, Monterey Bay, Scripps Pier (La Jolla), Aqua Hedionda Lagoon (Oceanside), California; and Black Warrior Lagoon, Baja California, Mexico. Specimens of *L. sinensis* and *O. davisae* were not found in any of these samples; *O. similis* was present in the first four. Specimens similar to the arostrate American estuarine *O. neotropica* were found in samples from Black Warrior Lagoon. We were unable to locate samples from estuaries north of California.

Efforts to establish the presence of *L. sinensis* or *O. davisae* in the estuary from historical records also have proven unsatisfactory. Allen (1920) collected plankton samples from the San Joaquin River with a small plankton net, 60 μm mesh, twice weekly in the Stockton Channel, and at about 17-day intervals in Smith Channel and an adjacent area of the river channel, January 1913 to January 1915. He identified only two copepods, *Canthocamptus* sp. and *Cyclops* sp., from samples collected in 1913.

Esterly (1924) initiated studies of harbor and estuarine copepods from the "western shores of the American continents." He examined planktonic copepods which had been separated from over 150 plankton samples collected during ALBATROSS cruises of 1912 and 1913. Data from Sumner *et al.* (1914) indicate that these samples were taken from South San Francisco Bay (at about 37°35′N) through San Pablo Bay to Carquinez Strait, where the lowest salinity, 3‰, was encountered. Three nets were towed simultaneously—one net with 4-ft diameter with #000 mesh (1,000 μm) and two nets with 14-in diameter with #14 or #20 mesh (100 or 80 μm). The latter two nets should have collected all oithonids present; Esterly reported only calanoid copepods. He found two species, *Clausocalanus arcuicornis* and *Ctenocalanus vanus,* which are as small as most oithonids, and also *Eurytemora hirundoides,* a member of a genus today found associated with low salinity waters of the estuary. It is possible that Esterly was sent only the calanoids separated from the samples.

Caskey (1976) studied copepods collected from June 1972 to April 1974 at 13 stations along a USGS transect of the estuary from the southern tip of South San Francisco Bay through Suisun Bay. Only two oithonids were identified, *O. nana* and *O. helgolandica* (probably *O. similis*). These species were not treated separately, but Caskey mentioned that the specimens were confined to the central part of San Francisco Bay, in the vicinity of the Golden Gate, and were not found in salinities below 20‰.

Siegfried *et al.* (1978) collected plankton samples with a pump and filter from seven stations between Sherman and Chipps Islands in the Sacramento River from January to November 1976. No oithonid copepods were found. An unidentified species of *Cyclops* was the only cyclopoid copepod reported.

Painter (1966) reported *Oithona* sp. from San Pablo and Suisun bays having a seasonal distribution similar to *O. davisae.* He sampled San Pablo Bay from January to December 1963, and found that this *Oithona* sp. disappeared in early spring, was absent in summer, and reappeared again in fall. It was always most abundant in the most seaward station in San Pablo Bay during January and February, exceeding 1,000/m^3, and was found at less than 12‰ only during periods of high runoff in February and April.

The unidentified *Oithona* sp. collected by USGS (Hutchinson, 1981, and unpublished data) was most abundant in South San Francisco Bay, up to 20,000/m^3. It was reported there only from August to December 1980. It was found in North San Francisco Bay from January to April 1981, disappeared during May and June, and was common again from August to December 1981. In San Pablo Bay it was found from January to March and October to December 1981.

We are aware of the superficial similarity between the two rostrate species, *O. similis* and *O. davisae*, but based on distributional data and examination of several USGS samples, we suggest that most specimens identified as *Oithona* sp. in these latter two studies were *O. davisae*. If this species is not endemic to the Sacramento-San Joaquin Estuary, its introduction (prior to 1966) preceded that of *L. sinensis*.

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