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CALIFORNIAN ANOSTRACA: DISTRIBUTION, HABITAT, AND STATUS

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ABSTRACT

California has a diverse anostracan fauna of 17 species belonging to 6 genera. This is nearly 40% of all species currently described from North America. Six of these anostracans are endemic to California. This is the highest level of endemism among anostracans for any comparable geographic area in North America. The causes of this high endemism remain unclear except that they probably relate to the factors responsible for the high level of species diversity. Species richness within the state is attributable to the great variety of habitats occurring within the state. The distribution of each species appears to be controlled by geographical and seasonal variations in habitat water chemistry and temperature.

Historical and ongoing land use practices have resulted in significant loss of anostracan habitats, particularly in California's Central Valley. As a result of this ongoing habitat loss, several of the state's endemic species may warrant consideration as threatened or endangered species under state and federal endangered species acts.

We describe 4 new species, all endemic to California: *Branchinecta conservatio, B. longiantenna, B. lynchi,* and *Streptocephalus woottoni.*

As society deals with the problems of habitat degradation and elimination, species reductions and extinctions, and land development issues, it is particularly relevant to ask questions basic to informed action. Such questions include: with what kinds or organisms do we share the territory; where specifically are the various species found; and why are they limited to the observed distributions? The smaller and more restricted the habitat, the more important these questions become and the greater the urgency of answering them.

Ephemeral aquatic systems are among the most restricted of habitats. Such waters are often small, sometimes very small, and thus easily overlooked. Being seasonal, their presence may not be recognized if the area is viewed during the dry season. In any event, development for urban and agricultural uses, energy exploration and production, and recreation have eliminated uncounted numbers of such habitats and their constituent populations without knowledge of what species existed there. Nowhere is this more true than in the heavily agricultural and rapidly expanding urban areas of California.

The characteristic and highly endemic flora of California's "vernal pools" is well known (Holland, 1988; Holland and Jain, 1977). The impact on this flora of the unknowing and indiscriminate loss of these and other temporary aquatic habitats is a focus of concern and has been the subject of at least two symposia (Jain, 1976; Jain and Moyle, 1984). However, there is no parallel understanding of the fauna of such waters. Undoubtedly the most characteristic and conspicuous animals of temporary waters are the Anostraca or fairy shrimps. From a few scattered publications, California's anostracan fauna is known to be diverse and to contain at least two endemic species. But it is admittedly poorly known, and there is no published study from a statewide perspective. Thus, as a basis for land-use planning, species preservation, and species management, we undertook this study with the following purposes: to determine which species are found in California; to define their general and specific distributions; to summarize what we know about why each species is located where it is; and to establish which species are particularly vulnerable to human activities.

Information concerning California's 17 anostracans, including four new and six endemic species, is organized below under the heading of Results and Discussion into four major sections. If the fairy shrimp is new to science, it is described in the initial introductory section, otherwise the initial section covers the history of its discovery in California and explains any identification or taxonomic problems. A Distribution section locates its California occurrence and gives a brief characterization of the species' total range for perspective. In a Habitat section, we include information on pool classification and physicochemical nature as well as a description of the general environmental setting. A final Comments section includes other information which helps to explain occurrence (e.g., hatching requirements), documents coocurrence with other anostracans, and describes present and potential human impact on the species in California.

Materials and Methods

Collections provide the basic data for determining the fauna of a region. Denton Belk examined the collections of Clyde Eriksen and Larry Eng who have been collecting Californian Anostraca since 1953 and 1971, respectively. He also reviewed material from the National Museum of Natural History, Peabody Museum of Natural History, California Academy of Sciences, and Allan Hancock Foundation. The individuals acknowledged at the end of this paper also provided collections for review. An annotated list of more than 380 of the collections examined during this study is available at the California Academy of Sciences.

Habitat descriptions come mainly from Eng's and Eriksen's field notes, but miscellaneous information has been taken from collection labels and the literature. Physicochemical data come largely from Kubly (1982), and Eriksen's analyses which utilized a variety of standard limnological and laboratory instrumentation over his 25 years of field work. Miscellaneous data from collection labels and the literature have been incorporated as well. Much of the physicochemical data are casual measurements taken when a collection was made. However, some information was repetitively collected from a pool, either randomly or systematically. In such cases, each measurement has been given equal weight among our data tabulations on the basis that habitat conditions change substantially, daily and seasonally (Eriksen, 1966), and such information helps document the range of conditions tolerated. If an author reported a range rather than specific data, the low and high values were utilized. If a value was estimated (e.g., 5–6), the median (5.5) was entered. In certain instances data were taken from a paper in which Anostraca were not mentioned but involved a pool in which we knew fairy shrimp were present during the time of measurement. When an author presented data in a figure rather than a table, values were estimated from the figure. Although representing different measures, TDS (Total Dissolved Solids), salinity, and conductivity are often used interchangeably. In order to minimize confusion only TDS data were utilized in our review. Finally, turbidity is normally measured in JTUs (Jackson Turbidity Units) or NTUs (Nephelometric Turbidity Units). These can vary slightly, or perhaps not at all (Hach Co., Loveland, Colorado, 1984, Turbidity Measurement). Our tables incorporate both measurements as if there were no differences (Table 1).

Because common names are often desired/created by state and federal resource agencies in order to satisfy a perceived need for acceptance by lay people, we include common names for those species which are particularly rare or threatened in California. In selecting these names we have used the guidelines provided in the American Fisheries Society's Common and Scientific Names of Invertebrates (Turgeon *et al.*, 1988).

Abbreviations used in the text: USNM = National Museum of Natural History, Smithsonian Institution, Washington, D.C.; CASIZ = Department of Invertebrate Zoology, California Academy of Sciences, San Francisco, California; and DB = Denton Belk's collection.

The Study Area

California is a state of diverse topography, geochemistry, climate, and vegetation. Rainfall varies from near rain forest conditions in the northwest (latitude 42°) to trace amounts on the deserts of the southeast (latitude 32°). Elevation varies from 84 m below sea level in Death Valley to the high Sierra Nevada topped by 4,410-m Mt. Whitney. Temperatures range from year-round mild conditions near the 1,600 km long coastline, to subfreezing winters in the Sierra Nevada, to the oppressive summer heat in the Colorado Desert of southeastern California. Much of California has a Mediterranean climate with most of the moisture coming from winter storms of arctic origin and virtually none falling during summer (Major, 1977). The high sagebrush deserts of northeast and east-central California, while not strictly Mediterranean, also receive precipitation primarily in the winter. Most of the annual precipitation in the low desert of southeastern California occurs as rain during summer storms which have their origin in the Gulf of Mexico (Major, 1977). Various authors have divided California into provinces based upon vegetation (Stebbins and Major, 1965; Munz and Keck, 1973; Major, 1977), fauna (Van Dyke, 1919), and landform (Durrenberger, 1968). With regard to these various land classification schemes, the known distribution of the Californian anostracan species best correlates with a modification of the floristic subdivisions utilized by Stebbins and Major (1965). Our modification consists of eight regions (Fig. 1): North Coast Mountains, Central Valley, Central Coast Mountains, South Coast Mountains, Cascade-Sierra Nevada, Great Basin Desert, Mojave Desert, and Colorado Desert.

The North Coast Mountains Region (Klamath Mountains and part of the Northern Coast Ranges) (Fig. 1) is a land of rugged coniferous forest-covered mountains rising from the coast to elevations exceeding 2,200 m. It receives the greatest annual precipitation of any area in California (497–2,780 mm). At the more coastal, lower elevations, summer temperatures are cool and winter temperatures are only slightly cooler (Major, 1977).

The Central Coast Mountains Region (Southern Coast Ranges and part of the Northern Coast Ranges) (Fig. 1) is comprised of a series of largely chaparral-covered mountains and grassland valleys, extending from about 80 km north of San Francisco to Santa Barbara County. This Region is bordered on the west by the Pacific Ocean and on the east by the Central Valley. Elevations from 500–1,000 m are common and several peaks exceed 1,500 m. The climate is primarily Mediterranean with warm, dry summers and cool, wet winters. The

Table 1. Turbidity (JTU or NTU) of anostracan habitats in California and out-of-state. (Sources: Kubly, 1982; Maynard, 1977; White, 1967; White and Hartland-Rowe, 1969; Eriksen, unpublished.) $\bar{x}$ = mean value, SD = standard deviation of the mean, 95% CI = 95% confidence interval around the mean, N = number of observations in the range, min/max omitted = extreme values omitted. (If at least 10 observations exist, the minimum and maximum values are listed here but are omitted from the calculation for the other columns.) If no quantitative data exist, the range of turbidity may be described verbally.

	California							Out-of-state						
Species	$\bar{x}$	SD	95% CI	Range	N	Min/max omitted		$\bar{x}$	SD	95% CI	Range	N	Min/max omitted	
Branchinecta gigas	4,450	2,110	3,360	1,300–5,700	4	—	—	2,390	1,089	692	1,300–3,400	10	1,100	5,000
Branchinecta mackini	2,599	2,950	1,030	138–12,375	34	16	21,050	2,292	767	487	1,100–3,400	12	765	5,000
Branchinecta lindahli	1,865	3,443	1,454	18–15,800	24	11	21,050	3,483	—	—	— —	1	—	—
Branchinecta longiantenna	739	349	268	160–1,200	9	52	3,000				N/A			
Streptocephalus woottoni	403	755	792	2–1,920	6	—	—				N/A			
Branchinecta lynchi	137	194	162	4–565	8	—	—				N/A			
Artemia franciscana	47	43	36	4–120	8	3	120				no information			
Branchinecta conservatio	44	27	66	25–73	3	—	—				N/A			
Linderiella occidentalis	22	26	18	3–83	11	2	200				N/A			
Branchinecta coloradensis				clear-turbid				6	—	—	— —	1	—	—
Thamnocephalus platyurus				turbid							no information			
Streptocephalus texanus				no information							no information			
Streptocephalus seali				clear-tea							no information			
Eubranchipus oregonus				no information							clear-tea			
Eubranchipus serratus				no information							clear-tea			
Branchinecta dissimilis				clear							turbid			
Artemia monica				clear							N/A			

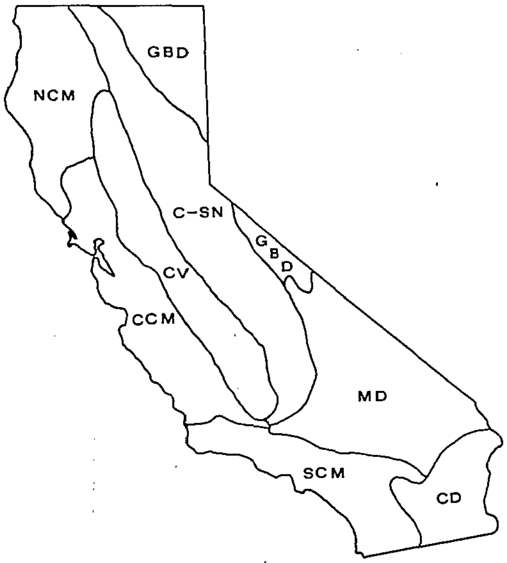

Fig. 1. Californian physiographic/anostracan regions. CCM = Central Coast Mountains Region; CD = Colorado Desert Region; C–SN = Cascade-Sierra Nevada Region; CV = Central Valley Region; GBD = Great Basin Desert Region; MD = Mojave Desert Region; NCM = North Coast Mountains Region; SCM = South Coast Mountains Region.

annual rainfall ranges from about 270–900 mm (Major, 1977).

The South Coast Mountains Region (Transverse and Peninsular ranges) (Fig. 1) is similar in many respects to the Central Coast Mountains Region; however, it has stronger desert affinities and at lower elevations the chaparral is replaced by coastal sage scrub vegetation (Mooney, 1977). This region is bounded by the Pacific Ocean on the west and by the deserts on the east. Much of this region lies between 500 and 2,000 m in elevation but several of the peaks ringing the Los Angeles Basin exceed 3,000 m. The climate here is largely Mediterranean. Annual precipitation is typically less than 320 mm (Major, 1977).

The Central Valley Region (Fig. 1), lying in the rain shadow of the Coast Ranges, varies in elevation from near sea level to about 300 m. Annual precipitation ranges from around 960 mm in the north to about 150 mm in the south. A Mediterranean climate is typical of this region.

The Cascade-Sierra Nevada Region (Cascade Range, Sierra Nevada) (Fig. 1), much of which is 3,000–4,400 m in elevation, separates the Central Valley from the deserts to the east. Precipitation varies widely with elevation, but much comes in the form of snow, and frost can occur on any day of the year (Williamson *et al.*, 1986).

The Great Basin Desert Region (Modoc Plateau, Great Basin Desert) occupies the area east of the Sierra Nevada and Cascade Ranges in the extreme northeastern and east central parts of the state (Fig. 1). Elevations are mainly between 1,500 and 2,000 m and precipitation ranges from about 500 mm to about 100 mm. Most precipitation occurs in winter but the Region has more summer rain than California's Mediterranean climate areas (Major, 1977). The Great Basin Desert's climactic mix favors sagebrush (*Artemisia tridentata*).

The Mojave Desert Region (Fig. 1), in many ways a transition area between the colder, more northern Great Basin and the hotter, more southern Colorado deserts, roughly corresponds with the distribution of creosote bush (*Larrea tridentata*). Although a number of isolated mountain peaks occur in the Region, elevations are usually between 500 and 1,500 m. Annual precipitation, mostly occurring in the winter, is generally greater than 110 mm (Major, 1977). Death Valley, while lying within this region, is ecologically quite different with high temperatures more typical of the Colorado Desert and an annual precipitation on only 40–50 mm.

The Colorado Desert Region is restricted to extreme southeastern California, from the Colorado River to the foothills west of the Salton Sea (Fig. 1). This desert is generally less than 500 m in elevation and ranges to below sea level. It is hotter and drier than the more northerly Mojave and Great Basin deserts. Annual precipitation is generally less than 115 mm, and much of this occurs in the form of summer storms (Major, 1977) originating in the Gulf of Mexico.

Habitat or Pond Types

Our physiographic-climatic regions are, of course, environmental generalizations. Within each region, anostracans are confined to restricted habitats. The terms roadside ditch, rock pool, playa, grassland pool, etc. used to describe these habitats, suggest the existence of a universally understood system for classifying temporary waters. However, this is not the case. For the purposes of this paper, we categorize temporary habitats utilizing 3 tiers of characteristics: hydrological, formational, and locational/descriptive. This scheme allows flexibility in accommodating special characteristics of specific waters.

We subscribe to 3 hydrological types: (1) seasonally astatic habitats (Decksbach, 1929, as translated by and reported in Hartland-Rowe, 1972), which may fill and redry 1 or more times during any given year depending on the seasonal nature of precipitation and drought; (2) perennially astatic habitats (Decksbach, 1929) which exhibit significant annual fluctuations in water level, but do not dry completely every year; and (3) aestival habitats (Daborn and Clifford, 1974), shallow, semipermanent water bodies that retain some water throughout the year, but freeze to the bottom during winter.

Formationally, the basins in which temporary pools occur are either geogenic or biogenic. Geogenic basins include those in earth slumps and old braided alluvium, depressions in lava flows and intermittent steams, playas, areas of wind deflation, rock weather pits, glacial cirques, etc. Biogenic basins include stock ponds, roadside ditches, quarries, borrow pits, animal wallows, etc.

Locational/descriptive characteristics may be general and inclusive (e.g., desert, grassland, alpine, snowmelt, rain pool, or saline sink). On the other hand, they may refer to unique regional pool types (e.g., Californian vernal pool defined by a largely indigenous, highly endemic annual flora (Thorne, 1984)).

Results and Discussion

In this first statewide study of the Californian Anostraca, we report 17 species in six families including four new species in two families. Six of these anostracans, including all four new species, are endemic to California. This is the highest level of endemism among anostracans for any comparable geographic area in North America.

Branchinecta conservatio, new species
Conservancy fairy shrimp
Fig. 2a–f

Material Examined.—Holotype ♂ USNM 216105 and paratypes of both sexes USNM 216106, CASIZ 050153, and DB 419 collected 19 February 1982. Other paratype collections used in preparing the description include additional specimens from the type locality collected 12 March 1979 (DB 392) and 28 January 1982 (DB 401, 420); individuals from grassland vernal pools on The Nature Conservancy's Vina Plains Preserve in Tehama County (DB 428, 429) and Flying M Ranch (which has a conservation easement with The Nature Conservancy) in Merced County (DB 431); beside Keefer Road 2.4 km from California Highway 99E in Butte County (DB 624).

Type Locality.—Olcott Pool, a seasonally astatic, 4 ha, winter/spring pool in the grassland ecosystem of The Nature Conservancy's Jepson Prairie Preserve. Located 18 km south of Dixon, Solano County, California (38°16′N, 121°49′W). Elevation 5 m.

Male.—Total length for largest mature male 27 mm; smallest 14 mm. Basal segment of antenna about 30% longer than distal segment. Basal segment with prominent elongate oval pulvillus near proximal end and extending across medial surface from near anterior to posterior edges. Distal segment with tip bent medially about 90°; lateral surface concave; proximal half of medial surface concave, distal half convex; posterior edge of bent tip with rasplike surface (Fig. 2a–f). Cercopods with plumose setae along medial and lateral borders.

Female.—Total length for largest mature female 23 mm; smallest 14.5 mm. Antennules about 15% shorter than antennae. Fusiform brood pouch extending to below abdominal segment 8, occasionally 7 or 9, and opening terminally. Thorax with cone-shaped dorsolateral lobe on each side of segments 11–5; largest lobes on segment 11, grading smaller on more anterior segments; sometimes absent from segments 8–5. Cercopods with plumose setae along medial and lateral borders.

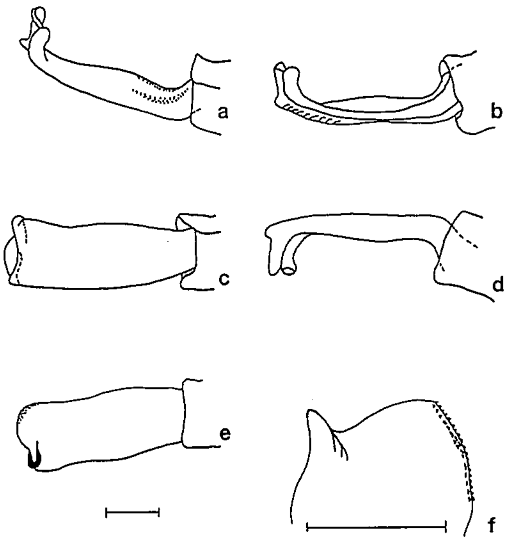

Fig. 2. *Branchinecta conservatio*, new species. Distal joint of antenna from a 26-mm paratype. a, anteromedial view; b, anterior view; c, lateral view; d, posterior view; e, medial view; f, ventral view of tip showing rasplike posterior edge. Scales equal 1 mm.

Etymology.—We chose the Latin word *conservatio* (keeping, preserving) as the specific epithet in appreciation of The Nature Conservancy's stewardship over a number of California's vernal pool ecosystems. The common name Conservancy fairy shrimp similarly honors The Nature Conservancy.

Remarks.—The large oval pulvillus at the proximal end of the basal segment of the male antenna in *B. conservatio* looks the same as the identically located pulvillus in *Branchinecta lindahli* Packard, 1883. However, the resemblance between these two ends here since the distal segment terminates very differently (compare our Fig. 2 with Lynch, 1964, fig. 4). Brood-pouch morphology also differs between these two species. It is fusiform in *B. conservatio* and usually ends under abdominal segment 8; whereas, it is cylindrical in *B. lindahli* and usually ends under abdominal segment 4.

The dorsolateral lobes on the thorax of female *B. conservatio* are similar to those found in *B. packardi* Pearse, 1912 (see Lynch, 1964, figs. 9, 10), the major difference being a lack of lobes on the first abdominal segment in *B. conservatio.*

Distribution.—This Californian endemic was found only in the grasslands of the northern two-thirds of the Central Valley spanning a north–south distance of about 300 km, at elevations between 5 and 145 m. Within this limited range, its populations were even more restricted, being known from only three disjunct localities: seven pools in the Vina Plains of Tehama County north of Chico, three pools on the Jepson Prairie Preserve immediately east of Travis Air Force Base, Solano County, and one pool near Haystack Mountain northeast of Merced, Merced County.

Habitat.—All pools were seasonally astatic, and located in swales in Central Valley grassland. In the Vina Plains, these swales are in old braided alluvium. The origin of the other pools is unknown. All pools were filled by winter and spring rains and lasted into June. *Branchinecta conservatio* was collected from November to early April when recorded pool temperatures ranged from 6–19°C. Little ecological information has accompanied the collections of this species. However, the type locality was studied by Barclay and Knight (1984). Their information shows the pool to be about 4 ha in extent with a maximum depth of 30 cm. Colloidal particles from its clay bottom are swept into the water column by wind-mixing, resulting in water so turbid (Secchi disc <5 cm) that rooted vegetation is absent. All pools containing this species were turbid and rather large; the smallest was about 1,500 m². Barclay and Knight's (1984) data, and ours from the Vina Plains, indicate that habitat pH straddles neutral, and conductivity, TDS, and alkalinity are all very low (Tables 4, 5).

Comments.—Males of *Branchinecta conservatio* appeared to be less tolerant of environmental stress than females, for when transported to the lab in crowded conditions, most males died while most females survived. Still, both sexes disappeared long before pools dried. *Branchinecta conservatio* was the only anostracan collected at Jepson Prairie; however, in the Vina Plains and near Haystack Mountain, it occurred sympatrically with, but rarely in the same pool as, *Branchinecta lynchi* and *Linderiella occidentalis*.

This species probably was once much more widely distributed in large, turbid pools throughout the Central Valley; however, the vast majority of these pools have been converted to cultivated fields (Holland, 1978, 1988). Because of its present very limited distribution and the continued loss of its habitat to cultivation and urbanization, the continued existence of *B. conservatio* is threatened. The Nature Conservancy's preserves on the Vina Plains and Jepson Prairie provide at least some refugia for the species.

Branchinecta longiantenna, new species
Longhorn fairy shrimp
Fig. 3a–c

Material Examined.—Holotype ♂ USNM 216107 and paratypes of both sexes USNM 216108, CASIZ 050151, and DB 423 collected 20 April 1982. Other paratype collections used in preparing the description came from the following locations: another collection from the type locality made on 24 April 1982 (DB 425); other pools in the Slanted Rocks Area of Souza Ranch, Contra Costa County (DB 399, 422, 426); a single pool at the Bat Rocks Area of Souza Ranch (DB 417); 2 pools beside a dirt road near the northwest end of Soda Lake (35°16″N, 119°55″W) in San Luis Obispo County (DB 628, 629); and a rock depression pool near Murietta's Caves at Altamont Pass, Alameda County, in 1937 (USNM 213714).

Type Locality.—Pool 117, a seasonally astatic, winter/spring, weathered depression pool in a sandstone outcrop at the eastern margin of the Coast Ranges. Outcrop located at an elevation of 290 m in the Slanted Rocks Area, Souza Ranch (37°46′N, 121°42′W), about 35 km southeast of Concord, Contra Costa County, California (T01S; R03E Mt. Diablo Meridian).

Male.—Total length for largest mature male 20.8 mm; smallest 12.1 mm. Antennae for largest male 10.4 mm, smallest 6.7 mm. Bent to lie along ventral thoracic surface, antennae reaching genital segments. Basal segments averaging 17% (7–20%) longer than distal segments ($N = 16$). Basal segment with prominent oval pulvillus near proximal end and shifted to slightly posterior position on medial surface. Band of prominent conical processes, each tipped with minute spine, along posterior half of medial surface from just below pulvillus to near distal end. Low wartlike mounds covering approximately distal 20% of surface. Basal segment thinner in midsection than at either end (Fig. 3a). Distal segment oval in cross section with region distal to medial bend having anteroposterior axis thinnest and with slight flattening of anterior surface near terminus; tip slightly longer on medial than lateral edge (Fig. 3b). Cercopods with plumose setae along medial and lateral borders.

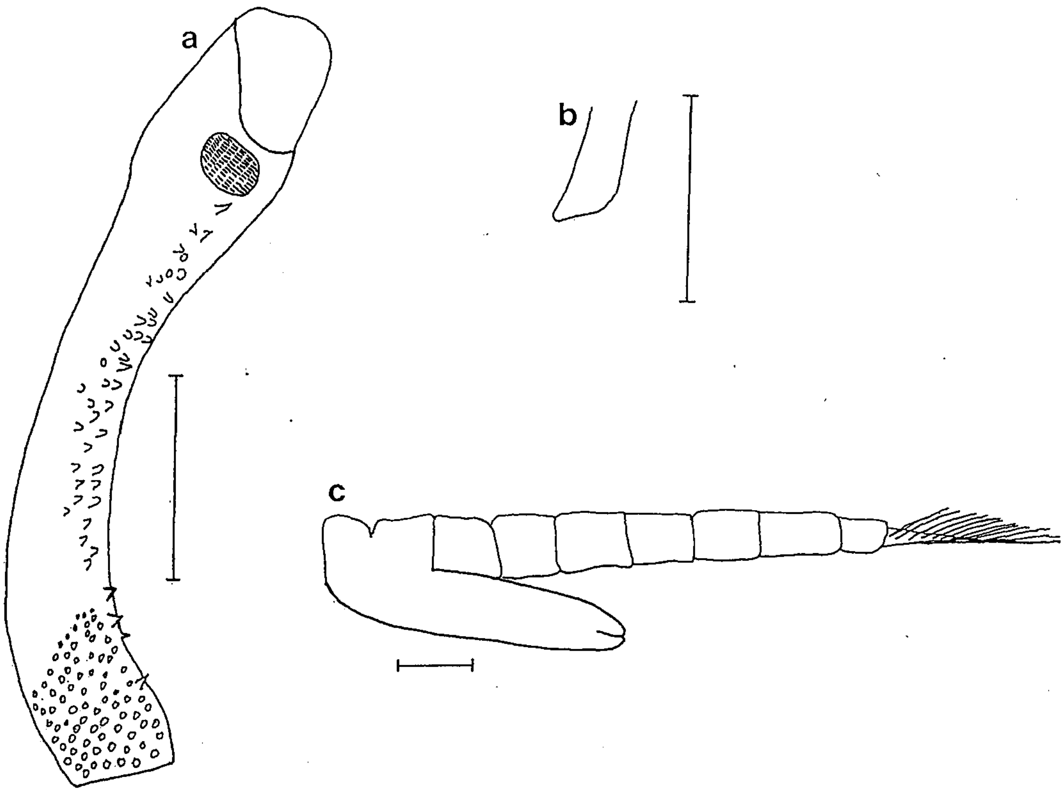

Fig. 3. *Branchinecta longiantenna,* new species. Male paratype 13.6-mm total length. a, basal segment of antenna in medial view; b, tip of distal segment of antenna in anterior view with longer medial edge to left. Female paratype 14.6-mm total length; c, lateral view of abdomen and cylindrical broodpouch. Scales equal 1 mm.

Female.—Total length for largest mature female 19.8 mm; smallest 13.3 mm. Antennules approximately same length as antennae. Cylindrical brood pouch extending to below abdominal segment 6, occasionally 7, and opening terminally (Fig. 3c). Thoracic segments lacking dorsal outgrowths. Cercopods with plumose setae along medial and lateral borders.

Etymology.—The trivial name emphasizes that the antennae of this species appear very long relative to body length. The common name, longhorn fairy shrimp, refers to this characteristic.

Remarks.—*Branchinecta longiantenna* differs from most branchinectids in having the portion of the antenna's distal segment beyond its medial bend flattened in the anteroposterior plane rather than the lateromedial plane. *Branchinecta mackini* Dexter, 1956, bears a superficial resemblance to *B. longiantenna.* However, male antennae differ in several respects. The two antennal segments are equal in length in *B. mackini,* whereas the basal segment is slightly longer in *B. longiantenna.* The antennae of both species terminate in a similar configuration; however, the longer edge is the anterior one in *B. mackini,* while it is the medial one in *B. longiantenna. Branchinecta longiantenna* lacks a ventrally directed process arising from the posteromedial surface at the proximal end of the basal segment as occurs in *B. mackini.* The medial surface of the basal segment in *B. mackini* bears only a few well-spaced and inconspicuous spines as compared to the pulvillus, prominent conical processes, and wartlike mounds that ornament the surface in *B. longiantenna.* The females differ in two notable respects. The antennules are longer than the antennae in *B. mackini,* whereas they are about the same length in *B. longiantenna.* Females of *B.*

Table 2. pH of anostracan habitats in California and out-of-state. (Sources: Anderson, 1958; Balco and Ebert, 1984; Barclay and Knight, 1984; Belk and Lindberg, 1979; Brown and Carpelan, 1971; Cole and Whiteside, 1965; Collie and Lathrop, 1976; Coopey, 1946, 1950; Dana *et al.*, 1977; Dexter and Ferguson, 1943; Eriksen and Brown, 1980; Fujita, 1978; Horne, 1967; Keeley, 1984; Kubly, 1982; Lynch, 1964, 1972; Mason, 1967; Maynard, 1977; McCarraher, 1970; Moore, 1955, 1963; Prophet, 1959, 1963a; Sublette and Sublette, 1967; White, 1967; White and Hartland-Rowe, 1969; Herbst, personal communication; Kubly and Cole, personal communication; collection list.) See Table 1 for an explanation of the column headings.

Species	California					Out-of-state				
	Median	Range	*N*	Min/max omitted		Median	Range	*N*	Min/max omitted	
Artemia monica	9.7	9.5–10.0	4	—	—			N/A		
Branchinecta mackini	8.7	7–9.8	67	7	9.8	8.8	7.9–9.3	16	7.4	9.5
Artemia franciscana	8.5	7.4–9.1	8	7.3	10.0	10.0	8.6–10.6	13	8.2	10.6
Branchinecta gigas	8.2	7.7–9.7	14	7	9.7	8.8	8.5–8.9	11	8.5	9.1
Branchinecta coloradensis	7.8	7.5–8.5	4	—	—	7.5	5.3–8.5	4	—	—
Branchinecta lindahli	7.6	6.8–9.3	63	6.7	9.8	9.2	6.8–10.1	27	6.6	10.3
Thamnocephalus platyurus	7.6	7.5–8.9	3	—	—	7.5	7.0–8.9	24	4.7	9.2
Streptocephalus texanus			no information			7.4	6.6–8.9	41	4.7	9.5
Branchinecta longiantenna	7.2	6.8–7.6	11	6.7	7.9			N/A		
Branchinecta conservatio	7.0	6.8–7.5	8	—	—			N/A		
Streptocephalus woottoni	6.9	6.4–7.1	6	—	—			N/A		
Branchinecta lynchi	6.8	6.3–8.1	22	6.1	8.5			N/A		
Linderiella occidentalis	6.6	6.2–8.1	22	6.1	8.5			N/A		
Eubranchipus serratus			no information			6.4	5.2–8.3	22	4.9	8.9
Streptocephalus seali	6.2	5–7.7	8	—	—	7.4	5–9	45	4.9	9.5
Branchinecta dissimilis	6.1	5.5–6.5	6	—	—	8.3	7.5–9.0	2	—	—
Eubranchipus oregonus			no information			6.0	5.8–6.2	6	—	—

mackini have outgrowths along the dorsal thoracic surface. Such structures are lacking in *B. longiantenna.*

Distribution.—This Californian endemic was found at only three disjunct locations, all of which were along the eastern margin of the Central Coast Mountains Region. Pools in this 335-km stretch between Concord, Contra Costa County, and Soda Lake in San Luis Obispo County were at elevations of 290–595 m. In the northern end of this distribution, *B. longiantenna* was collected from four pools on the Souza Ranch and one pool at Altamont Pass. To the south, 13 pools were found around the western and northern boundaries of Soda Lake.

Habitat.—*Branchinecta longiantenna* was collected from late December to late April in two quite different seasonally astatic grassland pool types: (1) small (approximately 1 m in diameter), clear-water depression pools in sandstone outcrops, and (2) clear to moderately turbid, clay- and grass-bottomed pools (1–62 m in diameter) in shallow swales of short grass or grass and low shrub vegetation of near desert conditions. Both pool types were filled by winter and spring rains. No water chemistry data were available for the sandstone depression pools, but water temperatures at times of collection ranged from 10–18°C. In the more southerly swale pools, temperatures from 12.3–28.0°C were recorded. TDS, alkalinity, and chloride levels were low, as they were in the habitats of other grassland species, but the range of values was slightly greater. A median pH of about 7.2 was similar to that for other grassland species as well (Table 2).

Comments.—To our knowledge the only studies of this species concern heavy metal tolerance (Mizutani and Ifune, personal communication), assimilation of dissolved organic matter (Mizutani, 1982), and filter-feeding rate (Patten, 1980). Therefore, we have little idea why its distribution and cooccurrence with other species is so restricted. For example, *B. longiantenna* was present in areas where *Branchinecta lynchi* also occurred (e.g., Souza Ranch) but *B. longiantenna* occurred alone in small rock pools very close to other seemingly identical pools that contained only *B. lynchi.* Only in the Soda Lake area, and only once, were *B. longiantenna* and *B. lynchi* collected together. *Branchinecta longiantenna* was collected a few times with *Branchinecta lindahli* near Soda Lake, although it seems not to otherwise extend into *B. lindahli*'s range.

Branchinecta longiantenna was not abundant in the Souza Ranch rock pools where its habitat is threatened by proposed development of wind-energy and water-storage projects. Current status of the species at Altamont Pass, which has had major wind-energy development, is unknown. In the Soda Lake area, most known sites are located in areas subdivided and roaded for sale and development as "ranchettes." To date, few such sites have been cleared, but the future could bring large scale habitat destruction. Because of existing and projected threats to its limited habitat, the future survival of this species is threatened.

Branchinecta lynchi, new species
Vernal pool branchinecta
Fig. 4a–c

Material Examined.—Holotype ♂ USNM 216109 and paratypes of both sexes USNM 216110 and CASIZ 050152 collected 29 April 1982. Additional paratype collections from Contra Costa County (DB 398, 406–410, 417, 418, 421, 422, 424), Glenn County (DB 434), Merced County (DB 432), Sacramento County (DB 404, 405, 411, 412), and Tehama County (DB 402).

Type Locality.—Pool 97, a seasonally astatic, winter/spring, weathered depression pool in a sandstone outcrop at the eastern edge of the Coast Ranges. Outcrop located at 290 m in the Slanted Rocks Area, Souza Ranch (37°46′N, 121°42′W), about 35 km southeast of Concord, Contra Costa County, California.

Male.—Total length for largest mature male 25 mm; smallest 11.2 mm. Basal segment of antenna approximately 30% longer than distal segment. Basal segment with small elongated pulvillus near proximal end and toward anterior edge of medial surface; ridgelike outgrowth just distal and posterior to pulvillus; variably developed moundlike bulge on anteriomedian side just below middle (Fig. 4a, b). Moundlike bulge sometimes with denticles scattered on surface. Distal segment with medial surface convex; lateral surface concave over distal 65%; tip curved medially and shaped as in Fig. 4c, d. Cercopods with plumose setae along medial and lateral borders.

Female.—Total length for largest mature female 25 mm; smallest 10.9 mm. Antennules shorter than antennae. Thoracic segment 4

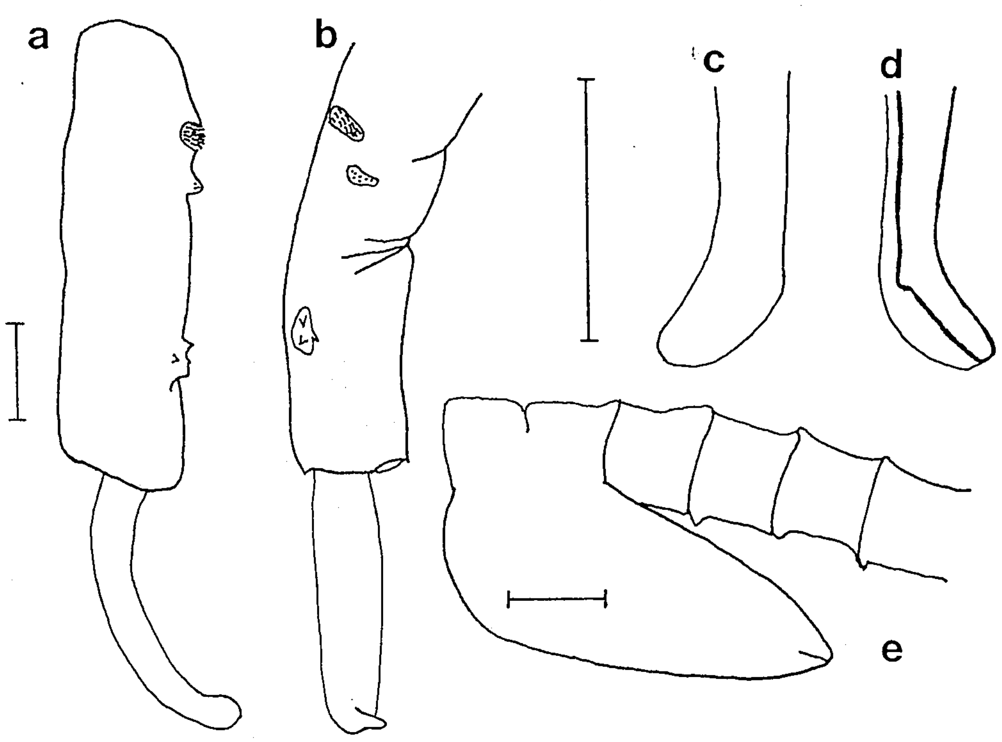

Fig. 4. *Branchinecta lynchi,* new species. Male paratype 23-mm total length. a, anterior view of right antenna; b, medial view of right antenna with anterior edge to left; c, anterior view of tip of left antenna's distal segment; d, posterior view of tip of left antenna's distal segment. Female paratype 16.5-mm total length; e, lateral view of pyriform broodpouch. Scales equal 1 mm.

with pair of ovoid dorsolateral protuberances. Thoracic segments 3, 5, 6, and sometimes 7–11 with 2 adjacent cone-shaped dorsolateral lobes of unequal size on each side of segment; medial of these adjacent lobes smaller than lateral ones. Pyriform brood pouch extending to below abdominal segment 5 or 6, and opening terminally (Fig. 4e). Cercopods with plumose setae along medial and lateral borders.

Etymology.—The species is named in honor of James E. Lynch who cleared up a long-standing problem in the systematics of North American branchinectids (Lynch, 1964) and made other significant contributions to the study of the genus *Branchinecta.* The common name, vernal pool branchinecta, acknowledges that this is the only frequently encountered *Branchinecta* in California's vernal pools.

Remarks.—The described species most similar in appearance to *B. lynchi* is *Branchinecta coloradensis* Packard, 1874. In fact, Linder (1941) presented a drawing of *B. lynchi* which he labeled *B. coloradensis* on page 191 of his monograph on the Anostraca. Linder might have recognized that he was dealing with a new species had it not been for the confusion that then existed in the nomenclature of *B. coloradensis* and two other branchinectids. Lynch (1964) cleared up this problem. In his final paper on the Anostraca, Lynch (1972) emphasized the importance of the male antenna as the cardinal specific character in the genus *Branchinecta.* Comparing the male antennae of *B. lynchi* and *B. coloradensis* reveals several differences. The basal segment outgrowth below and posterior to the pulvillus is ridge-like in *B. lynchi;* whereas it is cylindrical and often much larger in *B. coloradensis.* The bulge below the middle of the basal segment is typically smaller, more mound-like, and has fewer denticles (none in some cases) in *B. lynchi.* The distal segments are very different. In *B. lynchi,* the distal segment is only about twice as broad as thick, whereas in *B. coloradensis* it is about five times as broad as thick. Lastly, their apexes have dissimilar configurations (compare Fig. 4c, d with Lynch, 1964: 472).

The females of these two species exhibit taxonomically meaningful differences also, the easiest to see being brood-pouch shape. The shorter brood pouch in *B. lynchi* is pyriform, while the longer one in *B. coloradensis* is fusiform. The thoracic surface of *B. coloradensis* has, with variation, a dorsolateral boss on each side of segments 1–8 and, ventral to these, a conical lobe on each side of segments 2–10 (Lynch, 1964). By contrast, the thorax of *B. lynchi* has, again with variation, dorsolaterally a pair of unequal conical lobes on each side of segments 3 and 5–11, and two ovoid dorsolateral protuberances on segment 4 (see Linder, 1941: 191).

Distribution.—This Californian endemic is a species of grasslands in the Central Valley, Central Coast Mountains, and South Coast Mountains. Its 29 known pool sites range from the Vina Plains of Tehama County in the northern Central Valley, through most of the length of the Central Valley and eastern margin of the Central Coast Mountains Region, to the mountain grasslands north of Santa Barbara, a total of 615 km. Several disjunct populations are located 285 km further south on the Santa Rosa Plateau and in Skunk Hollow near Rancho California, Riverside County. The species was collected at elevations from 10–1,159 m.

Habitat.—*Branchinecta lynchi* was collected from early December to early May in two quite different seasonally astatic rain-filled pool types. One, which includes the type locality, contained clear water held in small, usually less than 0.5-m diameter, sandstone depression pools. Each of these small pools contained only a few shrimp. In the sandstone pools, pH values ranged from 5.5–7.0; other water chemistry data are lacking. The more common habitat was grassed (occasionally mud-bottomed) swale, earth slump, or basalt-flow depression pools in unplowed grasslands. These pools, predominantly "vernal pools" as discussed by Holland (1978) and Thorne (1984), varied dramatically in size, from one exceeding 10 ha, to an uncommonly small one only 5 cm deep and covering but 20 m². Published physicochemical data for a known site of *B. lynchi* (see Collie and Lathrop, 1976) and our field records demonstrate that this species occurs at temperatures between about 6 and 20°C in soft, poorly buffered waters (low TDS, conductivity, alkalinity, chloride) with a pH averaging about 7.0 (Table 2).

Comments.—*Branchinecta lynchi* was found relatively widely in California but was not abundant anywhere. It often cooccurred with other species but was never the numerically dominant one. The range of *B. lynchi* generally coincides with that of *Linderiella occidentalis.* Our data indicated that when they occur in the same grassland pools, *B. lynchi* is much less abundant. *Branchinecta conservatio, B. lindahli,* and *B. longiantenna* occur within the range of *B. lynchi;* however, neither *B. conservatio* nor *B. lindahli* has been collected from the same pool as *B. lynchi. Branchinecta lynchi* was, however, hatched from dried soils taken at Skunk Hollow, a Riverside County pool from which both *B. lindahli* and *S. woottoni* have been collected. At the Souza Ranch sandstone outcrop, *B. lynchi* occurred alone in small rock pools very close to other seemingly identical pools which contained only *B. longiantenna.* A single collection from the Soda Lake area contained both *B. lynchi* and *B. longiantenna.* Although the distributions of *B. lynchi* and *B. mackini* are quite different, the two were collected together on one occasion near Pixley in Tulare County where their ranges meet. The Pixley site had the highest pH, TDS, and conductivity, and the next to highest alkalinity for any pool of *B. lynchi* surveyed.

The grassland habitats in which *B. lynchi* occurs have been dramatically reduced during post-settlement time (Holland, 1988). This loss to agriculture and urban development continues. Its remaining habitats near Pixley and Haystack Mountain, in Sacramento County, and in the Vina Plains are mainly unplowed refugia in a sea of cultivated fields. Their habitat is threatened by wind-energy development at Souza Ranch and by urbanization in the Sacramento area. Subdivision and road construction pose a real threat of future development at Soda Lake. The Nature Conservancy preserves in the Vina Plains, the Haystack Mountain area, and the Santa Rosa Plateau provide small refugia, and several pools in the mountain grasslands of Santa Barbara

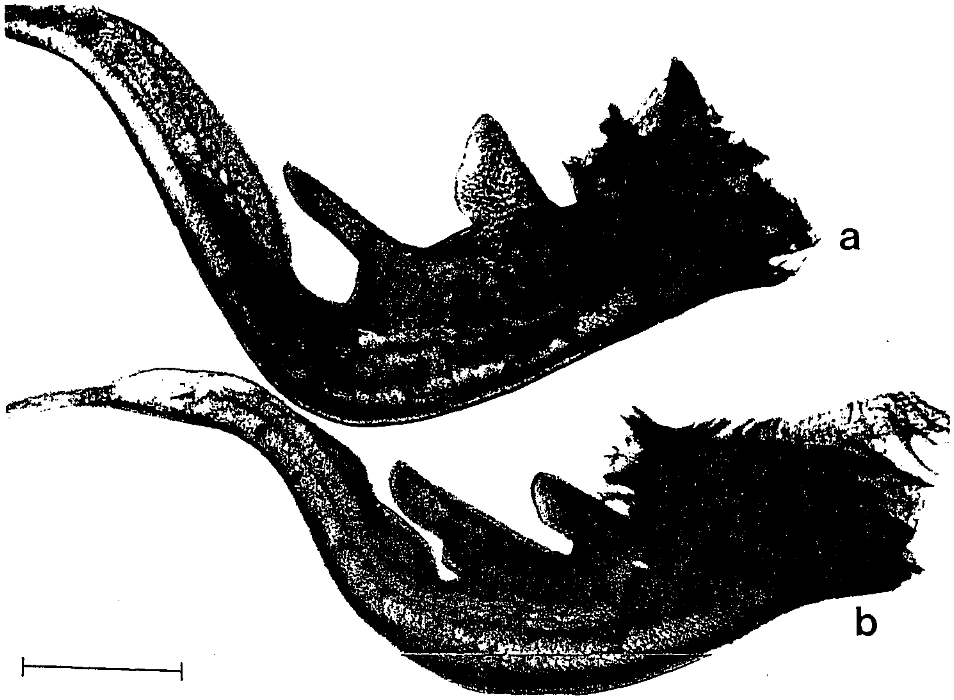

Fig. 5. Median views of fingers from right medial processes of: a, *Streptocephalus seali*, male measuring 17-mm total length; and b, *Streptocephalus woottoni*, new species, male paratype measuring 15.4-mm total length. Scale equals 0.5 mm.

County receive a degree of protection by their backcountry location. Because of historic and continuing habitat loss, the future survival of this species is threatened.

Streptocephalus woottoni, new species
Riverside fairy shrimp
Fig. 5b

Material Examined.—Holotype ♂ USNM 234417 and paratypes of both sexes USNM 234418 and CASIZ 064927 collected 28 March 1986. Other paratype collections used in preparing the description included additional specimens from the type locality collected 21 March 1985 (DB 694) and individuals from a natural slump west of Pala Road near Pechanga Indian Reservation in Riverside County (DB 689).

Type Locality.—A seasonally astatic swale pool deepened somewhat by excavation and located in a thin strip of disturbed coastal sage scrub and grassland vegetation between Murrieta Hot Springs Golf Course and California Highway 79, 5.3 km northeast of Interstate Highway 15 (33°32'N, 117°09'W), at an elevation of 335 m in Riverside County.

Male.—Total length for largest mature male 23 mm; smallest 14 mm. Frontal appendage cylindrical, bilobed at tip, and extending only partway to distal end of basal segment of antenna. Spur of thumb a simple blade-like process. Finger with 2 teeth; proximal tooth shorter than distal tooth (Fig. 5b). Distal tooth with lateral shoulder equal to about half tooth's total length measured along proximal edge (Fig. 5b). Basal part of penis with short medial process having 3 spines on anterior surface. Eversible part of penis with longitudinal row of spines on medial and lateral sides. Cercopods separate with plumose setae along medial and lateral borders.

Female.—Total length for largest mature female 21 mm; smallest 14 mm. Brood pouch extending to abdominal segment 7, 8, or 9. Cercopods as in male.

Etymology.—The specific name honors Dr. Donald M. Wootton who introduced many students to, and excited them in, temporary waters and their fauna, particularly the phyllopod Crustacea. Clyde Eriksen is grateful to be among those so influenced. As this species is restricted to western Riverside County, we propose Riverside fairy shrimp as the common name for the species.

Remarks.—The described species most similar to *S. woottoni* is *Streptocephalus seali*

Ryder, 1879. Plumose setae edge the cercopods of mature male *S. woottoni*, whereas spines replace the setae on the distal half of the cercopods in mature *S. seali*. While the last abdominal segment is short in both species, *S. woottoni* lacks the confluent inner margins of the cercopods characteristic for male *S. seali* and *Streptocephalus similis* Baird, 1852. The numerous differences in the morphology of the finger are illustrated in Fig. 5.

As is typical of preserved streptocephalid specimens, no species-distinguishing characteristics are observable in females; however, both living male and female *S. woottoni* have the red color of the cercopods covering the ninth and 30–40% of the eighth abdominal segments. No red extends onto the abdominal segments in living *S. seali* of either sex.

Distribution.—This species has the most restricted distribution of any endemic Californian fairy shrimp. Aerial survey of the region indicated that additional pool sites are unlikely to be discovered. The five pools from which it was collected, four of which were discovered during the aerial survey, all lie in western Riverside County in an area about 13 by 7 km, between elevations of 348 and 413 m, in the vicinity of Temecula and Rancho California.

Habitat.—All pools appeared to be seasonally astatic, and occur in tectonic swales or earth slump basins in patches of grassland and agriculture interspersed in coastal sage scrub vegetation. Pools, filled by winter and spring rains generally beginning in November, persisted into April or May. All reported habitats exceeded 750 m^2 and 30 cm in depth at maximum filling. Perennial vegetation immediately surrounding these pools was minimal, but two contained emergent *Eleocharis*. One pool contained a good deal of dead, but rooted, woody portions of terrestrial vegetation which grew in the basin when dry. The more open or vegetationless pools had turbid water, while deeper or partially vegetated pools were clear. TDS, alkalinity, and chloride were very low, conditions corroborated by pH at neutral or just below (Table 2).

Comments.—There have been no studies of the biology of this new species. However, like *S. texanus*, but unlike *S. seali* from California and Arizona, *S. woottoni* appears to be a warm water species since it did not appear until later in the season. Early February collections from the type locality contained only mature *Branchinecta lindahli* (a species known to hatch well at temperatures as low as 5°C; Belk, 1977a). Mid-March collections from this pool, in water temperatures of 17.8°C, contained mature *B. lindahli* and immature *S. woottoni*. By late March, only mature *S. woottoni* remained in water temperatures >23°C. Three of five collection sites demonstrated the cooccurrence of these two species. *Streptocephalus woottoni* was always taken in deeper water among loose emergent vegetation. Although not collected in the field together, *B. lynchi* has been hatched from the soil of Skunk Hollow which contains *S. woottoni*.

Streptocephalus woottoni has the most restricted distribution of any of the Californian anostracans. This species is threatened by agricultural and urban development at all of the five known sites. Unless significant conservation actions are implemented, the future survival of this species is endangered. The federal government has been petitioned to list *S. woottoni* as an endangered species.

Artemia franciscana Kellogg, 1906

Artemia franciscana was described from specimens collected at a saltworks on the west shore of San Francisco Bay in Redwood City. The specific name *franciscana* dropped from general use after Daday (1910), synonymized all *Artemia* under *A. salina* (Linnaeus, 1758). In his review of experiments which tested for reproductive isolation, Barigozzi (1974) concluded that the sexually reproducing *Artemia* from Argentina, Europe, and North America are fully reproductively isolated and thus deserving of species status. He used *A. franciscana* for the North American species, but unexplainably indicated that the specific name *franciscana* "has not yet been proposed." Following Barigozzi's lead, Bowen and Sterling (1978) applied the name *A. franciscana* Kellogg to seven North American populations that grouped together electrophoretically, while differing from populations collected in the Old World. These workers chose *franciscana* because of the importance of the San Francisco Bay area as an identifiable source of the animals they and others use in their research. More recently, Bowen *et al.* (1985) suggested that use of the specific names *gracilis*, *fertilis*, and *guildingi* be discontinued. We support this suggestion. Since the specific name *franciscana* is not the oldest one published, we consider that it is time that the following comments be made in the interest of nomenclatural stability. We consider *Artemia gracilis* Verrill, 1869, a nomen dubium. The type locality was a bucket of water and Verrill was unable to locate any individuals in natural waters around the collection site. The lack of an identifiable extant population means that the electrophoretic, autecological, chromosomal, and crossing studies helpful in establishing species identity in this complex of sibling species cannot be applied. *Artemia fertilis* Verrill, 1869, and *Artemia guildingi* Thomas, 1834, have not been used as valid names for more than 50 years. Their reuse would only add confusion to the literature.

Distribution.—Because of its restriction to highly saline waters, *A. franciscana* has a spotty distribution in California from approximately sea level to 1,495 m in elevation. Coastal locations include a number of sites around San Francisco and Monterey Bays (Central Coast Mountains Region), and San Diego Bay (South Coast Mountains Region) (Bowen *et al.*, 1985; Browne and MacDonald, 1982). In the Mojave Desert, populations of *Artemia*, which are probably this species, are known from Koehn Playa Lake in Kern County, and from South Panamint (Kubly and Cole, personal communication), Deep Springs, and Owens Lakes in Inyo County. In the arid southern end of the Central Valley and Central Coast Mountains Regions, populations of *Artemia* exist near Lemoore (Kings County), and in and around Soda Lake in San Luis Obispo and Kern Counties. Outside California, localities of *A. franciscana* are scattered through western North America from Saskatchewan to several states in Mexico. Populations also occur on several Caribbean Islands.

Habitat.—*Artemia franciscana* dwells in seasonally and perennially astatic hypersaline playas, ponds, and pools in coastal and highly arid regions. Most of these habitat types are natural, but the species also thrives in salterns. All natural habitats fill with winter and spring rains, although the salterns are flooded periodically. Habitat TDS varies from about 1.1–3.2 times as great as sea water. As a result any colloids present are precipitated, leaving clear although sometimes tea-colored water. Chloride dominates these habitats while alkalinity is comparatively low. Known pH values range from 8.4–10.0 (Table 2).

Comments.—*Artemia franciscana* has not been found with other anostracans in California, but, in other parts of its North American range, it is said to have been present with *Branchinecta lindahli* (see Lynch, 1964), *B. cornigera* (see Anderson, 1958; Lynch, 1960; Hartland-Rowe, 1966), and *B. campestris* (see Broch, 1965). However, because habitats of *Artemia* are much more saline than those reported for species of *Branchinecta*, the cooccurrence with the two branchinectids may be the result of vertical habitat partitioning with the branchinectids living in a layer of less dense fresh water atop a hypersaline lower layer as described by Anderson (1958) in the Grand Coulee of Washington State. Broch (1965) noted a similar, albeit temporal, separation between *A. franciscana* and *B. campestris* occupying the same pools, with the latter occurring during the cool, lower salinity phase of the pools. As the water warmed and salinity increased, *A. franciscana* hatched and the population of *B. campestris* declined and disappeared.

Artemia franciscana is commercially cultured and has been introduced into many parts of the world (see Bowen *et al.*, 1985; Browne and MacDonald, 1982). Because of widespread distribution and culturing, and because the highly saline pools and soils in which *Artemia* thrives would be difficult to reclaim or develop, the continued existence of this species does not appear threatened.

Artemia monica Verrill, 1869
Mono brine shrimp

Artemia monica most likely evolved within Mono Lake from a stock of *A. franciscana* that dispersed there early in its evolution as a salt lake. As the saline character of the lake became unique so did the biology of its population of *Artemia* (Bowen *et al.*, 1984, 1985).

Distribution.—This Californian endemic occurs only in Mono Lake, located in the Great Basin Desert of Mono County (37°57′N, 119°01′W), at an elevation of 1,965 m.

Habitat.—Mono Lake is an ancient, permanent, clear-water, carbonate-rich, saline lake with a pH of 9.7 (Mason, 1967) and a TDS of 96.4 g/l (Herbst and Dana, 1980). Yearly water temperatures throughout its 48-m depth range from 4–24°C (Lenz, 1980).

Comments.—In contrast with other species of *Artemia,* the embryonated eggs of *A. monica* are demersal (a characteristic well adapted to a stable lake), do not need a period of desiccation, and require one to three months of preincubation before hatching in March at an optimal temperature of 5°C (Bowen *et al.,* 1984). Lenz (1980) found *A. monica* present throughout the year, although densities are greatly reduced during winter. *Artemia monica,* like *A. franciscana,* is a hyposmotic regulator over a considerable range of salinities, although, unlike *A. franciscana,* it will not survive acute exposure greater than about 5,000 mOsM (Herbst and Dana, 1980). Nor will it survive in the ionic medium which supports *A. franciscana.* Because the City of Los Angeles diverts most of its inflow, Mono Lake's volume has dramatically decreased resulting in an approximate doubling of its salt concentration over the past 40 years. Another doubling will bring *A. monica* to the edge of its osmoregulatory ability, and further concentration would likely result in the extinction of this species (Herbst and Dana, 1980). Mono Lake's population of *Artemia* supports a small commercial fishery dealing in frozen shrimp. Being commercially valuable and possessing biological characteristics that differ from other commercially exploited *Artemia,* add to the importance of protecting and conserving the Mono Lake species. The future survival of the Mono brine shrimp is threatened by continued degradation of its only habitat. The U.S. Fish and Wildlife Service, using the common name, Mono brine shrimp, has determined that listing this species as an endangered species under the Endangered Species Act of 1973 may be warranted and has added it to their list of candidate species (U.S. Fish and Wildlife Service, 1988).

Branchinecta coloradensis Packard, 1874

This species has been considered a member of the Californian anostracan fauna since Lilljeborg (1889) misidentified a mixed collection of *B. lindahli* and *B. lynchi* from San Francisco as *B. coloradensis.* A second record, this time by Dexter (1956), was also a misidentification caused by nomenclatural confusion cleared up by Lynch (1964). We discuss these cases of misidentification under *B. lindahli.* The collections we examined represent the first valid records of *B. coloradensis* in California.

Distribution.—All but one of the 12 Californian collection sites were in the far eastern portion of the state. Eight of those were from a 60-km stretch of Great Basin Desert, 1,300–1,600 m in elevation between Alturus and Susanville in Lassen County. A Mojave Desert collection was made about 500 km further south at the edge of Panamint Dry Lake (475 m in elevation), west of Death Valley National Monument. In contrast, about halfway between these two desert locations, *B. coloradensis* was taken at two sites within 10 km of each other, on either side of the Sierra Nevada crest, at elevations of 3,050 and 3,500 m. A single Central Valley record came from a grassland pool about 15 km east of Modesto in Stanislaus County at an elevation of only 62 m. Outside California, *B. coloradensis* is known from either high mountains or high deserts of all states west of the Rocky Mountains except Idaho and New Mexico. East of the Rockies it has been reported from Oklahoma, Alberta, and Saskatchewan.

Habitat.—*Branchinecta coloradensis* was typically found in seasonally astatic snowmelt pools, several of which were in manmade roadside ditches in the Great Basin Desert. In the high Sierra Nevada, *B. coloradensis* was also found in aestival habitats of glacial origin. The winter rain-filled grassland pool in the Central Valley, where freezing temperatures are rare, was an atypical habitat for *B. coloradensis.* The high elevation aestival habitat contained *B. coloradensis* in October before freeze-up; the time of all other occurrences, from March into July, correlated directly with elevation. Habitat temperatures ranged from about 1–26°C. *Branchinecta coloradensis* appeared in pools which varied in size from 20 m^2 to

2.6 km long but which were annually predictable. The exposed, mud-bottomed Great Basin Desert pools were highly turbid, while water in the high mountain habitats was clear. The only other habitat information available showed pH in the Great Basin Desert pools mainly between 7.5 and 7.9, although we obtained one reading of 8.5 (Table 2).

Outside California, *B. coloradensis* is found in the same high desert and high mountain habitats within similar temperature ranges (Shantz, 1905; Coopey, 1946; Horne, 1967; Eriksen, unpublished). Several Great Basin desert pool pH measurements of 8.5 (Coopey, 1946; Eriksen, unpublished) corroborated the highest measurement from a Californian site, and an alpine pool, a habitat unmeasured in California, registered a low pH of 5.3 (Maynard, 1977).

Comments.—Shantz (1905), Coopey (1946), and Maynard (1977) surmised that embryonated eggs of *B. coloradensis* hatch in near 0°C water under surface ice, since nauplii are present when the ice breaks up. Hatching at near freezing temperatures is an adaptation to aestival or snow-filled seasonally astatic pools. The fact that *B. coloradensis* is found in similar climatic and geomorphic regions as other anostracans, but has not been collected in the same pool with one, is also unique. Although *B. coloradensis* is not common in California, it occurs in areas remote from significant human occupation and development; therefore, its continued existence does not appear threatened by human activities.

Branchinecta dissimilis Lynch, 1972

This species has not previously been reported from California. However, Dexter (1956) published what he considered the first Californian record of *B. lindahli,* under the synonym then current, *B. coloradensis.* We reject Dexter's record for reasons discussed under *B. lindahli,* and suspect he may have misidentified specimens of *B. dissimilis.*

Distribution.—*Branchinecta dissimilis* has been collected from 9 sites in the Sierra Nevada between Monitor Pass south of Lake Tahoe, to the area west of Bishop in Inyo County, a total distance of only 150 km. All collections were between 2,440 and 3,506 m in elevation, and generally at or above timber line. Outside California, *B. dissimilis* is known only from Deschutes, Harney, and Lake counties in Oregon (Lynch, 1972; Eriksen, unpublished).

Habitat.—In California, *B. dissimilis* was collected from seasonally astatic or aestival, glacially scoured, alpine puddles, pools, or lakes usually in granitic basins, filled by snowmelt. Collections were taken from June to mid-September, at temperatures of 17–24°C. Although habitats were mud-bottomed, water was clear though sometimes tea-colored. Observed pH readings of 5.7–6.5 correlated well with very low conductivity, TDS, and alkalinity (Tables 2, 4, 5). Although other *B. dissimilis* habitats are also seasonally astatic and filled by snowmelt, they differ by being turbid, having a pH of 7.5–9.0 and occurring at elevations around 1,500 m (Lynch, 1972) in the sedimentary, intermontane Great Basin Desert of Oregon.

Comments.—Little is known about this species because its Californian habitat is located in rugged mountain terrain many km from roads or trail heads. Its range in the Sierra Nevada overlapped the southern end of the distribution of *Streptocephalus seali. Branchinecta dissimilis* appeared where *S. seali* began to drop out and occurred both at higher elevations and further south. It was the dominant fairy shrimp at elevations exceeding 2,500 m, although two collections of *B. coloradensis* from above 3,000 m show the latter to be in the area as well. *Branchinecta dissimilis* has not been collected with other anostracan species in California, but, in an Oregon pool, it was found, surprisingly, with the alkaline-water species, *B. mackini* (see Lynch, 1972). Threats to this species are minimal because its Californian habitats are remote from areas of detrimental human activities.

Branchinecta gigas Lynch, 1937
Giant fairy shrimp

The first Californian population of *B. gigas* noted in the primary scientific literature is one at Rabbit Dry Lake in San Bernardino County (Brown and Carpelan, 1971). A collection at the California Academy of Sciences (CASIZ 025250), taken from Mirror Lake on the China Lake Naval Weapons

Center in Kern County, 22 January 1966, is labeled "new state record." The only report on this collection appears in the May 1966 issue of the California Academy of Sciences newsletter.

Distribution.—Seven of the eight California sites were located in a 160 by 50-km swath down the middle of the Mojave Desert, between elevations of 695 and 895 m. Middle Alkali Lake, at 1,403 m in the Great Basin Desert of extreme northeastern California, harbored the remaining Californian population. Outside California, *B. gigas* ranges northward through the intermontane basins of other western states, and east of the Rocky Mountains into Montana, North Dakota, Alberta, and Saskatchewan.

Habitat.—In California, *Branchinecta gigas* was usually associated with seasonally astatic, playa lakes which obtain water from unpredictable winter and spring rains. Middle Alkali Lake, a 29 km long aestival playa, was the largest of the recorded habitats for this species. *Branchinecta gigas* was collected from late January to early May, in 8–21°C water. All habitats contained highly turbid, alkaline water of high pH, moderate TDS and conductivity, and moderate to high chloride (Tables 1–5).

Comments.—Daborn (1975) reported that *B. gigas* hatches in the low salinity water (<1.26 g/l) of thawing aestival lakes and hatching ceases as salinity increases. An analogous situation undoubtedly exists in seasonally astatic habitats when filled by rain or flash flood (see discussion under *B. mackini*). The occurrence of *Branchinecta gigas* in waters of such a wide range of ionic concentrations is at least partially explained by the fact that it hyperosmotically regulates at low TDS and tolerates high TDS by osmoconforming (Broch, 1988). Females produce mature eggs 30–33 days after hatching, will produce up to three clutches, will live up to 60 days, and will grow to the amazing length, for an anostracan, of at least 86 mm (Daborn, 1975). *Branchinecta gigas*, the only North American predatory anostracan, was typically associated with *B. mackini*, a major prey species.

Its restricted and relatively rare occurrence in California makes *B. gigas* particularly vulnerable to activities that damage or destroy its habitat. Most of the Californian habitats are either within military weapons testing ranges, or receive frequent use by off-road recreational vehicles, airplanes, or the space shuttle. Eriksen *et al.* (1986) have demonstrated that mere compression of dry lake bed soil by vehicles destroys a significant number of entrapped anostracan eggs. Because of the rarity of *B. gigas* within the state, and because its habitats are vulnerable to degradation as a result of ongoing human activities, the future survival of this species in California is uncertain.

Branchinecta lindahli Packard, 1883

Lilljeborg (1889) published what he thought was the first record of *Branchinecta coloradensis* in California; however, he misidentified specimens that are *B. lindahli*. Linder (1941) pointed out that Lilljeborg's specimens were a subsample of a large collection made by Dr. G. Eisen at "San Francisco" in 1874. A portion of the Eisen collection is at the Smithsonian Institution (USNM 82102). Denton Belk examined this collection and determined that it contains a large number of mature specimens of *B. lindahli*. Linder (1941) stated that most of the male specimens he examined in a portion of the Eisen collection housed at the Zoological Museum of the University of Uppsala exhibited second antennal morphology like that described for *B. lindahli* by Shantz (1905). However, the Uppsala subsample contained, in addition to *B. lindahli*, specimens of the new species we describe in this paper as *B. lynchi*. Linder (1941: 191) presented drawings of *B. lynchi* labelling them *B. coloradensis*. Apparently the confusion that existed in identifying *B. lindahli* and *B. coloradensis* (Lynch, 1964), and specimens in the Uppsala collection of an undescribed species having a resemblance to *B. coloradensis*, led Linder to conclude that *B. lindahli* and *B. coloradensis* were one and the same species.

Dexter (1956) reported what he considered the first Californian record of *B. lindahli* under the synonym then current, *B. coloradensis*. The population he listed came from upper Convict Creek Basin in the high Sierra Nevada. However, collections we examined from this general area contained only *B. dissimilis,* a species undescribed in 1956. Owing to these considerations, we reject Dexter's record, and suspect he may have misidentified specimens of what we know today as *B. dissimilis.* This is a good example of why all new records should be documented with voucher specimens in a public museum.

Distribution.—*Branchinecta lindahli* was the most commonly collected and widespread anostracan in the State (66 sites): the western two-thirds of the Mojave Desert (500–1,203-m elevation) contained 23 widespread collection sites; the arid portions of the Central and South Coast Mountains Regions from Soda Lake in San Luis Obispo County to San Diego (335–1,308-m elevation), 20 sites; the arid southwestern half of the Central Valley (17–90 m), nine sites; and Santa Cruz Island (Santa Barbara County), two sites. *Branchinecta lindahli* is the only anostracan found on the California Channel Islands. Outside California, *B. lindahli* occurs in all states west of the Rocky Mountains except Idaho, and in the Great Plains from southern Alberta to Kansas. It is also known from Baja California, Mexico, including Guadalupe Island.

Habitat.—*Branchinecta lindahli* was collected from mid-December to early May in seasonally astatic pools which collect water from winter and spring rains. These pools were typically unpredictable, often quite small, and comparatively short-lived. They varied in type and origin from roadside ditches, arid grassland swale pools, and playas, to small water-filled pockets created by gas accumulations in an old lava flow, and a weathered basin in a quartz monzonite dome. Habitat water was typically turbid; *B. lindahli* was occasionally collected in clear-water habitats. Temperatures ranged from 1.5–22.2°C. *Branchinecta lindahli* was commonly collected from very soft waters, as low in TDS, chloride, conductivity, and alkalinity as for any Californian anostracan (Tables 3–5). However, it was also taken, though much less frequently, from pools with very high levels of these parameters, levels exceeded only by *A. franciscana, A. monica, B. mackini,* and *B. gigas.* The pH range measured, 6.4–9.8, was greater than for any other Californian anostracan (Table 2). Habitat records for *B. lindahli* outside California demonstrate an even wider tolerance. Not only has it been collected at 34.5°C, in a "strongly alkaline pond with water the color of black ink," and at a pH of 9.9 (McCarraher, 1970), but it has been found swimming in the same pool as *Artemia* at a TDS greater than sea water (Lynch, 1964).

Comments.—Belk (1977a) demonstrated that *B. lindahli* hatched best from 5–20°C, poorly at 25°C, and not at all at 30°C. He also found that its 1-h LD/50 at 36°C was intermediate between the coldest and warmest water Arizona species with which he worked. Thus, its temperature physiology explains, at least in part, the winter and spring occurrence of *B. lindahli* in California. The wide range of ionic strengths in which this species hatches (<1–3 ppt; Horne, 1967) is certainly one of the reasons for its occurrence in such a wide array of TDS. It also demonstrates that the mechanism for arresting eclosure is unlike that for *B. mackini,* a species with which it may coexist, and for which hatching ceases at TDS >1 ppt (Brown and Carpelan, 1971).

Not unexpectedly, development time is controlled by temperature. In the cool spring, maturation took 20 days of its 27-day longevity, while later in the season only 9–12 days were required (Maynard, 1977; Donald, 1983). Maynard (1977) noted that *B. lindahli* can invest much energy in early development and maturity but does so at the expense of animal and clutch size. She argued that such a strategy gives the species an advantage in smaller and more temporary waters, and in drought years. This advantage, and the possibility that drought one year enhances hatching the following year (Donald, 1983), provides an explanation for its Californian occurrence in the smallest, most temporary and erratic pools and puddles.

Branchinecta lindahli has been collected with *B. gigas, B. longiantenna, B. lynchi, B. mackini,* and *Streptocephalus woottoni* in California. Outside California it is known to coexist with *B. campestris, B. packardi, B. paludosa, S. texanus, Thamnocephalus platyurus, Eubranchipus bundyi,* and *Artemia* sp. (Horne, 1967; Lynch, 1964; McCarraher, 1970). It has also occurred in pools where *Eubranchipus intricatus* and *Eubran-*

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Much of the habitat of *B. lindahli* in California has been lost or degraded through agricultural and urban development, and human activities on desert playas. As such impact continues, so will the elimination of local populations; however, given *B. lindahli*'s widespread occurrence, there appears to be no immediate threat to the survival of the species.

Branchinecta mackini Dexter, 1956

The first Californian location reported for *B. mackini* was Bicycle Dry Lake, San Bernardino County. Dexter (1956) mentioned having specimens from this population in his paper describing the species; however, he designated a playa in Nevada as the type locality.

Distribution.—*Branchinecta mackini* (58 known sites) was nearly as common as *B. lindahli* in California. It was as widespread, being found in 10 Great Basin Desert locations (elevations 1,216–2,094 m), throughout the Mojave Desert and along the South Coast Range's interface with the Mojave Desert (35 sites) at 410–1,206 m, and at 13 locations in the southwestern portions of the Central Valley (as far north as Contra Costa County) at elevations of 17–99 m. Outside California, *B. mackini* ranges north to Washington, Alberta, and Saskatchewan, and east to Utah and Nebraska.

Habitat.—*Branchinecta mackini* inhabits seasonally astatic and aestival playas, roadside ditches, and earth fault pools all associated with alkaline soils. Waters ranged in size from a playa 20 km long, to small roadside ditches but a few m in length. In the Great Basin Desert, these systems fill largely by snowmelt, generally in March and April. Occasional summer storms of tropical origin create flash floods which bring water to some Mojave Desert playas and ditches, but generally habitats in the Mojave Desert and Central Valley fill by winter and spring rains from November through March. Habitat temperatures have been measured from 1–32°C (Brown and Carpelan, 1971), but the great majority of temperatures measured during this study were near 15°C.

Pools were typically exposed, mud-bottomed, without vegetation, and turbid. Only 2 of 58 collection sites contained clear water, although several were lightly turbid. With the exception of *Artemia, B. mackini* occupies waters of greater average TDS, chloride, conductivity, and pH than other Californian anostracan species. With regard to alkalinity, it stands alone (Table 4). Information from outside California does not significantly add to its habitat breadth.

Comments.—*Branchinecta mackini* hatches at temperatures of 1–32°C, partially explaining its appearance at any season when sufficient water is available. A hyposmotic shock, normally accomplished by rapid runoff into the pool basin, is necessary to trigger the hatching process. As solution of soil salts raises the TDS to about 1 g/l, hatching ceases (Brown and Carpelan, 1971). Sexual maturity was reached in 12–17 days during a warm fall, but required 21–31 days during a cold spring (Maynard, 1977). White and Hartland-Rowe (1969) recorded individuals living 107 days. Such information helps explain why *B. mackini* was restricted to pools with longer average duration than *B. lindahli.*

Branchinecta mackini swims well at 1°C and has a 12-h LD/50 of 30°C for early season cooler water individuals, and 34.5°C for mature warmer water forms (Eriksen and Brown, 1980). Such temperature liability further explains its appearance whenever water is present. According to Brown (1972), *B. mackini* is capable of both hypo- and hyperosmotic regulation. Broch (1988) also demonstrated hyperosmotic regulation but concluded that *B. mackini* tolerates high TDS by osmoconforming. Whatever the ultimate resolution of this point, the conclusions of Brown and Broch explain, at least, in part, this species' tolerance of such a wide array of ionic concentrations. *Branchinecta mackini* is a major prey species for *B. gigas* (Daborn, 1975; White, 1967), and the two species are often found together in larger habitats. In smaller pools, it occasionally coexists with *B. lindahli;* in Bicycle Dry Lake (San Bernardino County) it has been found with *Thamnocephalus platyurus;* and in a roadside swale pool at the edge of the Pixley National Wildlife Refuge in Tulare County, it was surprisingly collected with *B. lynchi.* Outside California, *B. mackini* has been collected once with *B. cornigera* (Lynch, 1958) and with *B. campestris* (Lynch, 1960).

Because this species is widespread and many of its populations occur in parts of California that are remote from centers of human activity, it is not in any immediate danger of extinction. However, Eriksen *et al.* (1986) have shown that off highway vehicle use of its playa habitats destroys a significant proportion of its encysted eggs. What effect this will have over the long term on local population size or survival is unknown.

Eubranchipus oregonus Creaser, 1930

Eubranchipus oregonus has not previously been reported from California. A Smithsonian collection (USNM 204553) may be from the state; however, we have been unable to locate the collection site which is listed on the label as Brocot, California.

Distribution.—The only positively identified site for *E. oregonus* in California is along Deetz Road, 1.7 km west of Interstate Highway 5 just south of Weed in Siskiyou County (41°22′N, 122°23′W) (DB 685). The site is at 1,170 m in the Cascade Range about 70 km from the Oregon border. Outside California, *E. oregonus* ranges through valleys in western Oregon, Washington, and into British Columbia. Disjunct populations occur in four Oklahoma counties (Creaser, 1930; Mackin, 1936; Prophet, 1963c).

Habitat.—The Deetz Road pool is not only seasonally astatic but does not form every year. When it forms, it does so from snowmelt usually in early February and lasts through April. The pool is held by deep clays in a natural drainage under a railroad span crossing a wet meadow which in turn is surrounded by coniferous forest. At maximum filling the pool is about 8 × 3 × 0.2 m and holds clear water of poor buffer capacity (Beatty, personal communication). Coopey (1950) described a site near Seattle, Washington, as a "temporary, *Typha* bordered pond" with a maximum depth of 1.3 m, containing much detritus, and filled with "yellow to brown stained water." The Seattle pond filled in late November and was dry by late June or July. During Coopey's observations, temperatures ranged from 1°C (under ice cover) to 16°C, and the water was mildly acid (pH 5.8–6.2). Coopey felt that such a habitat was characteristic for *E. oregonus* in western Oregon and Washington.

Comments.—Coopey (1950) provided the following information on *E. oregonus.* Hatching began three days following pool-filling and lasted about five weeks, being 75% complete within the first 10 days. The process was continuous without distinct broods. Although eggs hatched at temperatures of 4–9°C, 10–15°C was required to bring females to maturity. Males disappeared as water temperatures reached 16.5°C and females were absent when pool temperatures reached 26.5°C. Whether thermal limits were surpassed or merely the end of a life-span was reached is not known. In any event, the female life-span of 23–25 weeks appears to be one of the longest for North American Anostraca (excluding *Artemia*) (Coopey, 1950). The forested areas of northern California have been poorly surveyed for the presence of Anostraca. Such surveys must be completed before the status of this species in California can be truly determined. However, the only known population of *E. oregonus* in California is currently threatened as human population and activities continue to increase in the Weed area.

Eubranchipus serratus Forbes, 1876

This species has not previously been reported from California.

Distribution.—*Eubranchipus serratus* is known from a single collection (CASIZ 025264) made at McCoy Flat, 6 km west of Eagle Lake in Lassen County. McCoy Flat, about 120 km from the Oregon border at an elevation of 1,650 m, lies in the eastern edge of the Cascade Range near its interface with the Great Basin Desert Region. Outside California, *E. serratus* spans the continent, with the United States—Canadian border being about its northern limit (except for localities in British Columbia), and with the southernmost populations being in Arizona, Oklahoma, and Virginia.

Habitat.—Information specific to the Californian collection site is limited to knowledge that it occurs in an area of coniferous forest and winter freeze. Since the collection was made in early December, the pool was most likely filled by rain. Studies outside California (Coopey, 1946; Dexter and Ferguson, 1943; Prophet, 1963a; Eriksen, unpublished), indicate that *E. serratus* occurs in seasonally astatic waters in forests, meadows, and grasslands that are subject to winter freezing. Autumn, winter, and spring collections have been made at water temperatures of 1–17°C. In one instance the pool surface reached 23.5°C, but the bottom water was a comparatively cool 15.1°C. The habitats are usually mud-bottomed, but contain clear though often tea-colored water. Pools usually possess significant amounts of living and dead vegetation, are very low in TDS, conductivity, and chloride, and are poorly buffered (Tables 3–5). Habitat pH is usually slightly acidic, although measurements from 4.9–8.2 have been recorded (Table 2).

Comments.—Eggs of *E. serratus* will not hatch at temperatures of 20°C, but do so after a week or two of wetting at 6–15°C (Prophet, 1963b). Belk (1977a) also found no hatching at 20°C or above, poor hatching success at 15°C, and good hatching at 5° and 10°C. Hatching apparently occurs below 4°C, since Dexter and Ferguson (1943) reported hatching under a heavy ice cover, conditions under which *E. serratus* developed for several weeks. The length of the life cycle and time to maturity depends on temperature, but individuals have been known to survive approximately nine weeks, reaching sexual maturity after five weeks, and also about 11.5 weeks, reaching sexual maturity in 6–8 weeks (Dexter and Ferguson, 1943; Coopey, 1946). *Eubranchipus serratus* dies in 28°C water, prefers temperatures of 15–17°C, and will not voluntarily swim into water above 17°C (McGinnis, 1911). Species habitat descriptions and temperature tolerance information thus help explain why *E. serratus* occurred in the coniferous forests of northeastern California. In this Californian locality *E. serratus* was apparently the only fairy shrimp present; however, elsewhere it is known to cooccur with *B. cornigera* (Lynch, 1958). *Eubranchipus serratus*, like *E. oregonus*, is known from a single Californian location, a location in a forest which is heavily logged. However, as mentioned above for *E. oregonus*, because the coniferous forests of northern California have been poorly surveyed for the presence of Anostraca, additional populations of this species may exist.

Linderiella occidentalis (Dodds, 1923)
Californian linderiella

This Californian endemic was originally described from specimens collected on the Stanford University campus, in Santa Clara County.

Distribution.—*Linderiella occidentalis* is known from 39 different sites in California. About half of these are located along the east side of the Central Valley from east of Red Bluff (Tehama County) to east of Madera (Madera County) at elevations between 40 and 168 m. The species crosses the Central Valley in the Sacramento area and is found in the Central and South Coast Mountains Regions from Boggs Lake, 90 km north of San Francisco Bay in Lake County, south, in a series of disjunct populations, to Riverside County, at elevations of 10–1,159 m.

Habitat.—*Linderiella occidentalis* was collected from late October to early May, at 6–17°C, in seasonally astatic pools and ponds filled by winter and spring rains. These waters were most commonly in swales in old alluvial soils underlain by hardpan, were grass-bottomed, and contained clear though often tea-colored water. Infrequently, collections came from mud-bottomed pools with lightly turbid water. Occasionally *L. occidentalis* inhabited clear-water depression pools in sandstone or old lava flows. Pool size varied from about 1 m^2 to the 40-ha Boggs Lake. Water chemistry data showed that *L. occidentalis* inhabited poorly buffered soft waters (very low alkalinity, TDS, conductivity, and chloride), a consequence of which was that pH varied about a unit to either side of neutral, both seasonally and daily (Table 2).

Comments.—*Linderiella occidentalis* hatches best at around 10°C, a common mean temperature throughout its distribution, and will hatch rapidly if eggs have been presoaked and high dissolved oxygen and temperatures below 20°C are present (Lanway, 1974). A similar high temperature may be limiting to adults as well, for *L. occidentalis* disappeared from pools when mean air temperature exceeded 17–21°C (Patton, 1984).

Table 3. Total alkalinity (mg/l) of anostracan habitats in California and out-of-state. (Sources: Anderson, 1958; Barclay and Knight, 1984; Brown and Carpelan, 1971; Cole and Brown, 1967; Coopey, 1946; Dana, 1984; Dana *et al.*, 1977; Eriksen and Brown, 1980; Fujita, 1978; Horne, 1967; Kubly, 1982; Mason, 1967; Maynard, 1977; McCarraher, 1970; Moore, 1955, 1963; Prophet, 1959, 1963a; Shantz, 1905; Sublette and Sublette, 1967; White, 1967; White and Hartland-Rowe, 1969; Herbst, personal communication; Kubly and Cole, personal communication.) See Table 1 for an explanation of the column headings.

	California							Out-of-state						
Species	$\bar{x}$	SD	95% CI	Range	*N*	Min/max omitted		$\bar{x}$	SD	95% CI	Range	*N*	Min/max omitted	
Artemia monica	29,375	7,189	11,436	19,500–36,700	4	—	—				N/A			
Branchinecta mackini	1,594	504	145	146–2,810	49	95	3,304	788	269	134	319–1,361	18	315	1,388
Artemia franciscana	482	447	374	74–1,307	8	73	9,474	38,516	21,511	13,667	4,938–77,000	12	3,148	87,000
Branchinecta gigas	454	142	109	302–657	9	146	931	702	167	112	407–962	11	315	1,003
Branchinecta lindahli	213	212	65	22–763	43	18	2,406	1,440	1,302	875	87–4,420	11	46	10,030
Streptocephalus texanus			no information					111	48	14	46–241	46	32	542
Thamnocephalus platyurus			no information					110	43	19	40–213	23	10	542
Branchinecta longiantenna	94	32	23	58–156	10	47	882				N/A			
Branchinecta lynchi	91	68	39	22–274	14	20	314				N/A			
Branchinecta coloradensis			no information					74	111	116	1–290	6	—	—
Streptocephalus woottoni	65	43	45	18–136	6	—	—				N/A			
Linderiella occidentalis	56	40	21	13–170	16	13	175				N/A			
Eubranchipus serratus			no information					43	21	12	18–82	14	14	122
Branchinecta conservatio	34	6	5	16–47	8	—	—				N/A			
Streptocephalus seali	13	3	7	9–15	3	—	—	91	—	—	4–403	42	3	508
Branchinecta dissimiis	1	—	—	— —	1	—	—			no information				
Eubranchipus oregonus			no information							no information				

Linderiella occidentalis is the only species of the genus which occurs in North America, but two or three other species inhabit Mediterranean climatic regions in Spain, France, and Morocco (Thiery and Champeau, 1988). *Linderiella occidentalis* often cooccurs with *B. lynchi,* in which case *L. occidentalis* heavily predominates, and infrequently cooccurs with *B. conservatio.*

Pools presumably supporting *L. occidentalis* were once widespread in the Central Valley. However, heavy agricultural and urban development of California's grasslands has destroyed most of the original pool sites. Holland (1978, 1988) found that by the late 1960s only about 11% of the preagricultural Californian grassland supporting these pools remained and the habitat loss is continuing. Pools persist in areas which, although often heavily grazed, have never been plowed. *Linderiella occidentalis* is protected on a few natural area preserves in the Central Valley, Central Coast Mountains, and Southern Coast Mountains Regions. However, most other remaining sites are threatened by continued agricultural conversion and urban development.

Streptocephalus seali Ryder, 1879

Dexter (1956) purported to give the first published records for *S. seali* in California, reporting on collections of this species from the high Sierra Nevada. However, other collections he (Dexter, 1953) and Creaser (1930) considered *S. texanus* were most likely the first published records of *S. seali* in California (see discussion under *S. texanus*).

Distribution.—*Streptocephalus seali* occurred primarily within the Cascade-Sierra Nevada Region. All but one of the 36 collections came from within the coniferous forest belt of the moderately high, glaciated mountains from immediately north of Lassen Volcanic National Park south to the Mammoth Lakes area, a distance of about 400 km. A single collection from a small meadow surrounded by coniferous forest near Sanger Lake (Del Norte County) at an elevation of 1,586 m, was the only other recorded population of *S. seali.* This was also the only anostracan population known from the North Coast Mountains Region. Collection sites in the Cascade–Sierra Nevada Region were typically at elevations between 2,100 and 2,500 m, although sites at 2,770 m and 3,032 m exist. *Streptocephalus seali* is North America's most widely distributed fairy shrimp, occurring from southern Canada to the southernmost state in Mexico and from coast to coast across the United States.

Habitat.—*Streptocephalus seali* was collected from late June to mid-September at temperatures of 10.6–23.4°C in perennially astatic, seasonally astatic, and aestival habitats where winter snows lie deep. The most common habitat was a meadow pool surrounded by coniferous forest. Such pools are glacially formed, usually margined by *Carex,* often strewn with granite outcrops or boulders and fallen conifers, are mud-bottomed, and have clear although commonly tea-colored water. This species was also collected from a small crater lake and a cirque lake, both perennially astatic habitats. These general conditions suggest slightly acidic, soft water of low buffer capacity. The only field measurements available come from the perennially astatic Lower Inyo Crater Lake in Inyo County. This habitat is lightly turbid, has very low buffer capacity, and a pH of 6.8–7.1 during the time shrimp are present (Eriksen *et al.,* 1988) (Tables 1, 2).

Outside California, *S. seali* has been collected from high mountain, clear, snowmelt pools, to low elevation, summer rain-filled, tea-colored forest pools and "mud holes." Recorded temperatures typically range from 0.5–35°C (one 42°C) in waters of low to moderate alkalinity and conductivity and of wide pH variation (4.9–8.7) (Tables 2, 5).

Comments.—The widespread distribution and diversity of habitats occupied by this species in North America suggest that it is either physiologically very labile or a complex of sibling species. There is some evidence for the latter. First, the high mountain habitats of Arizona (Belk, 1977a) and California, filling as they do with snowmelt, are quite different from the plains and bayou locales to the east and south which are filled by rain. Secondly, different hatching mechanisms are indicated for the eggs in these contrasting conditions. Those from the lowland populations hatch only between 10 and 32°C (Moore, 1963; Prophet, 1963b). The

Table 4. Chloride (mg/l) of anostracan habitats in California and out-of-state. (Sources: Anderson, 1958; Brown and Carpelan, 1971; Cole and Brown, 1967; Cole and Whiteside, 1965; Collie and Lathrop, 1976; Coopey, 1946; Dana, 1984; Dana *et al.*, 1977; Dexter and Ferguson, 1943; Eriksen and Brown, 1980; Fujita, 1978; Horne, 1967, 1974; Keeley, 1984; Kubly, 1982; Mason, 1967; Maynard, 1977; McCarraher, 1970; Moore, 1955, 1963; Prophet, 1959; Sublette and Sublette, 1967; White, 1967; White and Hartland-Rowe, 1969; Herbst, personal communication; Kubly and Cole, personal communication.) See Table 1 for an explanation of the column headings.

	California							Out-of-state						
Species	$\bar{x}$	SD	95% CI	Range	N	Min/max omitted		$\bar{x}$	SD	95% CI	Range	N	Min/max omitted	
Artemia franciscana	24,324	10,928	9,137	6,420–34,000	8	1,720	35,000	15,339	15,705	7,350	1,550–51,400	20	121	106,750
Artemia monica	18,375	985	1,566	17,500–19,500	4	—	—				N/A			
Branchinecta gigas	445	224	160	181–935	10	106	1,372	260	71	635	210–310	2	—	—
Branchinecta mackini	432	516	147	14–2,412	50	5	2,545	490	485	406	140–1,467	8	—	—
Branchinecta lindahli	115	161	51	4–460	41	3	2,200	280	326	207	0–1,040	12	0	1,071
Branchinecta longiantenna	66	51	37	5–155	10	5	420				N/A			
Branchinecta lynchi	29	31	16	1–96	17	1	115				N/A			
Streptocephalus texanus				no information				25	116	34	2–800	47	2	3,252
Linderiella occidentalis	17	20	10	1–71	19	1	82				N/A			
Thamnocephalus platyurus				no information				11	12	6	2–45	19	2	158
Streptocephalus woottoni	9	5	5	5–19	6	—	—				N/A			
Streptocephalus seali				no information				7	6	5	1–19	9	0	315
Branchinecta conservatio	7	8	71	1–13	2	—	—				N/A			
Branchinecta coloradensis				no information				5	7	11	0–15	4	—	—
Eubranchipus serratus				no information				2	2	2	0–7	9	—	—
Eubranchipus oregonus				no information							no information			
Branchinecta dissimilis				no information							no information			

high elevation forms in Arizona (and by inference the Californian ones) presumably hatch in the cold water of snowmelt. Belk, who had no trouble rearing *S. seali* from Louisiana, could not hatch a single egg from animals in Arizona. In seeking some explanation, he (Belk, 1977b) determined that the mountain-inhabiting *S. seali* had eggs and embryos more than twice the volume of those from Louisiana. Adult temperature tolerances also differed. Belk (1977a) recorded an LD/50 temperature of 38°C for the mountain population in Arizona, while Moore (1955) reported 44.5°C for animals from the bayous in Louisiana. Moore also noted that several hours at 42°C was lethal for the bayou animals, as was 40°C, but only after 18 h of exposure. Finally, he showed that warm water *S. seali* could not be cold-conditioned, being sluggish even at 7–8°C.

Streptocephalus seali did not coexist in Californian pools with other anostracan species. *Branchinecta dissimilis* and *B. coloradensis* are found within the same general range in the Sierra Nevada as *S. seali,* but on the average occur at higher elevations. In other parts of North America, *S. seali* has been collected with *S. texanus, T. platyurus, Dexteria floridana, Eubranchipus bundyi, E. vernalis,* and *Branchinella alachua.*

The remote location of many of the pool sites of *S. seali* in California provides passive protection for this species, and, as a result, it does not appear threatened in the state.

Streptocephalus texanus Packard, 1871

Creaser (1930) presented a map of North America showing *Streptocephalus texanus* in California. Dexter (1953) published a second record from what we determine to be Pacific Grade Summit in Alpine County. Douglas Whitaker reported to Dexter that the Alpine locality was 64 km southeast of the site mapped by Creaser (Dexter, personal letter to D. Belk), indicating that Creaser's record is from the Sierra Nevada in El Dorado County. We do not accept these records as valid. All of the *Streptocephalus* that we have examined from the Sierra Nevada have been *S. seali.* This includes a 1946 collection (USNM 82077) from Pacific Grade Summit and a 1927 collection (USNM 61542) from near Upper Echo Lake in El Dorado County. Moore (1966) pointed out that reliance on differences in adult male cercopod morphology to distinguish between *S. seali* and *S. texanus,* as emphasized by Creaser (1930), has led to misidentification of subadult *S. seali* as *S. texanus.* Moore cited Dexter's records for *S. texanus* from Louisiana and Florida as examples of such misidentification. Even Creaser, who clarified the taxonomy of these two anostracans, incorrectly identified a collection of *S. seali* from Kansas as *S. texanus* (USNM 78735).

Distribution.—California's four verified records for *S. texanus* are all from the extreme southeastern portion of the state at elevations between 100 and 400 m. They lie only a few km west of the border of California-Arizona in an 85-km stretch of Colorado Desert which straddles the town of Blythe. Outside California, *S. texanus* occurs in arid portions of all Rocky Mountain states, and in the Great Plains from Nebraska south. An eastern penetration into Missouri, and a western and southern extension into Arizona and northern Mexico, respectively, round out its continental occurrence. Two disjunct West Indies collections (Moore, 1966) complete its known distribution.

Habitat.—*Streptocephalus texanus* was taken from seasonally astatic, Colorado Desert granitic tanks, or pools in dry stream channels (washes). These habitats fill with winter, spring, and summer rains, but this species was collected only during early October and late May–June. In one pool the water was green with algae and had limited visibility, but nothing more is known about the physicochemistry of its Californian habitats. Outside California, *S. texanus* has been collected from water temperatures of 13–37°C, with wide pH differences, and low to moderate alkalinity, salinity, and conductivity (Horne, 1967; Prophet, 1963a) (Tables 2–5).

Comments.—Eggs of *Streptocephalus texanus* hatch at 15–32°C and hatching is not affected by TDS between 91 and 1,998 ppm (Prophet, 1963b; Horne, 1967). Individuals will live at 37°C for a period of time, but will not survive more than 5 days in water less than 10°C (Prophet, 1963a). When cultured in the laboratory at 20°C, *S. texanus*

Table 5. TDS (mg/l) of anostracan habitats in California and out-of-state. (Sources: Anderson, 1958; Bowen *et al.*, 1984; Cole and Whiteside, 1965; Cole *et al.* 1967; Lana, 1984b; Fujita, 1978; Herbst and Dana, 1980; Kubly, 1982; Mason, 1967; Maynard, 1977; White, 1967; White and Hartland-Rowe, 1969; Herbst, unpublished; Kubly and Cole, personal communication.) See Table 1 for an explanation of the column headings.

	California				
Species	$\bar{x}$	SD	95% CI	Range	*N*
Artemia franciscana	88,911	60,213	46,284	34,914–172,000	7
Artemia monica	87,219	10,541	13,090	75,000–96,400	5
Branchinecta mackini	1,364	950	304	486–4,800	40
Branchinecta gigas	1,218	311	260	807–1,622	8
Branchinecta lindahli	596	677	217	35–3,060	40
Branchinecta longiantenna	315	161	108	130–590	11
Thamnocephalus platyurus			no information		
Streptocephalus texanus			no information		
Branchinecta lynchi	185	132	84	48–410	12
Linderiella occidentalis	94	60	33	33–273	15
Streptocephalus woottoni	77	44	46	35–135	6
Branchinecta conservatio	26	7	17	20–33	3
Branchinecta coloradensis			no information		
Streptocephalus seali	21	1	2	20–22	3
Eubranchipus oregonus			no information		
Eubranchipus serratus			no information		
Branchinecta dissimilis	10	—	—	— —	1

takes 11 days to reach sexual maturity. Thus, its thermal physiology helps explain the occurrence of this species in the hottest of Californian deserts.

Streptocephalus texanus often cooccurs with *Thamnocephalus platyurus* both in California and elsewhere. Outside California, *S. texanus* has been found with *B. lindahli, B. packardi,* and once with *B. coloradensis,* although in the latter case the two species were not mature at the same time. Based on the paucity of collections, *S. texanus* appears to be rare within the state; however, like several other Californian anostracan species occurring in remote, sparsely populated areas, the status of *S. texanus* in the state cannot be accurately assessed until more systematic surveys have been completed.

Thamnocephalus platyurus Packard, 1879

Dexter (1953) published the first Californian record for *T. platyurus* based on specimens cultured from soil samples collected near Baker and Barstow in the Mojave Desert of San Bernardino County.

Distribution.—*Thamnocephalus platyurus* is an uncommon species in California (8 known sites). It is known only from the Mojave and Colorado deserts, both areas which are subject to occasional summer rains. The northernmost record for this species in California comes from specimens reared from soil samples taken in a dry playa bed in Eureka Valley (Kubly and Cole, personal communication). All Californian records for this species are between elevations of 1,235 m above and 65 m below sea level. Outside California, *T. platyurus* ranges north to Wyoming, east to Missouri, and south into central Mexico.

Habitat.—*Thamnocephalus platyurus* was collected from mid-May through mid-October, the hottest time of the year in the Californian deserts. A January 1965 record suggests unseasonally warm weather preceded its collection. Horne (1971) documented a similar situation in central Texas. *Thamnocephalus platyurus* was found in a variety of seasonally astatic pools including playas, a borrow pit, a roadside ditch, a tank, and a swale. It has been found swimming in only five of these sites; specimens from the other sites were raised from soil samples. Except for the tanks, these habitats are typically fleeting, clay-bottomed, and highly turbid. The only physicochemical data available came from a playa where 28°C and a pH of 7.5 were recorded. Information from outside California shows that *T. platyurus* is a species of high temperatures (17–36.5°C) and low to moderate alkalinity, TDS, chlo-

Table 5. Continued.

California		Out-of-state						
Min/max omitted		$\bar{x}$	SD	95% CI	Range	*N*	Min/max omitted	
—	—	146,603	54,605	28,077	61,300–221,160	17	31,700	258,455
—	—				N/A			
362	5,546	1,725	589	331	976–3,394	15	840	3,800
—	—	1,588	322	216	976–2,016	11	840	2,482
34	3,500	2,861	—	—	— —	1	—	—
95	1,450				N/A			
no information					no information			
no information					no information			
27	481				N/A			
11	275				N/A			
—	—				N/A			
—	—				N/A			
no information		10	—	—	— —	1	—	—
—	—				no information			
no information					no information			
no information					no information			
—	—				no information			

ride, and conductivity (Prophet, 1963a). Habitat pH varies considerably to either side of neutral (Table 2).

Comments.—Little is known about the Californian populations of this species. Work with non-Californian animals indicates that *T. platyurus* does not hatch below about 17°C or above 32°C (Prophet, 1963b; Belk, 1977a). Adults tolerate temperatures as high as 38–40°C but die in 20 min at 44°C (Hillyard and Vinegar, 1972). They have a 1-h LD/50 of 41°C (Belk, 1977a) and will not survive five days at 10°C (Prophet, 1963a). These data indicate that *T. platyurus* tolerates the warmest conditions of any North American anostracan. It also handles an exceptionally wide pH range (4.7–8.2), probably an adaptation to living in poorly buffered waters (Prophet, 1963a). Both its thermal and osmoregulatory physiology help explain its Californian distribution in hot, low alkalinity, desert habitats with summer rains.

Thamnocephalus platyurus was collected twice with *S. texanus* and once with *B. mackini* in California. Outside the state, it occurs occasionally with *B. lindahli* (Dexter, 1953), typically with *S. mackini*, and *S. dorothae* (Belk, 1977a). The future of this species in California is uncertain because it is uncommon and dwells in habitats which are frequently heavily impacted by human activities. Only at Bicycle Dry Lake on the Fort Irwin Military Reservation in San Bernardino County, and here only because of public exclusion, is it presently provided a modicum of protection from significant habitat destruction. This species, like *S. texanus* with which it may coexist in the Colorado Desert Region, requires additional study to determine its actual status in California.

Conclusions

California's diverse anostracan fauna is widely distributed throughout all but the North Coast Mountains Regions. Six of the state's 17 species are endemic. The state's diverse anostracan fauna may be attributed to a diversity of habitats, some of which it shares with neighboring states and some that are restricted to California. Two factors appear to be most important in controlling anostracan species distribution: (1) chemical nature of the habitat; and (2) thermal variations resulting from pools filling at different seasons and from distribution of pools along altitudinal and latitudinal gradients (Belk, 1977a). The validity of the importance of these two factors was affirmed and reinforced by Geddes (1983) in a review of the biogeography and ecology of Australian

Anostraca. California's anostracan diversity, which exceeds that of the diverse fauna of Arizona (Belk, 1977a) by 25% and includes six endemic species, is most likely explained by the greater habitat diversity found in California.

Much of the anostracan habitat in California has been lost through urbanization and agricultural, water, and energy development. These and other threats to the Californian fairy shrimps and their habitats continue. Pesticides and acid precipitation constitute an unquantified but real threat to some species. Many desert locales are being heavily impacted by rapidly expanding, though largely unquantified, off-highway recreational vehicle use. Playas and washes seem to be particularly attractive, since they have no vegetation.

All of the endemic species occurring in the Central Valley are threatened because of extreme rarity and ongoing habitat loss. *Branchinecta conservatio* and *B. longiantenna* are exceptionally vulnerable. Although more widely distributed than the former two species, the other two Central Valley endemics, *B. lynchi* and *Linderiella occidentalis,* are also threatened, because rapid urbanization and agricultural conversion is occurring in parts of the Central Valley where historical use was limited to grazing. Continuing water diversions threaten the endemic *Artemia monica* of Mono Lake in the Great Basin Desert Region.

In Riverside County, California's rarest fairy shrimp, *Streptocephalus woottoni,* is seriously threatened by that area's burgeoning population and resultant urbanization. Only five populations are known, and none are presently receiving protection. Four of the five sites have already been seriously degraded. Two are within currently proposed housing development projects.

So little is known of *T. platyurus, S. texanus,* and the two species of *Eubranchipus* in California that it is impossible to adequately evaluate the threats to them at this time. However, off-road vehicle activity is known to seriously degrade anostracan habitats in desert areas and as California's population continues to grow the impacts from this and other off-road activities will continue to increase. Protection of ephemeral aquatic habitats in the desert from degradation by the uninformed or uncaring recreationist is clearly a high priority for the long term protection of California's desert species.

Both species of *Eubranchipus,* while perhaps common elsewhere, are apparently rare in California. Both are known from single localities within active timber-producing areas and are at least potentially threatened by timber-harvesting activities and development. These species need to be provided particular consideration during the environmental review process for federal, state, and local timber-harvest planning and development projects.

In summary, all six of the fairy shrimps endemic to California are threatened by ongoing habitat destruction and modification. At least three of these species occur primarily in vernal pools which they share with several species of threatened or endangered Californian plants. Four other anostracan species, while occurring outside California, are rare within the state and may also be threatened. However, additional data are required before an accurate evaluation of their status can be made. The other Californian species do not appear to be under any immediate threats of extinction.

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