BRANCHIOPOD DIVERSITY IN SAN DIEGO COUNTY, CALIFORNIA, USA

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Abstract: Branchiopod crustaceans (fairy, clam, and tadpole shrimp) are common faunal elements in ephemeral aquatic habitats. They are adapted to the temporary presence of water and to specific sets of environmental parameters (e.g., salinity, temperature, pH). These organisms are often overlooked due to the limited time they and their habitat exists. San Diego County provides a diversity of ephemeral habitats ranging from coastal vernal pools to desert playas. However, only one branchiopod species has previously been reported from the area. Our studies have revealed a diverse fauna of four species of fairy shrimp in three families, three species of clam shrimp in two families, and one species of tadpole shrimp. Two of the fairy shrimp have ranges almost entirely restricted to San Diego County and are threatened with extinction due to habitat loss.


The branchiopods in the orders Anostraca (fairy shrimp and brine shrimp), Conchostraca (clam shrimp) and Notostraca (tadpole shrimp) are often the dominant fauna of the early successional stages of ephemeral water (Sublette and Sublette 1967, Ebert and Balko 1984, Dodson 1987) and have been used extensively for aquaculture (Belk et al. 1991). Many branchiopods have specific habitat requirements (e.g., temperature, pH, alkalinity, etc.) (Shantz 1905, Prophet 1963, Procter 1964, Horne 1967, Moore 1967, Broch 1969, McCarraher 1970, Brown and Carplan 1971, Hillyard and Vinegar 1972, Alexander 1976, Belk 1977a, Moore 1979, Donald 1983, Thiery 1987, Broch 1989, Eng et al. 1990). Due to these requirements, they, like other ephemeral pool plants and animals, are prone to endemism (Eng et al. 1990, Mura 1991).

California's temporary inland waters and saline lakes support a diverse, but poorly studied branchiopod fauna (Wootton and Mattox 1958, Lynch 1966, Sassaman 1989, Eng et al. 1990, Ahl 1991, Sassaman 1991). The twenty described species of Anostraca in California, seven of which are endemic, comprise forty-four percent of the total species diversity in the United States (Eng et al. 1990, Belk and Serpa 1992, Fugate in press) and another is currently being described (M. Fugate, pers. obs. and D. Belk, pers. comm.). The Conchostraca and Notostraca have not been recently reviewed but are represented by at least eight and four species, respectively (Wootton and Mattox 1958, Lynch 1966, Sassaman 1989, Ahl 1991, Sassaman 1991, unpubl. data). Five of the seven endemic fairy shrimp have only recently been described, and due to urban and agricultural expansion most warrant consideration as threatened or endangered (Eng et al. 1990).

San Diego County specifically has experienced a tremendous loss of habitat and the review of Eng et al. (1990) and the subsequent description of a new endemic fairy shrimp (Fugate, in press) make obvious the lack of information on the county's branchiopod fauna. Prior to this study, only one branchiopod species was reported from San Diego County (Balko and Ebert 1984, Ebert and Balko 1987, Eng et al. 1990). Due to the diversity of habitats in the county, it was thought more species might be present. The present paper presents information on the distribution and biology of branchiopods from San Diego County.

STUDY AREA

Eng et al. (1990) divided California into eight regions, two of which are represented in San Diego County: the South Coast Mountains, occupying the western two-thirds of the county, and the Colorado Desert, occupying Anza Borrego State park and the surrounding area. Eight South Coast Mountain sites were sampled (Fig. 1, Table 1). These sites are primarily vernal pool complexes in various states of disturbance (Bauder 1986, Zedler 1987). These pools typically fill during winter or early spring rains. Four Colorado Desert sites were sampled (Fig. 1, Table 1). These sites are primarily playas except the Mortero Wash site which is a pool formed in a desert wash. The desert sites can fill from either cool winter rains or warm summer thunderstorms.
METHODS
Samples have been collected since 1988 by either sampling with aquatic dip nets after rainfall filled pools or by hydrating soil samples in the laboratory. Soil samples consisted of sediment from the top 2-5 cm of dry pools. These samples were washed through 500 and 180 um sieves and the soil in the 180 um sieve was examined for branchiopod eggs. The eggs of most branchiopods can be identified to genus and in some cases to species (Alonso and Alcarez 1984, Mura 1986, 1991, Mura and Thiery 1986, Thiery and Gasc 1991). Samples with eggs were hydrated by placing 150 ml of sediment in a 10 gallon aquarium and adding 2.5 l of deionized water. The aquaria were continuously illuminated with fluorescent light and "grow lights", aerated vigorously for 24 hours, stirred and then gently aerated. Upon hatching, shrimp were fed small amounts of baker's yeast until they stirred and then gently aerated. Upon hatching, shrimp species identification is problematic in both Conchostraca et al. 1990, Sirnovich, unpubl. data and Notostraca (Belk 1989, Sassaman 1991). The original descriptions or re-descriptions of species, but they were fixed or frozen. Hydrations were conducted at temperatures, between 10 ° and 25° as these temperatures have often been described using size-dependent characters without accompanying development studies and we have chosen to accept the earliest name recorded in the literature for species, consistent with the International Code of Zoological Nomenclature. Animals were fixed in 10% formalin or Bouin’s solution and then transferred to 70% ethanol or were frozen for protein electrophoresis. Voucher specimens and their collection data are available in the University of San Diego Branchiopod Collection.

RESULTS AND DISCUSSION
Eight branchiopod species were found in San Diego County: four fairy shrimp species in three families, three clam shrimp species in two families, and one tadpole shrimp (Table 1). Present collections may underestimate the total diversity in the county, due to both the limited sampling of pools and the specific requirements of individual species which may prevent all the species present from hatching after a natural filling or hydration.

Anostraca (Fairy Shrimp)

Branchinecta lindahli Packard is common throughout western North America (Eng et al. 1990, Maeda-Martinez 1991) and is found in a wide variety of habitats from roadside ditches to playas and prairie potholes, but rarely in undisturbed vernal pools. This species hatches from 0-25°C, tolerates temperatures up to 36°C as an adult (Belk 1977a), and is found over a wide range of pH and salinity values (McCarraher 1970, Eng et al. 1990). Development times in the laboratory or the field can be as short as 8 to 12 days (Donald 1983, Fugate unpubl. data) at some temperatures. Branchinecta lindahli was the only species previously reported from San Diego County (Balko and Ebert 1984, Ebert and Balko 1984, Eng et al. 1990). However, reexamination (by M. Fugate and D. Belk) of the voucher specimens from these studies has shown them to be Branchinecta sandiegoensis. The species was subsequently found in desert playas which also contained combinations of Thamnocephalus platyurus, Eocycicus diguetii and/or Triops newberryi (Table 1). Branchinecta lindahli was also found in a single road rut on Naval Air Station Miramar and a few individuals in one rut on Del Mar Mesa (Table 1, Fig. 1). Branchinecta sandiegoensis Fugate, although collected in 1962 and deposited in collections of the United States National Museum, Washington, D.C., was misidentified as B. lindahli. This species was recognized as a new species in 1990 and was recently described (Fugate 1992 in press). Only limited information on its physiological requirements and life history exists. It was found usually in shallow (<30 cm) pools, predominantly on mesas, after winter and spring rains, at water temperatures of 10-26°C. Our preliminary laboratory results suggest that the species can hatch at cool temperatures (10-15°C) (unpubl. data).

This species is currently known only from San Diego County samples (Table 1, Fig. 1) and from Valle de las Palmas, Baja California Norte, Mexico (presumably the same mesa system). It is commonly the only branchiopod species in a pool, but was found in the same two pools as Streptocephalus woottoni and Eocycicus californicus at Otay Mesa and in a pool with S. woottoni at Naval Air Station Miramar. In these mixed pools, B. sandiegoensis was found earlier in the season than the other species. Also, a few B. lindahli (<0.1%) were found with it in one rut on Del Mar Mesa.

The U.S. Fish and Wildlife Service has been petitioned to list B. sandiegoensis as an endangered species (D. Hogan, pers. comm.) due to its restricted distribution and the loss of approximately 97% of this habitat in San Diego (E. Bauder, T. Oberbauer, pers. comm.). Streptocephalus woottoni Eng, Belk and Eriksen is California’s most restricted endemic fairy shrimp. This species was described from five large (>750 m²) and deep (>30 cm) pools near Murrieta in Riverside County (Eng et al. 1990). At these sites, Branchinecta lynchii and B. lindahli were present as well, however, S. woottoni appeared later. Eng et al. (1990) suggested that it Otay
hatched at warmer temperatures than the endemic branchinectids. Our laboratory results suggest that it tolerates a range of temperatures (at least 10-25°C) and that it has a development time of a month or more (unpubl. data). The longer developmental time may account for its restriction to deep pools, rarity, and late appearance.

In San Diego County the species was found in one pool at Naval Air Station Miramar and in two pools on Otay Mesa (Table 1, Figure 1). The Miramar vernal pool is large and deep (>80 cm) and has been disturbed by vehicles. The Otay pools are slightly smaller but again deep (>30 cm). These pools have been modified for cattle use and contained water into the summer of 1991. At both sites, *B. sandiegoensis* eggs were present, but we have not observed adults of the two species together in these pools. Their appearance seems to be sequential with *B. sandiegoensis* appearing first. In all three pools the emergent plant *Eleocharis* was present, as also noted in some of the Riverside County pools sampled by Eng et al. (1990).

The U.S. Fish and Wildlife Service has proposed this species for listing as an endangered species (F.R. 56:57503) due to its limited distribution and the threat of development at the sites in Riverside and San Diego Counties. The Naval Air Station Miramar site is currently the only site even nominally protected through federal ownership.

*Thamnocephalus platyurus* Packard ranges from Wyoming and Missouri to Central Mexico and throughout the southwest (Belk 1975, Maeda-Martinez 1991), but is known from only a few sites in southern California (Eng
Table 1. Distribution of branchiopods in San Diego County (an X denotes the species is present).

<table>
<thead>
<tr>
<th>Sampling Location</th>
<th>Anostraca</th>
<th>Conchostraca</th>
<th>Notostraca</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>BRSA*</td>
<td>BRLI</td>
<td>STWO*</td>
</tr>
<tr>
<td>South Coast Mountains</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. Del Mar Mesa</td>
<td>X</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>2. Arroyo Sorrento</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3. Naval Air Station</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4. La Jolla</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5. Mission Trails</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6. Otay Mesa</td>
<td>X</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>7. San Marcos</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8. Ramona</td>
<td>X</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Colorado Desert</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Clark Dry Lake</td>
<td>-</td>
<td>X</td>
<td>-</td>
</tr>
<tr>
<td>10. Blair Valley</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
<tr>
<td>11. Benson Dry Lake</td>
<td>-</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>12. Morroco Wash</td>
<td>-</td>
<td>-</td>
<td>X</td>
</tr>
</tbody>
</table>

BRSA* = Branchipecta sandiegoensis
BRLI = B. lindahli
STWO* = Streptocephalus woottoni
THPL = Thamnocephalus platyurus

* species endemic to California.

Table 1 continues...
Pacific Coast but that development in Los Angeles and Orange Counties probably destroyed intervening sites. In San Diego County, *C. californicus* was found with *B. sandiegoensis* and *S. woottoni* (Table 1).

*Eocyzicus digueti* Richard is considered here to be the senior synonym of *Eocyzicus concavus* Mackin since the differences between the two species are, as in *Cyzicus*, likely to vary with size. This species is known from Kansas south into central Mexico and west to southern California and Baja California (Mattox 1954, Woottin and Mattox 1958, Maeda-Martinez 1991). Almost nothing has been reported about the biology of this species, but it appears to be found in desert playas (Sublette and Sublette 1967, Kubly 1982). In Anza Borrego playas, it was found with *B. lindahli*, *T. platyurus* and *T. newberryi* (Table 1).

*Eulimnadia texana* Packard is widely distributed in the southern U.S. west of the Mississippi, in central Mexico and in Baja California (Sassaman 1989, Maeda-Martinez 1991). Little information has been published on the biology of this species but it is capable of both bisexual and unisexual reproduction and sex ratios are almost always female-biased (Sassaman 1989). Our laboratory results suggest that it prefers temperatures above 20°C and reaches maturity quickly (within a few weeks) (unpubl. data). The species was found only in one small desert pool at Mortero Wash with *T. platyurus* and *T. newberryi*. *Eulimnadia texana* was not found in the large desert playas that we sampled.

**Notostraca** (Tadpole Shrimp)

*Triops newberryi* Packard is one of three species described by Packard (1883) which were synonymized with *Triops longicaudatus* by Linder (1952) and Longhurst (1955). Clear evidence exists from morphological, electrophoretic and biological differences that *T. longicaudatus* consists of two species, *T. longicaudatus* and *T. newberryi* (ms. in prep.). *Triops newberryi* is found primarily in playas west of the continental divide while *T. longicaudatus*, is more common east of the divide (Simovich et al. 1988, Sassaman 1991). The physiological requirements of *T. longicaudatus* have been the subject of several studies (Horne 1967, 1971; Hillyard and Vinegar 1972, Scott and Grigarick 1979), but little is known about *T. newberryi*. Kubly (1982) reported physico-chemical data for southern California playas, some of which contain populations of *T. newberryi* (Sassaman 1991). The species reproduces bisexually and unisexually and has a female-biased sex ratio similar to *E. texana* (Sassaman 1991). It was found in the Colorado Desert of San Diego County with *B. lindahli* in winter and with *T. platyurus*, *E. digueti* and *E. texana* during summer months (Table 1).

The following species are known from areas immediately surrounding San Diego County and could possibly be found in the county with increased sampling: *Branchinecta lynchii* Eng, Belk and Eriksen, Riverside County; *Linderiella* spp., Riverside County; *Streptocephalus texanus* Packard, Riverside and Imperial Counties, *Triops longicaudatus* Packard, Baja California Norte, Mexico.

**CONCLUSIONS**

The eight species found in San Diego County represent approximately 25% of the diverse branchiopod fauna found in California and an eight-fold increase over the number previously reported. The species are equally divided between the two biogeographic areas represented in San Diego County. Three of the species are found only in the South Coast Mountain region, four, only in the Colorado Desert region and only one species, *B. lindahli* is found in both (Table 1). This result corroborates the findings of many previous studies (Prophet 1963, Horne 1967, Broch 1969, Belk and Cole 1975, Bernice 1972, Hartland-Rowe 1972, Belk 1977, Sam and Krishnaswamy 1979, Alonso 1985, Bowen et al. 1985, Bowen et al. 1988, Broch 1989) and most recently Eng et al. (1990), that the thermal and chemical properties of water are two of the main factors determining branchiopod biodiversity. A strong historical component also appears to be involved in the biogeography of inland waters (e.g., Stebbins 1976, Dumont 1980, Frey 1982, Belk 1984). For example, of the eight endemic species of Anostracans in California, five (one undescribed) are found entirely or mostly in the Central Valley, two only in extreme Southern California, and the last is found only in Mono Lake (Eng et al. 1990, Fugate and Belk unpubl. data).

Our lack of understanding as to precisely how these physical, chemical and historical factors influence branchiopod distributions may have led us to underestimate the total diversity in the county, since our sampling was exhaustive neither in time nor space. In the field, different species may appear in the same pools when they fill at different times of the year or a succession of species may appear over the lifetime of a pool (Schäfer 1931ab, 1934; Relalack and Clifford 1980; Donald 1983, Thiéry and Gasc 1991; this study). In the laboratory hatching may occur at water temperatures ranging from 0°C to 40°C, but most species hatch over a more narrow range (Nourisson 1964, Belk and Belk 1975, Belk 1977b, Simovich ms. in prep.) These results suggest that unless a pool is sampled several times over a year and over several years or hydrated in the laboratory over a wide range of temperatures, species may be missed.

A better understanding of this problem is crucial because *S. woottoni* and *B. sandiegoensis* from San Diego County, and all of the other California endemics
are threatened with extinction due to urban and agricultural expansion (Eng et al. 1990). San Diego County has already lost 97% of its vernal pools (E. Bauder, pers. comm.) and many of those that remain show signs of disturbance. It appears from this study that disturbance may change species composition by allowing fragmented habitat can have major effects on their genetic structure and resilience (Frankel and Soulé 1981, Harris 1984).

The destruction of vernal pools and other similar habitats threatens not only branchiopods, but many other animal and plant species (Jain 1976, Herbst 1982, Jain and Moyle 1984, Jeffries 1991, Shoup 1991). Our understanding of the physiological requirements and life histories of branchiopods and vernal pool communities is extremely limited (Kerfoot and Lynch 1987). It is, therefore, essential that we ensure the survival of the few remaining temporary pools and playas in San Diego County.

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_____ 1934. Über die Zeit des Vorkommens von Chirocephalus (Drepanosaurus) convergens (Schäfer, Pristecephalus carmutanus (Brauer) und Streptocephalus torvicornis (Waga).
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