California Linderiella Fairy Shrimp
(*Linderiella occidentalis*)

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Legal Status
Federal: None
State: None

Global and State Conservation Status: G3G4S2S3: Global rank, G3G4 somewhere between a G3 = Vulnerable: At moderate risk of extinction due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors, and a G4 = Apparently Secure: Uncommon but not rare; some cause for long-term concern due to declines or other factors; State rank, S2S3 = somewhere between an S2 indicating imperiled in the state because of rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the state, and an S3 which indicates vulnerable in the state due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.

Recovery Plan: Recovery Plan for the Vernal Pool Ecosystems of California and Southern Oregon (USFWS 2005).

Species Description and Life History

The California linderiella fairy shrimp is a typical Branchinectid anostracan. It is also known as the California fairy shrimp or the California linderiella. Live animals are off-white to grayish color and are translucent, but unlike similar fairy shrimp in the genus *Branchinecta*, tend to be slightly smaller and have distinctive red eyes (USFWS 2007). Depending on the rapidity of development, mature animals may vary in length from 3 to 38 mm (0.12 to 1.5 in.); however, specimens may shrink as much as 11 to 32 percent upon preservation (Rogers 2002).

The California linderiella fairy shrimp occurs within the range of conservancy fairy shrimp (*Branchinecta conservatio*) and vernal pool fairy shrimp (*Branchinecta lynchi*). But while having different microhabitat requirements from *B. conservatio* and thus not typically occurring in the same pools as this species, it often co-occurs in pools also inhabited by *B. lynchi*, in which case *Linderiella* is predominant (Eriksen and Belk 1999).

During the dry season, anostracans survive as diapausing (dormant) embryonated cysts in, or on, the substrate (Sars 1896, 1898; Eriksen and Belk 1999; Rogers and Fugate 2001). Following seasonal rains and the subsequent hydrologic charge leading to seasonal inundation, some cysts hatch and nauplii (early larval form) swim upwards. Their basic swimming motion is upside down, and larval forms cannot typically be identified to species. The duration of maturation is highly variable, and is dependant on temperature and habitat type, which influences the time of inundation (Helm 1998, Erikesen and Belk 1999). However, the minimum time to maturation is 31 days, the longest known for any Californian species of fairy shrimp, and may be related to the typically large pools this species prefers (Eriksen and Belk 1999, USFWS 2007).

The females produce and store their oocytes in a ventral brood patch. Males approach the females from beneath to amplex. Amplexus is sustained for 1 or 2 seconds, as mating is rapid and the female is released immediately afterward (Rogers 2002b). Following amplexus, the female typically sheds her cysts as the shell forms over the fertilized oocyte (Murugan *et al.* 1996), and the cysts fall to the substrate; alternatively, they may remain within the brood patch and sink to the substrate after the mother's death (USFWS 2007). The cysts lie dormant in the substrate until the pool dries and re-inundates during the subsequent rains. Beyond inundation of the habitat, the specific cues for hatching are unknown, although temperature (Hall 1959, Belk 1977, Al-Tikrity and Grainger 1990, Belk and Nelson 1995, Helm 1998, Eriksen and Belk 1999, Rogers in review) and conductivity or solute concentration (Anderson 1958; Broch 1969, 1988; Brown and Capelan 1971; Brown 1972; Bowen *et al.* 1988) are believed to play a large role.

The California linderiella fairy shrimp is typically univoltine (i.e., one generation per year); however, animals of different ages may be present if a pool partially inundates, allowing some cysts to hatch, and then later increases in volume, hydrating cysts that were further upslope.

Planktonic Crustacea are important in the food web, as they represent a high-fat, high protein resource for migratory waterfowl. Mallard (*Anas platyrhynchos*), green-winged teal (*A. crecca*), bufflehead (*Bucephala albeola*), greater yellowlegs (*Tringa melanoleuca*), and killdeer (*Charadrius vociferus*) all forage actively in Central Valley vernal pools on the invertebrate and amphibian fauna during the winter months (Proctor 1964, Horne 1966, Mellors 1975, Silveira 1996, Dumont and Negrea 2002). Predator consumption of fairy shrimp cysts aids in distributing populations of fairy shrimp. Predators (e.g., birds and amphibians) expel viable cysts in their excrement, often at locations other than where they were consumed (Proctor 1964, Wissinger *et al.*1999). If conditions are suitable, these transported cysts may hatch at the new location and potentially establish a new population. Cysts are also transported by wind and in mud carried on the feet of animals, including livestock that may wade through habitat (Rogers in prep.). This type of dispersal aids ephemeral pool crustaceans in exploiting a wide variety of ephemeral habitats (Rogers 2000).

Habitat Requirements and Ecology

This species is entirely dependent on the aquatic environment provided by vernal pool wetland ecosystems. The California linderiella fairy shrimp depends on the presence of water in winter and early spring, and the absence of water during summer. Vernal pool wetlands are dependent on intact sub-watersheds and the surrounding uplands that support those watersheds, and are a component of the larger grassland ecosystem of the California's Central Valley.

The California linderiella fairy shrimp needs the cold winter waters to hatch and grow—typically appearing after the first frosts-- and the dry summers to desiccate the resting cysts and prevent fungal infection. Habitats supporting the California linderiella fairy shrimp are typical in Central Valley floristic provinces below 300-m (984-ft) elevation. Typical habitat for California linderiella fairy shrimp in California includes large, clear vernal pools (Eng *et al.* 1990, USFWS 2007), although this species have been found in turbid, tea-colored, or small pools. Linderiella fairy shrimp are the most heat-tolerant fairy shrimp species in California, and are able to tolerate water temperatures from 41 to 85 degrees F (USFWS 2007)

California linderiella fairy shrimp typically use wetland habitats that persist longer in duration than those used by fairy shrimp species within the genus *Branchinecta* (Eriksen and Belk 1999). Various physiochemical factors have been examined in laboratory experiments and existing California linderiella fairy shrimp habitats, including alkalinity, total dissolved solids (TDS), and pH (Rogers in review). The importance of many of these parameters has recently been called into question with evidence that the type and amount of dissolved salts may be a more important habitat requirement. Considering the daily fluctuations in pH of a given habitat, this is to be expected. During daylight hours, hydrophytes are photosynthesizing, removing the CO2 (from HCO3) from the water, and raising pH. During the night, hydrophytes are respiring, increasing the CO2 (and thereby, the HCO3) in the water, and lowering the pH. If there is rainfall, the distilled precipitation will lower the pH, as will winds that cause surface action. Alternatively, when the habitats are drying and losing volume through evaporation, pH, alkalinity, TDS, and electrical conductivity will increase, just as they decrease when the pools inundate or reinundate.

Some vernal pools need a certain amount of grazing. Unless some other disturbance (e.g., weed control programs, vehicular use of pools, fire fuels control) prevents thatch deposition, vernal pools without significant grazing pressure become overgrown with native and exotic plants that generate deep thatch layers on the pool substrate. As this thatch layer decomposes, it oxidizes the water, which can suffocate gill-breathing invertebrates (Rogers 1998). Therefore, moderate grazing may be a necessary habitat suitability component. Conversely, excessive livestock grazing can be detrimental to California linderiella fairy shrimp. High stocking rates tend to deposit a great deal of manure into vernal pools. This type of organic waste also oxidizes the water, causing similar undesirable results as seen with too little grazing pressure (Rogers 1998). It is important not to alter grazing regimes in conservation areas until the importance of grazing to those particular systems are assessed.

Common wetland plant species that co-occur with California linderiella fairy shrimp generally need the same hydrological conditions. Therefore, the presence of these plant species within a potential habitat implies a greater potential for a population of these shrimp to be present. These plants may include toad rush (*Juncus bufonius*), coyote thistle (*Eryringium* spp.), downingia (*Downingia ornatissma* or *bicornuta*), goldfields (*Lasthenia* spp.), woolly marbles (*Psilocarphus* spp.), and hair grass (*Deschampsia* spp.).

Similarly, the hydrology of pools dominated by vernal pool plant species that require short inundation periods may not support shrimp species. Plants within these short duration pools may include Mediterranean barley (*Hordeum murinum*), toad rush, false dandelion (*Hypochoeris radicata*), and Italian rye grass (*Lolium multiflorum*).

Conversely, wetland habitats that support plant species that need perennial or very long-term periods of soil saturation cannot support special-status shrimp species because the shrimp's cysts must dry out before they can hatch (Eriksen and Belk 1999). If they remain wet or moist through the warmer summer months, the cysts will contract fungal infections. These plants include cattails (*Typha* spp.), willow (*Salix* spp.), cottonwood (*Populus* spp.), duckweed (*Lemna* spp.), sedges (*Cyperus* spp.), Baltic rush (*Juncus balticus*), and bulrush (*Schenoplectus* and *Scirpus* spp.).

California linderiella fairy shrimp are a component of a larger invertebrate community structure (Rogers 1998). This invertebrate community includes mostly planktonic Crustacea dependent on temporary wetlands, including copepods, cladocerans, and ostracodes—as well as flatworms and a suite of insect species, including vernal pool haliplid beetle (*Apterliplus parvulus*), scimitar backswimmers (*Buenoa scimitra*), Ricksecker's hydrochara (*Hydrochara rickseckeri*), and many others (Rogers 1998). These habitats are usually low in opportunistic species like mosquitoes and chironomid midges in the genus *Chironomus* (Rogers 1998).

As prey items of birds, California linderiella fairy shrimp are an intermediate host for avian cestodes (tapeworms) (Rogers in review). Anostracans that are hosting a cestode tend to be bright pink in color. The change in color is due to the presence of cestode cysticercoids (intermediate life stage). The parasitic tapeworm castrates the host, which causes the host animal to accumulate lipids (probably linked to carotenoid pigments) that would otherwise be expended by the host during reproduction (Amat *et al.* 1991).

No specific bacterial, viral, or protozoan diseases have been reported for the California linderiella fairy shrimp. Occasionally, specimens with black markings or lesions will appear in collections. These black markings, sometimes referred to as "black disease," are actually evidence of the normal immune response of all Crustacea to any bacteria, where any foreign bacteria is infused with melanin to lethal levels (Bang 1983). Branchiopod crustaceans are commonly found with phoretic (carried) ciliate protozoan colonies around the mouth and portions of the head, which are abandoned with the exuvia (external shell) by the crustacean with each molt.

Species Distribution and Population Trends

Distribution

California linderiella fairy shrimp are the most common fairy shrimp in California, and are found in almost any grassland supporting vernal pools. Their range is reported as occurring from Shasta County south to Fresno County, across the Central Valley, and the Coast and Transverse Ranges from Willits in Mendocino County south to near Sulfur Mountain in Ventura County (USFWS 1994). They have been collected at elevations as high as 3,800 ft. In Yolo County the California linderiella fairy shrimp has been reported from seasonally inundated pools formed from borrow pits along the Union Pacific Railroad just east of the Yolo Bypass levee and along the Sacramento Northern Electric Railroad grade southwest of Saxon in the Yolo Bypass (CNDDB 2008). The species also likely occurs or has potential to occur in vernal pool and other seasonal wetland habitats in Yolo County including Grasslands Regional Park, and in grasslands along the western edge of the Central Valley north of Winters.

Population Trends

An unknown amount of vernal pool habitat and California linderiella fairy shrimp occurrences have been lost. Attempts have been made to calculate lost vernal pool acreages (e.g., Holland 1978, 1988, 1998; Bauder and McMillan 1988). Due to current pressures of the increasing human populations in California and Oregon, more vernal pool habitat is being encroached on and affected throughout the species' range.

The CNDDB vernal pool crustacean records (2005) may be somewhat misleading due to the inconsistency of the data presented. Some records refer to individual pools while others refer to pool complexes, and others still refer to groups of complexes. Additionally, the CNDDB is not updated when a particular site or population is extirpated. Because of issues such as these, it is difficult to determine what actually constitutes a population or occurrence.

In addition, survey maps and records tend to show where vernal pool crustaceans are located and do not emphasize where they are not located. Compounding these difficulties, records are typically a reflection of where surveys have been conducted, rather than a delineation of special-status shrimp distribution. As a result, it is difficult to establish baseline conditions for this species across the entire species' range, as well as within the Plan Area. Where adequate data do not exist, consistent data reporting would help to prevent ambiguous interpretation or mischaracterization of species' conservation needs.

Threats to the Species and Other Conservation Issues

As described previously, the greatest threat to vernal pool invertebrates is the elimination, loss, or modification of their habitat by development. Filling of vernal pools or modification of the watershed that supports those pools either eliminates the habitat or disrupts the pool ecosystem to where it is overcome by opportunistic invertebrate species and invasive, opportunistic, and non-native plants that out-compete the obligatory vernal pool species (Rogers 1998).

Excessive livestock grazing in vernal pool terrain can be detrimental to vernal pool invertebrate communities. High stocking rates tend to deposit a great deal of manure into vernal pools. The organic waste oxidizes the water, leaving gill-breathing invertebrates without oxygen (Rogers 1998). Conversely, vernal pool grasslands are disturbance systems and need a certain amount of grazing. Vernal pools from which all grazing has been removed may become overgrown with native (i.e., spikerush [*Eleocharis* spp.], coyote thistle [*Eryngium* spp.]) and exotic (i.e., manna grass [*Glyceria declinata*], Italian rye grass, etc) plants that generate deep thatch layers on the pool substrate. As this thatch layer decomposes, it also oxidizes the water, which can suffocate gill-breathing invertebrates (Rogers 1998). Both lack of grazing and excessive grazing cause an increase in organic matter in the habitat that eliminates the natural vernal pool invertebrate community and promotes opportunistic and invasive species (Rogers 1998). Therefore, moderate grazing or other disturbance may be a necessary component for suitable habitat, and removal of grazing or excessive grazing are threats to the California linderiella fairy shrimp.

Damage to the watershed that supports vernal pools and vernal pool complexes will affect vernal pool invertebrate communities. Elimination of the watershed will not allow the pools to pond properly and will curtail the movement of nutrients into the pool from overland flow (Rogers 1998). Road run-off entering the watershed and conveyed to occupied pools may carry petroleum by-product residue or sediment from vehicles from paving or road maintenance activities. Furthermore, pesticide, herbicide, fertilizer, and sediment run-off from agricultural activities may enter the watershed and may be injurious to vernal pool invertebrates. Ground disturbance from development activities may also loosen soil and allow sediment to enter the watershed.

Non-native invasive species are a threat to vernal pool invertebrate communities. There is concern that bullfrogs (*Rana catesbeiana*) may feed on federally protected vernal pool crustaceans (Balfour and Morey 1999). Manna grass and Italian rye grass are both exotic vernal pool plants, which tend to produce heavy thatch and eventually organic loads upon decomposition, which oxidize the water (Rogers 1998). It has also been demonstrated that introduction of the non-discriminating, predatory mosquitofish (*Gambusia affinis*) into vernal pools to control perceived local mosquito problems reduces fairy shrimp populations (Leyse et al. 2004).

Habitat fragmentation is also a threat to vernal pool invertebrates because development surrounding small pool complexes may prevent waterfowl or shorebirds from feeding at the pools, thereby preventing genetic flow between occupied habitats. Furthermore, small pool complexes surrounded by development may not be buffered against the runoff from developed areas and changes in the watershed hydrology. Additional threats to the vernal pool invertebrate community structure include off-road vehicle use of vernal pool habitat for recreational mud-bogging, conversion of vernal pools into deep stock tanks that do not dry during summer, and draining of vernal pools.

Actual acreages of potential California linderiella fairy shrimp habitat within the Plan Area are unknown at this time. In addition, areas to be specifically set aside for preservation have not been identified. There should be an overall net gain of occupied California linderiella fairy shrimp habitat within the Plan Area, with specific preserve areas encompassing optimal habitat.

Restoration and creation of California linderiella fairy shrimp habitat have been demonstrated to be feasible (Rogers 1998). However, specific habitat parameters for this and other vernal pool invertebrate species are still poorly understood. For example, this species appears to need a minimum pool volume and a minimum pool surface area within a given habitat to be occupied. Because this species has been found in a wide variety of natural and artificial vernal pool habitats, it is likely an opportunist, similar to most temporary water fauna.

The primary data gap regarding conservation of vernal pool invertebrates is lack of distributional data for the species within and adjacent to the Plan Area. It is not feasible economically or temporally to survey the entire Plan Area, but it may be effective and efficient to estimate California linderiella fairy shrimp distribution through aerial photographic interpretation. Some specific areas will need to be physically verified as to whether they support potential California linderiella fairy shrimp habitat. Artificial habitats, like railroad toe-drains, stock tanks, roadside scrapes, also will need to be verified. Management data gaps include the role of the surrounding uplands in vernal pool habitats and the role, seasonality, and intensity of grazing and other disturbances in vernal pool ecosystems.

Guidelines in selecting vernal pool habitat for conservation of the California linderiella fairy shrimp and other vernal pool dependant organisms should consider the following general principals:

- Vernal pools are not independent microcosms. Active movement of organisms occurs between adjacent pools within complexes, between adjacent complexes, and between distant complexes (e.g., Proctor 1964; Eng *et al.* 1990; Amat *et al.* 1991; Rogers 1998, in prep. Eriksen and Belk 1999; Wissinger et al. 1999; Rogers and Fugate 2001).
- Vernal pools are dependent on the surrounding topography (which may be mound-intermound) as a watershed.
- Vernal pools selected for conservation must exhibit the same biological and geomorphological functions as the habitat being compensated for (e.g., pools occurring on Mehrten formations tend to be very shallow, and cannot be used to replace deeper pools occurring on other landforms).
- Unimpaired vernal pools exhibiting a diverse invertebrate and botanical community are desirable as compensation for artificial habitat, such as a railroad toe-drain that supports California linderiella fairy shrimp but no other vernal pool invertebrates or plants.
- Vernal pool habitat comprises a spectrum of variation, including pools that are shallow, deep, of long ponding duration, of short ponding duration, of varying densities, occurring on various geomorphic surfaces and soil types, and supporting various invertebrate and plant communities. It is imperative to preserve the greatest range of variation and attributes within vernal pool complexes to reflect the diversity of vernal pool habitats.
- Vernal pools within complexes tend to vary broadly between topomorphy, area, depth, botanical community structure, invertebrate community structure, and vertebrate use. Therefore, restored or constructed vernal pool habitats must reflect the diversity of natural, adjacent, unimpaired reference systems.

- No estimates are currently available regarding the minimum self-sustaining population size, vernal pool size, or habitat complex size for California linderiella fairy shrimp or other vernal pool organisms. The estimated loss of extant habitat (e.g., Holland 1978, 1988, 1998; Bauder and McMillan 1988) suggests that these species need the maximum amount of available habitat.
- Vernal pools are systems that require participation from all aspects of the floristic and faunistic community, including vertebrates. To ensure success, moderate, managed grazing is needed (see discussion above under "Habitat Requirements and Ecology").

Contributors to this species account:

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