5-YEAR REVIEW
Longhorn Fairy Shrimp (*Branchinecta longiantenna*)

GENERAL INFORMATION:

Species: Longhorn Fairy Shrimp (*Branchinecta longiantenna*)
Date listed: September 19, 1994
Federal Register (FR) citation: 59 FR 48136 (Service 1994)
Classification: Endangered

State Listing:
Not listed. Currently, there are no invertebrates listed as threatened or endangered under the California Endangered Species Act.

BACKGROUND:

Species overview:

Longhorn fairy shrimp are tiny freshwater crustaceans of the class Branchiopoda. They have delicate elongate bodies, large and stalked compound eyes, and 11 pairs of phyllopods, or swimming legs that also function as gills (Service 2012, p. 2). Fairy shrimp have soft shells, a characteristic of their order Anostraea (Service 2012, p. 2). Longhorn fairy shrimp are easily distinguished from other fairy shrimp by the male's extremely long second antennae, which range from 6.7 to 10.4 millimeters (0.3 to 0.4 inch) in length (Eng *et al*. 1990, p. 253). Female longhorn fairy shrimp may be confused with alkali fairy shrimp (*Branchinecta mackini*), but there are no dorsal outgrowths on the thoracic segments of female longhorn fairy shrimp, while these structures are present on female alkali fairy shrimp (Eng *et al*. 1990, pp. 253–255). Helm (1998) observed that longhorn fairy shrimp require a minimum of 23 days, but averaged 43 days, to reach maturity in artificial pools (p. 133).

Longhorn fairy shrimp are endemic to California (Service 2005, p. II-187). The species is dependent on soil-bottom vernal pools and rock pools in seasonally inundated wetlands (Service 2005, p. II-189). However, based on known occurrences, the species does not seem to demonstrate a strong affinity for a specific vernal pool type (Vollmar 2015, p. 15). The environmental variables that drive the highly restricted distribution of the species, discussed further in **Distribution and abundance**, are currently unknown (Vollmar 2015, p. 15). Longhorn fairy shrimp are highly adapted to the harsh and unpredictable conditions of vernal pool ecosystems (Service 2005, p. II-189). One such adaptive mechanism is the production of dormant eggs, or cysts, that persist through the desiccation phases of seasonally inundated wetlands (Kneitel et al. 2017, p. 129). These cysts can remain viable in the soil for several years (Service 2012, p. 9).

Most recent status review:

U.S. Fish and Wildlife Service. 2012. Longhorn Fairy Shrimp (*Branchinecta longiantenna*). 5-Year Review: Summary and Evaluation. U.S. Fish and Wildlife Service, Sacramento Fish and Wildlife Office, Sacramento, California. 32 pp.

We did not recommend a status change in the 2012 status review.

FR notice citation announcing this status review:

U.S. Fish and Wildlife Service. 2021. Endangered and Threatened Wildlife and Plants; Initiation of 5-Year Status Reviews of 76 Species in California and Nevada. Federal Register 86:27462–27464.

We did not receive information from the public regarding longhorn fairy shrimp in response to the notice.

ASSESSMENT:

Information acquired since the last status review:

This 5-year review was conducted by the U.S. Fish and Wildlife Service's (Service) Sacramento Fish and Wildlife Office. Data for this review were solicited from interested parties through a Federal Register notice announcing this review on May 20, 2021 (Service 2021). We also contacted species experts, and land managers at the San Luis National Wildlife Refuge Complex, Carrizo Plain National Monument, and East Bay Regional Park District to request any data or information we should consider in our review. Additionally, we conducted a literature search, obtained data from an occurrence search of the California Natural Diversity Database (Diversity Database) maintained by the California Department of Fish and Wildlife, and reviewed information in our files, including a review of longhorn fairy shrimp 10(a)(1)(A) recovery permit reports and reports associated with Habitat Conservation Plans. New information about species distribution and threats is available from monitoring at the Refuge Complex and Monument and from ongoing longhorn fairy shrimp habitat research in Contra Costa and Alameda Counties. The information acquired from these efforts is discussed further in the **Distribution and abundance** and **Threats** sections.

Distribution and abundance:

Longhorn fairy shrimp occur in five geographically disjunct populations in different counties in California (refer to **Figure 1** below). From the time of listing to the first 5-year review in 2007, four populations were known in Brushy Peak Preserve, Vasco Caves Preserve, San Luis National Wildlife Refuge Complex, and Carrizo Plain National Monument (Service 1994, p. 48137; Service 2007b, p. 3). A fifth population was discovered in the Alkali Sink Conservation Bank prior to the 2012 status review (Service 2012, p. 2). For the purpose of this 5-year review, a "population" is a cluster of individual longhorn fairy shrimp locality records that are in close proximity and within a few miles of each other. Populations are defined by entire vernal pool complexes, rather than individual pools (Service 2012, p. 3). "Locality" does not necessarily coincide with a single vernal pool, nor do we think a locality necessarily represents a biological population. Rather, localities are convenient for reference to various parts of a population.

Although there is consistent monitoring and surveying of longhorn fairy shrimp in some populations, it is difficult to extract population dynamics and trends from the available data. Abundance is influenced by many variables that may be difficult to control for, including how long pools have been filled, depth of inundation, air temperature, sampling schedule, and sampling effort (Takahashi, *in litt*. 2021). Surveys typically account for presence or absence of

longhorn fairy shrimp in individual pools, and abundance is not measured (Takahashi, *in litt*. 2021). The most common survey method for longhorn fairy shrimp is with the use of dip nets to collect individuals (Heffernan 2018, p. 2). This method only detects juvenile and mature individuals in the water column and does not detect cysts in the soil. Dry-season sampling of vernal pool soil samples can detect *Branchinecta* spp. cysts (Bell *et al.* 2017, p. 8). However, species-level identification of the cysts based on morphological differences is not yet viable, and genetic analyses are limited due to cost (Bell *et al.* 2019, p. 7). Therefore, the ability to measure effective population size accounting for both longhorn fairy shrimp individuals and cysts is currently limited. Additionally, abundance can change dramatically from year to year depending on weather patterns (Bell, *in litt*. 2021). Timing, duration, and intensity of precipitation influences how many eggs are produced and how many cysts hatch during the wet season (Bell, *in litt*. 2021). As a result of these survey limitations and life history variables, distribution is much better understood than overall abundance of the species. Distribution and abundance of each population of longhorn fairy shrimp are discussed further below.

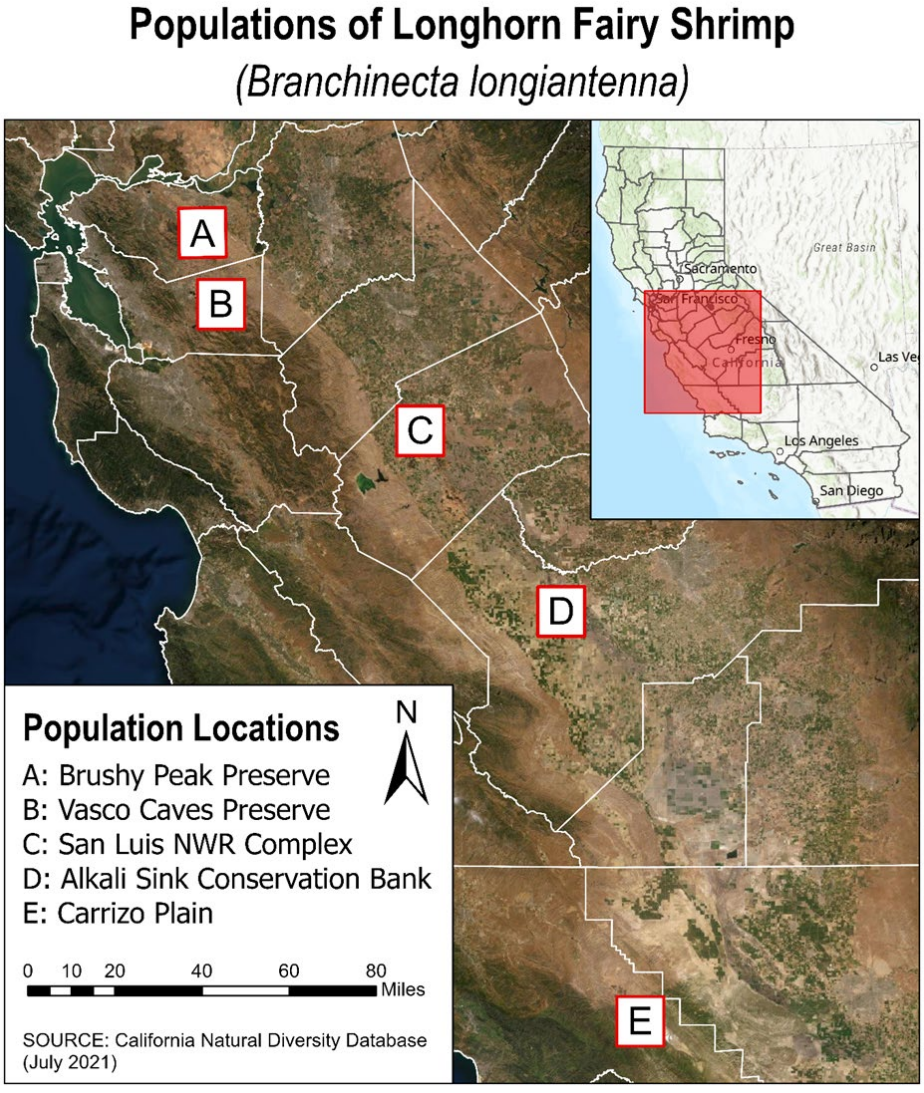

Figure 1. Longhorn fairy shrimp population map (Diversity Database 2021).

Brushy Peak Preserve, Alameda County, and Vasco Caves Preserve, Contra Costa County

Brushy Peak is a 507-acre preserve owned by the Livermore Area Recreation and Park District, and Vasco Caves is a 1,400-acre preserve owned by the East Bay Regional Park District (Service 2012, p. 7). Both preserves are protected, managed by the East Bay Regional Park District, and characterized by rock outcrops with indentations that seasonally pool water and support fairy shrimp (Service 2012, p. 7). Brushy Peak, Vasco Caves, and the surrounding areas are the study sites for ongoing longhorn fairy shrimp habitat research funded by the Central Valley Project Conservation Program. The research project began in 2016 when previous surveys between 2009 and 2014 detected the presence of longhorn fairy shrimp in only three rock pools during two of the six survey years, suggesting the species could be in danger of stochastic extirpation at these two locations (Bell *et al.* 2017, p. 2). The research that began in 2016 aims to (1) assess the severity of this threat through extensive surveying of suitable rock outcrop habitat and (2) characterize factors that may influence longhorn fairy shrimp presence in rock pools (Bell *et al.* 2017, p. 2). **Table 1** below summarizes survey results from 2016 through 2020. This series of surveys indicates that longhorn fairy shrimp is more widely distributed in these two populations than previously thought; however, the species is still considered rare and threatened by stochastic extirpation.

Table 1. Wet season survey results for longhorn fairy shrimp habitat research in Contra Costa and Alameda Counties, California. The number of pools surveyed and number of pools with detected longhorn fairy shrimp are cumulative across survey years.

Survey years	Total unique pools surveyed (cumulative)	Total unique pools with longhorn fairy shrimp presence (cumulative)
2016–2017	807	45
2017–2018	873	55
2018–2019	931	75
2019–2020	No surveys conducted	No surveys conducted
2020–2021	931	76

San Luis National Wildlife Refuge Complex, Merced County

The San Luis National Wildlife Refuge Complex (Refuge Complex) encompasses four units: San Luis National Wildlife Refuge, Merced National Wildlife Refuge, San Joaquin River National Wildlife Refuge, and Grasslands Wildlife Management Area. The San Luis and Merced units were sampled for longhorn fairy shrimp and other branchiopods by Vollmar Natural Lands Consulting in 2015. Among all large branchiopods detected on the Refuge Complex, longhorn fairy shrimp were the least common (Vollmar 2015, p. 13). The species was detected in two out of 76 sampled pools, or 3% of sampled pools, with two individuals observed in one pool and 11 in another (Vollmar 2015, p. 13). Vollmar Natural Lands Consulting attributed the low numbers of longhorn fairy shrimp detected during this survey to a combination of the inherent rarity of the species, severe drought, warmer than average winter temperatures, and waterfowl predation (Vollmar 2015, p. 14).

The Service's refuge biologists have also consistently sampled vernal pools in the Refuge Complex since 2017 (Takahashi, *in litt*. 2021). These sampling efforts focus on determining presence of vernal pool species, including longhorn fairy shrimp, in pools within the Refuge Complex (Takahashi, *in litt*. 2021). Different pools were surveyed in different years, and abundance data was not collected. Longhorn fairy shrimp were observed in the San Luis National Wildlife Refuge unit in February of 2018 and 2019 (Heffernan 2018, p. 5; Heffernan 2019, p. 5), but were not detected in any other units . Service biologists partially attribute low longhorn fairy shrimp presence to species rarity and timing of the surveys in early spring, when the species is likely to have completed their life cycle (Heffernan 2020, p. 5).

Alkali Sink Conservation Bank, Fresno County

The Alkali Sink population of longhorn fairy shrimp was first discovered in 2009. The two Diversity Database occurrences of the species in Alkali Sink were recorded in March 2009 (Diversity Database 2021). These occurrences were found in vernal pools that were 6–13 centimeters (2.4–5.1 inches) deep in alkali sinks surrounded by California annual grassland (Diversity Database 2021). In 2009, tens of thousands of longhorn fairy shrimp were observed at one occurrence and hundreds to thousands were observed at the other occurrence (Diversity Database 2021). At the time of the previous 5-year review, Alkali Sink was a proposed conservation bank in western Fresno County (Service 2012, p. 3). A conservation bank (bank) is a property or suite of properties (i.e., umbrella bank, phased bank, etc.), providing habitat or other conservation values that are conserved and managed in perpetuity, and provides ecological functions and services for specified listed species or resources. Mitigation and conservation banks function to offset adverse impacts that occurred elsewhere; therefore, the Service approves a specified number of credits that the bank owner may sell to developers or other project proponents for use as compensation to offset adverse impacts their projects will likely have on listed species. The Alkali Sink Conservation Bank was formally established in 2016, and longhorn fairy shrimp within the 946-acre preserve are protected and managed for the benefit of the species (Diversity Database 2021). The conservation bank is managed and monitored by the California Department of Fish and Wildlife in accordance with the *Alkali Sink Conservation Bank Long-Term Management Plan* (H.T Harvey and Associates Ecological Consultants 2012, entire). The management plan calls for annual vernal pool crustacean surveys for the first five years after establishment, then surveys every five years thereafter. Twenty-two pools were surveyed during 2017–2018 surveys and longhorn fairy shrimp was found in two pools, one of which contained hundreds while the other contained fewer than 10 (California Department of Fish and Wildlife 2018, p. 22). It is unclear whether the localities surveyed by the California Department of Fish and Wildlife are the same occurrences recorded in the Diversity Database. Change in longhorn fairy shrimp abundance in this population cannot be determined without additional surveys.

Carrizo Plain, San Luis Obispo County

Longhorn fairy shrimp are found on protected and private lands on the Carrizo Plain. The Carrizo Plain National Monument (Monument) is managed by the Bureau of Land Management (Bureau), and occurrences of longhorn fairy shrimp inside the Monument boundary are protected (Service 2012, p. 7). The occurrences outside of the Monument boundary are on private lands and not protected. The previous 5-year review reported the presence of longhorn fairy shrimp in

19 vernal pools within the Monument and 20 vernal pools on private land outside the Monument (Service 2012, p. 6). Since that time, the Bureau conducted a series of vernal pool surveys starting in the wet season of 2014–2015 to confirm the continued presence of longhorn fairy shrimp and other federally listed branchiopods in the Monument (Bureau 2015, p. 1). In the years prior, 2012–2014, fairy shrimp hatching was limited due to drought and other unfavorable environmental conditions (Bureau 2015, p. 1). Surveys were conducted in 2015–2017 and 2019 and reported observations of mature longhorn fairy shrimp is summarized in **Table 2**. Severe drought conditions in 2018 prevented adequate ponding in known occurrences of longhorn fairy shrimp and the Bureau could not conduct surveys (Chase, pers. comm. 2022). Surveys were conducted by dip netting, so only mature longhorn fairy shrimp were sampled. A negative observation of mature longhorn fairy shrimp during the surveys does not indicate the absence of the species in the pool because individuals may be present as cysts. Additionally, only a subset of pools was sampled during each survey year and total abundance data was not collected, similar to surveys conducted in the Refuge Complex. In the Monument, longhorn fairy shrimp were observed in 20 unique pools in at least one survey year. Since the previous status review reported the presence of longhorn fairy shrimp in 19 vernal pools within the Monument, at least one of the recently surveyed vernal pools represents a new locality (Service 2012, p. 6).

During the 2019 wet season, Helm Biological Consulting sampled eight pools across three locations in the Monument for branchiopods. Longhorn fairy shrimp was found within five soil-bottom pools (Helm, *in litt*. 2019). It is uncertain whether these occurrences include those discussed in the previous status review and locations surveyed by the Bureau or if they represent new localities of the species. As mentioned in the previous status review, further surveys in new locations both within and surrounding the Monument may reveal additional vernal pools that contain longhorn fairy shrimp (Service 2012, p. 6).

Table 2. Wet season survey results for longhorn fairy shrimp during 2015–2017 and 2019 in Carrizo Plain National Monument, California (Bureau 2015, p. 3; Bureau 2016, p. 4; Bureau 2017, pp. 4–5; Bureau 2019, pp. 3–4). Surveys were conducted by the Bureau. The Pool Number identifies unique pools that were surveyed, and the Result indicates whether mature longhorn fairy shrimp were observed.

Pool number	2015 Result	2016 Result	2017 Result	2019 Result
10	Yes	Yes	Yes	Yes
24	Yes	No	No	Yes
25	Not surveyed	Not surveyed	No	Yes
25A	Yes	Yes	Yes	Yes
25B	No	Not surveyed	Yes	Yes
41	No	No	Yes	No
121	Not surveyed	Not surveyed	Yes	Not surveyed
131, 132 (joined)	Not surveyed	Not surveyed	Yes	Not surveyed

Pool number	2015 Result	2016 Result	2017 Result	2019 Result
133	Yes	Yes	Yes	Not surveyed
134	Yes	No	Yes	Not surveyed
139	Not surveyed	No	Not surveyed	Yes
140	Not surveyed	Yes	Not surveyed	No
141	Not surveyed	No	Yes	Yes
146	Not surveyed	Not surveyed	Yes	Not surveyed
150	Yes	No	Not surveyed	Not surveyed
153	Not surveyed	Not surveyed	No	Yes
154	Yes	Not surveyed	Not surveyed	Yes
169	No	Yes	Not surveyed	Not surveyed
174	Not surveyed	Yes	Not surveyed	Yes
175	Not surveyed	Not surveyed	Yes	Yes

Threats:

At the time of listing, the primary threats to longhorn fairy shrimp were identified as urban development, conversion of native habitats to agriculture, and stochastic extinction by virtue of the small, isolated nature of many of the remaining populations (Service 1994, pp. 48147–48151). Additional threats identified in the Recovery Plan include: activities associated with the occasional placement of a trailer on a parcel, construction of the associated dirt access road near Soda Lake in Carrizo Plain National Monument, and ongoing and future wind energy developments in Contra Costa and Alameda Counties (Service 2005, p. II-190). Threats to the species identified at the time of the 2012 5-year review include: potential disturbance from wind energy leases, drought, climate change, degradation of habitat from invasive weedy plant species, inappropriate grazing regimes, and risks associated with small population size (e.g., extirpation from random demographic, environmental, stochastic, and genetic events, increased genetic drift, inbreeding) (Service 2012, pp. 10–16). These threats continue to act on the species. Currently, the primary threats to all populations of longhorn fairy shrimp are nonnative plants and climate change (Forrest, *in litt*. 2021; Takahashi, *in litt*. 2021; Bell, pers. comm. 2021).

Nonnative plant species

Vernal pools in California are threatened by aggressive encroachment of invasive plants and grasses into pool boundaries (Gerhardt and Collinge 2003, p. 1044). While the highly dynamic hydrological cycle of vernal pools historically allowed for some resilience against invasion by

nonnative plants, climate change has and continues to facilitate encroachment by nonnative plants (Pyke 2004, p. 179; Faist and Beals 2018, p. 256). Nonnative annual grasses have successfully invaded many vernal pools in California (Faist and Beals 2018, p. 256), with annual invasive grasses tending to have a greater biomass than native grasses (Gerhardt and Collinge 2007, p. 926). The resulting thatch layers have drastic impacts on vernal pools, such as shorter inundation duration during wet seasons (Pyke and Marty 2005, p. 1620). Additionally, nonnative annual plants can create a deep litter layer that recruits other invasive plant species adapted to a deeper litter layer while simultaneously inhibiting native species unaccustomed to these conditions (Faist and Beals 2018, p. 256). The resulting positive feedback layer allows for further encroachment and changes to pool conditions (Faist and Beals 2018, p. 256). Nonnative grass encroachment can decrease available habitat for longhorn fairy shrimp and some rock pools have been observed to be completely filled with soil and annual grasses (Bell, pers. comm. 2021). Additionally, changes to vernal pool inundation depth and duration due to the presence of nonnative grass thatch and litter will likely impact longhorn fairy shrimp. However, the species' ecology is poorly understood, so the extent of impacts due to changes in hydrology from climate change is unknown outside of what is discussed below (Bell *et al.* 2017, p. 5).

Climate change

The most significant threat to longhorn fairy shrimp in the future is climate change and its impacts on vernal pool habitat. Change in temperature and precipitation will likely affect all abiotic factors regulating vernal pool communities, including period of inundation, depth of inundation, pool size, water chemistry, water temperature, number of inundations (habitat stability), and timing of inundation (Kneitel *et al*. 2017, p. 130). In turn, abiotic factors influence biotic parameters of survival, reproduction, population density, and community structure (Kneitel *et al*. 2017, p. 130). Overall, Shin and Kneitel (2019, p. 93) predict that vernal pool endemic species that passively disperse, including longhorn fairy shrimp, will decline with increased temperatures and delayed seasonal inundation in California vernal pool systems.

The severity of future impacts depends on the trajectory of future greenhouse gas emissions. Bedsworth *et al*. (2018, entire) provides the most current assessment of climate change in California and uses two Representative Concentration Pathways (RCPs) from the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (2014, entire). Future conditions are projected using two different emissions pathways, one in which greenhouse gas emissions continue to increase into the next century (RCP 8.5) and one in which greenhouse gas emissions stabilize by mid-century and then decline to levels seen in the 1990s by the end of the century (RCP 4.5) (Bedsworth *et al*. 2018, p. 20). The potential variability of climate conditions for California vernal pools under the two emissions pathways include: little change to climate conditions (RCP 4.5) and continuation of current trajectory of climate change conditions to increased extreme climate events (RCP 8.5). Using the variability of potential future climate conditions allows us to consider a range of potential impacts to the species. **Table 3** summarizes the statewide potential future climate conditions under both emissions scenarios. We expect future conditions to align most closely with projected changes under RCP 8.5 based on the confidence analysis in Bedsworth *et al*. (2018, p. 22).

In addition to the statewide assessment for California from Bedsworth *et al*. (2018), there are regional climate change assessments that provide more precise predictions of temperature change

for the Brushy Peak Preserve, Vasco Caves Preserve, and Carrizo Plain longhorn shrimp populations. For the Brushy Peak and Vasco Caves Preserves populations in the San Francisco Bay Area, Ackerly *et al*. (2018) predicts a 4.4ºF temperature increase by midcentury in comparison to the historical average, whereas Bedsworth *et al.* (2018, p. 14) describes a 3.3ºF increase under the two emissions scenarios described above. For the Carrizo Plain population along the Central Coast, Langridge (2018, p. 13) predicts a 5.0ºF increase by midcentury in comparison to the historical average under RCP 8.5 and a 3.8ºF increase under RCP 4.5. **Table 3** summarizes the regional potential future climate conditions. While the regional projections are slightly less severe than the statewide projections, experts and land managers agree that vernal pools and longhorn fairy shrimp will be threatened by climate change effects (Forrest, *in litt*. 2021; Takahashi, *in litt*. 2021; Bell, pers. comm. 2021).

Table 3. Potential future statewide and regional climate conditions in California based on Bedsworth *et al*. (2018), Ackerly *et al*. (2018), and Langridge (2018).

Climate Projection	Temperature increase
Statewide RCP 4.5	4.4ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Bedsworth *et al*. 2018, p. 23).
Statewide RCP 8.5	5.8ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Bedsworth *et al*. 2018, p. 23).
San Francisco Bay Area RCP 4.5	3.3ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Ackerly *et al*. 2018, p. 14).
San Francisco Bay Area RCP 8.5	4.4ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Ackerly *et al*. 2018, p. 14).
Central Coast RCP 4.5	3.8ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Langridge 2018, p. 13).
Central Coast RCP 8.5	5.0ºF increase by 2040– 2069 in comparison to 1976–2005 averages (Langridge 2018, p. 13).

Under RCP 4.5, we expect extreme events such as drought to become more frequent but with enough rain days to allow successful reproduction to occur and adequate time between drought events for populations to recover. Due to variability under RCP 8.5, we expect climate effects to range from those described under RCP 4.5 to more extreme weather events, such as an extended multi-year drought and flooding. We expect the severity of impacts to the longhorn fairy shrimp due to climate change will scale to the magnitude of future climate change effects.

Effect of temperature increase. An increase in temperature would threaten longhorn fairy shrimp habitat availability, survival, and reproduction. A severe temperature increase of 5.8ºF will likely result in a shorter hydroperiod, or period of inundation, and decrease in maximum depth of water in vernal pools due to a higher rate of evaporation. This will likely result in a shorter wet season

and decrease in longhorn fairy shrimp reproduction, leading to depletion of cyst banks and fewer mature fairy shrimp in the following breeding season. A more moderate temperature increase of 4.4ºF will likely also result in decreased abundance and reproduction through the same mechanisms, although at a slower rate than for a temperature increase of 5.8ºF. There may also be differential responses to a temperature increase based on vernal pool type and microhabitat characteristics. Rock pools only lose water through evaporation, in contrast to soil-based vernal pools that can lose water through evaporation and infiltration (Bell, pers. comm. 2021). As a result, rock pools may be able to retain water longer under these conditions (Bell, pers. comm. 2021). Longhorn fairy shrimp populations in the soil-based pools of Merced, Fresno, and San Luis Obispo Counties may be more impacted than populations in the rock pools of Alameda and Contra Costa Counties.

Additionally, temperature may also impact reproductive success. Temperature is believed to be an important hatching cue for longhorn fairy shrimp cysts (Bell *et al.* 2017, p. 5). A moderate to severe temperature increase would increase the temperature of water in vernal pools, with shallow pools being more sensitive to temperature changes than deeper pools. This may be beneficial for reproduction if the temperature increase allows water temperatures to reach the optimum range for hatching (Bell, pers. comm. 2021). Alternatively, it may be detrimental for reproduction if the temperature increase exceeds the maximum thermal threshold (Bell, pers. comm. 2021). These mechanisms can also interact when a temperature increase results in a decrease in maximum depth of water in a vernal pool, creating shallow pools that are more sensitive to temperature increases. For particularly shallow pools, the increase in temperature and evaporation may eliminate some pools entirely, resulting in loss of habitat and longhorn fairy shrimp mortality. Finally, a temperature increase may threaten vernal pool habitat quality by promoting growth of nonnative plants and algae. High temperatures have been observed to result in late season filamentous algal growth in rock pools that trap fairy shrimp (Bell, pers. comm. 2021).

Effect of increased extreme weather events. More frequent extreme weather events, such as multi-year droughts and flooding, will likely have negative impacts with some ambiguous effects on longhorn fairy shrimp. All future climate projections predict an increase in drought frequency, duration, and intensity. Under RCP 8.5, multi-year droughts combined with a temperature increase will likely decrease or eliminate hydrological functioning in parts of or entire vernal pool complexes. This would threaten longhorn fairy shrimp habitat availability, survival, and reproduction. Species experts have observed a greater number of pools drying out in the middle of the wet season, which disrupts the breeding cycle and reduces the number of eggs that are produced (Bell, pers. comm. 2021). A severe multi-year drought may result in local extirpation of populations, depending on the length of viability of desiccated cysts in the soil bank. Under RCP 4.5, there will likely be enough rain days to allow successful reproduction to occur and adequate time between droughts for populations to recover. Under these conditions, cysts in the soil bank will allow for a measure of resilience against drought events.

An increase in flooding has ambiguous effects on longhorn fairy shrimp and would depend on timing and severity. Flooding during the wet season may help maintain sufficient inundation and hydroperiod for reproduction. Flooding may also increase habitat connectivity and be a vector for longhorn fairy shrimp to colonize new pools within the complex or to repopulate pools where the species was extirpated due to drought. However, in some complexes, there are downstream

pools that do not have longhorn fairy shrimp even though they are present in upstream pools (Bell, pers. comm. 2021). This indicates that species presence is, in part, controlled by microhabitat conditions and/or invertebrate community structure (Bell, pers. comm. 2021). As a result, flooding may displace adults and cysts from suitable pools and into unsuitable habitat. Flooding may also result in greater nutrient and soil runoff and pollution in pools, altering the abiotic characteristics (e.g., nutrient load, turbidity, pH, dissolved oxygen concentration) and biotic characteristics (e.g., community structure, invasive species) of longhorn fairy shrimp habitat. Proximity to agricultural and grazing areas can further increase nutrient loads including nitrogen and phosphate (Kneitel *et al*. 2017, p. 130). The order of fairy shrimp to which longhorn fairy shrimp belongs is shown to be sensitive to water nutrient levels (Kneitel *et al*. 2017, p. 130). Longhorn fairy shrimp ecology needs to be better understood to develop more informed predictions of how the species will be impacted by climate change and other threats. This is discussed further in **Recommendations**.

Habitat Conservation Plans

Habitat Conservation Plans are planning documents required as part of an application for an incidental take permit. They describe the anticipated effects of the proposed taking; how those impacts will be minimized, or mitigated; and how the Habitat Conservation Plan is to be funded. Being included as a covered species under a Habitat Conservation Plan can result in habitat being set aside and managed for the species as mitigation for impacts associated with covered activities, such as planned urban development, within the Habitat Conservation Plan permit area. In addition to mitigation, avoidance, and minimization, other conservation measures (e.g., monitoring, seasonal work windows, habitat management, etc.) are implemented. Habitat Conservation Plans can also utilize banks, in-lieu fee programs, or other mechanisms to preserve habitat in perpetuity and contribute to a regional conservation strategy.

Table 4 describes Habitat Conservation Plans that include longhorn fairy shrimp, the year the permit for the Habitat Conservation Plan was issued, and the amount of longhorn fairy shrimp take authorized. No take of longhorn fairy shrimp or its habitat has occurred under Habitat Conservation Plans. More information about Habitat Conservation Plans that include longhorn fairy shrimp as a covered species can be found at: https://ecos.fws.gov/ecp/species/4294.

Table 4. Summary of Habitat Conservation Plans that include longhorn fairy shrimp and description of take authorized.

Habitat Conservation Plan	Permit term	Description of longhorn fairy shrimp take associated with Habitat Conservation Plan
Kern Water Bank	10/02/1997–10/01/2072	The longhorn fairy shrimp was included as a covered species under this Habitat Conservation Plan because of its potential to be introduced into the Kern Water Bank (Service 1997, p. 35). Longhorn fairy shrimp is not known to occur in this area (Service 1997, p. 23), and no incidental take of the species was authorized (Service 1997, p. 54).

Habitat Conservation Plan	Permit term	Description of longhorn fairy shrimp take associated with Habitat Conservation Plan
San Joaquin County Multi-Species Habitat Conservation and Open Space Plan	05/31/2001–05/30/2051	The longhorn fairy shrimp has not been documented in San Joaquin County; however, potential suitable habitat exists within the permit area (Service 2001, p. 102). Preconstruction surveys are required for areas identified as potential habitat and known occupied sites will be fully avoided (Service 2001, pp. 102–103). Take is authorized when it is associated with creation or restoration of habitat, when conducting controlled burns, from livestock disturbance and/or trampling, and from monitoring activities (Service 2001, p. 191).
East Contra Costa County Habitat Conservation Plan and Natural Community Conservation Plan	07/25/2007–07/25/2037	Known occurrences of the longhorn fairy shrimp within the permit area are restricted to the Vasco Caves Regional Preserve, which will not be impacted by covered activities (Service 2007a, pp. 87–88). No direct effects to the species are anticipated unless additional occupied areas are identified within the permit area (Service 2007a, p. 134). Indirect effects may occur as a result of management and monitoring activities, and include altered hydrology, spread of exotic plants, and increased risk of wildfire from increased human presence (Service 2007a, p. 134). Maximum authorized take of the species under this Habitat Conservation Plan is 56 acres of suitable habitat (Service 2007a, p. 134).
PG&E Bay Area Operations and Maintenance	10/02/2017–10/02/2047	Authorizes the permanent loss of 0.002 acre and temporary loss of 0.2 acre of habitat annually (Service 2017, p. 177). Total permanent and temporary habitat loss authorized over the permit term is 0.1 acre and 1 acre, respectively (Service 2017, p. 177). To off-set these impacts, 1.3 acres of habitat will be conserved for the species (Service 2017, p. 95).
PG&E Multiple Region Operations and Maintenance	06/29/2020–06/29/2050	Take of longhorn fairy shrimp is authorized by region. Within the Central Coast region, authorized take includes the permanent loss of 0.06 acre and temporary loss of 0.34 acre of habitat annually (Service 2020, p. 90). Total permanent and temporary habitat loss authorized within the Central Coast region over the permit term is 1.67 acres and 10.25 acres, respectively (Service 2020, p. 90). Within the Sacramento Valley and Foothills region, authorized take includes the permanent loss of 0.06 acre and temporary loss of 0.36 acre of habitat annually (Service 2020, p. 92). Total permanent and temporary habitat loss authorized within the Sacramento Valley and Foothills region over the permit term is 1.65 acres and 10.81 acres, respectively (Service 2020, p. 90). To off-set this habitat loss, habitat will be conserved at a 3:1 ratio for permanent impacts and a 0.5:1 ratio for temporary impacts (Service 2020, p. 32–33).

Recovery criteria:

General recovery criteria for longhorn fairy shrimp and 19 other listed plants and animals are described in the *Recovery Plan for Vernal Pool Ecosystems of California and Southern Oregon*

(Recovery Plan) (Service 2005, entire). The Recovery Plan uses an ecosystem-level approach because many of the listed species and species of concern co-occur and are impacted by the same threats. The overarching recovery strategy for longhorn fairy shrimp is habitat protection and management. The five key elements that comprise this ecosystem-level recovery and conservation strategy are: (1) habitat protection; (2) adaptive management, restoration, and monitoring; (3) status surveys; (4) research; and (5) public participation and outreach. Downlisting recovery criteria for longhorn fairy shrimp include:

1. Habitat protection: Accomplish habitat protection that promotes vernal pool ecosystem function sufficient to contribute to population viability of the covered species.
    1A. Suitable vernal pool habitats within each prioritized core area for the species is protected. Downlisting criteria 1A. specific to the longhorn fairy shrimp is protection of 95% of suitable species habitat within the North Carrizo Plain, South Carrizo Plain, Altamont Hills, and Grasslands Ecological Area vernal pool core areas.
    1B. Species occurrences distributed across the species geographic and genetic range are protected. Protection of extreme edges of populations protects the genetic differences that occur there. Downlisting criteria 1B. specific to the longhorn fairy shrimp is protection of 100% of species occurrences. **Table 5** summarizes the protection status of longhorn fairy shrimp populations.
    1C. This is a general criteria for reintroductions and introductions that must be carried out and meet success criteria. However, for downlisting the longhorn fairy shrimp, no reintroductions or introductions are described. Reintroductions and introductions are described for delisting the species.
    1D. Additional occurrences (i.e., localities) identified through future site assessments, GIS and other analyses, and status surveys that are determined essential to recovery are permanently protected.
    1E. Habitat protection results in protection of hydrology essential to vernal pool ecosystem function, and monitoring indicates that hydrology that contributes to population viability has been maintained through at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.

2. Adaptive habitat management and monitoring:
    2A. Habitat management and monitoring plans that facilitate maintenance of vernal pool ecosystem function and population viability have been developed and implemented for all habitat protected in 1A–E above.
    2B. Mechanisms are in place to provide for management in perpetuity and long-term monitoring of 1A–E above (i.e., funding, personnel, etc.).
    2C. Monitoring indicates that ecosystem function has been maintained in the areas protected under 1A–D for at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.

3. Status surveys:
    3A. Status surveys, 5-year status reviews, and population monitoring show populations within each vernal pool region where the species occur are viable

(e.g., evidence of reproduction and recruitment) and have been maintained (stable or increasing) for at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.

3B. Status surveys, status reviews, and habitat monitoring show that threats identified during and since the listing process have been ameliorated or eliminated. Site-specific threats identified through standardized site assessments and habitat management planning also must be ameliorated or eliminated.

4. Research:
    - 4A. Research actions necessary for recovery and conservation have been identified (these are research actions that have not been specifically identified in the recovery actions but for which a process to develop them has been identified). Research actions (both specifically identified in the recovery actions and determined through the process) on species biology and ecology, habitat management and restoration, and methods to eliminate or ameliorate threats that have been completed and incorporated into habitat protection, habitat management and monitoring, and species monitoring plans, and refinement of recovery criteria and actions.
    - 4B. Research on genetic structure has been completed for reintroduction and introduction efforts and results incorporated into habitat protection plans to ensure that within and among population genetic variation is fully represented by populations in 1A–E above. As described in 1C above, reintroductions and introductions are not described for downlisting the longhorn fairy shrimp, just for delisting the species.
    - 4C. Research necessary to determine appropriate parameters to measure population viability for each species have been completed.

5. Participation and outreach:
    - 5A. Recovery Implementation Team is established and functioning to oversee rangewide recovery efforts.
    - 5B. Vernal pool regional working groups are established and functioning to oversee regional recovery efforts.
    - 5C. Participation plans for each vernal pool region have been completed and implemented.
    - 5D. Vernal pool region working groups have developed and implemented outreach and incentive programs that develop partnerships contributing to achieving recovery criteria 1–4.

Table 5. Known populations of longhorn fairy shrimp and protection status.

Population	**Landowner(s)**	**Protection status**
Brushy Peak Preserve	East Bay Regional Park District	Protected – Public land
Vasco Caves Preserve	Livermore Area Recreation and Park District	Protected – Public land

Population	Landowner(s)	Protection status
San Luis National Wildlife Refuge Complex	U.S. Fish and Wildlife Service	Protected – Public land
Alkali Sink Conservation Bank	Meyers Farming, LLC	Protected – Conservation bank
Carrizo Plain	Bureau of Land Management	19 localities protected – Public land
	Private	20 localities not protected – Private land

Most of the recovery criteria analysis in the 2012 5-year review remains valid (Service 2012, pp. 16–25). The 2012 5-year review determined that none of the recovery criteria have been fully met, and we reach the same conclusion in this assessment. New information acquired relevant to each criterion is described in **Table 7**. Refer to **Appendix, Table 1A** for an assessment of all recovery criteria.

Table 7. Downlisting criteria with new information for longhorn fairy shrimp. Assessment of status in Service (2012) and information acquired since 2012. The status remains as described in the 2012 assessment unless stated otherwise

Recovery criteria	Criterion still valid?	2012 status	2021 status
1A. Suitable species habitat within each prioritized core area for the species is protected.	Yes.	Not met.	Not met. 32% of the Altamont Hills core areas and 71% of the Grasslands Ecological Area core areas are protected (Witham *et al*. 2014, p. 15). The percentage of Carrizo Plain core areas that is protected is unknown.
1B. Species occurrences distributed across the species geographic and genetic range are protected.	Yes.	Partially met.	Partially met. Occurrences on private lands in the Carrizo Plain population are unprotected. The Alkali Sink population, which was unprotected as of the previous status review, is now protected in a conservation bank.
1D. Additional occurrences (i.e., localities) are permanently protected, if determined essential to recovery goals.	Yes, although "locality" needs to be more clearly defined.	Partially met.	Partially met. Occurrences on private lands in the Carrizo Plain population are unprotected. Localities in the Alkali Sink population, which was unprotected as of the previous status review, are now protected in a conservation bank.
1E. Habitat protection results in protection of hydrology essential to vernal pool ecosystem function, and monitoring indicates that hydrology that contributes to population viability has been maintained through at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.	Yes, although habitat protection alone does not result in protection of hydrology essential to vernal pool ecosystem function. Climate change needs to be considered in the recovery criteria.	Not met.	Not met. Qualitative and quantitative monitoring of hydrology is conducted at some longhorn fairy shrimp localities. However, more consistent, multi-year monitoring is necessary to determine whether hydrology that contributes to population viability has been maintained. Hydrological functioning under various climate change projections should be also assessed.
2A. Habitat management and monitoring plans that facilitate	Yes.	Mostly met.	Mostly met. According to the previous status review, the San Luis and Merced National Wildlife Refuge Comprehensive

Recovery criteria	Criterion still valid?	2012 status	2021 status
maintenance of vernal pool ecosystem function and population viability have been developed and implemented for 1A–E.			Conservation Plans was expected to be completed in 2012. The plans are currently still in progress. This criterion was previously not relevant to the Alkali Sink population. This criterion is now met for the Alkali Sink population after establishment of the conservation bank and creation of the Alkali Sink Conservation Bank Long-Term Management Plan.
2B. Mechanisms are in place to provide for management in perpetuity and long-term monitoring of 1A–E, as previously discussed (funding, personnel, etc.).	Yes.	Partially met.	Mostly met. The San Luis National Wildlife Refuge Complex is managed by the Service, the Carrizo Plain National Monument is managed by the Bureau of Land Management, the Vasco Caves and Brushy Peak Preserves are managed by East Bay Regional Park District, and the Alkali Sink Conservation Bank is managed by the California Department of Wildlife. Therefore, funding for management and protection of vernal pool species depends on funding to these agencies. This criterion has been partially met for these sites through budget practices of the involved agencies.
4A. Research actions necessary for recovery and conservation of the covered species have been identified.	Yes.	Not met.	Partially met. At the time of the previous status review, the Service had not processed any scientific or recovery permits in support of longhorn fairy shrimp research. Additionally, there was no ongoing or proposed research. Currently, there are multiple active recovery permits in support of longhorn fairy shrimp research. Research funded by the Central Valley Project Conservation Program is occurring at the Brushy Peak Preserve and Vasco Caves Preserve populations. The research team identified and is making progress towards completing research actions.

Conclusion:

After reviewing the best available scientific information, we conclude that longhorn fairy shrimp remains an endangered species. While there is increased monitoring of longhorn fairy shrimp populations, such as at Brushy Peak Preserve, Vasco Caves Preserve, San Luis National Wildlife Refuge Complex, and Carrizo Plain National Monument, we cannot yet determine population trends. Therefore, we are limited in our assessment of the species status and status towards achieving recovery criteria. Some threats to the species, such as habitat loss due to land conversion, have been ameliorated or eliminated as a result of land protection. However, longhorn fairy shrimp remains highly vulnerable to the risks associated with narrow distribution and small population size (e.g., extirpation from random demographic, environmental, stochastic, and genetic events, increased genetic drift, inbreeding). These risks are magnified by the increasing frequency of extreme weather events with climate change, a threat that is not addressed in the Recovery Plan. Additionally, the limited connectivity among populations essentially eliminates the possibility of recolonization from source populations in case of extirpation, barring human intervention. The evaluation of threats affecting the species under the factors in 4(a)(1) of the Endangered Species Act and analysis of the status of the species in our 2012 status review (Service 2012) remains an accurate reflection of the species' current status.

RECOMMENDATIONS FOR FUTURE ACTIONS:

Here we propose several habitat conservation and ecological research recommendations which will aid in the recovery and conservation of longhorn fairy shrimp. Some of these recommendations have already been discussed in previous status reviews (Service 2007b, pp. 21–22; Service 2012, pp. 25–26) and remain valid.

1. *Acquire and manage habitat*. All populations of longhorn fairy shrimp should be protected. Resource agencies and private partner groups should work to ensure protection of localities on private lands in the Carrizo Plain population through acquisition or conservation easement.

2. *Determine population status and implement regular population monitoring*. Develop a standardized monitoring method to monitor the status and trend of occurrences to (a) track any threats, (b) estimate current population sizes and the number and distribution of populations, and (c) determine whether the species is stable, increasing, or declining. The monitoring method should account for all important population metrics, which may include presence, abundance of fairy shrimp and eggs, and number of generations present (i.e., instars, juveniles, and breeding adults). Work with landowners and managers to implement multi-year monitoring programs. Survey for additional localities within the five known populations.

3. *Explore the effect of climate change on vernal pool hydrology and species viability*. Assess how climate change, including increase in temperature and frequency of extreme weather events, will impact vernal pool hydrology through modeling. Determine how these impacts differ among pool types, i.e., rock outcrop pools versus soil-bottom pools. Work with partners to model current hydrology and vernal pool connectivity. Assess how future climate conditions will impact reproduction and, consequently, population

dynamics. Determine which populations are most vulnerable to climate change to prioritize conservation actions.

4. *Designate a suitable unit of assessment*. Consult with species experts and land managers to develop a geographically and ecologically appropriate unit of assessment to describe a longhorn fairy shrimp population subcategory. Currently, the use of "locality" or "occurrence" is not standardized. Defining a unit of assessment will aid in more precise assessments of recovery criteria.

5. *Develop habitat suitability criteria*. Determine the role of microhabitat characteristics and local community structure in habitat suitability for longhorn fairy shrimp. Determine range of suitable abiotic conditions (e.g., turbidity, nutrient concentration, oxygen concentration, light availability, pool depth, hydroperiod) for the species. Model pool characteristics in relation to landscape and abundance. Work with partners to apply information towards (a) restoring and creating suitable habitat and (b) predicting vulnerability of localities as habitat conditions change due to climate change.

6. *Develop research needs and actions*. Support ongoing longhorn fairy shrimp research at Brushy Peak and Vasco Caves Preserves, and support other studies to fulfill research needs, including:

    - Genetic diversity within and among populations.
    - Whether genetic diversification occurs due to highly variable habitat features.
    - The use of environmental DNA, or eDNA, as a complementary survey tool to the use of dip nets and soil samples.
    - Biotic and abiotic parameters for species occurrence.

7. *Assess recovery criteria*. Consider reassessing longhorn fairy shrimp's recovery criteria to account for climate change impacts. Additionally, to continue tracking progress towards meeting recovery criteria, we need additional information about the species and its habitat, including:

    - Species characteristics, including environmental stimuli that trigger hatching of eggs, length of cyst viability, and stratification of cysts.
    - Percentage of protected land within identified core areas.
    - Survey of localities on private lands.
    - An assessment of the effectiveness of current habitat management plans.

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Approve MICHAEL FRIS Digitally signed by MICHAEL FRIS Date: 2022.09.02 09:35:48 -07'00' **Date** _____

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APPENDIX

Table 1A. Delisting recovery criteria assessment for longhorn fairy shrimp.

Recovery criteria	Status
1A. Suitable vernal pool habitats within each prioritized core area for the species is protected.	Not met. 32% of the Altamont Hills core areas and 71% of the Grasslands Ecological Area core areas are protected (Witham et al. 2014, p. 15). The percentage of Carrizo Plain core areas that is protected is unknown.
1B. Species occurrences distributed across the species geographic range and genetic range are protected. Protection of extreme edges of populations protects the genetic differences that occur there.	Partially met. Within the five known populations, species localities are distributed across the species' geographic range, and the genetic range is protected. Extreme edges of the longhorn fairy shrimp's range are protected. Therefore, this criterion is close to fulfillment in the sense that the majority of localities are protected from land-use conversion, although other threats may be present. Occurrences on private lands in the Carrizo Plain population are unprotected. The Alkali Sink population, which was unprotected as of the previous status review, is now protected in a conservation bank.
1C. Reintroductions and introductions must be carried out and meet success criteria.	This criterion is described for delisting the longhorn fairy shrimp, but not for downlisting the species.
1D. Additional occurrences (i.e., localities) are permanently protected, if determined essential to recovery goals.	Partially met. Occurrences on private lands in the Carrizo Plain population are unprotected. Localities in the Alkali Sink population, which was unprotected as of the previous status review, is now protected in a conservation bank.
1E. Habitat protection results in protection of hydrology essential to vernal pool ecosystem function, and monitoring indicates that hydrology that contributes to population viability has been maintained through at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.	Not met. Qualitative and quantitative monitoring of hydrology is conducted at some longhorn fairy shrimp localities. However, more consistent, multi-year monitoring is necessary to determine whether hydrology that contributes to population viability has been maintained. Hydrological functioning under various climate change projections should be also assessed.
2A. Habitat management and monitoring plans that facilitate maintenance of vernal pool ecosystem function and population	Mostly met. According to the previous status review, the San Luis and Merced National Wildlife Refuge Comprehensive Conservation Plans was

Recovery criteria	Status
viability have been developed and implemented for all habitat protected, as previously discussed in 1A–E.	expected to be completed in 2012. The plans are currently still in progress. This criterion was previously not relevant to the Alkali Sink population. This criterion is now met for the Alkali Sink population after establishment of the conservation bank and creation of the Alkali Sink Conservation Bank Long-Term Management Plan.
2B. Mechanisms are in place to provide for management in perpetuity and long-term monitoring of 1A–E, as previously discussed (funding, personnel, etc.).	Mostly met. The San Luis National Wildlife Refuge Complex is managed by the Service, the Carrizo Plain National Monument is managed by the Bureau of Land Management, the Vasco Caves and Brushy Peak Preserves are managed by East Bay Regional Park District, and the Alkali Sink Conservation Bank is managed by the California Department of Wildlife. Therefore, funding for management and protection of vernal pool species depends on funding to these agencies. This criterion has been partially met for these sites through budget practices of the involved agencies.
2C. Monitoring indicates that ecosystem function has been maintained in the areas protected under 1A–D for at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.	Not met. Consistent monitoring of ecosystem function has not occurred for any of the known populations of this species; therefore, the Service is unable to determine if the ecosystem function has been maintained at extant localities that has supported viable populations through a variety of hydrologic conditions.
3A. Status surveys, 5-year status reviews, and population monitoring show populations within each vernal pool region where the species occur are viable (e.g., evidence of reproduction and recruitment) and have been maintained (stable or increasing) for at least one multi-year period that includes above average, average, and below average local rainfall, a multi-year drought, and a minimum of five years of post-drought monitoring.	Not met. Monitoring has not occurred over a period of time and hydrologic conditions that meets the requirements specified in the Recovery Plan at any of the sites with known occurrences; therefore, the Service is unable to determine if this criterion has been met. The Recovery Plan states that standardized status surveys should establish parameters that evaluate population sizes to determine overall trends in species status rangewide (e.g., evidence of reproduction and recruitment). Specific monitoring parameters have not yet been identified.
3B. Status surveys, status reviews, and habitat monitoring show that threats identified during and since the listing process have been ameliorated or eliminated. Site-specific treats identified	Not met. Informal monitoring of known populations of longhorn fairy shrimp has occurred at all five population. For all known populations, biologists have noted observations of longhorn fairy shrimp when out in the field, but survey methods have not been standardized between locations. The

Recovery criteria	Status
through standardized site assessments and habitat management planning also must be ameliorated or eliminated.	primary threat to this species described in the 1994 final listing rule is habitat loss due to agriculture conversion and urbanization. While this continues to be a threat to vernal pool species in general, most known populations of longhorn fairy shrimp are protected from land-use conversion on public lands. Therefore, this threat has been removed from protected populations. Other threats exist, however, such as the increased risk of local extirpations from stochastic events because of the small number of isolated populations for this species, and risks from environmental disturbances, including climate change, degradation of habitat from invasive weedy plant species, inappropriate grazing regimes, and other unforeseen events.
4A. Research actions necessary for recovery and conservation of the covered species have been identified (these are research actions that have not been specifically identified in the recovery actions but for which a process to develop them has been identified). Research actions (both specifically identified in the recovery actions and determined through the process) on species biology and ecology, habitat management and restoration, and methods to eliminate or ameliorate threats that have been completed and incorporated into habitat protection, habitat management and monitoring, and species monitoring plans, and refinement of recovery criteria and actions.	Partially met. At the time of the previous status review, the Service had not processed any scientific or recovery permits in support of longhorn fairy shrimp research. Additionally, there was no ongoing or proposed research. Currently, there are multiple active recovery permits in support of longhorn fairy shrimp research. Research funded by the Central Valley Project Conservation Program is occurring at the Brushy Peak Preserve and Vasco Caves Preserve populations. The research team identified and is making progress towards completing research actions.
4B. Research on genetic structure has been completed for reintroduction and introduction and results incorporated into habitat protection plans to ensure that within and among population genetic variation is fully representative by populations protected in 1A–E.	Partially met. See 1C and 4A, above.
4C. Research necessary to determine appropriate parameters to measure population viability for each species have been completed.	Partially met. See 4A, above.

Recovery criteria	Status
5A. Recovery Implementation Team is established and functioning to oversee rangewide recovery efforts.	Not met. There are no active Recovery Implementation Teams for vernal pools or the species.
5B. Vernal pool regional working groups are established and functioning to oversee regional recovery efforts.	Not met. No regional working groups have been established in the areas of concern for longhorn fairy shrimp.
5C. Participation plans for each vernal pool region have been completed and implemented.	Not met. This action has not been initiated.
5D. Vernal pool region working groups have developed and implemented outreach and incentive programs that develop partnerships contributing to achieving recovery criteria 1–4.	Not met. This action has not been initiated.