

cyst (organisms in a resting stage) bank in any given year. Thus, the San Diego fairy shrimp is adapted to highly variable environments.

San Diego fairy shrimp require functioning vernal pools for their conservation (Belk 1998). Both the pool basin and the surrounding watershed are essential for a functioning vernal pool system (Hanes and Stromberg 1998). Loss of upland vegetation, increased overland flow due to urban runoff, and alteration of the micro-topography can all alter the narrow physiological parameters that the San Diego fairy shrimp requires for survival.

The maintenance of genetic variability is crucial to the survival of a species with declining populations and a limited range, such as the San Diego fairy shrimp (Gilpin and Soule 1986; Lesica and Allendorf 1995). Vernal pool complexes throughout the range of the San Diego fairy shrimp are critical for the conservation of this species. Likewise, the pools within a multi-pool complex are also important for the local population of San Diego fairy shrimp to remain viable. Vernal pool complexes identified as necessary in the Recovery Plan for Vernal Pools in Southern California must be secured in a configuration that maintains habitat function and viability. There are several reasons for this. Each vernal pool complex is unique in soil type, species composition, and hydrology (Service 1998). This high degree of variability in habitat combined with the unpredictability of winter rains (pool filling events) has given rise to a genetic structure between pool complexes (Davies 1996; Davies *et al.* 1997). This means that San Diego fairy shrimp living in one pool complex may not be adapted to a pool complex elsewhere in the species range. This research also revealed that within pool complexes there was a low degree of genetic variability. The genetic structure and low genetic variability suggests that there is a low degree of gene exchange between different pool complexes. This research indicates that pool complexes throughout the range contain unique genetic traits necessary for the conservation of San Diego fairy shrimp.

The life cycle of the San Diego fairy shrimp is such that in any single breeding event there may be individuals present from multiple generations. This has the effect of dampening the effects of genetic drift and inbreeding that are normally associated with a small population size. In particular this makes the preservation of existing vernal pools a high priority for critical habitat designation because of the cyst banks that are present in natural pools (Belk

1998). Creation of vernal pools has not been successfully implemented as a viable measure to compensate for impacts to vernal pools. Restoration of vernal pools has been successfully completed; however, restoration must be carefully pursued. Restored pools may lack the multi-generational cyst bank. In the event that soils are transported from existing vernal pools to a restoration site, soils may be mixed, compacted, or otherwise mistreated so that the cyst bank can no longer function (Hathaway *et al.* 1996). Thus, restored pools may not exhibit the necessary genetic dynamics of natural pools and may not contribute as significantly as natural vernal pools.

Vernal pools have a discontinuous occurrence in several regions of California (Keeler-Wolf *et al.* 1995), from as far north as the Modoc Plateau in Modoc County, south through San Diego County to the international border with Mexico. Vernal pools form in regions with Mediterranean climates, where shallow depressions fill with water during fall and winter rains and then evaporate in the spring (Collie and Lathrop 1976; Holland 1976, 1988; Holland and Jain 1977, 1988; Thorne 1984; Zedler 1987; Simovich and Hathaway 1997). The presence of the surrounding watershed is a vital component of a vernal pool ecosystem. The term "watershed" is commonly associated with riverine drainages, however, in the context of this discussion the term "watershed" refers to the land surrounding a single vernal pool or vernal pool complex that contributes to the hydrology of the vernal pools. These watersheds can vary in size from a few hundred meters to much larger areas around the vernal pools.

In years of high precipitation, overbank flooding from intermittent streams may augment the amount of water in some vernal pools (Hanes *et al.* 1990). Vernal pool studies conducted in the Sacramento Valley indicate that the contribution of subsurface or overland flows is significant only in years of high precipitation when pools are already saturated (Hanes and Stromberg 1996). Downward percolation of water in vernal pool basins is prevented by the presence of an impervious subsurface layer, such as a claypan, hardpan, or volcanic stratum (Holland 1976, 1988). The integrity of both the vernal pool and the surrounding watershed is crucial to the long term survival and conservation of the San Diego fairy shrimp.

Researchers have found that vernal pools located in San Diego County are associated with five soil series types: Huerfueño, Olivenhain, Placentia,

Redding, and Stockpen (Bauder and McMillan 1998). These soil types have a nearly impermeable surface or subsurface soil layer with a flat or gently sloping topography (Service 1998). Due to local topography and geology, the pools are usually clustered into pool complexes (Bauder 1986; Holland and Jain 1977). Pools within a complex are typically separated by distances on the order of meters, and may form dense, interconnected mosaics of small pools or a more sparse scattering of larger pools.

Vernal pool systems are often characterized by different landscape features including mima mound (miniature mounds) microtopography, varied pool basin size and depth, and vernal swales (low tract of marshy land). Vernal pool complexes that support one to many distinct vernal pools are often interconnected by a shared watershed. Chemistry, geophysics, and hydrology influenced by watershed characteristics determine the distribution of vernal pool species (Dehoney and Lavigne 1984; Eng *et al.*, 1990, Branchiopod Research Group 1996), therefore ecosystems on which the San Diego fairy shrimp and its vernal pool habitat depend are best described from a watershed perspective (see Recovery Criteria 1 and 2 in the Recovery Plan for Vernal Pools of Southern California, Service 1998). California's vernal pools begin to fill with the fall and winter rains. Before ponding occurs, there is a period during which the soil is wetted and the local water table may rise. Some pools in a complex have a substantial watershed that contributes to water input; others may fill almost entirely from rain falling directly into the pool (Hanes and Stromberg, 1998). Even in pools filled primarily by direct precipitation, subsurface inflows from surrounding soils can help dampen water level fluctuations during late winter and early spring (Hanes and Stromberg 1998).

Vernal pools exhibit four major phases—the wetting phase, when vernal pool soils become saturated; the aquatic phase, when a perched water table develops within the watershed and the vernal pool contains water; a waterlogged drying phase, when the vernal pool begins losing water as a result of evaporation and loss to the surrounding soils but soil moisture remains high; and the dry phase, when the vernal pool and underlying soils are completely dry (Keeley and Zedler 1998). Upland areas within vernal pool watersheds are also an important source of nutrients to vernal pool organisms. Vernal pool habitats derive most of their nutrients from detritus, which is