Avian Uses of Vernal Pools and Implications for Conservation Practice

Joseph G. Silveira

U. S. Fish and Wildlife Service, Sacramento National Wildlife Refuge Complex, Willows, CA 95988 (joe_silveira@fws.gov)

Abstract. Vernal pool landscapes consist of vernal pools and their surrounding physiographical and biological environments. They provide important habitats for both resident and migratory birds. Avian species are adapted to exploit the various zones and hydrologic phases of vernal pools which are characterized by spatial and temporal patterns of wet to dry habitats. Waterfowl and shorebirds use different types of wetland habitats in relation to their annual behavioral and energy cycle. During the spring, ducks feed on invertebrates which are abundant in ephemeral wetlands such as vernal pools. Invertebrates are important sources of protein and calcium needed for migration and reproduction. Cackling and Ross' geese, during spring hyperphagia, spend long hours grazing on protein rich plants in herbaceous habitats adjacent to vernal pools. Several species of shorebirds are observed in vernal pool landscapes during winter, spring migration, and nesting periods. On a local scale, vernal pools are part of a complex of habitats where a diversity of birds use various resources. On a regional scale, vernal pool landscapes of the Central Valley's eastern margin enhance migratory bird habitats of the valley floor. Vernal pools are also significant on a continental scale, providing vital links in the California portion of the Pacific Flyway corridor. Vast, intact vernal pool landscapes are necessary for continued large scale avian use. Conservation easements that protect core areas, and land management agreements which include livestock grazing to maintain avian diversity, are needed to protect irreplaceable vernal pool landscapes in the future.

Citation. Pages 92-106 *in:* C.W. Witham, E.T. Bauder, D. Belk, W.R. Ferren Jr., and R. Ornduff (Editors). Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. California Native Plant Society, Sacramento, CA. 1998.

Introduction

California has a tremendous variety of wetland habitats and associated natural communities (Mason, 1957; Holland, 1978; 1986; Sawyer and Keeler-Wolf, 1995; Ferren et al., 1996). Vernal pools are a special class of ephemeral or temporary wetlands that have inundation patterns unique to Mediterranean climates, which results in a unique and rich flora and invertebrate fauna (Zedler, 1987; Eng et al., 1990). Vernal pools occur in an environment influenced by geology, geomorphology, soils, topography, hydrology, and local climate which in turn influences vegetation and wildlife use.

Vernal pools of California's Great Central Valley are an important component of wetland habitats used by wintering waterfowl (Heitmeyer et al., 1989). Few published studies document avian uses of vernal pools. In fact, a state guide to wildlife habitats of California (Mayer and Laudenslayer, 1988) lumps vernal pools with annual grassland habitat, but fails to mention special vertebrate fauna such as the western spadefoot toad (*Scaphiopus hammondi*) and California tiger salamander (*Ambystoma californiense*) and winter/spring waterbird use. However, the association of birds with vernal pools in California has long been acknowledged. In 1924 Grinnell et al. (1930) observed and recorded waterfowl use in the "rain-pools" at Dale's, Tehama County. Thousands of ducks were observed feeding in the shallow waters of the Waterford – La Grange "vernal lakes" in Stanislaus County (Medeiros, 1976). A list of birds known or expected to feed in the vicinity of vernal pools, primarily in San Diego County, has been compiled by Zedler (1987), and The Nature Conservancy (1988) gives an account of bird use and lists species known from the Vina Plains Preserve, Tehama County. Baker et al. (1992) reported on avian abundance on vernal pools at the Santa Rosa Plateau Preserve, Riverside County. In unpublished reports, Lovio (1983) and Peters (1993) document avian use of vernal pools at the Jepson Prairie Preserve, Solano County, and San Luis National Wildlife Refuge Complex, Merced County, respectively. Jones and Stokes Associates (1990) also mention the association of birds with vernal pools in Sacramento County. The association of waterfowl and vernal pools was likely exploited by native Californians. Net weights, also know as "charmstones", suggest hunting of migratory waterfowl and have been found at Placer and Solano County vernal pools (Roop, 1981). Today, hunting blinds and old (historic) duck and goose decoys are found in vernal pool landscapes as diverse as those on the Vina Plains Preserve and Table Mountain, Butte County.

The purposes of this review are: describe avian diversity associated with vernal pool habitats and phenology; explain how vernal pools may function during the annual cycle of waterfowl; illustrate the role of vernal pools as a component of Central Valley wetland habitats; note their importance to avian conservation; and, suggest strategies for vernal pool conservation and management.

AVIAN USES OF VERNAL POOLS

The following discussion is based on observations of avian occurrences and use of vernal pool complexes in the Central Valley and northeastern California (Table 1). Avian diversity of vernal pool landscapes is characterized by both waterbirds and landbirds including several special-status species (Table 1). Vernal pool characteristics, avian adaptations to wetland habitats, the annual energy cycle in waterfowl, and the distribution of Central Valley vernal pool habitats and wetland complexes are discussed to illustrate the importance of vernal pools to waterfowl ecology.

Vernal Pool Phenology, Size, Zonation, and Avian Use

Vernal pools are represented by a variety of basin shapes and sizes that occur in pool complexes of various densities and hydroperiods depending on geology, soils, topography, hydrology, and climate (Holland and Jain, 1988; Holland and Dains, 1990). Consequently, vernal pool landscapes are used by a diversity of avian species because of distinct habitat features such as water surface area, water depth, inundation period, soil moisture gradient, vegetation zones and condition, invertebrate biota, composition of and proximity to wetland complexes, tradition, and disturbance.

The hydroperiod of vernal pools is based on winter rainfall patterns. The pools typically flood for short periods in late winter and early spring when California receives most of its precipitation. Vernal pool flora and fauna are adapted to long dry, hot periods (Alexander, 1976; Holland and Jain, 1988; Eng et al., 1990). Although not well documented, the relatively short hydroperiod results in an extremely productive wetland invertebrate fauna relative to other Central Valley seasonal wetlands. Additionally, when flooded, vernal pools are relatively shallow, resulting in optimal foraging depths for a variety of waterbirds (Table 2).

Vernal pools with a large surface area are reported to receive greater waterfowl use than smaller pools (Baker et al., 1992). In general, vernal pools are relatively small, isolated wetlands which support small flocks of waterfowl, shorebirds, and other waterbirds. Often, only a single bird or pair of birds are observed. When compared to managed wetlands in Central Valley flood basins where waterfowl populations reach extremely dense concentrations, vernal pools may seem insignificant as waterbird habitat. However, California's vernal pool habitats show parallels with better studied and more understood ephemeral ponds in the Prairie Pothole Region of the mid-west (Pederson et al., 1989) and the Playa Lakes Region of the southwest (Bolen et al., 1989). All three systems have short, yet very productive hydroperiods which coincide with high waterfowl use in a short period of their annual behavioral and energetic cycle. Birds typically use these systems in isolated pairs or small flocks. Therefore, pool size and density are not as important in spring when waterfowl are paired and less gregarious than in fall and winter.

Avian use of vernal pools and thus, the importance of vernal pool complexes to birds, has traditionally been underestimated. This can be attributed to three factors: 1) Vernal pools are ephemeral by nature, their patterns of seasonal flooding and associated invertebrate production do not allow much time to census birds. 2) Vernal pools mostly occur in small, isolated basins. This leads to survey access and coverage difficulties. 3) The social structure of birds in late winter and spring makes their detection difficult. It is easy to mistake fall and winter use of bigger wetlands by large, gregarious flocks as superior to spring use of small wetlands by pairs and small flocks. However, as discussed later, spring use of wetlands is critical to waterfowl survival and recruitment.

Vernal pool zonation within the hydroperiod and differences across wet and dry phases result in an array of avian micro and macrohabitats from open water to mudflats and dry pool beds with associated meadows, grasslands, and scrub communities. Avian use of vernal pools span these habitats and associated periods (Table 1; Figure 1). Dabbling ducks feed in the pool, and rest in the pool and on shore. Deeper pools are used by diving ducks. American Wigeon (*Anas americana*), American Coots (*Fulica americana*), and Canada Geese (*Branta canadensis*) graze along the shoreline and adjacent grasslands and meadows. Tundra Swans (*Cygnus columbianus*) rest on large vernal pools during spring migration. Shorebirds feed in shallow pools, on drying pool beds of larger pools, along the shoreline, and in adjacent habitats. Cliff Swallows (*Hirundo pyrrhonota*) glean mud from vernal pools for nest material. Tricolored Blackbirds (*Agelaius tricolor*) forage in dry pool beds. Brewer's Blackbirds (*Euphagus cyanocephalus*) and American Pipits (*Anthus rubescens*) glean from the pools shoreline. Burrowing Owls (*Athene cunicularia*) use mima mounds for burrow sites. Mallards (*Anas platyrhynchos*), Meadowlarks (*Sturnella neglecta*), American Avocets (*Recurvirostra americana*), and Horned Larks (*Eremophila alpestris*) nest in adjacent grasslands and alkali meadows. Lesser Nighthawks (*Chordeiles acutipennis*) nest in dry vernal pool beds.

Morphological and Behavioral Adaptations to Wetland Habitats

Waterfowl and shorebird populations are thought to be limited by winter resources (Baker and Baker, 1973; Owen, 1980). Distinct bill morphologies, body size, and tarsal length allow similar species to occupy the same general habitat by exploiting different microhabitats (Baker and Baker, 1973; Lack, 1974;

TABLE 1. Annotated list of vernal pool birds[1].

Birds	Species[2]	Observation notes	Observation location[3]
Great Blue Heron	*Ardea herodias*	aquatic and terrestrial phase feeding	sr, ls, eg, wg
Great Egret	*Casmerodius albus*	aquatic phase feeding	sr, ls, eg, wg
Snowy Egret	*Egretta thula*	aquatic phase feeding	sr, ls, eg, wg
Tundra Swan	*Cygnus columbianus*	aquatic phase resting	vp
Pacific White-fronted Goose	*Anser albifrons frontalis*	aquatic phase resting, grazing at pool edge	sr, fm, eg
Lesser Snow Goose	*Chen caerulescens c.*	aquatic phase resting, grazing at pool edge	ls, sr, eg, wg
Ross' Goose	*Chen rossii*	aquatic phase resting, grazing at pool edge	ls, sr, fm, eg, bv, fr
Western Canada Goose	*Branta canadensis moffitti*	aquatic phase resting, grazing at pool edge	vp, ls, fm, eg
Lesser Canada Goose	*Branta canadensis parvipes*	aquatic phase resting, grazing at pool edge	vp, ls, fm, eg
Taverner's Canada Goose	*Branta canadensis taverneri*	aquatic phase resting, grazing at pool edge	vp, ls, sr, fm, eg
Cackling Canada Goose	*Branta canadensis minima*	aquatic phase resting, grazing at pool edge	vp, sr, ls, fm, eg, bv, fr
Aleutian Canada Goose	*Branta canadensis leucopareia*	aquatic phase resting, grazing at pool edge	sr, eg, wg
Wood Duck	*Aix sponsa*	aquatic phase feeding, resting, pair pond	vp, ls, fm
Green-winged Teal	*Anas crecca*	aquatic phase feeding, resting, pair pond	vp, ls, sr, fm, eg, wg
Mallard	*Anas platyrhynchos*	aquatic phase feeding, resting, pair pond, nest at pool edge	vp, ls, sr, fm, eg, wg, bv
Northern Pintail	*Anas acuta*	aquatic phase feeding, resting, pair pond	vp, ls, sr, fm, eg, wg
Cinnamon Teal	*Anas cyanoptera*	aquatic phase feeding, resting, pair pond	vp, ls, sr, fm, eg, wg
Northern Shoveler	*Anas clyeata*	aquatic phase feeding, resting, pair pond	vp, ls, sr, fm, eg, wg
Gadwall	*Anas strepera*	aquatic phase feeding, resting, pair pond	vp, ls, sr, fm, eg, wg
Eurasian Wigeon	*Anas penelope*	aquatic phase resting, grazing at pool edge, pair pond	ls, sr, eg, wg
American Wigeon	*Anas americana*	aquatic phase resting, grazing at pool edge, pair pond	vp, ls, sr, fm, eg, wg
Ring-necked Duck	*Aythya collaris*	aquatic phase feeding, resting	vp, fm
Common Goldeneye	*Bucephala clangula*	aquatic phase feeding, resting	vp, ls, fm
Bufflehead	*Bucephala albeola*	aquatic phase feeding, resting	vp, fm
Hooded Merganser	*Lophodytes cucullatus*	aquatic phase resting	vp
Common Merganser	*Mergus merganser*	aquatic phase resting	vp, fm
Ruddy Duck	*Oxyura jamaicensis*	aquatic phase feeding, resting	vp, fm
Turkey Vulture	*Cathartes aura*	use of mima mounds and vernal pool shoreline[4]	fm
White-tailed Kite	*Elanus leucurus*	flyover/foraging	ls
Bald Eagle	*Haliaeetus leucocephalus*	use of mima mounds and vernal pool shoreline[4]	fm
Northern Harrier	*Circus cyaneus*	flyover/foraging	vp, ls, sr, fm, eg, wg
Swainson's Hawk	*Buteo swainsoni*	flyover/foraging	ls, eg, wg
Red-tailed Hawk	*Buteo jamaicensis*	use of mima mounds and vernal pool shoreline[4]	vp, ls, sr, fm, eg, wg
Ferruginous Hawk	*Buteo regalis*	use of mima mounds and vernal pool shoreline[4]	fm
Rough-legged Hawk	*Buteo lagopus*	flyover/foraging	vp, ls, fm, eg
Golden Eagle	*Aquila chrysaetos*	use of mima mounds and vernal pool shoreline[4]	fm
American Kestrel	*Falco sparverius*	flyover/foraging	vp, ls, sr, fm, eg, wg
Merlin	*Falco columbarius*	flyover/foraging	fm
Peregrine Falcon	*Falco peregrinus*	flyover/foraging	ls, sr, eg
Prairie Falcon	*Falco mexicanus*	flyover/foraging	vp, fm, eg
American Coot	*Fulica americana*	aquatic phase resting, grazing at pool edge	vp, ls, sr, fm, eg, wg
Lesser Sandhill Crane	*Grus canadensis canadensis*	aquatic phase feeding	ls, eg
Greater Sandhill Crane	*Grus canadensis tabida*	aquatic phase feeding	ls, eg
Black-bellied Plover	*Pluvialis squatarola*	feeding on shoreline and mudflats, nest at pool edge	eg
Killdeer	*Charadrius vociferus*	feeding on shoreline and mudflats	vp, ls, sr, fm, eg, wg

TABLE 1. Annotated list of vernal pool birds (continued)[1].

Birds	Species[2]	Observation notes	Observation location[3]
Mountain Plover	*Charadrius montanus*	feeding on shoreline and adjacent alkali meadows and grasslands	eg
Black-necked Stilt	*Himantopus mexicanus*	aquatic phase feeding, nest at pool edge	sr, eg, wg
American Avocet	*Recurvirostra americana*	aquatic phase feeding, nest at pool edge	sr, eg, wg
Greater Yellowlegs	*Tringa melanoleuca*	aquatic phase feeding	vp, ls, sr, fm, eg, wg
Spotted Sandpiper	*Actitis macularia*	feeding on shoreline and mudflats	vp, ls, fm, eg
Willet	*Catoptrophorus semipalmatus*	feeding on shoreline and mudflats	eg
Whimbrel	*Numenius phaeipus*	feeding on shoreline and mudflats	vp, sr, fm, eg
Long-billed Curlew	*Numenius americanus*	feeding on shoreline and mudflats	vp, sr, fm, eg
Western Sandpiper	*Calidris mauri*	feeding on shoreline and mudflats	vp, ls, sr, fm, eg, wg
Least Sandpiper	*Calidris minutilla*	feeding on shoreline and mudflats	vp, ls, sr, fm, eg, wg
Dunlin	*Calidris alpina*	feeding on shoreline and mudflats	vp, ls, sr, fm, eg, wg
Long-billed Dowitcher	*Limnodromus scolopaceus*	feeding on shoreline and mudflats	vp, ls, sr, fm, eg, wg
Morning Dove	*Zenaida macroura*	nest at vernal pool edge	vp
Burrowing Owl	*Athene cunicularia*	nest in mima mounds	fm, eg
Short-eared Owl	*Asio flammeus*	grasslands near vernal pools	vp
Lesser Nighthawk	*Chordeiles acutipennis*	nest in dry vernal pool bed and adjacent alkali meadows	eg
Black Phoebe	*Sayornis nigricans*	in willows and on fences near pools	ls, sr, eg, wg
Western Kingbird	*Tyrannus verticalis*	on fences near pools	vp, ls, sr, fm, eg, wg
Horned Lark	*Eremiphila alpestris*	use of dry vernal pool bed, nest at pool edge	vp, fm, eg
Tree Swallow	*Tachycineta bicolor*	flyover/foraging	wg
Cliff Swallow	*Hirundo pyrrhonta*	nest material from shoreline and mudflats	vp, ls, sr, fm, eg, wg
American Crow	*Corvus brachyrhynchos*	flyover	ls, eg
Common Raven	*Corvus corax*	flyover/foraging	sr, fm
Mountain Bluebird	*Sialia currucoides*	on fence next to pool	vp, fm
American Pipit	*Anthus rubescens*	feeding on mudflats and dry vernal pool bed	vp, sr, fm, eg
Loggerhead Shrike	*Lanius ludovicianus*	on fence next to pool	vp, ls, sr, fm, eg, wg
Yellow-rumped Warbler	*Dendroica coronata*	in willows near pools	vp, ls, sr, fm, eg, wg
Lark Sparrow	*Chondestes grammacus*	habitat adjacent to pool	ls, wg
Savannah Sparrow	*Passerculus sandwichensis*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
Grasshopper Sparrow	*Ammodramus savannarum*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
Song Sparrow	*Melospiza melodia*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
Lincoln's Sparrow	*Melospiza lincolnii*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
Golden-crowned Sparrow	*Zonotrichia atricapilla*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
White-crowned Sparrow	*Zonotrichia leucophrys*	habitat adjacent to pool	vp, ls, sr, fm, eg, wg
Red-winged Blackbird	*Agelaius phoeniceus*	feeding on mudflats and dry vernal pool bed	sr, eg
Tricolored Blackbird	*Agelaius tricolor*	feeding on dry vernal pool bed	eg
Western Meadowlark	*Sturnella neglecta*	feeding on mudflats and dry vernal pool bed	vp, ls, sr, fm, eg, wg
Brewer's Blackbird	*Euphagus cyanocephalus*	feeding on mudflats and dry vernal pool bed	sr
Brown-headed Cowbird	*Molothrus ater*	feeding in adjacent habitats	ls, sr, eg, wg
Northern Oriole	*Icterus galbula*	cottonwood tree near pools	fm
Lesser Goldfinch	*Carduelis psaltria*	on thistles next to vernal pools	ls, wg

[1] Raveling and Silveira (unpublished data), Silveira (unpublished data).
[2] Numerical analysis: 24 families; 56 genera; 81 species; 7 subspecies; 86 total taxa; 44 waterbirds; 42 landbirds; 10 special status species.
[3] Sacramento Valley: Vina Plains Preserve (vp), Sacramento National Wildlife Refuge (sr), Llano Seco Rancho (ls). San Joaquin Valley: Flying M Ranch (fm), East Grasslands (eg), West Grasslands (wg) (combined, eg and wg comprise the Grasslands Ecological Area). Northeastern California: Big Valley (bv), Fall River Valley (fr).
[4] Flyover/foraging at all Central Valley locations.

TABLE 2. Waterfowl and shorebird diversity in foraging behaviors and habitats for selected species[1].

Species	Foraging Guild	Substrate	Water Depth
Snow Goose	terrestrial/aquatic–gleaner/grubber	tubers, seeds, herbs	dry, mudflat, < 10 inches
Ross' Goose	terrestrial–grazer/gleaner/grubber	short grasses, seeds, roots	dry, mudflat
Western Canada Goose	terrestrial/aquatic–grazer/gleaner	short grasses, seeds	dry, mudflat, < 10 inches
Cackling Canada Goose	terrestrial–grazer/gleaner	short grasses, seeds	dry, mudflat
Wood Duck	aquatic/ terrestrial–gleaner	open water in riparian vegetation	< 10 inches
Green-winged Teal	aquatic–gleaner	open water, dense vegetation	< 10 inches
Mallard	aquatic–gleaner	small openings in dense vegetation	< 10 inches
Northern Pintail	aquatic–gleaner	open water with short, sparse vegetation	< 10 inches
Cinnamon Teal	aquatic–strainer/gleaner	open water, small openings in vegetation	< 10 inches
Northern Shoveler	aquatic–strainer/gleaner	open water, small openings in vegetation	< 10 inches
American Wigeon	aquatic/terrestrial–gleaner/grazer	small openings in vegetation, open water, short grasses	dry, mudflat, < 10 inches
Ring-necked Duck	aquatic–gleaner	scattered dense emergent vegetation	> 10 inches
Killdeer	terrestrial/aquatic–gleaner	short, sparse herbs open water	dry, mudflat
Mountain Plover	terrestrial/aquatic–gleaner	short, sparse herbs open water	dry, mudflat (alkali)
Black-necked Stilt	aquatic gleaner	open water	< 6 inches
American Avocet	aquatic sweeper	open water	< 8 inches (alkali)
Greater Yellowlegs	aquatic gleaner	open water	< 6 inches
Long-billed Curlew	terrestrial/aquatic–gleaner/prober	open water	dry, mudflat, < 3 inches
Western Sandpiper	aquatic–prober/gleaner	open water	mudflat, < 4 inch
Dunlin	aquatic–prober/gleaner	open water	mudflat, < 4 inches
Long-billed Dowitcher	aquatic–prober/gleaner	open water	mudflat, < 4 inches

[1] After Fredrickson and Reid (1988a) and Helmers (1992).

Reid, 1993). Northern Shoveler (*Anas clypeata*) and Cinnamon Teal (*Anas cyanoptera*) strain micro-organisms from the waters surface while Northern Pintail (*Anas acuta*) and Green-winged Teal (*Anas crecca*), with slender bills, tip for seeds, plants, and invertebrates from the pond bottom and water column (Lack, 1974). American Wigeon have short bills adapted for terrestrial grazing, while mallards are generalists, foraging in many habitats. Snow Geese (*Chen caerulescens*) have stout bills suited for digging tubers and grubbing for seeds in aquatic and terrestrial habitats, while Canada Geese and Ross' Geese (*Chen rossii*) have bills adapted for terrestrial grazing (Owen, 1980). White-fronted Geese (*Anser albifrons*) are generalists, with bill morphology suited to grazing and grubbing. Plovers (*Charadrius* spp.) have bill shapes and leg lengths adapted for terrestrial gleaning, Curlews (*Numenius* spp.) for terrestrial and aquatic probing and gleaning, Sandpipers (*Calidris* spp.) for aquatic probing, yellowlegs (*Tringa* spp.) for aquatic gleaning, and Avocets for aquatic sweeping (Helmers, 1992). Bill morphologies and foraging behaviors have been selected for various feeding substrates and water depths so that avian species are adapted to a variety of microhabitats (Table 2). These are some of the explanations of why so many avian species can coexist in the seemingly small wetland environment of vernal pool landscapes during a critical period in their annual cycle.

The Annual Energy Cycle in Waterfowl

Birds have adapted to exploit resources associated with various stages of their life histories. These stages include reproduction, molt, migration, and maintenance (Bellrose, 1980) and are identified by an annual cycle of behavioral and physiological changes and their associated energetic costs and nutrient demands (Fredrickson and Reid, 1988a). Energy requirements, habitat, and food selection are different depending on species, age, sex, molt, pair status, and disturbance (Fredrickson and Reid, 1988a; Heitmeyer and Raveling, 1988) (Table 3). After fall migration (August–September), pintail in the Central Valley are in poor body condition, but replenish lost body reserves during early winter (October–November). The cold winter period (December–January) causes declines in body condition. Weight gains

TABLE 3. Diets of selected waterfowl species during their annual behavioral and energy cycle[1].

Species	Reproduction	Fall Migration\ Prealternate Molt	Winter Maintenance	Prebasic Molt	Spring Migration
Cackling Canada Goose[2]	grasses, sedges	seeds, grasses	seeds, grasses		grasses
Northern Pintail	invertebrates	moist-soil seeds[3], invertebrates	rice, emergent seeds[4]	midge larvae[5], other invertebrates	moist-soil seeds, invertebrates[6], midge larvae
American Wigeon	invertebrates, grasses	emergent seeds, submerged plants	rice, emergent plant stems	grasses, sedges, midge larvae	grasses, invertebrates
Northern Shoveler	zooplankton, other invertebrates	emergent seeds, zooplankton	emergent seeds, rice	zooplankton	zooplankton, other invertebrates

[1] Adapted from Raveling (1979a), Fredrickson and Reid (1988a), and Heitmeyer and Raveling (1988).
[2] Geese molt during the nesting period.
[3] Primarily seeds from pricklegrasses (*Crypsis schoenoides, C. vaginiflora*), watergrass (*Echinochloa crus-galli*), smartweeds (*Polygonum* spp.), and spike-rushes (*Eleocharis* spp.).
[4] Primarily seeds from hard-stemmed tule (*Scirpus acutus* var. *occidentalis*) and alkali bulrush (*Scirpus maritimus*).
[5] Primarily Chironomidae.
[6] Primarily copepoda, cladocera, and eubranchiopoda.

and nutrient reserves build during the spring (February–March) prior to migration and reproduction (Miller, 1986; Heitmeyer and Raveling, 1988). Cackling Canada Geese (*Branta canadensis minima*) breed on the west coast of arctic Alaska (May–August) and arrive on their California wintering grounds during October. Fall migration and winter are periods of nutrient deficiency for cacklers. Prior to spring migration and reproduction (February–April) cacklers increase body condition and build nutrient reserves to reach their arctic breeding grounds in good condition (Raveling, 1978; 1979a; 1979b).

Seasonal wetlands are critical to waterbird survival and recruitment (Fredrickson and Reid, 1988b; Reid, 1993). Reproduction, molt, and flight (e.g., migration and courtship flights) are the most energy consuming activities (Fredrickson and Reid, 1988a). Depending on habitat quality and disturbance to feeding and resting birds, it takes from three to eight days for a mallard to replenish fat reserves used during an eight hour flight (Fredrickson and Reid, 1988a). Therefore, small, isolated, intact vernal pools become important refueling stations that enhance survival of migratory waterbirds because they provide food and rest.

Nutrient reserves obtained during spring are critical to successful reproduction on northern breeding areas (Krapu, 1981). Ducks shift from a diet of seeds to invertebrates during a period of spring protein loading (Taylor, 1978). Aquatic invertebrates (insects, crustaceans, snails, annelids) comprise the largest component of foods for Pintails during egg formation (Krapu, 1974a), and anostracans comprise two-thirds of the invertebrate diet of breeding hen Gadwalls (Serie and Swanson, 1976). For dabbling ducks, diets consisting of invertebrates contain all the essential amino acids and calcium necessary for maximum egg production (Krapu, 1974b; Krapu and Swanson, 1975). Temporary wetlands provide high protein invertebrate foods for breeding ducks (Swanson et al., 1974; Fredrickson and Reid, 1988b, 1988c; Reid, 1985). Vernal pools are known to contain a diversity of aquatic invertebrates adapted to this ephemeral wetland environment (Alexander, 1976, Eng et al., 1990) and are therefore important to breeding and migratory waterfowl. During spring, paired dabbling ducks often seek small isolated wetlands (Heitmeyer and Vohs, 1984). Thus, vernal pools also function as pair water in the breeding territory of local nesting ducks such as Mallards and Cinnamon Teal.

Canada Geese shift from a predominately carbohydrate rich seed diet in autumn and early winter to one of high protein grasses in late winter and spring (Raveling, 1979a). They graze for prolonged periods (McLandress and Raveling, 1981a; Johnson and Raveling, 1988) accumulating body reserves which are necessary for long distance spring migration and reproduction (Barry, 1962; Ankney and MacInness, 1978; Raveling, 1978; 1979b; McLandress and Raveling, 1981b). Grasslands and alkali meadows associated with vernal pool landscapes in

California also provide critical spring foraging habitat for Cackling Canada, Ross', and Pacific White-fronted geese. Additionally, migratory shorebirds use temporary wetlands as stopover areas that may provide enough food to nearly double their body mass in a relatively short period (Helmers, 1993). In the Central Valley, vernal pools are important spring stopover areas for migrating shorebirds.

Vernal Pool Habitats and Wetland Complexes in the Central Valley

California has a variety of wetlands and associated terrestrial natural communities in the Central Valley (Holland, 1978; 1986; Sawyer and Keeler-Wolf, 1995). These include riparian forest and scrub habitats, valley oak overflow lands, freshwater emergent wetlands, vernal pools, and alkali sinks and meadows. Managed seasonal and permanent marshes on valley floor, federal and state refuges and private duck clubs, and reservoirs and stock ponds on valley terrace cattle ranches are very significant wetlands. These various types of natural and managed wetland habitats occur in various patterns and densities forming large wetland complexes (Fredrickson and Reid, 1986). Wetland complexes provide migratory birds with a mosaic of habitats where avian species can satisfy different behavioral and energetic needs during their annual cycle (White and James, 1978; Fredrickson and Reid, 1988a; 1988b; Heitmeyer and Raveling, 1988). Migratory waterfowl use a variety of these habitats in their ancestral Central Valley wintering grounds (Heitmeyer et al., 1989). Mallards, Gadwall (*Anas strepera*), and Cinnamon Teal are more common in densely vegetated (closed) wetlands; Pintail and Shovelers in open marshes; and, Wigeon and Green-winged Teal in both open and closed wetlands, and inundated alkali meadows (Heitmeyer and Raveling, 1988). Waterfowl are adaptable species and use wetlands in accordance with seasonal and climatological driven wetland dynamics (Heitmeyer and Vohs, 1984). For example, a variety of wetland types and associated foods are used by waterfowl when available on the Sacramento National Wildlife Refuge (Heitmeyer and Raveling, 1988) (Table 4). Cackling Canada Geese begin grazing in alkali meadows and grasslands associated with vernal pools after the onset of winter rains, typically in December and January. Food resources in managed wetlands become depleted by waterfowl during fall and winter. During February and March, vernal pools are used especially by Mallards, Wigeon, Green-winged Teal, Shovelers, Cinnamon Teal, and Pintail. Long-billed Dowitchers (*Limnodromus scolopaceus*), Greater Yellowlegs (*Tringa melanoleuca*), Avocets, and Black-necked Stilts (*Himantopus mexicanus*) begin feeding in pools shortly after they fill with winter rains. However, greatest shorebird use coincides with the peak migration of Dunlin and other sandpipers in March and April (Figure 1).

The importance of valley basin wetlands is well recognized, with National Wildlife Refuges and State Wildlife Areas established for migratory bird and endangered species conservation. Although separated from valley basin wetland complexes by agriculture and urbanization, large vernal pool complexes support significant waterbird use on the valley's eastern edge (Medeiros, 1976). During a survival investigation of cackling geese (Raveling et al., 1992) individually marked cacklers were observed using both valley basin and valley terrace wetlands in the northern Sacramento and northern San Joaquin Valleys (unpublished data). A brief description of these major wetland complexes follows.

Sacramento Valley. Significant wetlands are found on National Wildlife Refuges (NWR) managed by the U. S. Fish and Wildlife Service (USFWS), State Wildlife Areas (WA) and Ecological Reserves (ER) managed by the California Department of Fish and Game (CDFG), and Preserves owned by The Nature Conservancy (TNC). In the northern Sacramento Valley, Sacramento National Wildlife Refuge Complex (NWRC) is composed of several refuges and refuge units. These include Sacramento NWR, Delevan NWR, Colusa NWR, Sutter NWR, Butte Sink NWR, and Sacramento River NWR. In addition, the refuge holds conservation easements in privately owned lands (primarily duck hunting clubs) in Butte Sink, Willow Creek–Lurline, and North Central Valley National Wildlife Management Areas. Sacramento NWRC interests cover 55,000 acres in Tehema, Butte, Glenn, Colusa, and Sutter Counties. Gray Lodge WA, Upper Butte Basin WA, and Table Mountain WA (Butte County), Dales ER, Kopta Slough, Vina Plains (Tehama County), and Stony Creek Preserves (Glenn County) comprise significant non-federal wetlands. The Jepson Prairie Preserve (Solano County), and Stone Lakes NWR/Morrison Creek–Cosumnes River complex (Sacramento County) comprise significant vernal pool landscapes and habitat in the southern Sacramento Valley.

Vernal pool landscapes with significant waterbird use are located on Sacramento, Delevan, Colusa, and the Sacramento River (Llano Seco Unit and Ranch) NWRs, Dales ER, and Vina Plains and Jepson Prairie Preserves. These vernal pools occur on a variety of landforms with associated durapans and representative soils that include alluvial, basalt flow, and alkali pool landscapes (Holland, 1978; 1986; Sawyer and Keeler-Wolf, 1995). Rare and endangered flora and invertebrate fauna are protected at these sites (Stone et al., 1988; The Nature Conservancy, 1988; University of California, 1988; Oswald and Ahart, 1995; Oswald and Silveira, 1995). On Sacramento NWRC, peak waterfowl populations occur in December averaging 1,500,000 ducks and 400,000 geese. Peak shorebird use occurs in April with an average of 36,500 birds.

San Joaquin Valley. Significant wetlands are found on NWRs, WAs and ERs, State Parks, and TNC Preserves. San Luis NWRC is composed of several refuges and refuge units. These include San Luis NWR, Kesterson NWR, Merced NWR, and San Joaquin River NWR. Additionally, the refuge holds conserva-

TABLE 4. Wetland habitat types at Sacramento National Wildlife Refuge, inundation period, foods, and waterbird use during wet phase of marsh cycle[1].

Wetland Type	Inundation Period	Plants	Animal Foods	Birds	Bird Use
Alkali meadow	Nov–Apr 0–2 wks	saltgrass, chenopods, goldfields, grasses, gumweed	beetles, spiders, bees	cackling geese, coots, curlews, plovers, wigeon	feeding
Vernal pool	Nov–Apr 0–6 mos	downingia, navarretia, popcorn flower, coyote thistle, pricklegrass,	tadpole and fairy shrimp, cladocera, copepods, beetles	dabbling ducks, shorebirds, coots, geese	feeding, roosting
Seasonal flooded marsh – alkali bulrush	Aug/Nov–Mar/ Apr, 4–8 mos	alkali bulrush, spikerush, pricklegrass	fairy shrimp, cladocera	snow geese, shoveler, teal, avocets	feeding, roosting
Seasonal flooded marsh – moist-soil – sparse vegetation	Aug/Nov–Mar/ Apr, 4–8 mos	pricklegrass, smartweed, tules	minnows, snails, crayfish, insects, cladocera	shorebirds, geese, dabbling ducks, diving ducks, coots, herons,	feeding, roosting
Seasonal flooded marsh – tule – dense vegetation	Aug/Nov–Mar/ Apr, 4–8 mos	tules, cattails, pricklegrass, smartweed	minnows, snails, crayfish, insects, chironomids	dabbling ducks, tule geese, rails, herons, egrets, bitterns	feeding, roosting
Watergrass	Aug–May, 8 mos Jun/Jul, 1–2wks	watergrass, smartweed	minnows, snails, crayfish, insects, chironomids	mallards, curlews, ibis, rails, herons, egrets	feeding, roosting
Permanent pond	Jan–Dec 12 mos	tules, cattails, pondweed, arrowhead	carp, minnows, snails, crayfish, insects	dabbling & diving ducks, pelicans, cormorants, grebes, coots, herons,	feeding, roosting, nesting
Riparian scrub	Jan–Dec 3–12 mos	willows, cottonwoods, tules	carp, minnows, snails, crayfish, insects	mallard, wood duck, herons, egrets	feeding, roosting, nesting

[1] After Fredrickson and Reid (1986) and Sacramento National Wildlife Refuge Marsh Management Plan (U.S. Fish and Wildlife Service, 1996).

tion easements on privately owned lands (primarily duck hunting clubs and cattle ranches) in Grasslands National Wildlife Management Area. San Luis NWRC interests cover 85,000 acres in Merced and Stanislaus Counties. Los Banos WA, North Grasslands WA, and Great Valley Grasslands State Park (Merced County), with San Luis NWRC comprise over 160,000 acres of the Grasslands Ecological Area. TNC holds a conservation easement on the Flying M Ranch in eastern Merced County, where the largest intact vernal pool landscape in the Central Valley exists.

Vernal pool landscapes with significant waterbird use are located throughout the Grasslands Ecological Area and Flying M Ranch and vicinity. These vernal pools represent all landforms with associated durapans and representative soils and topography of the northern San Joaquin Valley that include alluvial, aeolian, and alkali pool landscapes (Holland, 1978; 1986; Holland and Dains, 1990). Rare and endangered, endemic flora and invertebrate and vertebrate fauna occur on these sites (Stone et al., 1988; Peters, 1993).

CONSERVATION ISSUES AND PRACTICE

Wetlands of the United States have declined with the advent of 19th century flood control and reclamation projects with California leading all states in wetland loses (Dahl, 1990). California's Central Valley has lost 95 percent of its wetland habitats, including vernal pools (Holland, 1978; Frayer et al.,

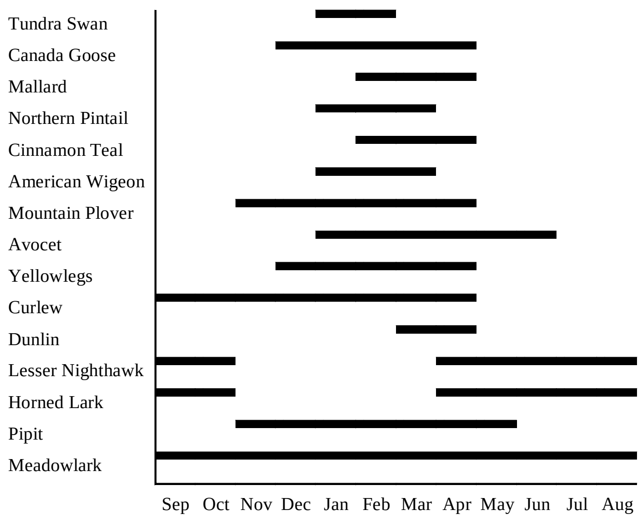

FIGURE 1. Typical periods of vernal pool habitat use for selected avian species.

1989; Kempka and Kollasch, 1990). However, the diversity of California wetlands may result in underestimates of actual wetland habitat losses (Mason, 1957; Ferren et al., 1996). Loss of natural wetlands has created an urgent need for better understanding of their value to the survival of migratory birds (Fredrickson and Drobney, 1979). For example, wetland hydrologic conditions on waterfowl wintering grounds influence not only winter and spring survival, but reproduction on breeding grounds as well (Heitmeyer and Fredrickson, 1981; Krapu et al., 1983; Reid, 1993).

Vernal pools are of strategic importance to the natural diversity of the Central Valley, including rare and endangered species, migratory birds, and waters of the United States. Bradford (1992) analyzed the distribution of 44 Central Valley endemic plants and found 14 to occur in vernal pools with an additional six from alkali lands associated with valley basin and basin rim vernal pools. An additional six plants and eight invertebrates, recently discovered and/or described from vernal pool and associated alkali meadow habitat, could be added to this analysis (Eng et al., 1990; Skinner and Pavlik, 1994).

Waterfowl and shorebirds may play an important role in the transport and dispersal of propagules among vernal pool complexes (Proctor, 1964; Proctor and Malone, 1965; Proctor et al., 1967) with important consequences for population and species level diversity of vernal pool plants and invertebrates. This is especially important for isolated habitats where extinctions can be offset by immigration (MacArthur and Wilson, 1967). Declines in avian use and associated local and long distance movements could have serious negative effects on vernal pool natural diversity. Waterfowl are long absent from many early 20th century California wintering areas (Grinnell et al., 1918).

On a local scale, vernal pools are part of a larger complex of wetland types (Table 4). On a regional scale, vernal pool landscapes support distant wetland complexes. The Vina Plains and Flying M Ranch/eastern Merced County are key waterfowl areas that enhance valley basin wetlands of the Sacramento NWRC and San Luis NWRC, respectively. Likewise, the Jepson Prairie and Stone Lakes NWR/Morrison Creek–Cosumnes River vernal pools provide important habitat for waterfowl that use the Suisun Marsh and northeast Delta, respectively. During periods of basin flooding on the valley floor, these alluvial and high terrace landscapes receive increased use by waterbirds that forage in shallow flooded and terrestrial habitats. On a continental scale, vernal pool landscapes provide critical links along the Pacific Flyway. Migratory birds must travel long distances between breeding and wintering areas. They cross international boundaries and are protected under the Migratory Bird Treaty Act of 1918. Vernal pools are of international importance for birds that migrate from Russia, Canada, Mexico, or Latin America. In fact, the Grasslands Ecological Area has been designated as part of the Western Hemispheric Shorebird Reserve Network (WHSRN). Other North American WHSRN sites in the Pacific Flyway include Mono Lake, San Francisco Bay, Grays Harbor in Washington, and Beaverhill Lake in Alberta. Over 90 percent of the continental waterfowl population is produced in northern latitudes while ninety-five percent of these birds winter in lower latitudes including California. Over 60 percent of the Pacific Flyway waterfowl population winters in the Central Valley (U. S. Fish and Wildlife Service, 1990). The seasonal nature and productivity of wetlands in general, and vernal pools and associated habitats (e.g., alkali meadows, grasslands) in particular, illustrate the importance of vernal pools as significant Central Valley wetlands.

Vernal pool landscape fragmentation results in physical and biological consequences (Saunders et al., 1991). They include a potential decline in waterfowl, shorebird, rare plant, and anostracan populations resulting from habitat loss as well as decreased use by avian species due to habitat degradation. Human disturbance, which interrupts feeding, resting, and reproductive behaviors, and uses energy associated with flight, has been identified as a major factor influencing the distribution of waterfowl (Wolder, 1993). Thus, urbanization resulting in small, fragmented vernal pool complexes may disrupt avian use while the creation of vernal pools on intact vernal pool landscapes only further degrades this unique natural resource (Jokerst, 1993). Vernal pool landscape fragmentation and mitigation has begun in the vicinity of the Vina Plains Preserve. Sacramento NWRC vernal pools occur on a refuge that is largely surrounded by rice agriculture. Stone Lakes NWR, the Morrison Creek–Cosumnes River vernal pools, and the Jepson Prairie are adjacent to one of the largest urban areas in the Central Valley. Land conversion on San Luis Island (Medeiros, 1979) has been abated through recent acquisition by San Luis NWRC. However, the Grasslands Ecological Area is broken by irrigated pasture and surrounded by row crops, vineyards, orchards, agricultural industry (e.g., poultry farms, dairies, vegetable and cogeneration plants), and threatened by urban sprawl. Continued pressure for flood control threatens to alter the natural hydrology and topography of eastern Merced County and Flying M Ranch vernal pools (Gunn, 1982). It is now of critical importance that measures be taken to conserve irreplaceable vernal pool landscapes in the Central Valley.

Vernal Pool Landscape Conservation Needs

Vernal pool landscapes are important to avian species. An existing body of knowledge supports the conservation of vernal pool plants, invertebrates, and landscapes (Holland and Jain, 1981; 1988; Griggs and Jain, 1983; U. S. Fish and Wildlife Service, 1985; Holland and Dains, 1990; Alexander and Syrdahl, 1992; Jokerst, 1993; Thorp and Leong, 1995). Conservation of waterfowl, other waterbirds, and wetland habitat (U. S. Fish and Wildlife Service, 1990) in vernal pool landscapes should be coordinated with greater issues of conservation biology, environmental law (e.g., Endangered Species Act, Clean Water Act), and national natural resource policy (e.g., 1994 Federal Native Plant Conservation Memorandum of Understanding, Ducks Unlimited Continental Plan).

Possible conservation objectives include: develop a vernal pool conservation team with expert representation in vernal pool ecology (biogeograpy and organismal biology) and wetlands conservation and coordinate through TNC scoping committee; identify large, intact vernal pool landscapes for conservation (i.e, Holland, 1998); determine important elements (i e., natural communities, rare species – NDDB); identify large, core vernal pool areas (e.g., Vina Plains, Jepson Prairie, Stone Lakes NWR/Morrison Creek–Cosumnes River, Flying M Ranch/ Southern Sierran Foothills, Grasslands Ecological Area) and develop conservation plans for these complexes and surrounding vernal pool landscapes; create patterns of land use practices around and within vernal pool landscapes consistent with agricultural and open space conservation – large preserves located in close proximity to other preserves sustain larger and more diverse numbers of plants and animals (Diamond, 1975; Pickett and Thompson, 1978); develop public and private partnerships (TNC, Ducks Unlimited, Trust for Public Land, American Farmland Trust); obtain conservation easements on large private cattle ranches via Land and Water Conservation Funds; monitor conservation agreements.

Avian Ecology and Vernal Pool Research Needs

Possible objectives include: identify migratory bird movement patterns, species abundance, and distribution in vernal pool landscapes including diurnal and nocturnal differences; determine abundance and distribution patterns of avian foods in vernal pool landscapes (e.g., vernal pool invertebrate phenology; behavioral and physiological waterfowl studies including esophageal and proximate analysis); determine threats and trends to spring migration habitats in the Central Valley and identify local and regional differences; monitor effects of livestock grazing and burning in vernal pool landscapes; determine effects of livestock grazing on aquatic invertebrates; determine the role of waterfowl and shorebirds in long term vernal pool conservation (e.g., waterbird dispersal of plant and animal propagules from the Orcuttieae and Eubranchiopoda).

Management of Vernal Pool Landscapes for Avian Diversity

It is very important to maintain the structural integrity and natural hydrologic regimes of vernal pool landscapes. Land leveling, excavation, and levee construction (e.g., to cultivate or increase basin size of vernal pools) are destructive to vernal pools through both direct impacts and indirect hydrologic affects. Artificial and prolonged flooding is detrimental to a flora and fauna that is adapted to short, cool season inundation periods followed by long, hot dry periods. Extended flooding will shift species composition of both plants and invertebrates to non-endemics. Cattails (*Typha* spp.) and alkali bulrush (*Scirpus maritimus*) invade vernal pools, and fairy shrimp (Anostraca) are eliminated under prolonged water regimes (Reid, 1985). The unique hydroperiod and shallow flooding of vernal pools results in abundant invertebrate prey and optimal foraging depths for waterfowl and shorebirds (Table 2). Excavation and levee construction for "wetland enhancement" would destroy these special features.

Management of Central Valley National Wildlife Refuges provides further examples of vernal pool management. The Llano Seco Unit of the Sacramento River NWR was established in 1991. The primary purposes of the refuge are to: protect endangered species and their habitats; protect migratory birds and their habitat; provide a place for management oriented research; and, provide the public opportunities for education and recreation in conservation oriented activities. A plan was developed which identifies natural resource management issues, objectives, and goals and guides refuge management activities (Silveira, 1992). A short grass association was identified as an important habitat for species such as Greater Sandhill Cranes (*Grus canadensis tabida*), Cackling Canada Geese, Long-billed Curlews (*Numenius americanus*), and Burrowing Owls, which the historic Llano Seco Rancho supported. Furthermore, the Arena Plains NWR was established in 1992 for similar purposes as the Llano Seco Unit. In addition to the above species, the Arena Plains NWR has occurrences of Kangaroo Rats (*Dipodomys* spp.), California Horned Lizards (*Phrynosoma coronatum frontale*), Mountain Plovers (*Charadrius montanus*), and native wildflowers, which all benefit from a short and/or sparse vegetation. Both refuges have vernal pools with associated California endemic tadpole and fairy shrimps and both refuges use livestock grazing programs for vegetation control to enhance native plant and wildlife habitats.

Livestock grazing and burning are important tools for managing grasslands, pastures, and vernal pools (Menke, 1992; Barry, 1995). Grazing has both negative and positive effects on wildlife habitat. Grazing in riparian habitats will degrade understory vegetation with negative impacts on breeding birds (Krueper, 1993). Grazing in prairie habitats during the breeding season reduces nesting cover resulting in increased predation and lower waterfowl production (Kirsch, 1969). However, certain guilds of migratory shorebirds require short and/or sparse foraging habitat (Baker and Baker, 1973; Helmers, 1992). Colwell and Dodd (1995) found greater shorebird species diversity and richness in grazed pastures and greater abundance of shorebirds in pastures containing livestock. Mountain Plovers wintering in the San Joaquin Valley prefer sparsely vegetated habitats such as alkali flats, recently burned and/or disked fields, and heavily grazed non-native annual grasslands (Knopf and Rupert, 1995). Cackling and Ross' geese require very short annual grasses during spring hyperphagia (Johnson and Raveling, 1988). Geese do not efficiently digest cellulose (Buchsbaum et al., 1986), therefore livestock grazing is an effective management tool for maintaining short, growing grasses with thin cell walls and highly digestible, nutritious compounds and elements.

Certain resident wildlife species also require sparse vegetation. For example, optimum habitat for the federal endangered Blunt-nosed Leopard Lizard (*Crotaphytus wislizenii silus*) consists of 30 to 50 percent bare ground (Chesemore, 1980). Kangaroo rats also require open habitats and show greater abundance in habitats managed by grazing. The removal of livestock from habitat containing seasonal pools has been reported to eliminate some populations of fairy shrimp due to increases in pool residual mulch (Bratton, 1990; Bratton and Fryer, 1990).

Livestock grazing is also reported to have beneficial effects on rare plants. Davis and Sherman (1992) demonstrated that the Sonoma Spineflower (*Chorizanthe valida*) decreased in cattle exclosures presumably from competition with non-native annual grasses. Muir and Mosely (1994) report mixed effects of livestock grazing on a rare plant of alkali seeps. Grazing from anthesis to seed set had negative effects on Alkali Primrose (*Primula alcalina*) while grazing after seed set and before anthesis created open ground which the species requires for germination.

It has been argued that grazing by large animals has been part of the California grassland ecosystem since the Pleistocene (Edwards, 1992). Grazing has been demonstrated to increase plant diversity and biomass (McNaughton, 1985). In fact, Menke (1992) has demonstrated the use of annual livestock grazing and periodic burns (every three years) in restoring native perennial bunchgrass on the Jepson Prairie Preserve. Livestock have also been used to reduce Yellow Starthistle (*Centaurea solstitialis*), a noxious weed. Intensive grazing from the rosette stage through bolting prior to spine development greatly reduces seed production and mature plant canopy (Thomsen et al., 1993).

Habitat management on the Sacramento National Wildlife Refuge Complex is monitored via a habitat management plan (Mensik and O'Halloran, 1990; U.S. Fish and Wildlife Service, 1996). Thus, the resulting effects of refuge management on wildlife and habitats are recorded for tracking and analysis so that management can be modified and improved if necessary. This assures conservation of migratory birds, endangered species and their various habitats.

There are examples of sound stewardship on private cattle ranches in the Central Valley. The Flying M Ranch, Llano Seco Ranch (Butte County), and Crane Ranch (Merced County), collectively, have vernal pools distributed on eight geomorphic surfaces. While cattle grazing is a primary objective, waterbird use remains high, rare vernal pool plants and shrimp are abundant, and noxious weeds are relatively scarce. Sound management is their desire. It reflects not only on their livelihood, but their love for the land. A bio-regional approach is necessary to determine objectives and set goals for long-term vernal pool conservation. However, private and public support for vernal pool landscape conservation must occur at a local level. Private landowners and local citizens must be given responsibility, with its obligations and rewards, for vernal pool ecosystem conservation.

Acknowledgments

I thank the following individuals for reviewing this paper and providing valuable comments and suggestions: Dr. Denton Belk, Session Chair for this conference; Dr. Edward C. Beedy, Jones and Stokes Associates; Raymond J. Bogiatto, California State University, Chico; Dr. David L. Chesemore, California State University, Fresno; Dr. F. Thomas Griggs, The Nature Conservancy, California; John G. Mensik, Sacramento National Wildlife Refuge Complex; and Dr. Frederic A. Reid, Ducks Unlimited, Western Regional Office.

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