THE GEOGRAPHIC AND EDAPHIC DISTRIBUTION OF VERNAL POOLS IN THE GREAT CENTRAL VALLEY, CALIFORNIA

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California is endowed with a wide array of plant communities, (Barbour and Major 1977), one of the most unique and distinctly Californian being vernal pools (Holland and Jain 1977). These ephemeral pools support a specially adapted florula of perhaps 200 species, including some of the state's rarest and most unusual plants (Powell 1974). Once widely distributed in much of the Central Valley (Hoover 1937), they have suffered considerable extirpation by agricultural development and urban expansion.

The purpose of this study was three-fold: 1) to map the current distribution of vernal pools in the valley, 2) to establish which soil associations support vernal pools today and 3) to estimate the area covered by pools in the pre-agricultural times so as to approximate the degree to which this habitat has been lost.

METHODS

The extensive nature of this survey required the use of aerial photography as an aid in mapping. Aerial imagery of agricultural and range lands is available at offices of the Agricultural Stabilization and Conservation Service (A.S.C.S.) in each county. These photos are of large enough scale (about 1:8,000) to clearly indicate vernal pools as blotchy light patches in a darker gray background of grassland. Furthermore, the photos usually have such prominent cultural features as towns, roads and reservoirs labeled. Section corners, township and range lines are usually identified, so that mapping is easily accomplished.

I visited the A.S.C.S. office in each of the twenty Central Valley counties and examined every photo in their collection. The A.S.C.S. photos gave excellent coverage of the entire valley: several counties had complete coverage, others excluded high mountain, forest, or desert lands (see Table 1).

Using a transparent plastic overlay I divided each section into ninths and counted the number of ninths which showed any sign of vernal pools. Thus, I generated frequency-density data for the entire valley on a one mile grid. Since the A.S.C.S. photos are organized by counties, I prepared shaded maps of each county and photographically reduced them to a scale of 1:500,000 before assembling the final map.

As each county map was prepared, I compared it with the Generalized Soil Map (Soil Conservation Service 1966 a-c, 1967 a-q) for that county. These maps indicate soil associations, broad groups of soils which have similar origins and properties. Unfortunately, different people compiled the maps for different counties. Similar soils in adjacent counties frequently had varied names. The list grew to include 108 soil series in 95 named associations by the time all twenty counties were scored. Many of these soil associations had similarities which allowed them to be grouped together; by studying the physiography, soil parent material and profiles of these soils as described in the report accompanying each map, I was able to group the associations together into ten categories which reflect major differences in soil type. These are summarized in Table 2. Each scored section was assigned to one of these larger categories to identify the relative abundances of the edaphic types or "settings" in which vernal pools occur (Table 3).

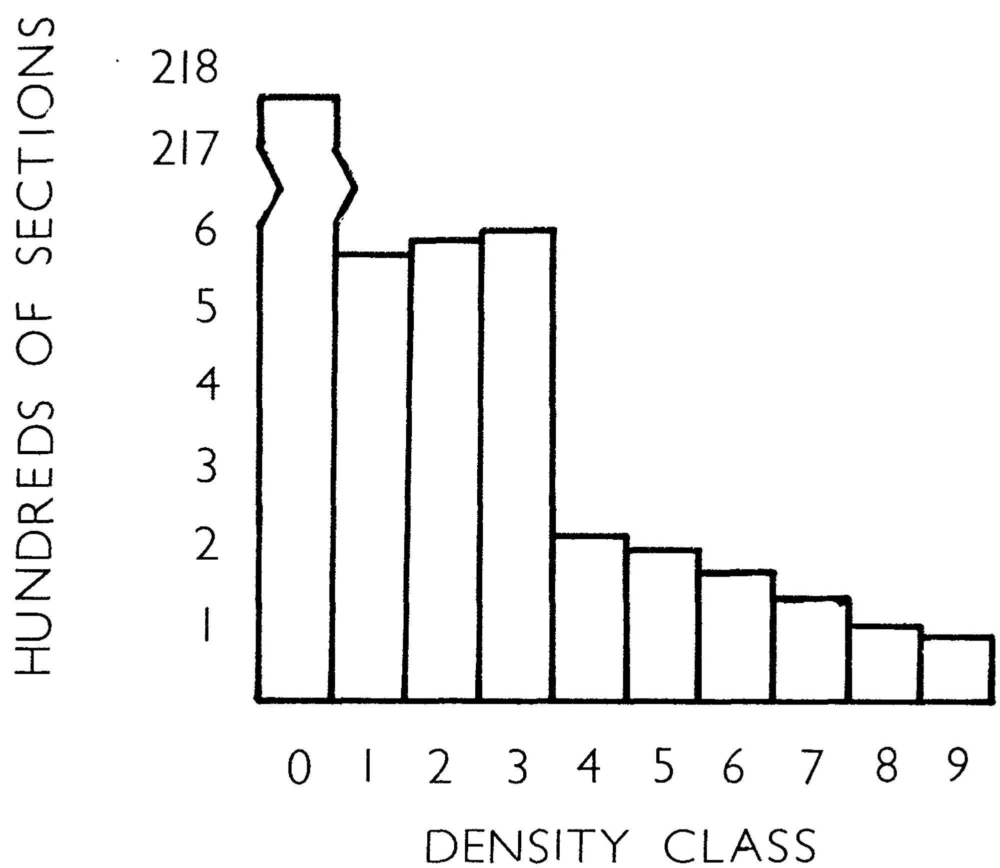
Since soil associations are defined to encompass similar soils, I assumed that those soils which now have pools on nondeveloped sites probably supported pools throughout their pre-agricultural distribution. By comparing the area of each association with the area which had pools as of the date of photography, I was able to estimate the percentage loss of this habitat for each association.

The four reconnaisance soil surveys covering the Central Valley (Holmes, et al., 1915; Nelson, et al., 1918; Holmes, et al., 1918; Nelson, et al., 1921) provided a second and independent approach to estimating the extent of habitat in pristine time. Although clearly out of date in terms of modern soil science, these old surveys have considerable historical value in describing the landscape as it appeared during the early decades of this century. Only the richest alluvial soils had been developed agriculturally at that time; much of what is under row crops today was then open range. These old surveys described the general topography and relief for each mapped member within each soil series. By carefully reading the soil descriptions for phrases like "hog-wallow," "low, ponded depressions," "hummocky microrelief," "pools form after winter rains," etc., I identified and tallied the areas for the soils which, judging from the descriptions, seemed to support vernal pools. This provided a check on my estimate derived from my study of the photographs.

RESULTS AND DISCUSSION

The maps of vernal pool distribution in the Great Central Valley are enclosed. Each cell on the map represents a section (1 mile square or approximately 259 ha). Except for southern Kern County, the entire map is based on the Mount Diablo base and meridian lines. There are nine shades of gray corresponding with the number of ninths of the section which had any identifiable vestige of vernal pools. Thus, darker sections represent more area under this type of habitat. Of the 24,424 sections surveyed, 2,654 (10.9%) had one or more pools.

Several general impressions emerge. There are still vernal pools in every Central Valley county. Some counties are predictably depauperate: Glenn, Colusa and Yolo Counties lack significant areas of hardpan soils; and as major farming areas, have little flat land outside of agricultural development. Although the habitat is more or less continuously extant through the entire length of the valley, it is quite fragmented. Fig. 1 shows the distribution of frequency classes for the entire map: 67% of the pool-bearing sections were assigned to the first three classes. Despite the overwhelming majority of low-frequency sections, a few counties have high average density. Dark patches are apparent in Tehama, Yuba, Solano and Madera Counties. Sacramento, Merced and Fresno Counties have many filled sections but do not appear as dark. This patchiness suggests an archipelago-like distribution of the habitat. These appearances are substantiated by the average density for the individual counties (Table 1): Yuba, Placer, Sacramento and Madera Counties have the highest average densities among the 20 Central Valley counties.



The overall picture is strikingly reminiscent of a bathtub ring around the margins of the valley, with an extra band through the center of the San Joaquin Valley. The majority of pools occur on the older alluvial terraces along the eastern margin of the valley, but they also occur on high terraces at the mouths of streams draining the eastern side of the inner Coast Ranges.

In the Sacramento Valley, defined here as the area from Shasta to Solano and Sacramento Counties, pools are mainly on soils of the Redding, San Joaquin and related high terrace series derived principally from acidic alluvium and having indurate iron or iron-silicate cemented hardpans. The Sutter Buttes of Sutter County are partially encircled by low terrace deposits, but here the soils are related to the Lewis series; these soils, transitional in nature between soils of the Madera and Fresno series, have weakly cemented lime-silicate hardpans and thus have an affinity with several San Joaquin Valley soils. Some of the pool-bearing terraces in parts of Shasta, Tehama. Butte, Yuba and Placer Counties have been buried by volcanic flows. These volcanics provide basic parent materials and an impervious rock substratum, in sharp contrast to the pedogenic hardpans common on the acidic alluvial terraces (Holland 1976). There are small pool-bearing patches of Corning soils in Yolo and Solano Counties, but most of the pools in Glenn, Colusa, Yolo and Solano counties occur on claypan soils (Solano, Capay and related series) formed on basin rims.

In the San Joaquin Valley (defined here as the region from Contra Costa and San Joaquin to Fresno County) the high east-side terraces are more dissected, producing a rolling terrain mantled with Whitney, Cometa, Montpellier, Rocklin and related series. Terrace-capping soils (Redding, San Joaquin, etc.) are still common, especially in Madera County, but the rolling topography of these dissected terraces provides an additional setting for vernal pools; the mouths of small watersheds in this rolling terrain were blocked by natural levees deposited by streams fed by Pleistocene runoff from the Sierra Nevada. This created vast vernal lakes like those near Hickman in Eastern Stanislaus County (Arkley 1964). It is interesting that these clay soils, which are perhaps less than 15,000 years old, provide the habitat for so many members of the tribe Orcuttieae, which represent an ancient component of the vernal pool florula (Crampton).

Just west of the terrace escarpment from Stanislaus County to Fresno County occurs a long strip of young alluvial soils. This area, which has been developed virtually completely for agricultural and urban uses, forms the eastern boundary of the basin areas. In the basins, vernal pools occur in two different settings. Alluvial soils related to the Fresno series have hardpans that are lime-silicate cemented and are usually somewhat saline or saline-alkaline; these might be classified as terrace deposits, but their formation under impaired drainage and their saline-alkaline chemistry make their inclusion in the basin soil group reasonable. In the San Joaquin Valley, vernal pools also occur on soils which formed in nondrained conditions under Typha-Scirpus marshes. Flood control, irrigation and reclamation projects have lowered the regional ground-water table in much of the San Joaquin basin to such a degree that the water table is above the soil surface only part of the year. Hence, there are new vernal pools developing out in the basins where marsh formerly occurred. These new pools are successional, rather than climax and should provide an exciting opportunity to study the floristics and population dynamic processes of colonization and speciation.

The virtually complete drainage and agricultural conversion of the Tulare and Buena Vista Lake basins in the southern San Joaquin Valley (Kings, Tulare and Kern Counties) has radically altered most of the area. The extant pools of this region occur mostly on older alluvial soils related to the Fresno and Lewis series along Cottonwood Creek in northern Tulare and adjacent Kings County and on the saline-alkaline soils of the basin rim west of Pixley. The valley floor in Kern County is virtually without pools. The few extant pools occur on alluvial terraces at the mouths of San Emigdio and Rag Canyons and in mountain valleys near Tehachapi and Glenville (Twissleman 1967).

The current distribution of vernal pools as mapped probably resembles the habitat's pristine distribution, but several qualifying statements are in order. Many currently pool-bearing sections are mostly cropland, with the pools surviving only in out-of-the-way corners. Thus, the modern distribution is considerably more fragmented. In addition, those nascent pools on Merced, Temple and related soils of the San Joaquin basin should be deleted from an estimate of the preagricultural distribution of the habitat, as these areas formerly supported marshes.

Of the nearly 5.34×10^6 ha mapped in the early reconnaisance surveys, 1.92×10^6 ha (about 36%) had descriptions suggestive of vernal pools. My survey of 6.33×10^6 ha indicated 2.31×10^6 ha (about 36%) might have supported pools; however, this includes some 6.27×10^5 ha of soils which should be deleted. Thus, my data imply that 1.68×10^6 ha, or about 31% of my survey area, might have supported pools. This discrepancy of percentages is an artifact of the larger area included in my survey. The aerial imagery included foothill regions which support no pools and which were omitted from the early surveys. Thus, I infer that about a third of the valley supported pools in pristine time. My survey indicates that nearly 10.9% of the sections had vernal pools as of the dates of photography; that is, about a third of the potential sections still had pools at that time. Note that some of the photos were ten years old when studied, hence my data tend to overestimate how much habitat remains.

CONCLUSIONS

The concentric zonation of species around individual vernal pools is a familiar feature to most California botanists, but probably few are aware of the concentric array of pool-bearing soils in the valley. The outermost ring is comprised of high terrace deposits of the Redding and related series having iron-silicate cemented pedogenic hardpans or by volcanic deposits related to the Tuscan and Toomes series. Next inward are lower old alluvial terraces with iron-cemented hardpans; these are the San Joaquin and related series; or where time has not allowed extreme profile development, the Hillgate and related soils. Next inward occur several claypan soils of the basin rims: these are the Solano and related series. In the San Joaquin Valley the lowest terraces have weakly silica-carbonate cemented indurate hardpans on the Fresno, Lewis and related soils. In the basins of the San Joaquin Valley a new type of vernal pool is forming today on soils which originally developed under saturated, marshy conditions but today have seasonal watertables favorable to the survival of typical vernal pool taxa.

Vernal pools, though still a relatively common microhabitat type feature in California, formerly enjoyed a much more continuous distribution in California's Great Central Valley. Agricultural and urban uses have encroached considerably on vernal pool-bearing soils, but about one-third of the pool area remains when the valley is considered on a section-wise basis. Pools, however, are considerably smaller than sections. Fig. 1 shows that nearly 2/3 of the pool-bearing sections were assigned to the classes 1 to 3 (i.e., only one, two or three of the ninths in a section had pools). This reflects many isolated pools in out-of-the-way corners of otherwise developed sections. If all ninths of these sections originally supported pools, I estimate that only about 12% (8903/73287) of the pools remained when the photographs were made. The need for an urgent conservation program to save them cannot be overemphasized.

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Table 1. Distribution of vernal pools in 20 counties of Great Central Valley, mapped from aerial photographs (Courtesy of A.S.C.S.).

County	Frequency class[a] 0	1	2	3	4	5	6	7	8	9	% of area surveyed	Year photo-graphy	Mean frequency
Shasta	926	34	45	30	9	7	5	1	2		27	1969	0.32
Tehama	1214	48	61	84	36	28	41	23	45	1	53	1972	0.94
Butte	772	40	48	43	11	7	4	2	1		56	1970	0.38
Glenn	1027	5	2	1	2						76	1970	t[b]
Colusa	1062	2	1	1							92	1970	t[b]
Sutter	449	23	15	8	1						100	1971	0.16
Yuba	318	16	21	22	16	9	16	10	4	12	70	1971	1.21
Placer	249	19	36	33	12	10	4	2	1		26	1971	1.38
Yolo	935	12	7	1							100	1971	0.03
Sacramento	503	104	87	57	38	25	21	24	13	7	100	1972	1.35
Solano	880	24	17	14	4	10	2	10	8	9	100	1972	0.41
San Joaquin	1216	29	11	8	2						100	1968	0.07
Contra Costa[c]	532	4	3	3	1						74	1966	0.04
Stanislaus	1340	54	44	15	4	4					100	1970	0.15
Merced	1485	63	73	116	39	51	35	18	6	1	100	1973	0.72
Madera	598	22	12	60	6	16	24	25	10	51	38	1973	1.44
Fresno	2564	39	39	55	10	7	2	14	3	8	46	1973	0.21
Tulare	1703	26	47	40	20	18	5	2	7	1	39	1973	0.28
Kings	1157	6	8	2	3	2	3				100	1971	0.06
Kern	3535	5	10	7	1						43	1973	0.01
Total	21770	575	589	600	215	195	162	132	100	91			0.46[d]

a) frequency classes refer to the number of ninths within a section with vernal pools

b) less than 0.01

c) includes 12 sections of eastern Alameda County

d) grand mean

Table 2. The principal edaphic settings of vernal pools in the Great Central Valley, California. Constituent associations are mapping units from the Soil Conservation Service Generalized Soil Maps for each of the 20 Central Valley Counties.

Group	Parent material and physiography	Type of impervious layer	Constituent associations
Redding	Mostly acidic alluvium on high old terraces.	Fe-Si cemented hardpan, claypan occasional.	Redding; Redding-Corning; Redding-San Joaquin-Rocklin; Redding-Igo; Redding-Pentz; Redding-Pentz-Peters; Corning-Hillgate; Corning-Keefers; Corning; Pentz-Pardee-Red Bluff; Red Bluff-Keefers; Whitney-Montpellier-Rocklin; Fiddymet-Trigo Rocklin; Cometa-Whitney; Cometa; Anita; Corning-Keefers; Clough-Palo Cedro; Porterville-Centerville; Newville-Nacimento; Delano-Cuyama.
San Joaquin	Mostly acidic alluvium on lower, old terraces	Fe cemented hardpan.	San Joaquin; San Joaquin-Alamo; San Joaquin-Ramona; San Joaquin-Madera; San Joaquin-Exeter; Exeter-San Joaquin; Glenn; Madera; Academy-Yokohl; Yokohl-Kimball.
Lewis-Fresno	Lowest ends of old, mixed alluvial terraces.	(Weakly) lime-silicate cemented hardpans.	Lewis; Lewis-Landlow; Landlow-Marvin; Fresno-El Peco; Fresno-El Peco-Pozo; El Peco; Dinuba; El Peco; Dinuba; Fresno-Traver; Waukena-Fresno.
Volcanics	Residual soils from basic extrusive rocks.	Shallow R-horizon.	Tuscan; Tuscan-Inks; Toomes; Toomes-Pentz Toomes-Inks; Toomes-Supan; Inskip.
Solano-Capay-Willows	Mixed sedimentary alluvium, on basin rims and in basins.	Clay, occ. silica-carbonate cemented. Saline and/or alkaline. Solonetz-like soils.	Solano-San Ysidro; Pescadero-Solano; Rossi-Waukena; San Ysidro-Antioch; Capay-Sacramento; Capay-Rincon; Capay-Clear Lake; Willows; Willows-Pescadero; Orestimba-Willows.

Table 2 (continued).

Group	Parent material and physiography	Type of impervious layer	Constituent associations
Hillgate	Sedimentary and granitic alluvium on low terraces and old fans, mostly in the Sacramento Valley.	Usually none, clay pans occ. Pools infrequent.	Hillgate-Arbuckle-Artois; Arbuckle-Kimball-Hillgate Tehama-Hillgate; Kimball-Placentia; Tehama-Plaza; Chular-Greenfield-Placentia; Tehachapi-Placentia; Churn-Perkins; Corning-Hillgate; Sehorn-Balcom.
Chino	Mostly granitic alluvium on basin rims and in basins.	Heavy soil, high water-table. Nascent pools.	Traver-Pond; Temple-Traver; Traver-Chino; Lethent; Grangeville-Temple; Merced-Temple; Temple-Chino; Merced-Chino; Rossi-Piper.
Residuals	Various igneous, sedimentary, or metamorphic rocks.	Shallow R-horizon. Pools infrequent.	Auberry-Fallbrook; Altamont-Diablo; Auburn-Whiterock; Auburn-Argonaut; Auburn-Brandy; Hornitos-Amador; Awanee-Sierra; Cibo-Porterville; Kettleman.
Aeolian	Wind-worked granitic sands.	Lime-cemented substratum.	Hillmar-Mocho; Hillmar-Delhi.
Alluvial	Recent mixed alluvium on young fans and recent flood plains.	Usually absent; pools rare.	Hanford-Hesperia; Hesperia-Traver; San Emigdio-Hesperia; Vina-Los Robles; Vina-Farewell.

Table 3. Number of sections classified by ten edaphic "settings" within each of the counties.

County	Redding	San Joaquin	Lewis-Fresno	Volcanics	Solano-Capay-Willows	Hillgate	Chino	Residuals	Aeolian	Alluvial
					Edaphic Setting					
Shasta	74			21		34		4		
Tehama	160			51		87				6
Butte	138			7						11
Glenn						10				
Colusa					4					
Sutter		9	28			10				
Yuba	51	41		6				28		
Placer	64	30		14		9				
Yolo	1				18			1		
Sacramento	183	172						21		
Solano	3				94			1		
San Joaquin	17	27	5		1					
Contra Costa[a]					11					
Stanislaus	86		13					22		
Merced	152	35	87		74		25	3	26	
Madera	61	71	88				6			
Fresno	13	24	50		7		35	10		38
Tulare	8	36	40				47		1	
Kings			5				15			
Kern		5				5	1			12
Total	1074	450	354	99	209	155	129	90	27	67

a) includes eastern Alameda County