Current Distribution and Historical Extent of Vernal Pools in Southern California and Northern Baja California, Mexico

Ellen T. Bauder and Scott McMillan

Department of Biology, San Diego State University, San Diego, CA 92182
(ebauder@sunstroke.sdsu.edu)

Abstract. Our primary goals are to reconstruct the historic distribution of vernal pools, to estimate losses of pool habitat, and to characterize important differences among pool types in the southern region of the California Floristic Province. Extensive losses of habitat, coupled with the high floral and faunal endemism of the pools, make an understanding of the historic patterns of pool and species distribution and the quality of losses in terms of distinctive pool types and species assemblages important in order to direct scientific studies, to design management plans and to set conservation priorities. To estimate the historical extent of vernal pools, we match known pool locations to soil series on the San Diego County soil maps. We focus on six soil series having phases with a gentle slope and low permeability. We assign urbanized lands to soil phases using indirect evidence, including 1928 aerial photographs, herbarium labels and local histories. The vernal pool habitat in San Diego County probably covered no more than 200 square miles prior to intensive cultivation and urbanization. A comparable analysis was not completed for the other Southern California counties because of the early and near complete loss of pools. Soil phase distributions are supplemented with sub-regional analyses of climatic variables and distributions of pool plant species in order to classify pools into four general types (coastal mesa, inland valley, inland mesa, and montane depression) and each type, in turn, into distinctive sub-types or phases. Narrowly endemic plant species are strongly correlated with soil type and climatic regime. We conclude that soils supporting pools were never extensive and have been almost completely lost to development. Unique pool sub-types may be at risk for elimination, along with the extinction of the narrow endemics they support.

Citation. Pages 56-70 *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

The necessary conditions—climate, topographic depressions and soils with poor drainage—for the formation of the ephemeral wetlands known as vernal pools, are all present in southern California and northern Baja California, Mexico, as they are in other parts of California and southern Oregon. Pools occur either on gently sloping mesas standing above the primary drainages or in valleys at the low end of a watershed. In the latter case, the pools may be quite large and warrant the name "vernal lake" rather than "vernal pool." Unlike the Great Valley, southern California and Baja California never had expanses of pools stretching for hundreds of miles. Pool landscapes are, and always have been, fragmented by mountains and the discontinuity of suitable soils and/or microtopography. This, coupled with a complex regional geology, produces great variation among pool groups in underlying parent material, soil properties, hydrology, micro- and landscape-level topography and sub-regional climate. Not surprisingly, distribution of the floral and faunal elements reflects the wide array of habitat conditions.

Our primary goals in this study are to reconstruct the historic distributions of vernal pools—especially in San Diego County; to estimate losses of pool habitat; and to characterize the important differences among pool types in southern California and northern Baja California, Mexico. We have made substantial progress in understanding the pre-urbanization distribution of vernal pools in San Diego County. Lack of information precluded the same depth of analysis for Orange, Los Angeles, and Riverside Counties. The current distribution of pools in Baja California probably comes much closer to the historic condition than it does anywhere else in our study area, although much exploration remains to be done. Quantifying losses has still eluded us, except to say that a very small percentage remain from the U.S./Mexico borderlands north, and those that remain are found in a disturbed and artificially fragmented landscape. The correspondence between plant species distributions and soil and climatic variables is strongly supported by our results. Further information on the hydrology and water chemistry of pools in different groupings would probably solidify our conclusions and provide insight into the distribution of vernal pool-dependent animals.

Methods

Reconstruction of Historic Distributions

Attempts to quantify the historic extent of vernal pools in San Diego County were begun in the late 1970s, stimulated by the state and federal listing of several vernal pool plants as endangered (Balko, 1979; Beauchamp and Cass, 1979; Villasenor and Riggan, 1979) and the recognition that habitat losses were already extensive. How much had been lost, the spatial distribution of losses and the quality of losses in terms of distinctive pool types and floral assemblages became important issues. Because vernal pool animals were little studied until recently, attention focused on the better-known plants. In 1979, Beauchamp and Cass (1979) completed a survey of San Diego County's pools for the California Department of Fish and Game (CDFG). They made an estimate of historic pool habitat in terms of "watershed acres," but it is not clear how they defined or calculated "watershed acres." Their number has been widely used as a baseline to calculate losses. About 10 years later, Oberbauer (pers. comm.) made an estimate of the original amount of pool habitat by outlining the primary areas with presumably suitable soil series and using a planimeter to estimate area. He has continued to update his maps by adding locations of pools mapped since 1979. Villasenor and Riggan (1979) estimated the surface area of ponding for pools in the area extending from just north of Los Peñasquitos Canyon (Del Mar Mesa) in the north to the San Diego River in the south, but made no attempt to estimate the number of pools or extent of pool habitat that may once have occurred in the area.

To reconstruct the historic distribution of vernal pools in San Diego County, we have essentially taken Oberbauer's approach, applied it more rigorously (except that we never reached the planimeter stage) and supplemented it with other tools. We began by studying maps indicating the locations of pools still remaining in San Diego County and adjacent areas in Orange and Riverside Counties, as well as verified locations of pools now lost. From this we constructed a map of the verified locations of pools (Figure 1). San Diego's pools have been carefully mapped during the last two decades by at least four major projects, including Beauchamp and Cass (1979), Villasenor and Riggan (1979), Bauder (1986), and the current regional multi-species planning efforts (Ogden, 1995; County of San Diego, 1997). By matching known pool locations to soil series—as shown on the county's Soil Survey maps (Bowman, 1973), we selected a limited number of soil series for closer analysis. Originally, we included any soil series that had low permeability, even though it was not associated with a subsurface clay or hardpan layer. Most of these soil series were discarded from further analysis because there was no compelling reason to believe they do or did support pools, or at least more than a very limited number of pools. Along the southern coast in San Diego County, the soil series could not always be identified because of urbanization in the early part of this century. To assign soil types to these areas, we used the soil phase of canyons incised into the coastal mesas with urbanized, unidentified soil series or we extrapolated from the soil mapping units of isolated, non-urbanized remnants.

In montane areas of San Diego County, detailed soil surveys have not been completed for the valleys and topographic depressions now supporting or believed to have supported vernal pools or lakes. Instead, these areas are assigned to general land categories such as "loamy alluvial" and "clayey alluvial." One exception is Cuyamaca Valley, where the California Department of Parks and Recreation (CDPR) had a soil survey completed of Cuyamaca Rancho State Park and adjacent lands (Borst, 1984). Soil surveys and maps for Orange County (Wachtell, 1978) and western Riverside County (Knecht, 1971) were examined as well, but not intensively. Soil surveys are not available for the areas of interest in northern Baja California, Mexico. We read student geological reports produced by undergraduate seniors majoring in geology at San Diego State University (Frazer, 1972; Craig, 1972). These reports are one of the requirements for a bachelor's degree in geological sciences.

Using the survey reports that accompany the soil maps of Orange, Riverside and San Diego Counties, we identified areas with soils suitable for the formation of vernal pools. We looked only at soil survey mapping units with slopes of 9% or less and a subsurface layer with permeability of 0.06 inches/hour or less (Table 1). We present here only the information collected on San Diego County. In some cases, extant pools are on soil mapping units not included in our analysis, which indicates one potential problem with our method. In general, the "missed" pools were mapped within an appropriate soil series but in a map unit having slopes greater than 9%. It is well recognized that the level of resolution of the soil maps is not sufficient to depict small, scattered patches of soils of different phases or even those belonging to different series. Therefore, mapping units may contain several phases of one soil series or a mixture of soil series, with the dominant series usually accounting for 75% or more of the area within the mapping unit polygon (Singer and Munns, 1991).

We looked at all the cismontane 7 1/2 minute quadrangle soil maps in San Diego County and outlined the polygons meeting our criteria. County-wide maps were created for each of seven soil types, including only the phases that met our criteria of slope and drainage (Table 1). These maps, along with the various reports cited above, provided us with the basis for our conclusions regarding the historical extent of pools, the spatial relationship of pool landscapes prior to urbanization, the degree of loss of pool habitat, and the association of plant taxa with specific soils. With these maps in hand, we more precisely

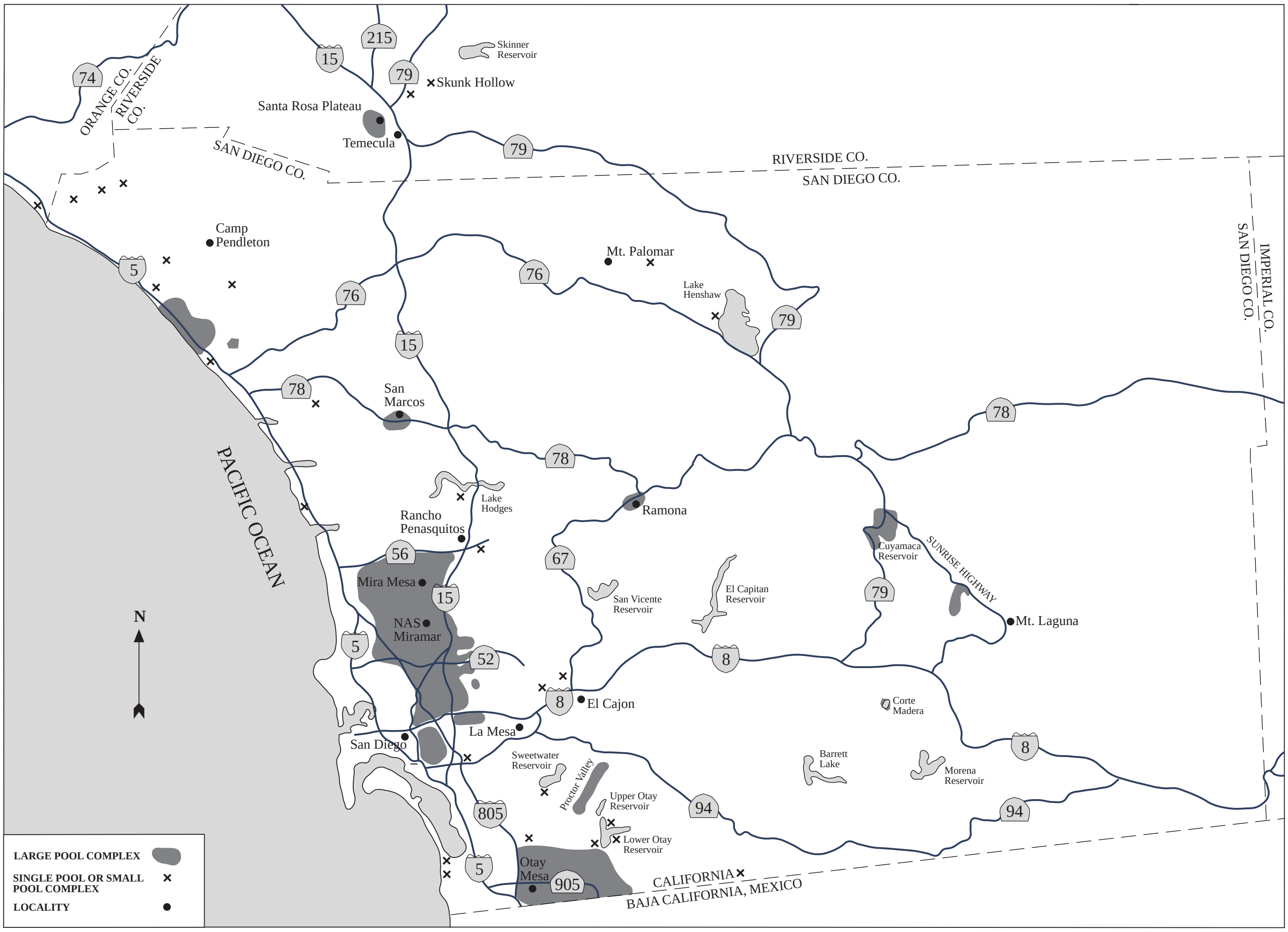

Figure 1. Verified locations of vernal pools in San Diego County and adjacent regions.

located all verified pool locations known to us and noted their degree of correspondence with soil mapping units.

To address the question of very early losses in areas with few, if any records of pools or pool plants, we chose three valleys having an appropriate soil series but a long history of cultivation as well. We also examined several urbanized areas, some with no soil series assigned, but suitable topography or proximity to areas with appropriate soils. We viewed aerial photos taken of these sites in 1928 (Cartographic Services, County of San Diego and Aerial Fotobank). These photos are available for most of the mountain crest-to-coast region. We looked primarily for evidence of Mima mound topography and slope contiguity with adjacent areas known to support pools. Photos taken in 1927 are available for Orange County as well, but time and budget constraints did not permit their inclusion in this study. Mima mound topography, also called Gilgai relief, is a distinctive pattern of micro-relief commonly associated with vernal pools in California (Hallsworth et al., 1955; Cox, 1984). The ground surface undulates with hemispherical soil mounds and isolated pool depressions that are frequently connected by swales or mini-drainages. The mounds are clearly visible in aerial photographs (Figure 2). San Diego State University now occupies the undeveloped area in the top half of the photograph. When mounds have been leveled or bladed, light dots appear in aerial photographs, as in the lower portion of Figure 2. As with the soil maps, the correspondence between pool presence and topographic indicators is not complete. Landscapes that are known to have pools may not be associated with mounds or the mounds may simply not show up in a particular aerial photograph. The photos also may suggest the presence of pools that are not actually there. To further document our conclusions about the historical presence of pools, we used herbarium records of obligate vernal pool taxa, old maps, and historical books and photos.

Quantifying losses is a very difficult task. The least complicated situation would be to use a planimeter around a large block of one pool-associated soil type that has been completely de-

TABLE 1 . San Diego County soil series with impermeable layers and slopes < 10% (Orange and Riverside Counties.)

SOIL SERIES	Symbol Of Mapping Unit	Symbol (Urbani-zation)	Type of Impervious Layer	Depth of Imp Layer (Inches)	Permeability (In/Hr)	pH (Surface /Subsurface)	Pool Locations
ALTAMONT	AtC		clay & clay loam	0-36	.06-.2	6.6/8.0	San Marcos ?
ARLINGTON	AvC		weakly cemented coarse sandy loam	33-48	.06-.2	6.7/6.5	Ramona ?
AULD	AwC		clay	0-54	.06-.2	6.8/7.8	San Marcos ?
BONSALL	BlC,BlC2, BmC, BnB		heavy clay loam	10-38	<0.06	6.2/8.0	Ramona ?
BOSANKO	BsC, BtB		clay & sandy clay loam	0-30	.06-.2	6.3/8.2	Alpine ? Ramona ?
CARLSBAD*	CbC, CbB	CcC	weakly cemented hardpan	39-50	<.06	6.0/6.5	
CHESTERTON*	CfB, CfC	CgC	sandy clay, cemented hardpan	19-34,34+	<.06	6.0/5.2	coastal mesas?
CLAYEY ALLUVIAL	Co		clay, clay loam		slow		Ramona ?
DIABLO	DaC	DcD	clay	0-32	.06-.2	6.8/7.8	Otay Mesa ?
HUERHUERO*	HrC, HrC2	HuC	clay and clay loam	12-55	<.06	5.3-/8.2	coastal mesas and Marron Valley
JAMES CANYON^	JcA, JcD		loam	none indicated	.6-2.0	6.8/6.8	Cuyamaca Valley
LAS FLORES	LeC, LeC2	LfC	sandy clay	14-38	<.06	5.8/6.8	San Marcos?
LAS POSAS	LpB, LpC, LpC2		clay and clay loam	0-33	.2-.63	7.3/6.8	
LINNE	LsE		clay loam	0-37	.2-.63	7.9/8.1	
LOAMY ALLUVIAL	Lu						mountains
OLIVENHAIN*	OhC	OkC	very cobbly clay loam & clay	10-42	<.06	5.7/5.3	coastal mesas
PLACENTIA*	PeC, PeA, PeC2, PfA, PfC		sandy clay	13-34	<.06	6.0/8.0	San Marcos, Ramona
RAMONA	RaA, RaB, RaC, RaC2		sandy clay loam	17-72	.2-.63	6.2/6.8	Ramona? San Marcos?
REDDING*	RdC, ReE	RhC	gravelly clay & indurated hardpan	15-30,30-45	<.06	5.8-4.5	central coastal mesas
SALINAS	SbA, SbC, ScA, ScB		clay	0-46	.06-.2	7.2/7.9	
SHINGLETOWN^			loam	10-20	.2-.06	6.0/6.7	Cuyamaca Valley
STOCKPEN*	SuA, SuB		gravelly clay, clay	21-60	<.06	6.5/8.0	Otay Mesa

* = soil series outlined on soils maps for detailed analysis
^ = not contained in USDA soils maps for San Diego County (Borst 1984)
? = co-occurrence of soils and pools unknown or uncertain

veloped. In many areas, estimations would require reconciliation of irregularly shaped soil areas with development patterns. In the least developed areas, there is a quilt of developed and undeveloped blocks, so that loss analysis would have to proceed property by property. We did not quantify losses, but examined them qualitatively.

Plant species lists are generally available at a very fine scale for extant pools throughout the region of our study. We completed a pool location: species presence matrix for over four dozen taxa (Appendix 1). This allowed us to determine the degree of concordance between soil series and species distributions. Additional data on climatic variables were collected to further characterize pool groups (Cartographic Services, County of San Diego). Plant nomenclature follows Hickman (1993).

FIGURE 2. Aerial photograph taken in 1928 of the area now occupied by San Diego State University.

RESULTS

Vernal pools in cismontane San Diego County are confined primarily to five soil series (Huerhuero, Olivenhain, Placentia, Redding and Stockpen). The Chesterton series appears suitable, but reliable records of vernal pools on Chesterton soils are few. In the earliest ecological study of vernal pools (Purer, 1939), reference is made to "thousands" of pools on the "Lindavista mesa [located] North and east of the city of San Diego...." The present-day communities of Linda Vista and Clairemont are located on mesas almost entirely with Chesterton soils. The 1928 aerial photographs, taken prior to development of these subdivisions, reveal broad mesas with prominent mounded microtopography. Many of the early herbarium labels cite Linda Vista as a location for vernal pool taxa (S. McMillan, unpublished data). However, old maps and history books indicate that there was a Linda Vista school and also a Linda Vista railroad station on the Santa Fe railroad line about 5-8 miles north of the Linda Vista subdivision (Peters, 1984; USGS, 1930). This area is now the northwestern end of Marine Corps Air Station Miramar (MCAS Miramar) in the midst of an extensive mesa of Redding soils that still supports numerous vernal pools.

Pools have recently been mapped in the Wire Mountain area of Marine Corps Base Camp Joseph H. Pendleton (MCB Camp Pendleton) on Chesterton and Carlsbad soils (J. Brown, pers. comm.; S. McMillan, pers. obs.). There is no evidence for the presence of vernal pools on Carlsbad soils, except at MCB Camp Pendleton where the mapped distinction between Carlsbad and Chesterton soils is not evidenced in the field by soil color, texture or slope or by differences in vegetation (S. McMillan, pers. obs.).

With the exception of Carlsbad soils, these soil series all have phases which can be thought of as expressions or subtypes that share similar properties: slopes of 9% or less; a thick clay layer in the B horizon—beginning approximately 1-2 feet below the soil surface—that retards drainage; and permeability less than 0.06 inches per hour. The soil series differ in their origins, distributions and other properties, such as pH (Table 2, Figure 3). Chesterton, Redding, and Olivenhain are acid soils in both the surface and subsurface layers. The other three soils are acidic at the surface but have alkaline subsurface layers. With the exception of the Placentia soils, all of the cismontane soil series supporting vernal pools were subject to past marine influences. These pool soils are distributed in a broad arc west of the mountains, called the San Diego embayment by geologists (Kennedy, 1975). It was an active area during the Pleistocene Epoch, with sea levels rising and falling numerous times, resulting in wave-cut terraces that were exposed or submerged, depending on the sea level. Chesterton, Huerhuero and Stockpen soils developed from sandy marine sediments. Redding and Olivenhain soils were formed on cobbly alluvium cut from an Eocene alluvial fan by rising Pleistocene sea levels and deposited on wave-cut terraces. They subsequently were exposed in late Pleistocene times. Placentia soils formed in granitic alluvium found in small- to medium-size inland valleys. The likelihood of pools having once been present on the smaller patches of Placentia soils is low, and to our knowledge there are no documented occurrences in these minor drainages.

Some pool soils are underlain by a more impervious hardpan or bedrock beneath the drainage-retarding clay layers. These substrates can range from cemented hard pans composed of cobbles held together by iron and silica cement (as in the Redding soils) to granitic, metamorphic, or basaltic rocks. Their role in vernal pool hydrology is essentially unknown, and these deeper substrates are clearly not necessary to the formation of pools, although in some cases they may be the primary factor (e.g., Hidden Lake on Mount San Jacinto).

Extent of Soils

Calculations based on the 1973 (Bowman) soil survey, indicate that the six soils of appropriate slope and profile development to support vernal pools originally covered approximately 183

TABLE 2. Attributes of soils associated with vernal pools (Bowman, 1973).

Soil Series	Layer(s) Retarding Drainage		pH (surface /subsurface)	Origins
	Soil Texture	Depth		
CHESTERTON	sandy clay cemented hardpan	19-34 34	6.0/5.2	marine sediment
HUERHUERO	clay & clay loam	12-55	5.3/8.2	marine sediment
OLIVENHAIN	clay & very cobbly clay loam	10-42	5.7/5.4	alluvium inundated by rising sea levels, then exposed
PLACENTIA	sandy clay	13-34	6.0/8.0	granitic alluvium
REDDING	gravelly clay indurated hardpan	15-30 30-45	5.8/4.5	alluvium inundated by rising sea levels, then exposed
STOCKPEN	gravelly clay, clay	21-60	6.5/8.0	marine sediments

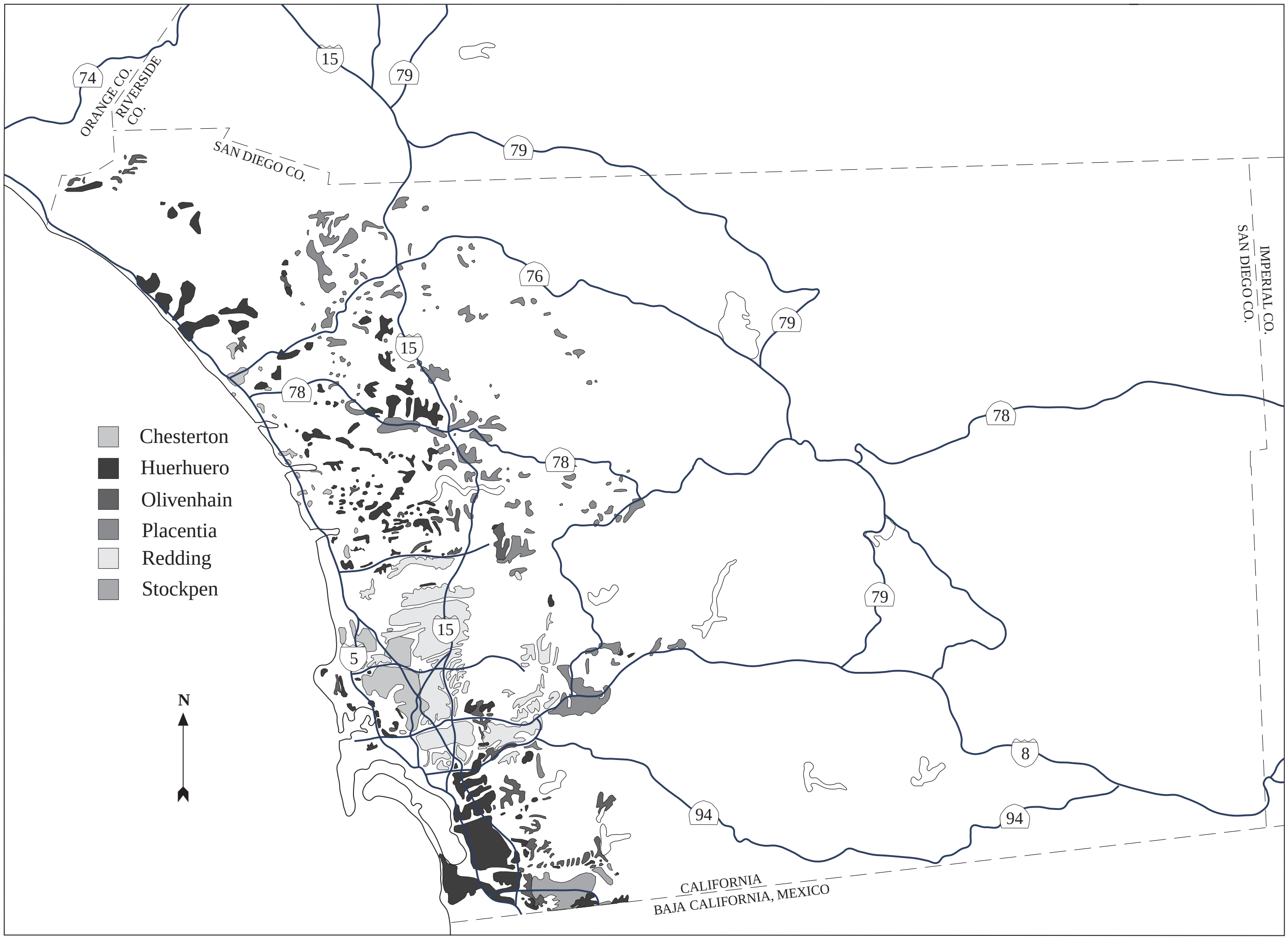

FIGURE 3. Coastal soil series associated with vernal pools in San Diego County.

square miles within San Diego County or approximately 5.3% of the county's area (Table 3). Urbanized land without identified soil series accounted for 0.89% of the County's total land area in 1973. A portion of that urbanized land was likely suitable for pool formation (see below), so we added about one half of the urbanized area to the extent of identified pool soils, for a total estimate of nearly 200 square miles of pool soils or 5.8% of the county's area. The areas in the mountains with pool soils have not been included, but their area is probably slightly less than that of the Stockpen soils on Otay Mesa.

The most common of the five pool-supporting soils was Huerhuero, with approximately 28% of the soil area likely to have had pools, or about 51.2 square miles. The Redding and Placentia soils were next in extent, with about 24% each of the total, Chesterton with 11%, and Olivenhain soils with 8%. Stockpen was the least common, with only 4% of the total area of pool soils, or 7.5 square miles. Otay Mesa, where Stockpen soils occur, extends across the border into Mexico. Even so, the mesa area in Mexico was never large, and its inclusion might inflate the number by only 20%, to 9 square miles. For purposes of mapping, we included completely urbanized land that we judged to have been relatively flat Huerhuero or Redding soils, resulting in a map depicting the putative maximum historical extent of vernal pool soils in cismontane San Diego County (Figure 3).

Losses

Losses of soil areas believed to have supported pools are extensive. Huerhuero and Redding soils were the most widespread soil series strongly associated with pools. Losses of Huerhuero soils have been nearly complete along the coast east and south of San Diego Bay. Recently discovered pool remnants at the southwest edge of San Diego Bay and along the eastern edge of the Tijuana Estuary, combined with evidence in the 1928 aerial photographs of extensive Mima mounds to the east, suggest that a very large area of pools may have been lost when Chula

Table 3. Estimated historic area of the primary vernal pool soils in San Diego County based on the USDA Soil Survey (Bowman, 1973).

Soil Series*	Area (miles^2)	% of County	% of Pool Soils
Chesterton	21.1	0.61	11.6
Huerhuero	51.2	1.49	28.0
Olivenhain	14.5	0.42	7.9
Placentia	44.7	1.30	24.5
Redding	43.3	1.26	23.8
Stockpen	7.5	0.22	4.1
Urban land[a]	30.6	0.89	
San Diego County (Total)	3,445.1		

* Only mapping units with slopes of 9% or less were included (see Table 1).

[a] Soils of many series prior to urbanization. Only a portion were likely to have had pools.

Vista and National City were developed. Small, but important patches of Huerhuero soils remain on Otay Mesa and at Marine Corps Base Camp Pendleton (MCB Camp Pendleton). Other, scattered areas of Huerhuero soils may still be undeveloped in the coastal North County region, extending from Rancho Santa Fe on the south through Carlsbad and San Marcos on the north. Occasional pools on Huerhuero soils are known in these areas (e.g., Poinsettia Lane in Carlsbad).

Most of the remaining vernal pools in San Diego County are on Redding soils, primarily on Marine Corps Air Station Miramar (MCAS Miramar) where GIS analysis indicates approximately 11.9 square miles of these soils are more or less undeveloped (E. Luciani, pers. comm.). This accounts for slightly over one quarter of the mapped Redding soils of suitable phase (Table 3). The majority of Del Mar Mesa (Peñasquitos), Mira Mesa, University City, Clairemont Mesa and Fletcher Hills have been developed. The entire mesa extending from downtown San Diego to La Mesa on the east and from Interstate 8 on the north to State Route 94 on the south was developed prior to World War II, with the exception of several very small pool remnants in Balboa Park, and at the U. S. Navy's former radio station at Chollas.

El Cajon Valley, Poway and Escondido quite probably supported numerous pools. These inland valleys share the same soil series (Placentia) as San Marcos and Ramona, two nearby inland valleys with records of a substantial number of pools now lost and with remnants of pool landscapes that still maintain a diverse vernal pool flora. Examination of early aerial photographs of the three valleys indicates intensive, widespread cultivation and provides no conclusive evidence of pools. More careful inspection of these photos may yield clues as might non-aerial historical photographs. A few pools have been reported from the Gillespie Field area of El Cajon Valley. The only pool records from Poway are west of the valley proper on mesas mapped with the Olivenhain soil series. Patches of Placentia soils may remain on the floor of numerous small drainages scattered from Vista and San Marcos to Bonsall and Fallbrook in the north. Pools have not been reported from these areas, and residential development has accelerated throughout the inland north county during the past two decades, so most properties would have been examined as part of the review process under the California Environmental Quality Act (CEQA).

Olivenhain soils support pools, but generally with fewer species compared to Redding soils. These pools may have shorter periods of inundation. Both soils are derived from the Linda Vista Formation. These soils occur also on the northern and western edges of Otay Mesa, to the east of Chula Vista, in the vicinity of Paradise Hills, on the southern flanks of Soledad Mountain south of La Jolla and in various locations north towards Poway and Rancho Bernardo. Nearly all of these areas have been developed, but pools have been recorded for many of them. With the exception of montane locations, Stockpen soils were historically the least extensive soils thought to support vernal pools in San Diego County, occurring only on Otay Mesa which straddles the international border with Mexico. Much of this mesa was cultivated and grazed during the last century. The Tijuana airport is on the southern edge of the mesa. Within the last two decades, development of industrial parks began on both sides of the border. A moderate number of pools remain and some restorable habitat is still undeveloped, but the majority of the pools have been lost. Two freeways and other proposed projects could diminish this limited soil type even further.

As indicated above, it is difficult to determine whether or not the Chesterton soils supported numerous vernal pools. A few pools are on Chesterton soil at the west end of the runways on MCAS Miramar and approximately 100 pools on Chesterton soil remain at MCB Camp Pendleton. In any case, Chesterton soils have been almost entirely developed.

Our view of the distribution of pool losses differs somewhat from that developed by Oberbauer, mainly because we are in doubt as to the nature and extent of vernal pools on Chesterton soils and we have expanded the area of Huerhuero soil loss.

Factors Affecting Distributions of Plant Species

Soils, topography, and the Mediterranean-type climate are dominant factors determining whether ephemeral pools or lakes will form at all. In the wetland habitat created by vernal pools, the

TABLE 4. Climatic variables affecting vernal pools and lakes in Southern California.

Pool Type	Elevation# (feet)	Annual Precipitation* (inches)
COASTAL MESAS		
Chula Vista	56	10.9
La Mesa	530	12.81
Montgomery Field	414^	13.1
Otay Mesa	510^	10.45
Oceanside Harbor	10	10.48
INLAND MESAS		
Santa Rosa Plateau+	2,400	14.95-16.57
INLAND VALLEYS		
El Cajon, Gillespie Field (west)	380^	10.71
El Cajon (east)	520^	14.13
Ramona	1,450	16.14
San Marcos	520^	12.55
MOUNTAINS		
Cuyamaca	4,640	38.7
Palomar	5,550	49.36

Elevation from NOAA Climatalogical Data, Station Index; otherwise, from USGS 7 1/2 minute quadrangle maps (^).
* Precipitation from County of San Diego (Cartographic Services) rainfall map.
+ All data from Lathrop and Thorne, 1976.

distributions of plant species, especially narrow endemics, appear to be affected by subtle differences in duration and pattern of ponding, water and soil chemistry, and sub-regional climatic variables such as total amount of precipitation, the temperature regime in winter and the probability of summer precipitation.

In southern California, climatic variables are most influenced by distance from the coast, topography, and elevation. Yearly average precipitation is lowest along the coast and rises with elevation inland, to a peak in the Peninsular Ranges to the east (Table 4). It then drops abruptly in the rainshadow of the mountains, where the upper Sonoran Desert (Colorado Desert) begins. Long-term means are 8.49-13.1 inches of precipitation at coastal locations and 24.28-49.36 inches in the mountains. Within a given "rainfall year" (July 1 to June 30), most of the precipitation falls from November through March and is concentrated in a half dozen storms that may occur within a few months or be spread more evenly over the wet season (Mooney and Parsons, 1973; Goldman et al., 1986). Only during winter months is precipitation greater than potential evapotranspiration (Greenwood and Abbott, 1980). At higher elevations to the east, rain from summer convective storms may produce up to 20% of the yearly precipitation during the June-August period (E. Bauder, analysis of U. S. Weather Bureau data for Cuyamaca dam), and a significant portion of the yearly precipitation in the mountains may fall as snow. In the mountains, below freezing temperatures often occur between October-November and April-May (Bowman, 1973). On the coastal terraces there is little or no frost.

Year-to-year variability in precipitation is substantial, a feature shared by all arid and semi-arid climates (Le Houe'rou, 1984). Since 1850, when record-keeping began in the City of San Diego, yearly precipitation at the Lindbergh Field weather station has ranged from 3.46 inches in the 1960-61 "rainfall year" to 25.98 inches in 1883-84 (U. S. Weather Bureau, Lindbergh Field). Over a l03-year period, Cuyamaca's annual precipitation totals have ranged from a low of 13.46 inches to a high of 74.65 inches, also in 1883-84 (data from Helix Water District and Cuyamaca Rancho State Park). Very dry or wet years can follow each other, and only a crude pattern of 15 mostly dry years followed by 12 mostly wet years is apparent (P. Abbott, pers. comm.).

Inland valleys share characteristics of both the montane and coastal climates, with precipitation higher and frost more common than along the coast, but snow and summer rainfall are rare. Although the valleys lie on the coast-to-mountain continuum, anomalies in topography may greatly affect their climate. Cold air often drains through canyons into low lying valleys, and mini rainshadows can develop as a result of adjacent mountains and hills. El Cajon Valley provides an example. It has occasional frost and lower rainfall compared to nearby La Mesa, which is situated to the west on the coastal terrace. The mean annual precipitation for La Mesa is 12.81 inches, but the western end of the El Cajon Valley, in the shadow of Mount Helix and Fletcher Hills, has a mean of 10.71 inches (Cartographic Services, County of San Diego). At the eastern end of the valley, 3-4 miles further inland, the mean rises to 14.13 inches (Table 4).

Endemism is common in vernal pools of the southern region of the California Floristic Province, as are highly restricted distributions (Table 5). San Diego County has two of the nine species in the genus *Pogogyne*, with *Pogogyne abramsii* restricted to the county and the even more narrowly distributed *Pogogyne nudiuscula* straddling the international border between San Diego County and Mexico. Two other species, *Downingia concolor* var. *brevior* (Cuyamaca Valley) and a newly discovered *Eryngium* species found along the coast on MCB Camp Pendleton (K. Marsden, pers. comm.), are San Diego County endemics as well. Riverside County has two narrow endemics, *Atriplex coronata* var. *notatior* from the San Jacinto Valley, and *Trichostema austromontanum* ssp. *compactum* located only in and around Hidden Lake, a small depressional wetland near the summit of Mount San Jacinto. Northern Baja California has

Table 5. Vernal pool species of very limited distribution.

Species	Location	Pool Type
Atriplex coronata var. *notatior*	San Jacinto Valley (W. Riverside County)	Inland Valley
Downingia concolor var. *brevior*	Cuyamaca Valley	Montane Depression
Eryngium sp. nova.	Camp Pendleton	Coastal Mesa
Eryngium sp. nova.	San Quintin (N. Baja California, MX)	Coastal Mesa
Pogogyne abramsii	San Diego	Coastal Mesa
Pogogyne sp. nova.	Valle de las Palmas (N. Baja California, MX)	Inland Mesa
Pogogyne nudiuscula	Otay Mesa	Coastal Mesa
Trichostema austromontanum ssp. *compactum*	Hidden Lake (Mt. San Jacinto, Riverside Co.)	Montane Depression

two narrowly distributed endemic pool species, both in the process of formal description (K. Marsden, pers. comm.; S. McMillan, unpublished data). One is a *Pogogyne* found only on a mesa in an inland valley known as Valle de las Palmas, about 15 miles south of the border city of Tecate and the other is an *Eryngium* species found along the coast in the vicinity of San Quintin.

All of the species listed in Table 5 are confined to one pool subtype. Pool types are general classifications based on two factors: topographic position (mesa or valley/depression) and sub-regional climate (frost, summer rain, total precipitation). Pool sub-types have a unique combination of topographic position, soils and sub-regional climate (Table 6). Experimental work on the germination ecology of *Trichostema austromontanum* ssp. *compactum* and *Downingia concolor* var. *brevior* suggests that they are well adapted to the climate of the small areas of montane wetland in which they are found, climates that differ sharply from other inland valleys as well as the coastal terraces (Bauder, unpublished data).

The three species of *Pogogyne* found in our region illustrate quite dramatically the “soil connection” and suggest also that sub-regional climatic variables may be controlling their distribution, as appears likely for the *Downingia* and *Trichostema*. *Pogogyne abramsii* is found entirely within San Diego County (Figure 4). *Pogogyne nudiuscula* is now restricted to southern San Diego County, but it used to occur in Mexico at the eastern edge of the city of Tijuana, where the Otay Mesa extends on both sides of the international border. It is believed to be extirpated from its Mexican locations. At present, these two species are separated by 25 miles, most of it now developed and much of it urbanized for over 50 years. Neither has been reported from the inland valleys or mountains. Unfortunately, herbarium

Table 6. The four main vernal pool types in southern California and northern Baja California, Mexico, with representative locations of subtypes (CA= California; MX= Mexico).

Pool Types and Subtypes	Locations of subtypes
Coastal Mesa	
Huerhuero soils	Stuart Mesa
	Otay Mesa
Redding soils	Del Mar Mesa
	Mira Mesa
	Kearny Mesa
	Tierrasanta
	San Diego Mesa
Olivenhain soils	Chula Vista
Stockpen soils	Otay Mesa (CA and MX)
Unknown soil types	Mesa de Colonet (MX)
	San Quintin (MX)
Inland Valley	
Placentia soils	San Marcos
	Ramona
Olivenhain soils	Proctor Valley
Willows and other soil types	Temecula/Hemet
Huerhuero soils	Marron Valley
Inland Mesa	
Murietta and Las Posas soils	Santa Rosa Plateau
Unknown soil type	Valle de las Palmas (MX)
Montane Depression	
Loamy alluvial, possibly other soils	Mount Laguna
Shingletown and James Canyon soils	Cuyamaca
Soils of granitic origin	Mount San Jacinto

labels are frustratingly vague about the locations of *Pogogyne* plants in the 19th century, frequently describing collection sites as “mesas east of San Diego.” The third undescribed species, *Pogogyne* sp., is found in Valle de las Palmas, Baja California, approximately 45 miles to the southeast of Otay Mesa and separated from it by rugged mountains.

Comparison of verifiable locations for each species with soil maps, strongly supports our contention that the three *Pogogyne* species never co-occurred nor were even close enough to interbreed. Each appears to be faithful to soil type, with *P. abramsii* found only on Redding soils and *P. nudiuscula* on Stockpen (Figure 5). If Chesterton soils supported *P. abramsii*, this conclusion regarding soil affinity would have to be modified, but the spatial relationships of the three *Pogogyne* species would remain unchanged (Figure 3). The questions surrounding the presence of vernal pools on Chesterton soils and the species they contained may never be answered because of inadequate information. The soil type for the new *Pogogyne* species is un-

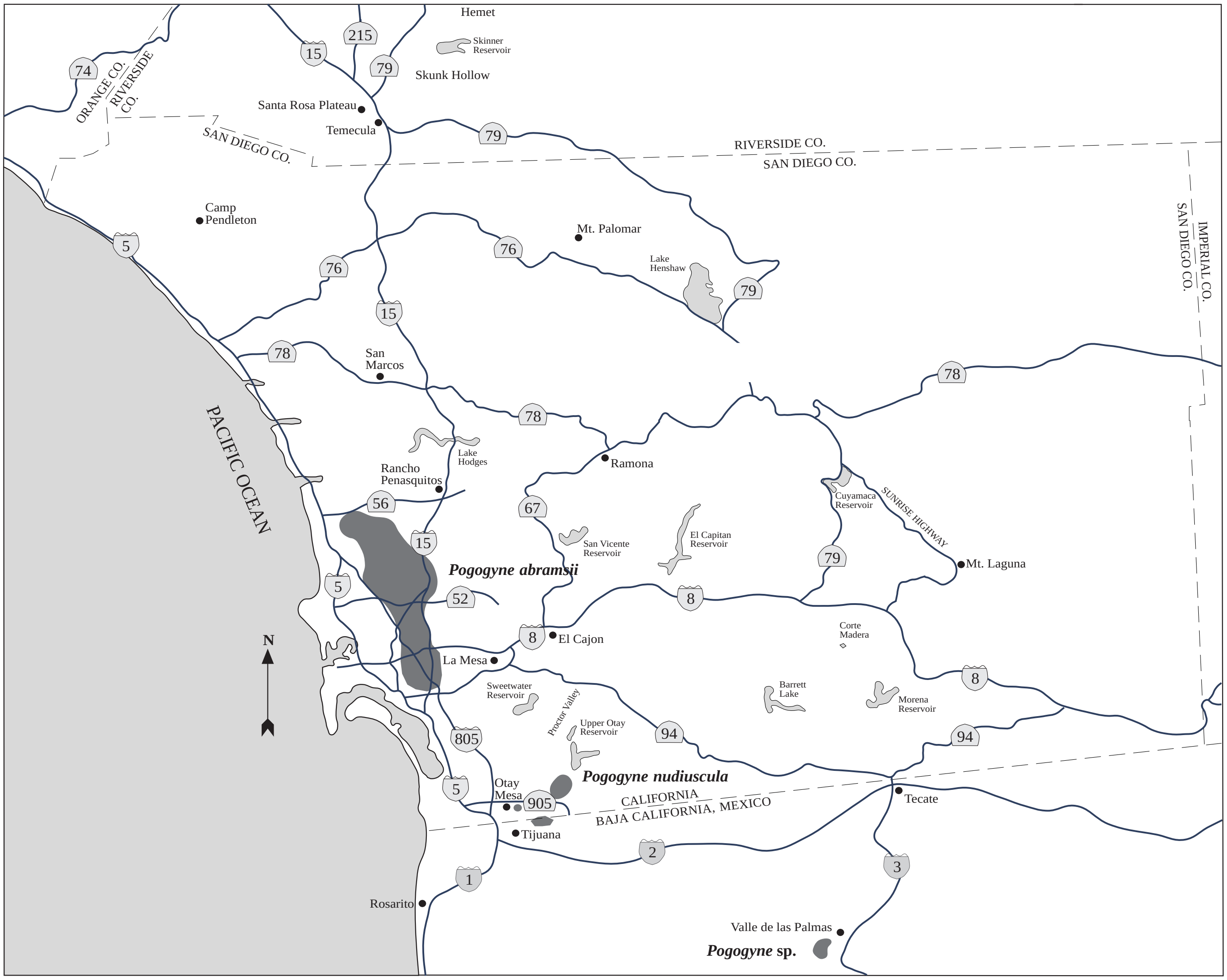

FIGURE 4. Distribution of *Pogogyne* species in the southern range of the genus.

known, but geological reports for the area strongly suggest that the soils are of different origin and structure than those on the coastal San Diego mesas (Diaeldin, 1967; Frazer, 1972; Williams, 1972).

CONCLUSIONS

Descriptions of all soil series mapped in San Diego County were examined to develop a list of those deemed likely to support vernal pools. Low-slope phases of seven soil series—Carlsbad, Chesterton, Huerhuero, Olivenhain, Placentia, Redding and Stockpen—were outlined on maps, and co-occurrence of these soils with pools was tested by reviewing all known locations of pools, 1928 aerial photographs, herbarium labels and local histories. It is estimated that vernal pool soils once covered an area of approximately 200 square miles, or 5-6% of the estimated area of the county. Losses of habitat have been extensive, with only remnants of most vernal pool landscapes remaining. The largest patch contains Redding and Olivenhain soils and occurs on NAS Miramar.

Information from the soil maps was combined with data on sub-regional climatic variables and vernal pool species distributions to describe vernal pool types and sub-types within southern California and northern Baja California, Mexico. Landscape position (mesa or valley/depression), distance from the coast and elevation (coastal, inland, montane), and soil series were the factors used to classify pools into types and sub-types. Coastal pools are found almost exclusively on mesas, but sustain different species depending on soil series (Huerhuero, Stockpen, Redding or Olivenhain). Inland valleys and mesas contain soils of alluvial derivation (valleys) or volcanic origin

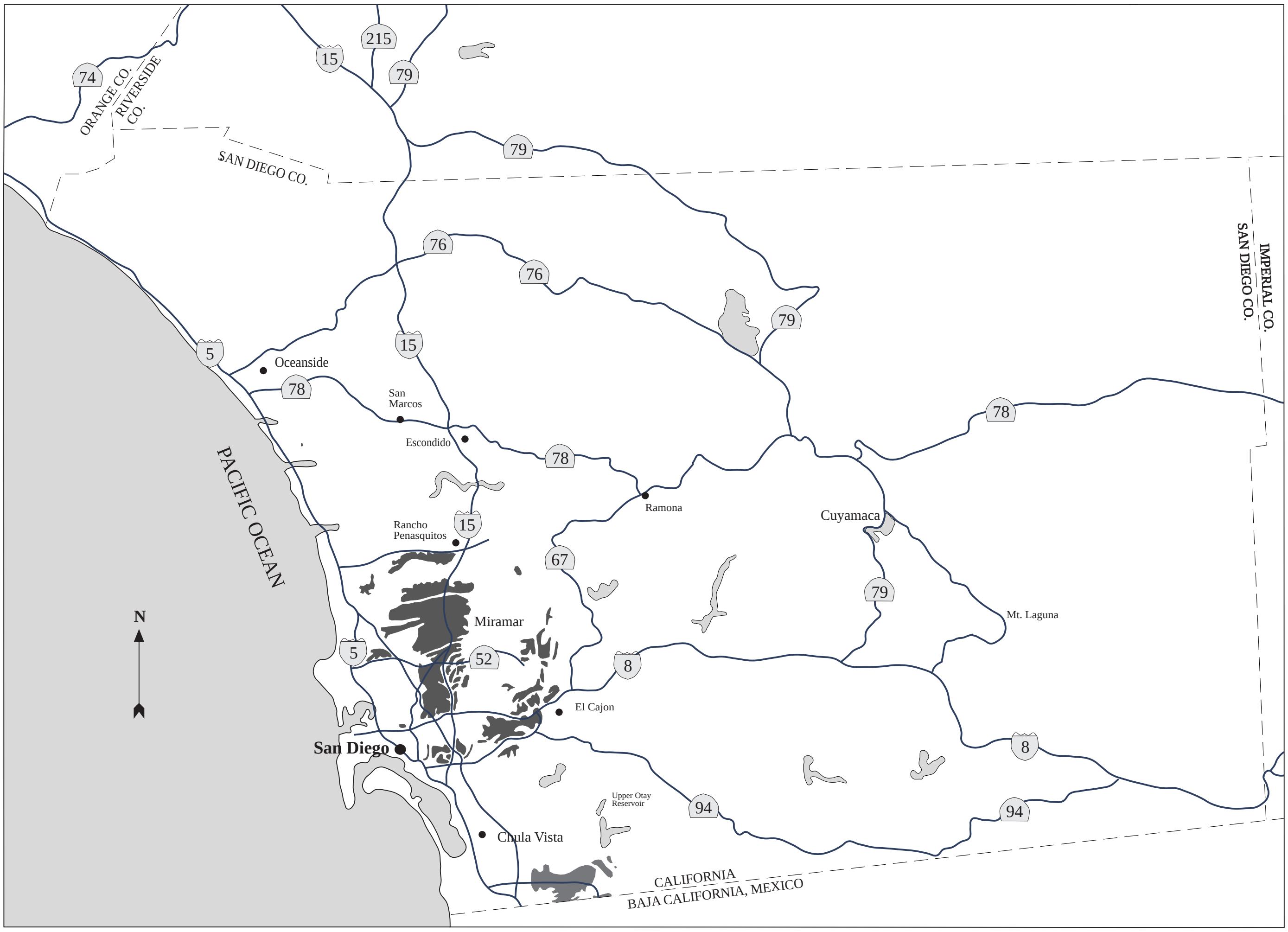

Figure 5. Historic distribution of Redding and Stockpen soils of low slope phases in San Diego County.

(mesas in Riverside County and in Mexico) and have a less moderate temperature regime. Montane pools are small depressional lakes with a much less moderate climate with a sharp temperature contrast between summer and winter.

Narrow endemic plant species appear to be limited to only one pool sub-type with a combination of soils and climate that differentiate it from other pool groupings. Loss of pool sub-types can therefore be expected to result in loss of a unique plant species assemblage and perhaps species, such as the aquatic invertebrates, whose endemism is yet undescribed.

Acknowledgments

We thank Juda Sakrison and Leah Swanekamp who outlined the soil polygons and prepared maps we used for the figures. Fred Sproul and Charlie Lough provided additional insight. John O'Leary and Pat Abbott offered useful suggestions and corrections, and we appreciate their careful reading of the manuscript.

Literature Cited

Balko, M.E. 1979. The biological evaluation of vernal pools in the San Diego region. City of San Diego, San Diego, CA.

Bauder, E.T. 1986. San Diego vernal pools: Recent and projected losses; their condition; and threats to their existence, 1979-1990. Report prepared for Endangered Plant Project, California Department of Fish and Game, Sacramento, CA.

Beauchamp, R.M. and T. Cass. 1979. San Diego regional vernal pool survey. California Department of Fish and Game, Sacramento, CA.

Borst, G. 1984. Soil survey of Cuyamaca State Park. Department of Agriculture, County of San Diego, San Diego, CA.

Bowman, R.H. 1973. Soil survey of the San Diego area, California. Soil Conservation Service, U. S. Department of Agriculture, Washington, D.C.

County of San Diego. In process 1997. Vernal pool mapping layer, San Diego regional vegetation mapping file. San Diego, CA.

Cox, G.W. 1984. The distribution and origin of Mima mound grasslands in San Diego County, California. Ecology 65: 1397-1405.

Craig, J.D. 1972. Geology of the Colonet-Camalu area: Northwestern Baja California, Mexico. Undergraduate research report, Department of Geology, San Diego State University, San Diego, CA.

Diaeldin, A.M. 1967. Geology of the southwestern portion of Otay Mesa, southwestern San Diego County, California. Undergraduate research report, Department of Geology, San Diego State University, San Diego, CA.

Frazer, M. 1972. Geology of Valle de las Palmas. Undergraduate research report, Department of Geology, San Diego State University, San Diego, CA.

Goldman, S.J., K. Jackson and T.A. Bursztynsky. 1986. Erosion and sediment control handbook. McGraw-Hill Book Company, NY.

Greenwood, N.H. and P.L. Abbott. 1980. The physical environment of H series vernal pools, Del Mar Mesa, San Diego County. Report prepared for California Department of Transportation, San Diego, CA.

Hallsworth, E.G., G.K. Robertson and F.R. Gibbons. 1955. Studies in pedogenesis in New South Wales, VII. The "Gilgai" soils. Journal of Soil Science 6(1):1-34.

Hickman, J.C. (Editor). 1993. The Jepson manual: Higher plants of California. University of California Press, Berkeley, CA.

Kennedy, M.P. 1975. Western San Diego Metropolitan Area, Section A. Pages 9-39 *in:* Geology of the San Diego Metropolitan Area, California. Bulletin 200, California Division of Mines and Geology. Sacramento, CA.

Knecht, A.A. 1971. Soil survey of western Riverside area, California. USDA, Soil Conservation Service and USDI, Bureau of Indian Affairs, Washington, D. C.

Lathrop, E.W. and R.F. Thorne. 1976. The vernal pools on Mesa de Burro of the Santa Rosa Plateau, Riverside County, California. Aliso 8(4):433-445.

Le Houe'rou, H.N. 1984. Rain use efficiency: a unifying concept in arid-land ecology. Journal of Arid Environments 7:213-247.

Mooney, H.A. and D.J. Parsons. 1973. Structure and function of the California chaparral—an example from San Dimas. Pages 83-112 *in:* F. diCastri and H.A. Mooney (Editors). Mediterranean-Type Ecosystems. Springer-Verlag, Berlin.

Ogden Environmental and Energy Services. 1995. Multiple species conservation program resource document. Prepared for the City of San Diego, San Diego, CA.

Peters, R. 1984. Miramar before the planes, of the U. S. Naval Air Station at San Diego, California: A rural settlement and one room school, 1890-1950.

Purer, E.A. 1939. Ecological study of vernal pools, San Diego County. Ecology 20:217-229.

Singer, M.J. and D.N. Munns. 1991. Soils: An introduction. Macmillan Publishing Company, New York, NY. 473 pp.

United States Geological Survey. 1930. 1901-1902 survey, La Jolla, Calif.. 1:62500 scale: Culture partially revised in 1930 by Bureau of Chemistry and Soils. Department of the Interior, Washington, D.C.

Villasenor, R., Jr., and R.B. Riggan. 1979. Kearny Mesa vernal pool survey. RECON, San Diego, CA.

Wachtell, J.K. 1978. Soil survey of Orange County and western part of Riverside County, California. USDA, Soil Conservation Service and Forest Service. Washington, D.C.

Williams, T.A. 1972. Geology of the western San Ysidro Mountains and eastern Otay Mesa, San Diego County, California. Undergraduate research report, Department of Geology, San Diego State University, San Diego, CA.

Appendix 1. Regional distribution of vernal pool species.

SPECIES	INLAND VALLEYS												
	El Cajon Valley	Escondido San Dieguito	Hemet	L.A. Mun. Airport	Marron Valley	Mission Valley	Skunk Hollow Murrietta	Proctor Valley	Ramona	San Jacinto River	San Marcos	Santa Ysabel	Valley Center
Ambrosia pumilla	X					X	X	X					
Atriplex coronata var. *notatior*			X							X			
Bergia texana							X			X			
Brodiaea filifolia			X							X	X		
Brodiaea jolonensis								X	X		X		
Brodiaea orcuttii		X	X		X				X		X		X
Centunculus minimus					X						X		
Crassula aquatica			X		X		X	X	X		X		
Deschampsia danthonoiodes			X		X			X	X		X		
Downingia bella													
Downingia concolor var. *brevior*													
Downingia cuspidata									X		X		
Echinodorus berteroi							X						
Elatine brachysperma					X		X	X	X		X		
Elatine californica							X						
Eleocharis acicularis							X						
Eleocharis macrostachya									X		X		
Eleocharis montevidensis					X								
Epilobium pygmaeum							X	X	X				
Eryngium aristulatum ssp. *parishii*								X	X		X		
Eryngium sp. nova													
Hordeum intercedens													
Isoetes howellii													
Isoetes orcuttii											X		
Juncus bufonius		X			X			X	X		X		
Lepidium latipes			X										
Lepidium nitidum									X				
Lilaea scilloides									X				
Limnanthes gracilis ssp. *parishii*												X	
Lythrum hyssopifolia					X			X	X		X		
Malvella leprosa							X						
Marsilea vestita			X				X			X			
Mimulus latidens													
Montia fontana													
Myosurus minimus var. *apus*			X		X		X	X	X				
Myosurus minimus var. *filiformis*									X				
Nama stenocarpum													
Navarretia fossalis			X				X	X	X	X	X		
Navarretia hamata	X												
Navarretia intertexta													
Navarretia prostrata													
Ophioglossum californicum		X											X
Orcuttia californica			X	X			X						
Phalaris lemmonii									X				
Pilularia americana											X		
Plagiobothrys acanthocarpus					X						X		
Plagiobothrys leptocladus			X										
Plantago elongata			X				X	X	X	X	X		
Plantago erecta					X		X			X	X		
Pogogyne abramsii						X							
Pogogyne nudiuscula													
Pogogyne sp. nova													
Psilocarphus brevissimus			X		X		X	X	X		X		
Psilocarphus tenellus					X								
Rotala ramosior							X						
Trifolium depaupertaum var. *amplectans*					X								
Verbena bracteata							X						

APPENDIX 1. Regional distribution of vernal pool species (continued).

SPECIES	MONTANE			COASTAL MESAS							INLAND MESAS	
	Cuyamaca	Laguna	Palomar	Del Mar Mesa	Kearny Mesa	Costa Mesa	Imperial Beach/ Ch V/Nat. City	Otay	Pendleton/San Luis Rey	San Diego	Santa Rosa	Valle de las Palmas
Ambrosia pumilla					X		X		X			
Atriplex coronata var. *notatior*												
Bergia texana								X				
Brodiaea filifolia									X		X	
Brodiaea jolonensis	X							X	X	X		
Brodiaea orcuttii	X			X	X				X	X	X	
Centunculus minimus		X	X	X	X		X	X	X	X	X	
Crassula aquatica				X	X	X		X	X	X	X	X
Deschampsia danthonoiodes	X	X	X	X	X		X	X	X		X	X
Downingia bella											X	
Downingia concolor var. *brevior*	X											
Downingia cuspidata				X	X			X		X	X	
Echinodorus berteroi												
Elatine brachysperma				X	X	X		X		X	X	X
Elatine californica	X	X		X	X				X		X	
Eleocharis acicularis			X	X	X						X	
Eleocharis macrostachya				X	X	X	X	X	X	X	X	X
Eleocharis montevidensis											X	
Epilobium pygmaeum						X	X	X				
Eryngium aristulatum ssp. *parishii*				X	X			X	X		X	
Eryngium sp. nova									X			
Hordeum intercedens						X						
Isoetes howellii				X	X			X			X	X
Isoetes orcuttii				X	X			X			X	
Juncus bufonius	X			X	X	X	X	X	X	X	X	X
Lepidium latipes								X	X			X
Lepidium nitidum	X				X	X		X	X		X	
Lilaea scilloides				X	X			X	X			
Limnanthes gracilis ssp. *parishii*	X	X	X								X	
Lythrum hyssopifolia	X		X	X	X	X	X	X	X	X	X	X
Malvella leprosa					X	X		X	X			X
Marsilea vestita						X	X	X	X		X	
Mimulus latidens								X				X
Montia fontana	X	X	X	X	X				X		X	
Myosurus minimus var. *apus*				X	X		X	X	X		X	X
Myosurus minimus var. *filiformis*				X	X			X				
Nama stenocarpum								X	X			
Navarretia fossalis				X	X		X	X	X			X
Navarretia hamata				X	X		X	X	X	X	X	
Navarretia intertexta	X										X	
Navarretia prostrata						X					X	
Ophioglossum californicum				X	X			X	X			
Orcuttia californica					X			X		X	X	
Phalaris lemmonii				X	X			X	X			
Pilularia americana				X	X			X	X		X	X
Plagiobothrys acanthocarpus				X	X			X	X	X		X
Plagiobothrys leptocladus												
Plantago elongata				X	X		X	X	X	X	X	
Plantago erecta				X	X		X	X	X			X
Pogogyne abramsii				X	X					X		
Pogogyne nudiuscula								X				
Pogogyne sp. nova												X
Psilocarphus brevissimus				X	X	X	X	X	X	X	X	X
Psilocarphus tenellus				X	X		X	X	X	X	X	
Rotala ramosior								X				
Trifolium depaupertaum var. *amplectans*				X	X							
Verbena bracteata						X		X				