

Changes in Great Valley Vernal Pool Distribution from 1989 to 1997.

prepared by

Robert F. Holland, Ph. D.

Auburn, CA 95603

prepared for

California Department of Fish and Game

Natural Heritage Division

1220 "S" Street

Sacramento, CA 95814

June 1998

Table of Contents

1. Introduction
2. Methods
3. Results
4. Discussion
5. Acknowledgments
6. References

List of Figures

- Figure 1. Air photo (71k bytes)
- Figure 2. Mapped polygon boundaries superimposed on SPOT image
- Figure 3. Map of the Holland Study Area, and Vernal Pool Density Classes

List of Tables

- Table 1. Attribute class characteristics
- Table 2. Area by County
- Table 3. Vernal Pool Losses by County

1. Introduction

Literally dozens of sensitive plant and animal species in California are associated with vernal pool habitats: at least four separate conferences have focused on the habitat since 1976 (Jain 1976, Jain and Moyle 1984, Ikeda and Schlising 1990, Witham et al. 1998). In spite of all this interest, detailed understanding of the habitat's distribution through out the Great Valley has remained elusive. The only published survey to cover the entire Great Valley (Holland 1976) was prepared in 1973 and 1974 from air photos no more recent than 1972. This early survey also suffers from low resolution (1:500,000 scale) and rudimentary cartographic sophistication.

Over the past three years, I have remapped the distribution of Great Valley vernal pools using modern cartographic techniques, including Geographic Information Systems, under contract with the US Fish and Wildlife Service (Holland 1998). This remap used vertically oriented, true color air photos to map surviving habitat complexes onto standard 1:24,000 USGS topographic quadrangles. These polygons were digitized using an Arc-Info based GIS and have been assembled into a synoptic data layer.

This study builds upon the recent remap in an important way. The recent remap, like its 1976 predecessor, suffered because it utilized photography spanning nearly a decade. By exploiting the capabilities of modern GIS, I was able to assemble imagery at precisely the scale of an available 1997 U2 flight covering virtually all of the remapped area. Thus, I was able to update the entire map to July, 1997 conditions. While U2 imagery is of insufficient scale (1:130,000) for initial mapping, it is sufficient to see any changes in land use. This report describes how the imagery was prepared and examines for each of the 30 counties included in the study area the rates at which habitat loss is occurring.

2. Methods

The 1996 remap utilized a series of slide images acquired over the years by a program in the California Department of Water Resources that monitors the production, distribution, and utilization of irrigation water through out California. This program uses a specially-equipped aircraft that takes true-color, vertically-oriented 35mm slides along systematically placed flight lines that assure complete coverage of the agriculturally important lands of California. The slides are used to map types of water use on fields down to one acre in size. This program operates five regional offices, three of which (Red Bluff, Sacramento, and Fresno) incorporate the present study area. Each regional office flies one or two counties (depending on their size) each year; each county is re flown every 5-7 years.

These slides can be projected at any scale. After experimenting with several approaches, I settled on a "display projector" as the optimum solution to conflicting needs for resolution, image brightness, and ability to work in a lighted room. This device projects slides, not on a wall, but on a television-like screen on the front of the unit. It projects the slides at roughly 1:10,400 scale, or a little more than twice that of a standard 7.5' quadrangle. The resolution at this scale is sufficient (although only barely) to read driver warnings such as "PED XING" painted on city streets. Vernal pools are readily apparent at this scale, as an irregularly dendritic array of gray to tan blobs in the golden brown of the summer grasslands in which the habitat occurs. [Figure 1](#) shows a sample area near Corning.

Each slide covered roughly one mile north-south and about 1.4 miles east-west. Using a stack loader, it was a simple, though tedious, process to click through every slide in every flight line while tracking location on the topographic sheets. When habitat was found, I mapped it directly onto the quadrangles. Habitat density within each polygon was qualitatively scored as low, medium, or high using the attribute classes of [Table 1](#). Ultimately, I examined somewhere over 40,000 slides covering part or all of 562 quadrangles covering the area below the conifer forests from Shasta Dam to Tehachapi Valley and west to the North Bay counties. The final study area is not known exactly, but probably approaches 18,000,000 acres. It includes all or part of 30 counties.

Attribute Class	Characteristics
0	Cut-outs, e. g. a cultivated field surrounded by habitat.
1	Pools are small; widely and patchily scattered. At least 2 and usually 5 or more pools within the delineated vernal pool complex.
2	Pools are larger; more numerous and more pervasively scattered, although still patchy within the delineated vernal pool complex.
3	Pools are all sizes and numerous. Pools are distributed over the entire delineated vernal pool complex. Also includes large, isolated playa-like pools.
4	Pools are present and persist in spite of obvious cultivation, usually of hay crops.
5	Pools are present and still visible in spite of subdivision into "starve-your-horse-slowly" parcels smaller than minimum mapping size.
6	Not used.
7	Pools were present in earlier photos, but were gone in 1997 U2 flight.
8	As in Attribute Class 1, but with obvious signs of disturbance.
9	As in Attribute Class 2, but with obvious signs of disturbance.

Table 1. Attribute class characteristics.

Craig Turner of DFG's Natural Heritage Division GIS staff digitized each quadrangle as mapping was completed. Check plots were compared with the manuscript quadrangles, flagging several errors for correction. These plots, together with the software, were ruthless in finding my mapping errors as well. These included about 40 "unclosed arcs", dangling line segments that went nowhere, and about two dozen polygons that lacked habitat density scores. Near the end of the project I returned to the slides and corrected all these errors.

The work summarized above lead to a new map of Great Valley vernal pool distribution, (Holland 1998), to which the reader is referred for salient details. New efforts undertaken for the present study are described below.

Once the data had been cleaned up, Craig Turner superimposed them on SPOT imagery available at NHD. SPOT is a proprietary French concern that provides satellite coverage for large parts of the world, including all of California. He printed these images on transparent media at 1:130,000 scale, matching that of a July, 1997 U2 flight that covered nearly the entire survey area. A sample print is shown in [Figure 2](#). The U2 imagery had been obtained by NASA-Ames Research Center for the California Department of Conservation Farm Lands Mapping Program and consisted of about 1500 9-inch square transparencies in false color infrared. The images were acquired over four flights during mid July, 1997. Each transparency covered about 16 x 16 miles; there was 60 per cent overlap of adjacent frames. The registration between the U2 photos and the SPOT images was spectacular.

U2 imagery was considered but rejected for the initial mapping because vernal pools are not readily visible at its small scale (1:130,000). Changes such as agricultural or urban development are readily visible at 1:130,000, however, because they are such a change in land use from the low-intensity, dispersed grazing that is typical of surviving vernal pool habitat. Using a light table, it took only a few days to locate each polygon in the U2 photos. Any change in land use within a polygon was readily apparent and was mapped onto the SPOT imagery. These changes were redigitized, then check plots were compared with manuscript maps.

3. Results

When the initial mapping was presented in 1996 (Holland 1998), I had drawn 7,034.3 miles of polygon boundary around 1781 polygons that enclosed 1,027,067 acres. However, this includes 86 Attribute Class 0 polygons (cut-outs surrounded by habitat) totaling 11,803 acres. Thus, the habitat then known extant consisted of 1695 polygons totaling 1,015,264 acres. Polygons were mapped on 345 of the 562 quadrangles included in the survey area; half of these had three or fewer polygons. One quadrangle had 43 polygons. The single largest polygon represents 36,447 acres of high-density habitat that falls on five quadrangles in eastern Merced county.

Heritage Program GIS staff then cookie-cut out each county for planimetry. Because of polygons that straddled county lines, this artificially increased the number of polygons from 1695 to 1929. [Table 2](#) summarizes by county the number and combined area of polygons within each density class as of the year of original photography and as of July 1997. Attribute Class 7 represents those polygons that apparently were lost over the interval between DWR and U2 photo dates. The data presented in [Table 2](#) differ with those presented in 1996 for several reasons: 1) The 1998 planimetry used a newer, more accurate algorithm, 2) The 1998 planimetry accurately followed county lines, while the 1996 planimetry arbitrarily assigned all of each polygon that straddled a county line to the county that had the majority of the polygon, and 3) Edits and corrections in digitizing. The data presented here in Table 2 are much more accurate than those presented in 1996.

Changes in Great Valley Vernal Pool Distribution from 1989 to 1997

COUNTY AND PHOTO YEAR	ATTRIBUTE CLASS									TOTAL
	0	1	2	3	4	5	7	8	9	
Alameda										
1986 polygons		7	4							11
acres		1481	1271							2751
1997 polygons		5	4				2			9
acres		1133	1271				348			2404
Amador										
1983 polygons		11	5	1						17
acres		807	2685	581						4073
1997 polygons		11	5	1						17
acres		807	2685	581						4073
Butte										
1994 polygons	11	36	34	10						80
acres	1248	23550	32315	3434						59299
1997 polygons	11	35	30	9			6			74
acres	1248	23461	31923	3359			555			58744
Calaveras										
1983 polygons	1	19	8	1						28
acres	381	2633	3607	165						6405
1997 polygons	1	19	8	1						28
acres	381	2633	3607	165						6405
Colusa										
1993 polygons	2	28	4							32
acres	18	4917	810							5727
1997 polygons	2	20	3				9			23
acres	18	3701	677				1348			4379
Contra Costa										
1985 polygons		14	4	1						19
acres		2296	507	279						3082
1997 polygons		14	4	1						19
acres		2296	507	279						3082
Eldorado										
1983 polygons		15								15
acres		1232								1232
1997 polygons		15								15
acres		1232								1232
Fresno										
1994 polygons	3	29	13	12	2					56
acres	240	13821	9604	4172	359					27955

Changes in Great Valley Vernal Pool Distribution from 1989 to 1997

1997 polygons	3	29	10	10	2		5			51
acres	240	13821	9186	4093	359		496			27459
Glenn										
1993 polygons		18	13							31
acres		6109	4690							10799
1997 polygons		11	12				8			23
acres		4053	4058				2688			8111
Kern										
1990 polygons		8	2					8		18
acres		1644	669					5086		7399
1997 polygons		6	2				2	8		16
acres		1093	669				551	5086		6848
Kings										
1991 polygons	2	7	2	3				10	3	25
acres	189	1409	358	4618				2040	3236	11660
1997 polygons	2	6	2	2			6	7	2	19
acres	189	1352	358	4541			377	1954	3078	11283
Lake										
1995 polygons		35			2					37
acres		2450			222					2672
1997 polygons		35			2					37
acres		2450			222					2672
Madera										
1987 polygons	1	39	34	7	3				1	84
acres	63	12689	70729	5945	452				1363	91178
1997 polygons	1	35	28	5	2		13		1	71
acres	63	11564	68445	5228	446		4130		1363	87047
Marin ¹										
1986 polygons		2								2
acres		262								262
1997 polygons		2								2
acres		262								262
Mariposa										
1976 polygons	1	7	8	6						21
acres	19	2370	3627	550						6547
1997 polygons	1	7	8	6						21
acres	19	2370	3627	550						6547
Merced										
1987 polygons	13	97	76	36	21	1				231
acres	2805	68584	139430	72025	2486	216				282741

Changes in Great Valley Vernal Pool Distribution from 1989 to 1997

1997 polygons	13	83	64	32	19	1	32			199
acres	2805	65081	113398	71376	2351	216	30317			252424
Napa										
1987 polygons	1	6	2							8
acres	19	681	624							1304
1997 polygons	1	5	1				2			8
acres	19	667	411				226			1078
Placer										
1994 polygons	16	50	32	18	4					104
acres	1378	10715	28424	7673	1529					48341
1997 polygons	15	46	28	15	4		12			93
acres	1342	10307	27527	7489	1529		1525			46852
Sacramento										
1993 polygons	1	138	53	9	3					203
acres	26	22417	12621	17691	255					52985
1997 polygons	1	134	53	9	3		4			196
acres	26	22202	12621	17691	255		215			52770
San Joaquin										
1988 polygons	17	92	52	24						168
acres	2597	18915	10430	7714						37059
1997 polygons	17	87	43	21			17			151
acres	2597	18409	9675	7379			1595			35463
Shasta										
1995 polygons	1	53	6	9						68
acres	27	13392	1605	9283						24280
1997 polygons	1	51	6	7			4			64
acres	27	13262	1605	9199			214			24066
Solano										
1994 polygons	7	44	16	1						61
acres	1105	12494	8113	18271						38878
1997 polygons	7	41	12	1			7			61
acres	1105	11765	7308	18271			1534			37344
Sonoma										
1986 polygons		39	20	1						60
acres		2437	1986	54						4477
1997 polygons		35	18	1			6			60
acres		2109	1544	54			770			3707
Stanislaus										
1988 polygons	7	69	59	18	7					153
acres	639	63300	20125	6878	1727					92031

Changes in Great Valley Vernal Pool Distribution from 1989 to 1997

1997 polygons	7	65	53	17	7		11			142
acres	639	62463	19639	6784	1728		1418			90613
Sutter										
1990 polygons		21	4							25
acres		1035	329							1364
1997 polygons		21	3				1			24
acres		1035	259				70			1294
Tehama										
1994 polygons	1	122	44	17	3				1	187
acres	128	82472	41226	13586	600				43	137927
1997 polygons	1	115	39	15	3		14		1	173
acres	128	80994	40961	12162	600		3167		43	134760
Tulare										
1993 polygons	4	44	15	12				15	6	92
acres	766	4246	6832	20922				3238	1669	36907
1997 polygons	4	39	15	11			11	12	4	81
acres	766	3711	6832	20837			2006	2031	1489	34900
Tuolumne										
1976 polygons		9	4							13
acres		846	3142							3988
1997 polygons		9	4							13
acres		846	3142							3988
Yolo										
1989 polygons		22	1							23
acres		3264	389							3652
1997 polygons		14	1				8			15
acres		2292	389				971			2681
Yuba										
1995 polygons		36	7	4						47
acres		6807	3863	1559						12229
1997 polygons		33	7	3			4			43
acres		6505	3863	1503			358			11871
DWR polygons	98	1115	527	196	45	1	0	33	12	1929
DWR acres	11649	389273	410010	195399	7631	216	0	10365	6311	1019204
1997 U2 polygons	89	1026	468	173	42	1	184	27	10	1747
1997 U2 acres	11613	373877	376187	191543	7490	216	54882	9072	5973	964358

Table 2. Number (above) and collective area (acres, below, rounded) of polygons within habitat density classes in each mapped county as of that county's photo date and after updating to 1997 U2 imagery. These data differ somewhat from those in Holland 1998

because of more precise planimetry and more accurate treatment of those polygons that straddled county lines. Cutouts (Attribute Class 0) and lost habitat (Attribute Class 7) have been removed from the totals.

Valley-wide, 184 polygons covering 54,882 acres disappeared in the interval between DWR and U2 flights. No changes were noted in eight counties: Amador, Calaveras, Contra Costa, Eldorado, Lake, Marin, Mariposa, Tuolumne. Habitat losses in the remaining counties ranged from a single Attribute Class 2 polygon covering 70 acres in Sutter County to 32 polygons covering 30,317 acres in Merced County. [Table 3](#) provides 3 expressions of habitat loss rate by county. Apparent trends in each county are described in the following paragraphs.

County & DWR photo date	Loss rate since DWR photo date, expressed as		
	Acres per year	Percent loss over interval	Percent loss per year
Alameda 1986	31.6	12.6	1.1
Amador 1983	0.0	0.0	0.0
Butte 1994	185.0	0.9	0.3
Calaveras 1983	0.0	0.0	0.0
Colusa 1993	337.0	23.5	5.9
Contra Costa 1985	0.0	0.0	0.0
Eldorado 1983	0.0	0.0	0.0
Fresno 1994	165.3	1.8	0.6
Glenn 1993	672.0	24.9	6.2
Kern 1990	78.7	7.4	1.1
Kings 1991	62.8	3.2	0.5
Lake 1995	0.0	0.0	0.0
Madera 1987	413.0	4.5	0.4
Marin 1986	0.0	0.0	0.0
Mariposa 1976	0.0	0.0	0.0
Merced 1987	3031.7	10.7	1.1
Napa 1987	22.6	17.3	1.7
Placer 1994	508.3	3.1	1.0
Sacramento 1993	53.7	0.4	0.1
San Joaquin 1988	177.2	4.3	0.5
Shasta 1995	107.0	0.9	0.4
Solano 1994	511.3	3.9	1.3

Sonoma 1986	70.0	17.2	1.6
Stanislaus 1988	157.5	1.5	0.2
Sutter 1990	10.0	5.1	0.7
Tehama 1994	1055.6	2.3	0.7
Tulare 1993	501.5	5.4	1.4
Tuolumne 1976	0.0	0.0	0.0
Yolo 1989	121.3	26.6	3.3
Yuba 1995	179.0	2.9	1.4

Table 3. Observed losses of vernal pool complexes by County over the period between DWR photo dates and July, 1997. These rates are derived from Table 2 and express losses for the interval as acres per year, the percent of habitat extant as of the DWR photo date that disappeared by July 1997, and as percent lost per year.

Alameda County was mapped from 1986 DWR slides. In the intervening 11 years only two polygons covering 348 acres disappeared, or slightly over 30 acres/year. This amounts to over 12 percent decrease in habitat over the interval, or about 1.1 percent per year.

No changes in habitat extent were noted in Amador County.

Butte County was mapped from 1994 DWR slides. In the intervening 3 years 6 polygons covering 555 acres disappeared, or 185 acres per year. This is almost a percent decrease over the interval, or about 0.3 percent per year.

No changes in habitat extent were noted in Calaveras County

Colusa County was mapped from 1993 DWR slides. In the intervening 4 years 9 polygons covering 1,348 acres disappeared, or 337 acres per year. This is over a 23 percent decrease over the interval, or nearly 6 percent per year. Only Glenn County has a higher loss rate when expressed as percent per year.

No changes in habitat extent were noted in Contra Costa County

No changes in habitat extent were noted in Eldorado County.

Fresno county was mapped from 1994 DWR slides. In the intervening 3 years 5 polygons covering 496 acres disappeared, or about 165 acres per year. This is a 1.8 percent decrease over the interval, or 0.6 percent per year.

Glenn County was mapped from 1993 DWR slides. In the intervening 4 years 8 polygons covering 2,688 acres disappeared, or about 672 acres per year. This is very nearly a 25 percent decrease over the interval, second only to Yolo County. Glenn County's annualized loss rate (6.2 percent per year) exceeds that observed in any other county.

Kern County was mapped from 1990 DWR slides. In the intervening 7 years, 2 polygons covering 551 acres disappeared, or about 79 acres per year. This is over a 7 percent decrease over the interval, or 1.1 percent per year.

Kings County was mapped from 1991 DWR slides. In the intervening 6 years, 6 polygons covering 377 acres disappeared, or nearly 63 acres per year. This is a 3.2 percent decrease over the interval, or 0.5 percent per year.

No changes in habitat extent were noted in Lake County.

Madera County was mapped from 1987 DWR slides. In the intervening 10 years 13 polygons covering 4,130 acres disappeared, or 413 acres per year. This is a 4.5 percent decrease over the interval, or 0.4 percent per year.

No changes in habitat extent were noted in Marin County. It should be noted that Marin County coverage was limited to overflight from adjacent Sonoma County: only a portion of northern Marin County was mapped.

No changes in habitat extent were noted in Mariposa County.

Merced County was mapped from 1987 DWR slides. In the intervening 10 years 32 polygons covering 30,317 acres disappeared, or nearly 3,032 acres per year. More than half of all habitat loss observed in this study was in Merced County. This is a 10.7 percent loss over the interval, or 1.1 percent per year.

Napa County was mapped from 1987 DWR slides. In the intervening 10 years 2 polygons covering 226 acres disappeared, or 22.6 acres per year. This is a 17.3 percent loss over the interval, or 1.7 percent per year.

Placer County was mapped from 1994 DWR slides. In the intervening 3 years 12 polygons covering 1,525 acres disappeared, or over 508 acres per year. This is a 3.1 percent drop over the interval, or just over 1 percent per year.

Sacramento County was mapped from 1993 DWR photos. During much of the intervening 4 years, Sacramento County had imposed a moratorium on new real estate development projects, so only 4 polygons covering 215 acres disappeared. This is a 0.4 percent decrease over the interval, or only 0.1 percent per year. However, Holland (1988) provides data indicating that over the interval from 1972 to 1993 some 30,512 acres disappeared, or over 1,450 acres per year, averaged over a much longer and more representative period. This is 36 percent decrease over the interval, or 1.7 percent per year.

San Joaquin County was mapped from 1988 DWR slides. In the intervening 9 years 17 polygons covering 1,595 acres disappeared, or over 177 acres per year. This is a 4.3 percent decrease over the interval, or about 0.5 percent per year.

Shasta County was mapped from 1995 DWR slides. In the intervening 2 years 4 polygons covering 214 acres disappeared, or 107 acres per year. This is almost a 1 percent decrease over the interval, or about 0.4 percent per year.

Solano county was mapped from 1994 DWR slides. In the intervening 3 years 7 polygons covering 1,534 acres disappeared, or over 511 acres per year. This is nearly a 4 percent decrease over the interval, or 1.3 percent per year.

Sonoma County was mapped from 1986 DWR slides. In the intervening 11 years 6 polygons covering 770 disappeared, or 70 acres per year. This is a 17.2 percent decrease over the interval, or 1.6 percent per year.

Stanislaus County was mapped from 1988 DWR slides. In the intervening 9 years 11 polygons covering 1,418 acres disappeared, nearly 158 acres per year. This is a 1.5 percent decrease over the interval, or 0.2 percent per year.

Sutter County was mapped from 1990 DWR slides. In the intervening 7 years 1 polygon covering 70 acres disappeared. This is a 5.1 percent decrease over the interval, or 0.7 percent per year.

Tehama County was mapped from 1994 DWR slides. In the intervening 3 years 14 polygons covering 3,167 acres disappeared, over 1,055 acres per year. This is a 2.3 percent decrease over the interval, or 0.7 percent per year.

Tulare County was mapped from 1993 DWR slides. In the intervening 4 years 11 polygons covering 2,006 acres disappeared, over 501 acres per year. This is a 5.4 percent decrease over the interval, or 1.4 percent per year.

No changes in habitat extent were noted in Tuolumne County.

Yolo County was mapped from 1989 DWR slides. In the intervening 8 years, 8 polygons covering 971 acres disappeared, over 121 acres per year. This is a 26.6 percent decrease over the interval, the highest observed in the entire study, or 3.3 percent per year.

Yuba county was mapped from 1995 DWR slides. In the intervening 2 years 4 polygons covering 358 acres disappeared, or 179 acres per year. This is a 2.9 percent decrease over the interval, or 1.4 percent per year.

4. Discussion

The eight counties in which no losses were noted (Amador, Calaveras, Contra Costa, Eldorado, Lake, Marin, Mariposa, Tuolumne) all are foothill or Coast Range counties that barely encroach upon vernal pool landscapes. Collectively, these eight counties account for less than 2.5 percent of the habitat extant in July, 1997.

Higher density polygons tended to be larger: Attribute Class 1 polygons average 350 acres apiece; Class 2 polygons average 779 acres, and Class 3 polygons average 1,000 acres. Similar increases are evident in the disturbed classes, 8 and 9.

In every county, the average size of each polygon increased about 1.4 percent over the interval since DWR photos. This suggests that losses are preferentially focused on smaller polygons that are entirely converted.

The 22 counties in which habitat losses were noted averaged 384 acres lost per year per county, but this was very unevenly distributed. As mentioned above, only 70 acres disappeared from Sutter County over a 7-year period, while over 30,000 acres disappeared from Merced County over 10 years. It is more telling to express habitat loss as percent lost per year, thereby facilitating comparisons among counties. Seen this way, habitat loss was most rapid in Colusa and Glenn counties (5.9 and 6.2 percent per year, respectively), high in Yolo County (3.3 percent per year) and near 1.4 percent per year over all. This over-all estimate is somewhat lower than the 2-3 percent per year reported in Holland (1988). This difference may reflect the increased precision of the present study, or the slow down in the building industry induced by the economic contractions of the late 1980s and early 1990s, or increasingly effective regulation.

By July, 1997, extant vernal pool landscapes throughout the Great Valley had fallen below 1,000,000 acres. Holland (1978) estimated that roughly 4,000,000 acres of vernal pool habitat existed in pre-agricultural time, suggesting that roughly three quarters of the original habitat has been lost. These losses have continued even over the past decade, in spite of considerable regulatory activity, political wrangling, and litigation. More than 5 percent of the habitat I mapped from the DWR slides had disappeared by 1997. Even at a loss rate of only 1.5 percent per year, 1,000,000 acres will have shrunk by half in just 46 years, down to about 12 percent of the original area. It is hard to imagine how these ecosystems can be expected to function normally in the face of an 88 percent reduction in extent. By analogy, how would a citizen feel who saw 88 percent of his assets appropriated?

5. Acknowledgments

I am pleased to acknowledge important GIS assistance from Craig Turner and Scott Collier of the California Department of Fish and Game Natural Heritage Division, and I am grateful to Molly Penbirth of the California Department of Conservation Farmlands Mapping Program for access to the U2 images at very modest cost.

6. References

- Holland, R. F. 1978. *The geographic and edaphic distribution of vernal pools in the Great Valley, California*. California Native Plant Society Special Publication No. 4. Sacramento, CA.
- Holland, R. F. 1988. What about this vernal pool business? In: Kusler, J. A., S. Daly, and G. Brooks (eds.). *Proceedings of the National Wetland Symposium: urban wetlands*: June 26-29, 1988, Oakland, California. Association of Wetland Managers, Berne, N. Y. pp. 351-355.
- Holland, R. F. 1998. Great Valley vernal pool distribution, photorevised 1996. Pages 71-75 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.
- Ikeda, D. H., and R. A. Schlising (Eds.). 1990. *Vernal pool plants: their habitat and biology*. Based on a symposium held at California State University, Chico, 14 June 1989. Studies from the Herbarium, California State University, Chico, Number 8.
- Jain, S. K. 1976. *Vernal pools: their ecology and conservation*. A symposium sponsored by the Institute of Ecology, University of California, Davis, May 1-2, 1976. 93 p.
- Jain, S. K., and P. Moyle (Eds.). 1984. *Vernal pools and intermittent streams: a symposium*, May 9 and 10, 1981 sponsored by the Institute of Ecology, University of California, Davis. 280 pp.
- Witham, C. W., E. T. Bauder, D. Belk, W. R. Ferren Jr., and R. Ornduff (Eds.). 1998. *Ecology, Conservation, and Management of Vernal Pool Ecosystems*. Proceedings from a 1996 Conference. California Native Plant Society, Sacramento. 285 pp.

Figure 1. Air photo mosaic of an area west of Corning in Tehama County, printed here at nominal 1:24,000 scale with polygon boundaries superimposed. Numbers within polygons correspond to attribute classes of Table 1.

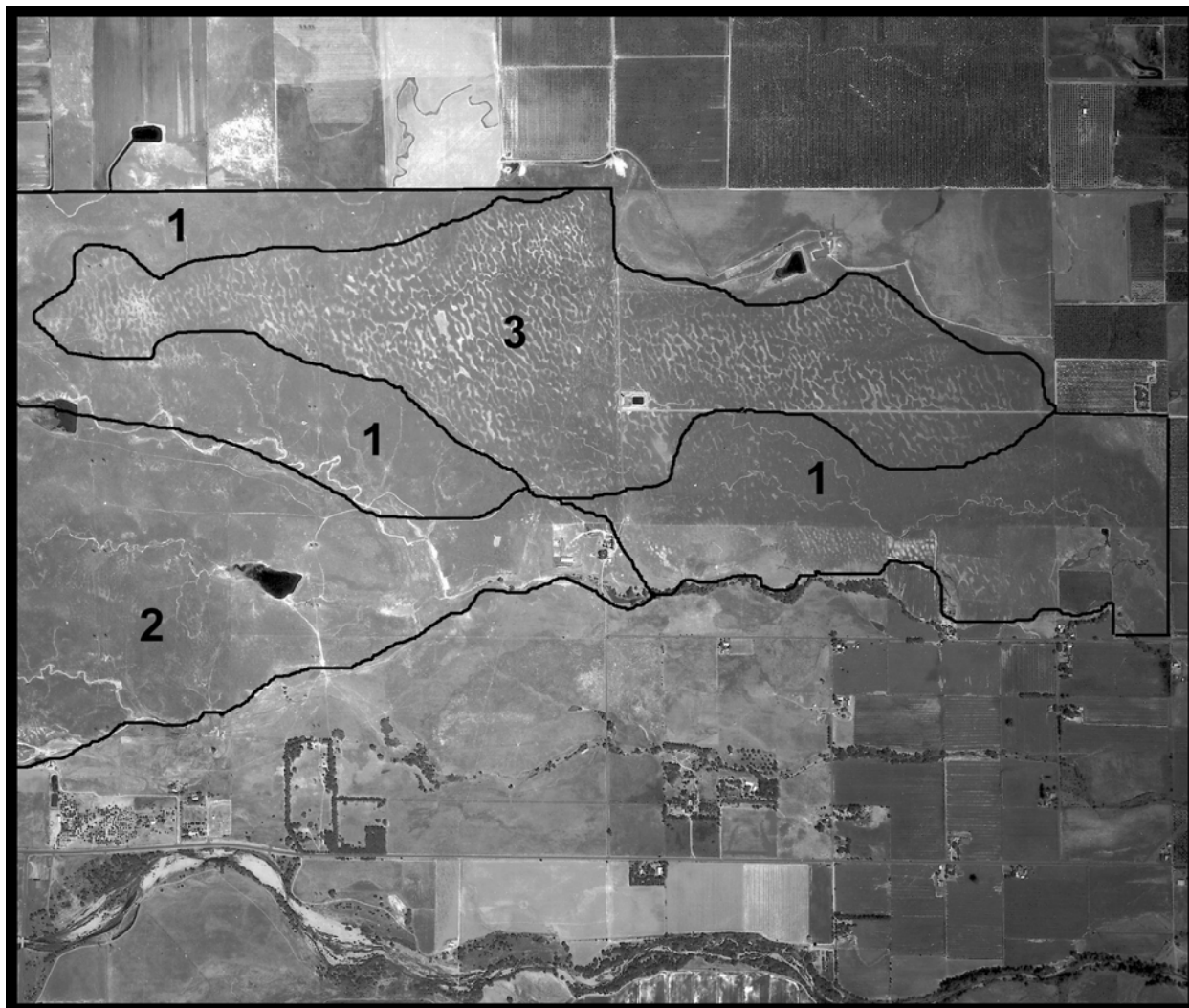


Figure 2. Mapped polygon boundaries superimposed on SPOT image of part of Merced and Madera County, centered over the Chowchilla River, printed here at nominal 1:130,000 scale. Note how some polygon boundaries follow natural features, while others are culturally imposed. Diagonally dashed pattern indicates 5 polygons converted from dispersed grazing to more intensive uses.

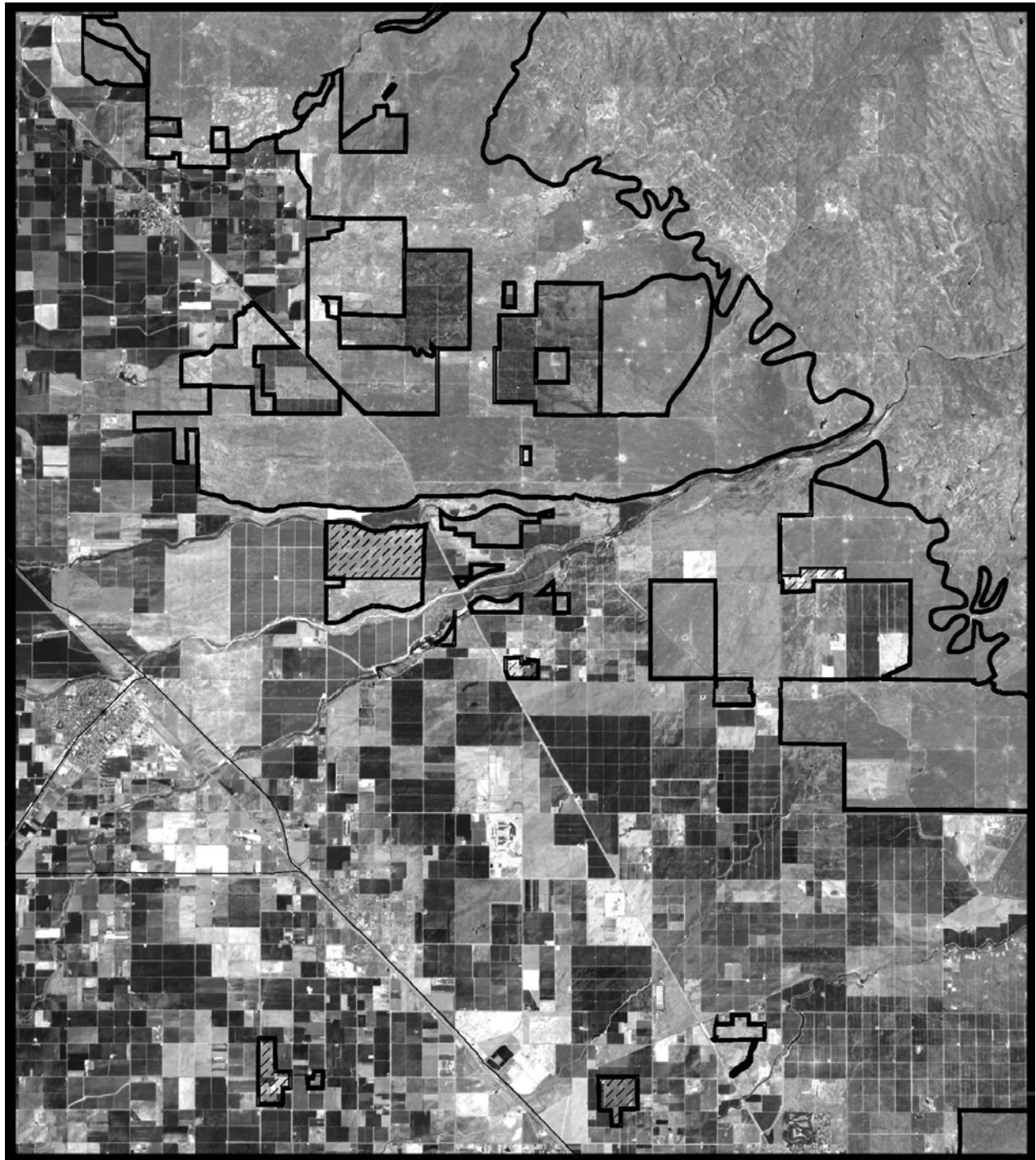


Figure 3. Map of the Holland Study Area, and Vernal Pool Density Classes.

