Great Valley Vernal Pool Distribution Rephotorevised 2005

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ABSTRACT. I interpreted aerial photography to map the extent of vernal pool habitat (i.e., vernal pool wetlands and the surrounding grassland matrix within which vernal pools typically occur) in California's Great Valley in 2005. I compared results with maps prepared previously for the 1976-1995 period and for 1997. The primary causes of vernal pool habitat loss were also obtained from aerial photograph interpretation. Approximately 1,051,000 acres of vernal pool habitat were documented in the Great Valley for the 1976-1995 period. In 2005, just over 914,000 acres remained, a reduction of nearly 137,000 acres. The amount of loss was not distributed evenly across the Great Valley. For example, Mariposa County has not lost any vernal pool habitat since 1976, but at the opposite extreme, Merced County lost nearly 24,000 acres (8% of baseline) and Placer County lost more than 17,000 acres (35% of baseline) of the vernal pool habitat found during initial mapping (in 1987 and 1994, respectively). Counties in western Sacramento Valley (Colusa, Glenn, Sutter, and Yolo) have also seen high losses, ranging from 40 to 75%. Eighty-one percent of the total habitat loss between the initial mapping period and 2005 (110,000 acres) was due to agricultural land conversions. Establishment of orchards and vineyards represents the largest category of land conversion, or almost 30%, which corresponds to nearly 40,000 acres loss of vernal pool habitat. Most of this loss was concentrated in southern Sacramento Valley and northern San Joaquin Valley. Urban development accounted for 26,000 acres (19%) of total habitat loss. Losses to urbanization (two-thirds of the total) were concentrated in Placer and Sacramento Counties with relatively small amounts of loss scattered in other parts of the Great Valley.

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INTRODUCTION

California vernal pools are ephemeral wetland ecosystems with a specialized biota that includes numerous localized plant and animal species. Typically, they form within shallow depressions in grasslands that are underlain by an impervious soil horizon. Beginning in early winter, the pools fill with rainwater and then slowly recede over the spring through evapotranspiration and subsurface lateral flow.

At the time of initial Spanish exploration in the late 1700s, about half of the area of the Great Valley was likely characterized by vernal pool landscapes (Holland and Hollander 2007). The 5-7 million acres of vernal pool landscapes present at that time have been much reduced, first by agricultural development and mineral extraction, followed by urban expansion. The most recent estimate of remaining vernal pool habitat (i.e., vernal pool wetlands and the surrounding grassland matrix within which vernal pools typically occur) was about 967,600 acres in 1997 (Holland 1998b), an 81-87 percent reduction from pre-Columbian time. Habitat loss, combined with the intrinsically localized distributions of many vernal pool taxa, has lead to several species of plants and animals being listed by state and federal governments as Threatened or Endangered. Many more species are consi-

dered to be Rare by the California Native Plant Society (2009).

Great Valley vernal pool habitat was initially mapped from aerial photographs over the period from 1976 to 1995 (Holland 1998a). Subsequently, this map was updated based on 1997 U2 aerial photography for the entire Great Valley, and the loss of habitat over that period was assessed (Holland 1998b). The objectives of the current study were to update the 1997 vernal pool habitat map to 2005 conditions, to evaluate changes to vernal pool habitat distribution, and, for the first time, to identify those land uses to which vernal pool habitat was converted.

MATERIALS AND METHODS

Previous Mapping Methods

1976 to 1995 Map (Baseline). The first digital map of Great Valley vernal pool habitat (Holland 1998a) documented 1,032,000 acres of remaining habitat. This baseline map was based on air photos taken over the period from 1976 to 1995, with the majority taken between 1982 and 1992 (Holland 1998a). The photos were vertically oriented, 35mm, true-color slides that covered about 1x1.4 miles, with 20 percent front- and side-lap, taken from a specially equipped aircraft that flew at constant height above the ground. The slides were taken as part of a program in the California Department of Water Resources that maps the origin, distribution, and use of agricultural water throughout cultivated California, by mapping crop types in California counties on an approximately 7-year rotation. Every slide in every flight line was visually examined for the characteristic vernal pool signatures. The photos were timed to coincide with peak irrigation demand during the mid-summer. During this season, the grassland has completely dried and formerly living annual plants now stand as dead straw. Vernal pools appear as irregularly dendritic features within the tawny matrix of dried annual grassland (Figures 1 and 2). When habitat was encountered, it was mapped onto paper 7.5' USGS topographic map sheets. Each sheet was digitized on an ArcINFO workstation upon completion. The density of vernal pools within each polygon was subjectively scored as either low, medium, or high and areas of disturbed habitat (e.g., areas of cultivation where extant habitat was still evident) were differentiated from areas of undisturbed habitat. Examples of low, medium, and high density vernal pool habitats are shown in Figures 1 and 2. Over an 18-month period, more than 40,000 slides (covering all or part of 345 7.5' USGS topographic map sheets) were examined in an approximately 18,000,000-acre study area that stretched from Shasta Dam south to the Tehachapi Mountains and west to include several North Bay counties.

1997 Map. In 1997, the California Department of Conservation Farmland Mapping and Monitoring Program sponsored a U2 flight covering the entire Great Valley. The resultant images were 9x9 inch false-color infrared transparencies at 1:130,000 scale. About 1,500 images were required to cover the valley. These images, in combination with readily available black-and-white SPOT satellite imagery, were used to update the baseline map to 1997 conditions. Individual vernal pools were not visible at the mapped scale of the U2 and SPOT images, but changes in land use were readily apparent.

Hundreds of vernal pool habitat polygons were converted to other uses. Hundreds more were reduced in size or split into two or more fragments. Polygon boundaries were modified to 1997 conditions. This revised map (Holland 1998b) allowed the first calculation of the rate at which vernal pool habitats in California's Great Valley were vanishing.

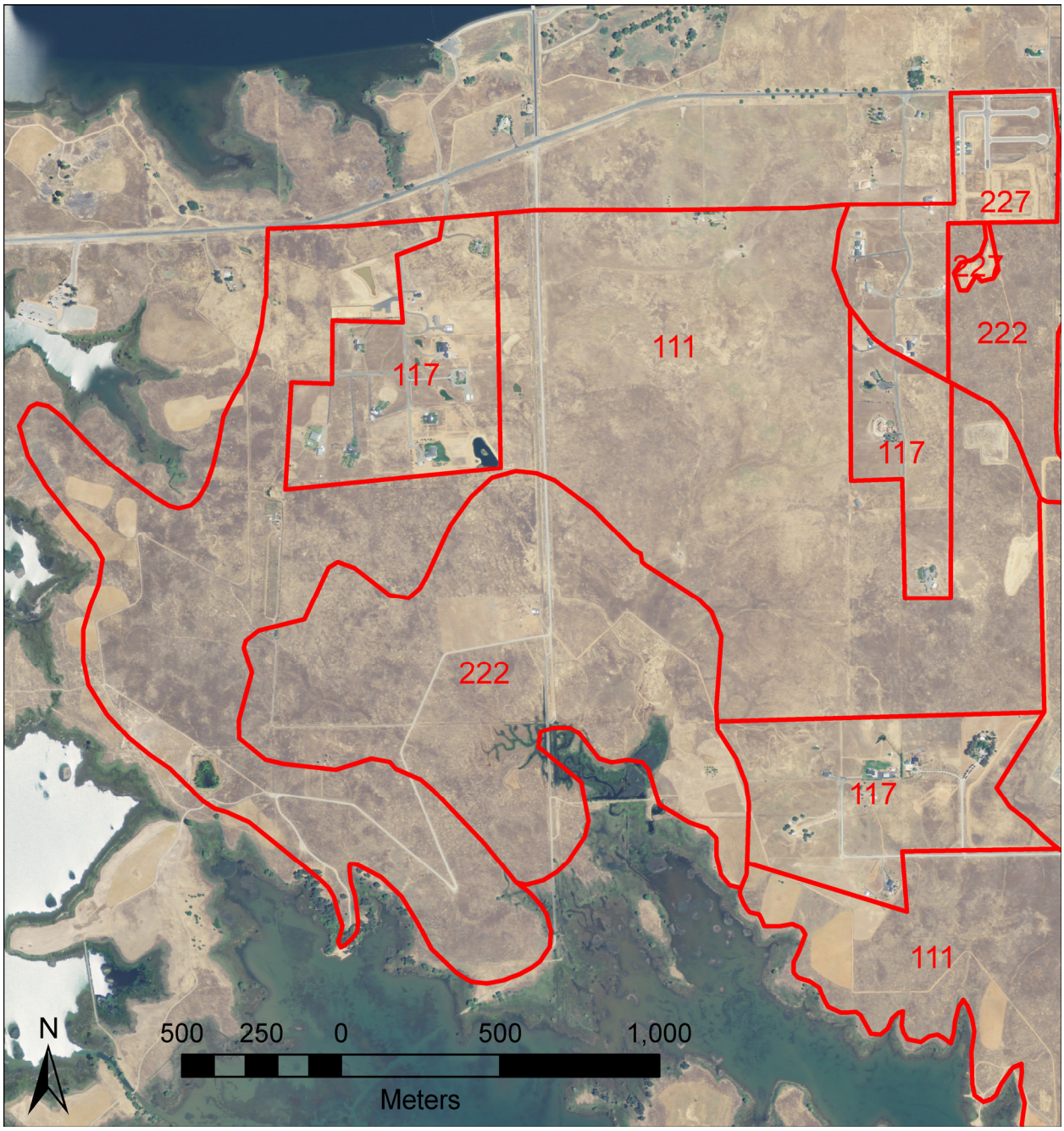

FIGURE 1. NAIP image from Thermalito Afterbay, Butte County. Red numbers indicate habitat scores in the original mapping, 1997, and 2005. The red lines are polygon boundaries. Low density habitat (ones) nearly surrounded an area of moderate density habitat (twos, near image center) in the original mapping. Three areas of low density habitat were converted to agricultural residential (sevens) between 1997 and 2005. Part of a second polygon of medium density (twos) was mapped in the northeast corner of the image; two portions of it were converted to agricultural residential between 1997 and 2005.

The calculation of habitat loss was confounded because the baseline photos were taken county-by-county over several decades. Two counties were mapped from photos just

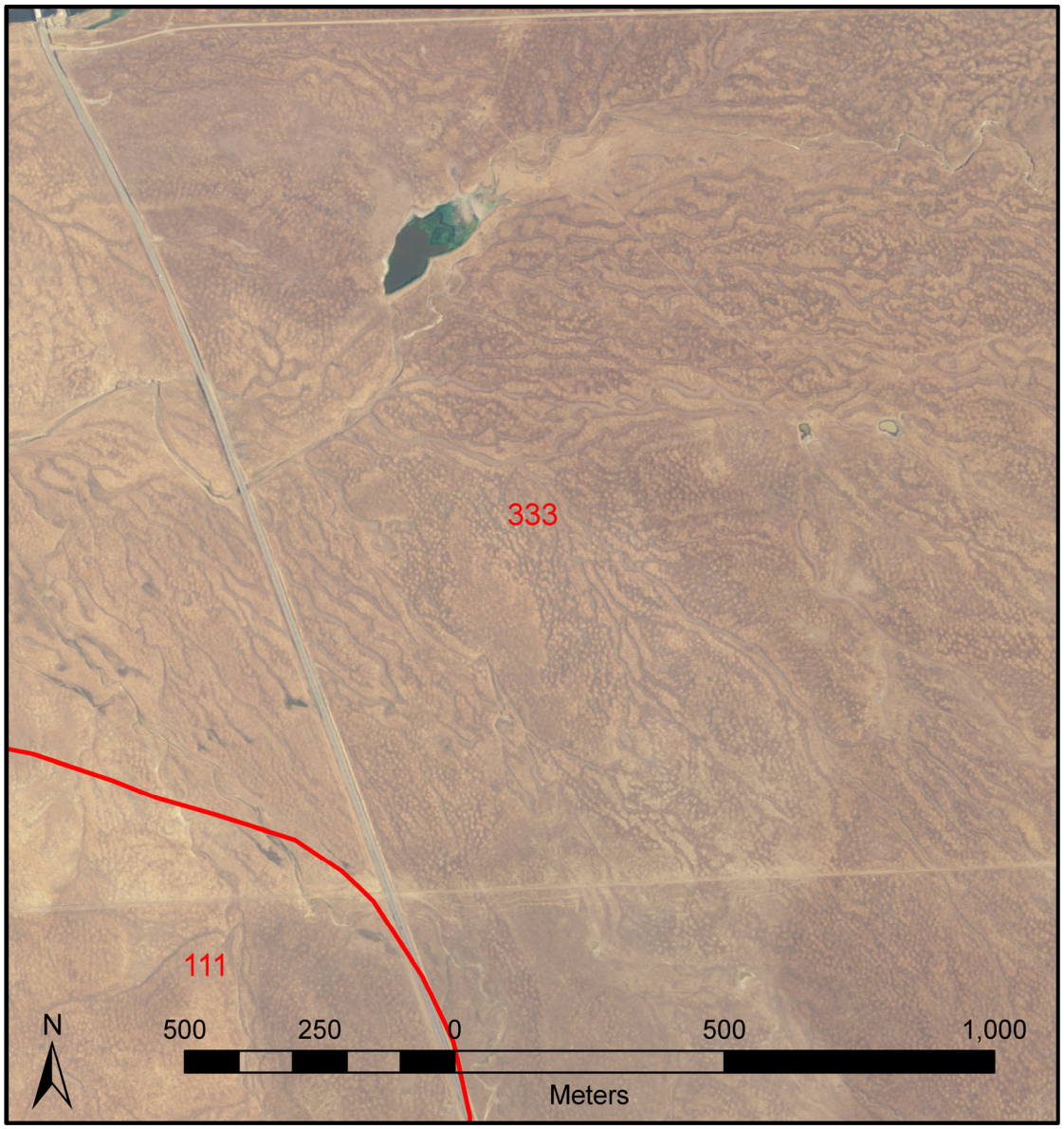

FIGURE 2. NAIP image of high density habitat (threes) and adjacent low density habitat (ones) near Snelling, Merced County. The long, narrow, dendritically-arranged dark features are individual vernal pools. Grassland appears as lighter brown to tan. The tiny light tan dots are individual grass-capped mima mounds surrounded by a darker brown matrix of lower-growing introduced forbs, principally *Erodium*.

two years old (i.e., 1995 photos). Two other counties were mapped from 1976 photos. Thus, it was possible to calculate annual habitat loss rates for each county, but not for the entire Great Valley. This map (Holland 1998b) has been publicly available for nearly a decade and was the starting point for the present study.

Mapping Methods for 2005

In 2005, the National Agricultural Imaging Program (NAIP)—administered by the USDA's Farm Service Agency—produced imagery for each of California's counties. The NAIP images are 1-meter pixel true color orthophoto mosaics that can be displayed using

Geographic Information Systems (GIS) over a large range of scales without loss of image quality. Working systematically from north to south, I examined each polygon from the 1997 map (Holland 1998b) in relation to the NAIP imagery. Polygon boundaries were revised to 2005 conditions. Due to the enhanced resolution provided by the NAIP imagery, it was possible to add a code indicating the current land use for every polygon, something that was omitted from previous studies. The land use classification was compiled *ad hoc*, increasing over the study to include 31 land uses (Table 1). Figure 3 shows several polygons in relation to landscape in Shasta County.

Once the 1997 polygons were updated to 2005 conditions, and attributed, the map and accompanying attribution underwent an extensive third-party quality assurance and quality control review. Placer Land Trust arranged for independent, anonymous review by a recognized vernal pool biologist and by a GIS expert. The review included attribute checking of random samples of polygons, checking attributes of known areas, assessment and correction of map topology, and comparing of check sums of acreages between years. Each mapped polygon was inspected against the NAIP imagery (and sometimes against other public-domain geospatial datasets if interpretation of a feature or attribute class was unclear). This review did not look outside the mapped polygons to see if additional habitat had been missed in the original mapping efforts. The purpose of the review was to confirm that each polygon was correctly attributed as extant or extirpated and the correct land conversion code was assigned. Overall polygon boundaries were not changed or adjusted, except in the cases of overlapping polygons. Overlapping polygons were adjusted so that the overlap acreage would not be calculated twice. As necessary, polygons were clipped to accurately portray existing land use.

TABLE 1. Land use codes used in this study.

Code	Land use
0)	Not converted
1)	Residential
2)	Gravel pits
3)	Dry-farmed hay and grain
4)	Flood control, waste water
5)	Orchard
6)	Woodlot
7)	Electrical yards
8)	Commercial and industrial
9)	Agricultural residential
10)	Not used
11)	Airports
12)	Golf course
13)	Irrigated pasture and alfalfa
14)	Olives
15)	Agricultural staging area
16)	Not used
17)	Landfill
18)	Rice
19)	Vines
20)	Marsh
21)	Unknown
22)	Mitigation bank
23)	Poultry
24)	Raw crops
25)	Gun club
26)	Park
27)	Nursery
28)	Not used
29)	Mixed intensive agriculture
30)	Dairy, feedlot
31)	Bare agricultural land
32)	Bare urbanized land
33)	Degraded since original mapping

This was especially necessary in some of the largest polygons where portions had been converted to agricultural residential land use (e.g., "ranchettes" or "hobby farms"). Once all polygons had been reviewed and reattributed as necessary, new areas and acreages were calculated for each polygon.

As a final step, the shapefile was thoroughly checked for topological errors (i.e., minute

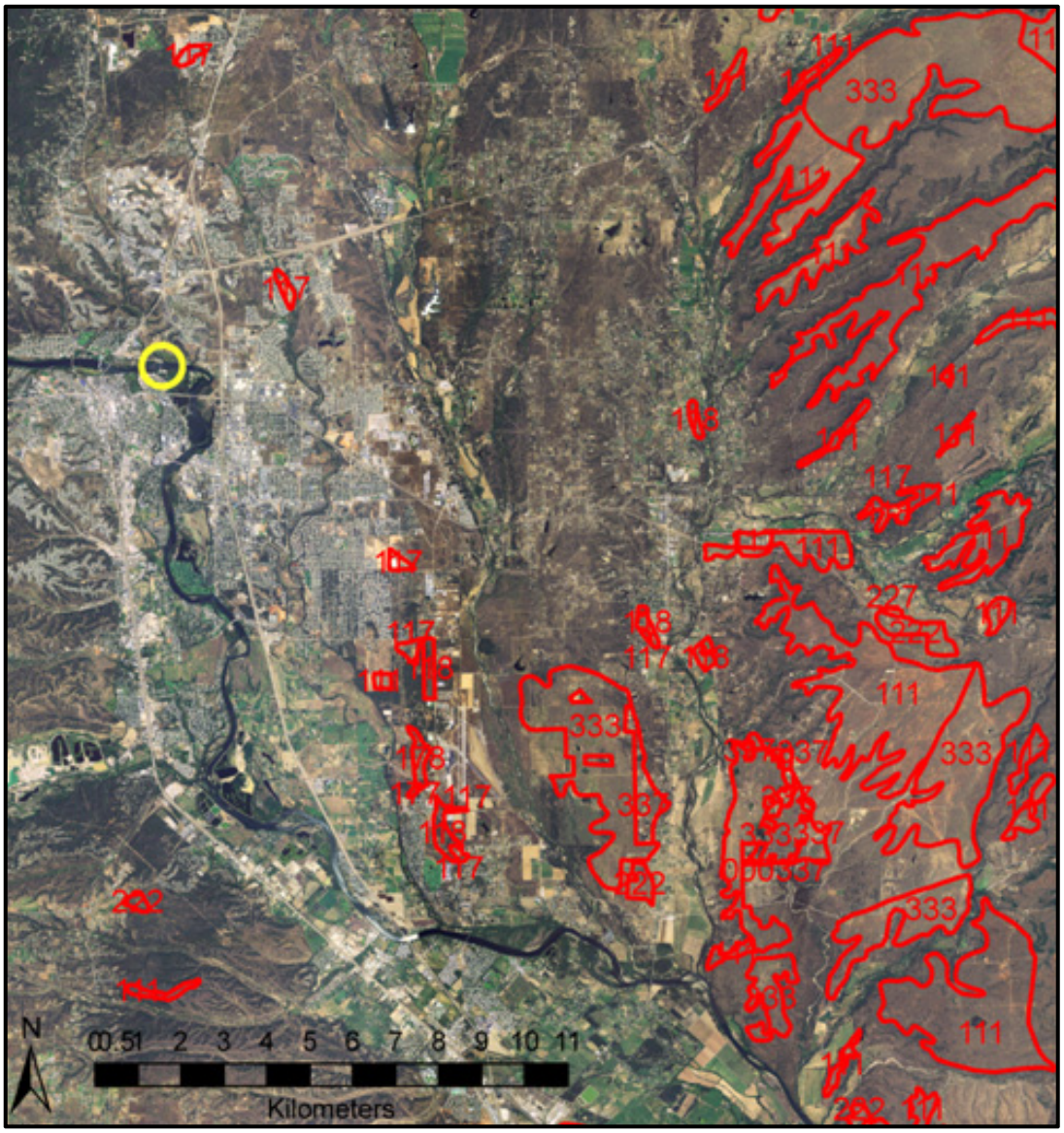

FIGURE 3. Image from Shasta County showing several habitat polygons in relation to landforms. The city of Redding is to the left; the 20 foot wide Sundial Bridge over Sacramento River is barely visible inside the yellow circle (impressive in an image that covers ~15 by 24 miles). The major north-south road is Interstate 5. Habitat losses since 1997 (sevens) are scattered along the eastern fringe of the greater Redding Metropolitan Area, especially around the airport (south of image center).

FIGURE 4. **ON FOLD-OUT PAGE OPPOSITE THIS PAGE** – Distribution of vernal pools in the Great Valley and North Bay in 2005. "Putative hardpan" and "putative claypan" (modified from Holland and Hollander, 2007) show the distribution of hardpan and claypan soils known to support vernal pools today, and thus represent a lower bound on the pre-agricultural extent of the habitat. The study area extent was determined by the limits of coverage of the Department of Water Resources 35 mm color slides.

Holland: Great Valley Vernal Pools, Rephotorevised 2005

mapping errors such as edges of adjacent polygons not quite meeting or overlapping). Any topological errors were discovered and corrected. The resulting attribute table was exported out of ArcGIS into Microsoft Excel. Excel was used to summarize the data, compute various data cross-tabulations, and display results graphically.

RESULTS

The final 2005 vernal pool habitat map is presented in Figure 4 (a foldout on page 113, with figure caption on page 112). Figure 5 summarizes the acreage of extant vernal pool habitat, by density class, for each of the three mapping periods. The acreage of habitat loss is also shown for the 1997 map and 2005 update. Tables 2 and 3 list the amount of habitat lost for each mapping period, by county, as well as the rate of habitat loss. Figure 6 summarizes the various land use changes that have resulted in vernal pool habitat loss and lists those counties where the majority of vernal pool habitat has been lost for each land use conversion. Table 4 displays these same data in detail.

Extent of Habitat Loss

There were just over 1,051,100 acres of extant vernal pool habitat in the (1976-1995) baseline map. By 1997, the acreage of extant habitat had been reduced to below 1,014,000 acres, and many previously contiguous areas of habitat had been fragmented. By 2005 there were just over 914,300 acres of extant habitat with additional fragmentation of the habitat that remained. Therefore, a total of nearly 137,000 acres, (roughly 13 percent) of vernal pool habitat was converted to other land uses since the baseline map was prepared (Table 2). About 4 percent of the habitat extant in the original mapping had been eliminated by 1997; an additional 9 percent was lost between 1997 and 2005. This is over 1 percent per year of the extant habitat in the baseline habitat map (Table 2).

Geography and Rate of Habitat Loss

While a large amount of habitat has been lost, the amount of loss is not distributed evenly across the study area. For example, not one of the 6,553 acres mapped in Mariposa County in 1976 had been converted by 2005. Merced and Placer Counties occupy the opposite extreme. Merced County lost 6,100 acres between 1986 and 1997, or 608 acres/year. Placer County lost 10,440 acres between 1994 and 1997, or 3,480 acres/year. These two counties account for almost one-half (46 percent) of the habitat loss documented in 1997. Large acreages of habitat loss continued in these two counties between 1997 and 2005. Merced County lost an additional 18,000 acres during this period, and Placer County lost 6,600 acres. In all, these two counties have lost 8 and 36 percent, respectively, of their baseline vernal pool habitat acreage. While the percentage of loss in Merced County is only 8 percent of the baseline habitat, this represents a loss of almost 24,000 acres, greatly exceeding the total acreage of loss in any other county during the assessment periods. Areas in central and western Sacramento Valley (Colusa, Glenn, Sutter, and Yolo Counties) have experienced dramatic percentage declines of vernal pool habitat, but these losses are dwarfed by declines elsewhere—in Sonoma, Napa and Marin Counties (Table 2).

Similar to the amount of habitat loss, the rate of habitat loss varies greatly across the study area. Habitat loss rates, in terms of acreage per year, have accelerated markedly in Madera, Stanislaus, Butte, Fresno, Merced, Kings, Kern, Sacramento, San Joaquin, and Sutter Counties between 1997 and 2005 relative to the baseline year and relative to 1997. Marked decelerations in habitat loss are evident in Glenn, Placer, and Solano Counties. When habitat losses are viewed in terms of the

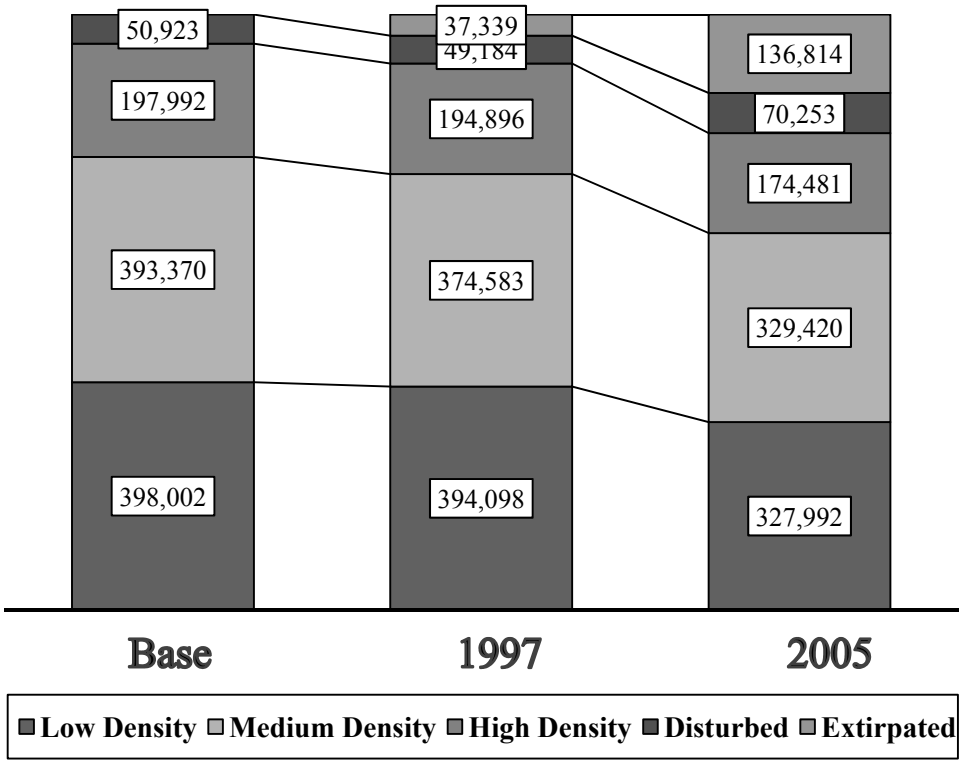

FIGURE 5. Acres of Great Valley vernal pool habitat, shown in low, medium and high density, with increasing acres of landscape loss considering base time, 1997, and 2005, due to disturbance and extirpation.

percentage of baseline habitat lost per year, slightly different, but equally compelling trends are observed. Six counties (Colusa, Glenn, Napa, Placer, Sutter, and Yolo) have lost more than 3 percent of their baseline habitat per year, since the baseline mapping year. For these counties this represents a time span of anywhere from 10 (Yolo County) to 18 years (Napa County). In some cases the rate of habitat loss is roughly even over this period (Colusa and Yolo Counties, both averaging nearly 5 percent of baseline habitat lost per year) while in other cases the rate of loss is declining (Glenn and Placer Counties) or increasing (Sutter and Napa Counties) (Table 2).

Causes of Habitat Loss

Various forms of agricultural land use conversion plainly exceed urbanization as a source of vernal pool habitat loss. Eighty-one percent of the total habitat loss between the baseline year and 2005 was due to agricultural land conversions (Table 4 and Figure 6).

Orchards, vineyards, and, less frequently, eucalyptus plantations (for pulp) represent the single largest cause of vernal pool habitat loss. Almost 30 percent of the total observed vernal pool habitat loss (approximately 40,000 acres) was attributed to this land conversion. Much of the loss (nearly two-thirds of the total) was concentrated in Merced, Stanislaus, and San Joaquin Counties. Much of the remaining loss occurred in Madera, Glenn, and Colusa Counties (Table 4, Figure 6).

The estimated amount of vernal pool habitat

TABLE 2. Total acreage of vernal pool habitat (by county) extant, and total and percent acreage lost, over the years indicated.

County	Base-line Year	Mapped Extant			Total Acres Lost			Total Percent Lost		
		Baseline	1997	2005	Base-97	97-05	Base-05	Base-97	97-05	Base-05
Alameda	1986	2,751	2,402	2,006	349	396	745	13	16	27
Amador	1983	4,087	4,087	3,846	0	241	241	0	6	6
Butte	1994	59,272	58,714	53,405	558	5,309	5,867	1	9	10
Calaveras	1983	4,088	4,088	3,846	0	242	242	0	6	6
Colusa	1993	5,703	4,409	2,110	1,294	2,299	3,593	23	52	63
Contra Costa	1985	3,150	3,150	3,125	0	25	25	0	1	1
El Dorado	1983	1,274	1,274	1,018	0	256	256	0	20	20
Fresno	1994	27,689	27,538	25,490	151	2,048	2,199	1	7	8
Glenn	1993	10,803	8,113	6,553	2,690	1,560	4,250	25	19	39
Kern	1990	9,389	9,302	8,681	87	621	708	1	7	8
Kings	1991	11,951	11,662	9,676	289	1,986	2,275	2	17	19
Lake	1995	2,541	2,541	2,410	0	131	131	0	5	5
Madera	1987	115,096	111,399	100,750	3,697	10,649	14,346	3	10	12
Marin	1986	260	260	162	0	98	98	0	38	38
Mariposa	1976	6,553	6,553	6,553	0	0	0	0	0	0
Merced	1987	285,031	278,956	261,180	6,075	17,776	23,851	2	6	8
Napa	1987	1,303	994	165	309	829	1,138	24	83	87
Placer	1994	48,516	38,076	30,895	10,440	7,181	17,621	22	19	36
Sacramento	1993	53,911	53,738	47,159	173	6,579	6,752	0	12	13
San Joaquin	1988	38,335	36,887	29,615	1,448	7,272	8,720	4	20	23
Shasta	1995	24,034	23,937	23,019	97	918	1,015	0	4	4
Solano	1994	38,896	37,334	35,400	1,562	1,934	3,496	4	5	9
Sonoma	1986	4,466	3,925	2,464	541	1,461	2,002	12	37	45
Stanislaus	1988	92,403	91,082	78,254	1,321	12,828	14,149	1	14	15
Sutter	1990	1,359	1,289	700	70	589	659	5	46	48
Tehama	1994	137,793	134,640	126,860	3,153	7,780	10,933	2	6	8
Tulare	1993	38,368	36,587	30,969	1,781	5,618	7,399	5	15	19
Tuolumne	1976	4,164	4,164	4,080	0	84	84	0	2	2
Yolo	1989	3,617	2,639	901	978	1,738	2,716	27	66	75
Yuba	1995	14,337	14,061	13,034	276	1,027	1,303	2	7	9
Totals		**1,051,140**	**1,013,801**	**914,326**	**37,339**	**99,475**	**136,814**	**4**	**10**	**13**

TABLE 3. Acreage and percent of vernal pool habitat (by county) lost over the years indicated.

County	Baseline Year	Acres Lost Per Year			Percent Lost Per Year		
		Base-97	97-05	Base-05	Base-97	97-05	Base-05
Alameda	1986	32	50	39	1	2	1
Amador	1983	0	30	11	0	1	0
Butte	1994	186	664	533	0	1	1
Calaveras	1983	0	30	11	0	1	0
Colusa	1993	324	287	299	6	7	5
Contra Costa	1985	0	3	1	0	0	0
El Dorado	1983	0	32	12	0	3	1
Fresno	1994	50	256	200	0	1	1
Glenn	1993	673	195	354	6	2	3
Kern	1990	12	78	47	0	1	1
Kings	1991	48	248	163	0	2	1
Lake	1995	0	16	13	0	1	1
Madera	1987	370	1,331	797	0	1	1
Marin	1986	0	12	5	0	5	2
Mariposa	1976	0	0	0	0	0	0
Merced	1987	608	2,222	1,325	0	1	0
Napa	1987	31	104	63	2	10	5
Placer	1994	3,480	898	1,602	7	2	3
Sacramento	1993	43	822	563	0	2	1
San Joaquin	1988	161	909	513	0	2	1
Shasta	1995	49	115	102	0	0	0
Solano	1994	521	242	318	1	1	1
Sonoma	1986	49	183	105	1	5	2
Stanislaus	1988	147	1,604	832	0	2	1
Sutter	1990	10	74	44	1	6	3
Tehama	1994	1,051	973	994	1	1	1
Tulare	1993	445	702	617	1	2	2
Tuolumne	1976	0	11	3	0	0	0
Yolo	1989	122	217	170	3	8	5
Yuba	1995	138	128	130	1	1	1

loss attributable to other types of agricultural land conversion (agricultural residential, bare agricultural land, irrigated pasture, and other agricultural activities) were roughly equivalent, ranging from 10 percent to 15 percent of the total habitat loss. With the exception of agricultural residential development, which is most common in northeastern Sacramento

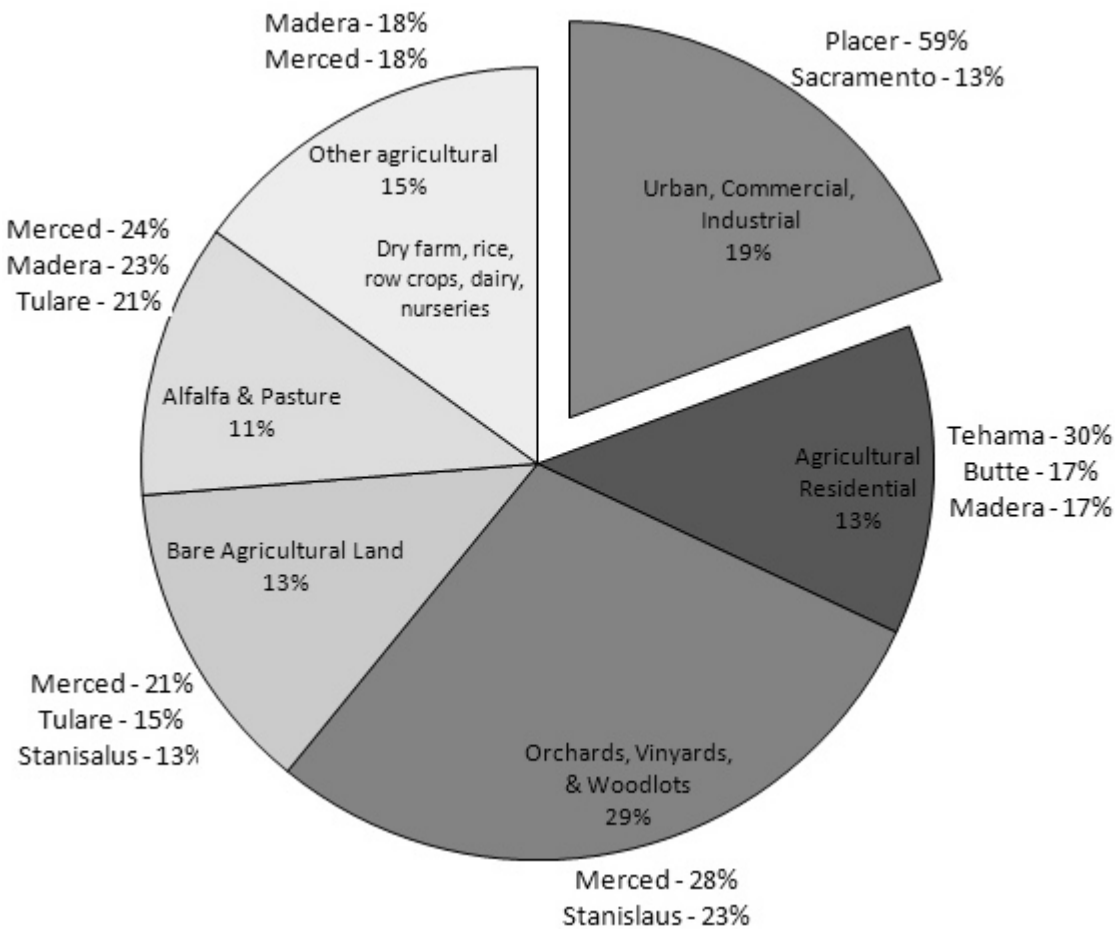

FIGURE 6. Great Valley vernal pool habitat loss (139,814 acres) by land use conversion (percent of baseline). Counties with significant acreages of loss are listed outside the pie chart. Percentages for counties indicate the contribution of the county to the Central Valley-wide loss for the category; for example, 59% of all vernal pool loss due to urban, commercial and industrial development occurred in Placer County.

Valley, these activities have been concentrated in San Joaquin Valley (Figure 6, Table 4).

Land conversions tied to population growth and urban development accounted for almost 26,000 acres or 19 percent of habitat loss. Most urban habitat loss (two-thirds of the total) was concentrated in Placer and Sacramento Counties (Figure 6, Table 4).

DISCUSSION

Over 13 percent of the extant vernal pool habitat found in the baseline mapping effort (Holland 1998a) had been eliminated as of 2005. Agricultural conversions (e.g., rangeland being converted to orchards or vineyards) are far and away the primary drivers of vernal pool habitat loss across the Great Valley. The vast majority of these habitat conversions occur outside the normal regulatory processes that apply to urban, commercial, infrastructure, and industrial development (AECOM 2009) and are, therefore, largely unmitigated. In other words, little to no vernal pool habitat is being created or preserved to compensate for this loss, resulting in an overall net loss of vernal pool habitat functions and services.

TABLE 4. Acres (rounded) of vernal pool habitat loss by county, and percent of land converted, represent the difference between the acreage for 2005 and the 1976-1995 baseline. Type of land conversion and county are listed. See also Figure 6.

County	Urban, Commercial, Industrial		Agricultural Residential		Orchards, Vineyards, & Eucalyptus		Bare, Plowed Agricultural Land		Alfalfa & Pasture		Other Agricultural	
	Acres	Percent of Conversion	Acres	Percent of Conversion	Acres	Percent of Conversion	Acres	Percent of Conversion	Acres	Percent of Conversion	Acres	Percent of Conversion
Alameda	389	0.00	0	0.00	151	0	0	0.00	135	0.00	69	0.10
Amador	21	0.02	69	0.05	29	0.02	0	0.00	121	0.09	0	0.00
Butte	1,127	0.82	2,946	2.15	936	0.68	464	0.34	26	0.02	368	0.27
Calaveras	21	0.02	69	0.05	29	0.02	0	0.00	121	0.09	0	0.00
Colusa	22	0.02	10	0.01	1,150	0.84	615	0.45	432	0.32	1,364	1.00
Contra Costa	0	0.00	0	0.00	0	0.00	26	0.02	0	0.00	0	0.00
El Dorado	101	0.07	155	0.11	0	0.00	0	0.00	0	0.00	0	0.00
Fresno	61	0.04	1,010	0.74	207	0.15	366	0.27	0	0.00	554	0.41
Glenn	0	0.00	54	0.04	2,643	1.93	851	0.62	87	0.06	615	0.45
Kern	124	0.09	293	0.21	0	0.00	92	0.07	0	0.00	198	0.15
Kings	372	0.27	11	0.01	0	0.00	798	0.58	901	0.66	193	0.14
Lake	0	0.00	27	0.02	22	0.02	0	0.00	82	0.06	0	0.00
Madera	103	0.08	2,913	2.13	3,386	2.47	473	0.35	3,453	2.52	4,018	2.94
Marin	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	97	0.07
Mariposa	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Merced	1,576	1.15	63	0.05	11,105	8.12	3,684	2.69	3,636	2.66	3,788	2.77
Napa	1,107	0.81	31	0.02	0	0.00	0	0.00	0	0.00	0	0.00
Placer	15,368	11.23	172	0.13	103	0.08	426	0.31	188	0.14	1,363	1.00
Sacramento	3,298	2.41	416	0.30	2,193	1.60	420	0.31	69	0.05	357	0.26
San Joaquin	60	0.04	1,137	0.83	4,503	3.29	1,654	1.21	506	0.37	860	0.63
Shasta	175	0.13	722	0.53	7	0.00	0	0.00	36	0.03	76	0.06
Solano	743	0.54	132	0.10	0	0.00	1,068	0.78	217	0.16	1,335	0.98
Sonoma	500	0.37	44	0.03	822	0.60	62	0.05	202	0.15	373	0.27
Stanislaus	19	0.01	1,116	0.82	9,202	6.73	2,379	1.74	489	0.36	944	0.69
Sutter	22	0.02	181	0.13	14	0.01	132	0.10	0	0.00	309	0.23
Tehama	325	0.24	5,286	3.86	2,570	1.88	448	0.33	1,443	1.05	861	0.63
Tulare	15	0.01	326	0.24	314	0.23	2,589	1.89	3,123	2.28	1,032	0.75
Tuolumne	39	0.03	0	0.00	0	0.00	0	0.00	0	0.00	44	0.03
Yolo	626	0.46	0	0.00	132	0.10	924	0.68	0	0.00	1,034	0.76
Yuba	266	0.19	94	0.07	0	0.00	125	0.09	74	0.05	742	0.54
Totals	**26,481**	**19.36**	**17,276**	**12.63**	**39,518**	**28.89**	**17,598**	**12.86**	**15,339**	**11.21**	**20,596**	**15.05**

Urbanization exceeds agricultural development as the primary cause of vernal pool habitat loss only in Placer County.

The rate of habitat loss increased sharply between 1997 and 2005, relative to rates of loss prior to 1997. And, while much vernal pool habitat still remains in many counties (despite significant losses), widespread loss of habitat was observed on the western side of Sacramento Valley, an area that did not have extensive areas of vernal pool habitat initially. If the current rate of annual habitat loss (12,434 acres/year) continues unchanged, vernal pool habitats (with the exception of vernal pool habitat preserves) will be completely eliminated from the Great Valley by 2087.

Given changes in GIS technology since the baseline maps were prepared, a brief discussion of the limitations of the mapping methodology used to prepare the current and historic maps is appropriate. The original maps were sketched by hand from a display screen at about 1:10,400 scale onto 1:24,000 scale topographic sheets, and later digitized by a technician using ArcINFO at a dedicated workstation and a digitizing tablet. It was the dawn of GIS technology. The 1997 update was drawn by hand on a light table onto 130,000-scale base maps. These base maps were edited by a technician on-screen using ArcView 3.2. The 2005 update was done entirely on-screen using ArcGIS version 9.2. With this technology, one may zoom in or out, overlay maps of topography, geology, or soils, or compare the photomosaic with other imagery from other dates. The 1997 methods were more accurate than the baseline mapping methods, and the 2005 methods were again more accurate than the 1997 methods.

Because the 2005 NAIP imagery afforded vastly superior image quality over the color aerial photography slides and satellite imagery used to prepare the baseline map and 1997 update, a variety of initial mapping errors were evident. For example, it was not uncommon to find polygons originally mapped from baseline imagery whose boundaries only approximated the detail visible in the 2005 images. There were also instances where habitat that was obviously extant in 2005 was not mapped in the initial baseline map, and, conversely, there were obvious areas of non-habitat that had been lumped with adjacent areas of extant habitat to create a single polygon. Correcting these errors accounts for the differences between the data reported here and those reported in 1998.

The clear conclusions are that significant vernal pool habitat loss is occurring throughout the Great Valley and that, despite the attention devoted to urban development, various forms of agricultural development have resulted in over four times more vernal pool habitat loss than urbanization.

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