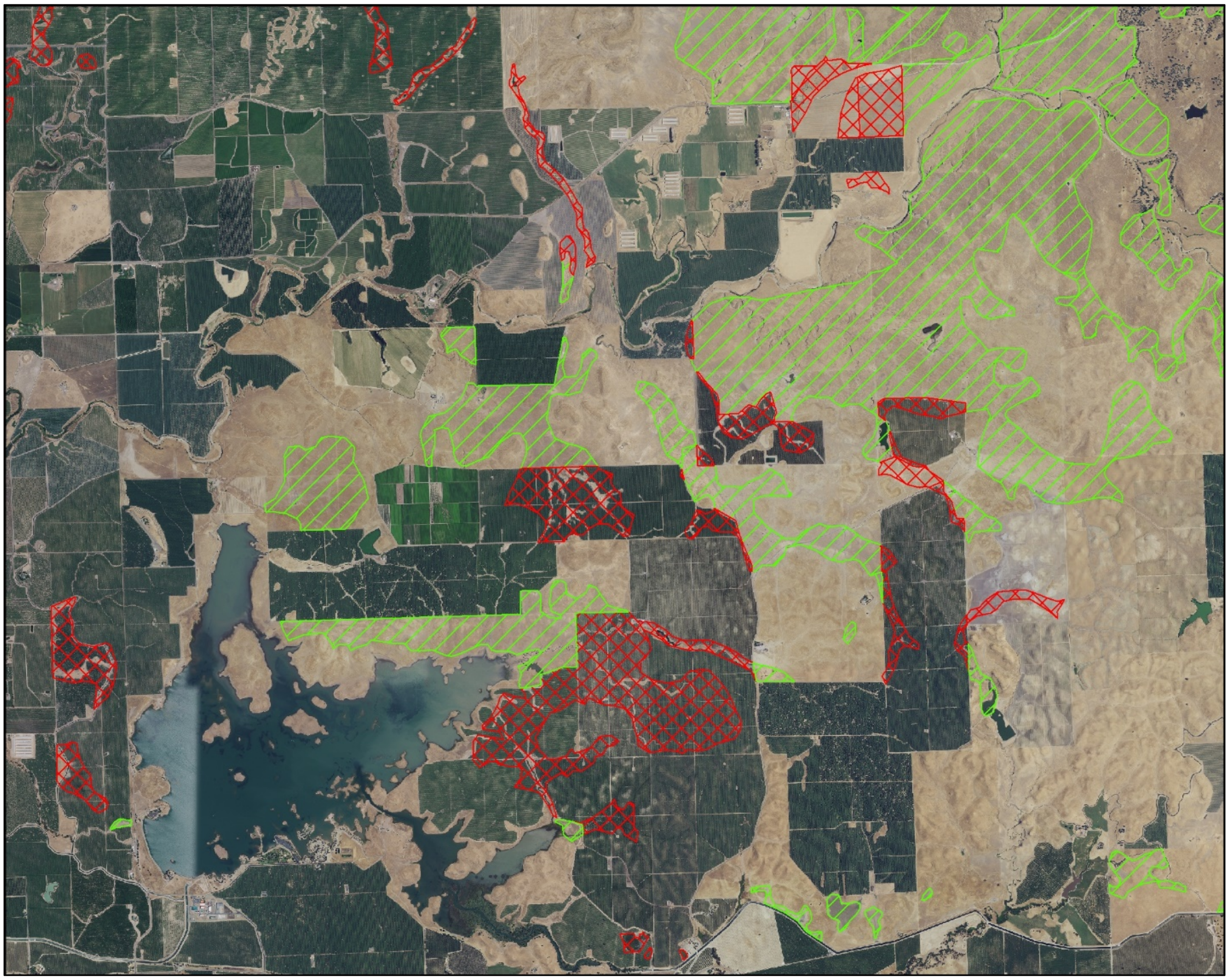
Changes in the Distribution of Great Valley Vernal Pool Habitats from 2005 to 2018



Aerial photo showing mapped polygons of extant (green hatching) and extirpated (red hatching) vernal pool habitat.

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Robert F. Holland contributed to the analyses of the 2018 geodatabase and provided insight into the limitations of the dataset and possible additional questions to be addressed.

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Changes in the Distribution of Great Valley Vernal Pool Habitats from 2005 to 2018

Abstract

This report documents the changes in extent and condition of vernal pool habitat in California's Great Valley between 2005 and 2018. "Vernal pool habitat" is defined as vernal pools and the surrounding upland (typically grassland) habitat matrix. The 2005 base map was created by using double-blind mapping protocol and covered 21.4 million acres in and surrounding the Sacramento and San Joaquin valleys (Witham et al. 2013). An update to that map using 2012 aerial imagery focused on the 807,820 acres identified in the 2005 map and areas immediately surrounding the previously mapped polygons (Witham et al. 2014). This report updates those mapping efforts based on 2018 aerial imagery.

The result of the 2018 remapping shows 737,337 acres of extant habitat. This is down from 2005, a net reduction of 70,482 acres over the period of 2005-2018. This number is slightly misleading as mitigation bank (and previously undetected) acreages were added during both the 2012 and 2018 mapping. The overall loss of natural vernal pool habitat over the 2005-2013 period was 76,023 acres.

This 2018 remapping effort revealed that most of the habitat loss between 2005-2018 was due to unregulated agricultural conversions. This is similar to the results of the 2012 remapping. As of the 2018 remapping, only 6.65% of the habitat loss was due to urban or industrial conversion. The remainder of the loss is attributed to various agricultural conversions with orchards comprising 56.6% of the acreage lost.

1 Introduction

The first GIS map of vernal pool habitat (Holland 1998a) was based on interpretation of Department of Water Resources aerial photography in the form of slides that encompassed approximately 1 by 1.4 miles per slide. These slides dated from 1987 through 1995 depending on the county. Subsequent updating of that GIS mapping (Holland 1998b, 2009) focused on land use changes within the originally mapped polygons.

A more recent mapping effort was based on *de novo* interpretation of 2005 high resolution geo-referenced imagery (Witham et al. 2013). That mapping was conducted double-blind by Robert Holland and Carol Witham. The 2005 map identified 807,820 acres of habitat in 1,909 polygons within the 21.4-million-acre study area.

A follow-up to the 2005 mapping effort was conducted by Holland and Witham using 2012 high resolution imagery (Witham et al. 2014). That remapping detailed losses by county, what habitat was lost to, and analyzed extant habitat against various databases of protected lands. This updated map focused on the 807,820 acres identified in the 2005 map and areas immediately surrounding the previously mapped polygons.

This report details a second update to the 2005 map. Remapping was conducted by Witham using the 2012 remapping geodatabase overlain on the 2018 National Agriculture Imaging Program (NAIP) high resolution aerial imagery. The remapping effort focused on all polygons previously mapped and areas immediately adjacent to them. Special attention was also given to identifying new mitigation banks in counties with high urban development pressure.

2 Description of Study Area

The 2005 study area (Witham et al. 2013) covered the entire Great Valley and surrounding foothills up to the top of the blue oak – foothill pine woodland as mapped by Kuchler (1976). This area encompassed 21.4 million acres. The original map included 807,820 acres of extant vernal pool habitat. The 2012 remapping (Witham et al. 2014) included those acres plus added some additional habitat to bring the total habitat area (both extant and recently extirpated) to 812,173 acres.

This second remapping effort based on 2018 NAIP imagery focused on those 812,173 acres of habitat previously mapped plus surrounding areas. Special focus was placed on counties where large scale (re-)creation of habitat is occurring. The resultant 2018 remapping includes 813,360 acres of habitat (both extant and extirpated). The study area included in the 2005 (and subsequent) mapping is illustrated in Figure 1 (page 3).

3 Methods and Materials

Refer to prior mapping reports (Witham et al. 2013, Witham et al. 2014) for a thorough discussion of the GIS data layers that were used to inform the mapping projects based on the 2005 and 2012 NAIP imagery. These reports also contain explanations of mapping limitations and data interpretation. Using the 2018 remapping geodatabase without understanding the constraints of the overall mapping project could lead to misinterpretations.

3.1 Baseline Map

The foundation of this study is the geodatabase produced from heads-up digitizing based on interpretation of 2005 NAIP imagery. Two mappers worked independently to map the study area and then met to compare maps and reconcile differences. This resulted in each polygon's boundary and attributes being considered at least four times. Appendix A provides more details on the methods used to create the 2005 map and subsequent remapping.

The 2012 map was produced by reviewing the 2005 map based upon 2012 NAIP aerial imagery. This included review of each polygon previously mapped plus areas immediately adjacent to mapped habitat. Counties with active mitigation banking were assessed in finer detail. The 2012 remapping used a slightly less laborious methodology with Holland and Witham mapping alternate counties and then reviewing the results together (Witham et al. 2014).

3.2 2018 Remapping

For the 2018 remapping effort, a more streamlined approach was used. The entire mapping was conducted by Witham. Numerous random polygons within each county were spot checked for

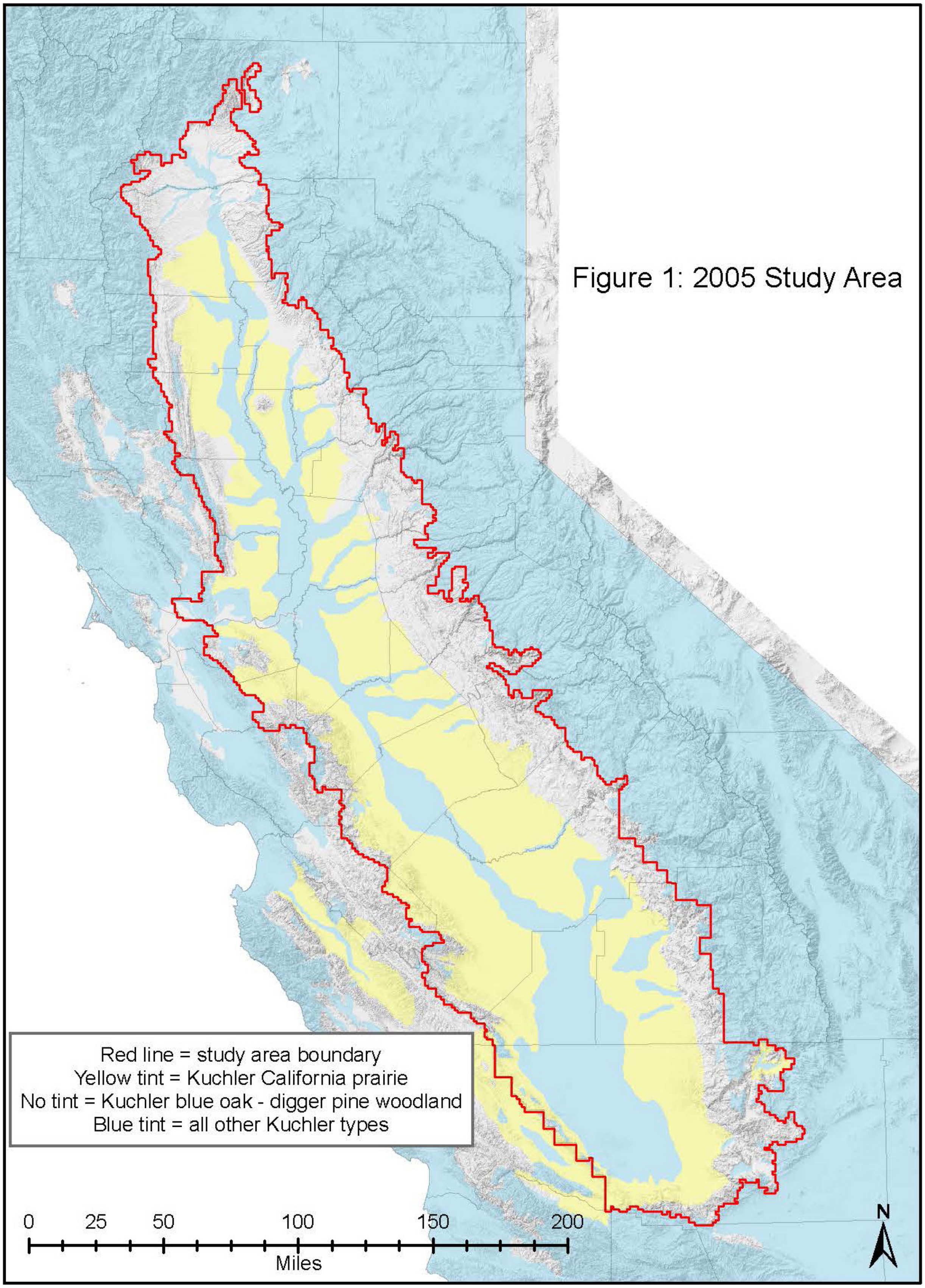


Figure 1: 2005 Study Area
Red line = study area boundary
Yellow tint = Kuchler California prairie
No tint = Kuchler blue oak - digger pine woodland
Blue tint = all other Kuchler types
0 25 50 100 150 200
Miles
N

accuracy. Then the geodatabase was analyzed for various parameters; this focused on identifying records which contained mutually exclusive attributes in similar fields. Following the various quality control analyses, discrepancies were resolved to produce the final geodatabase.

3.2.1 Materials

For the remapping project based on 2018 aerial imagery, the primary GIS data layers used were the 2018 NAIP imagery mosaics by county and the geodatabase produced using the 2012 imagery with changes as discussed below.

3.2.2 Geodatabase Structure

The GIS data provided with this report is formatted as a relational geodatabase. The geodatabase created during the 2005 mapping was used as the baseline for the 2012 remapping. Similarly, the 2012 geodatabase was used as the baseline for the 2018 remapping. Included with the primary geodatabase are several additional polygon and point shapefiles described as follows:

- **2018RemapVernalPoolsFINAL.mdb**
    - **VPMapping** (feature dataset)
        - **VernalPools2018** *(primary geodatabase):* Contains polygons and associated attributes from the 2005, 2012, and 2018 mapping efforts. The structure of this file is provided as Appendix B which details the fields used and lists the variables available for each field.
        - **AllCountiesStudyArea2005**: Polygon depicting the study area considered in the original 2005 mapping and subsequent remapping.
        - **LargePools2005**: Point file of all large vernal pools identified during the original 2005 mapping. The structure of this file is also provided in Appendix B.
    - **Derived_Data** (feature dataset)
        - **Extant2018**: Contains only those polygons determined to be extant in the 2018 remapping. The structure of this file is as described for the primary geodatabase.
        - **Extripated2018**: Contains only those polygons determined to be extirpated as of the 2018 imagery and mapping. The structure of this file is as described for the primary geodatabase.
        - **LargePools_Extirpated2018**: Point file containing large pools which were determined to be within extirpated polygons as of the 2018 remapping.
- **County_nrcs_a_ca.shp**: Shapefile used for county boundaries throughout the mapping and remapping projects.

4 Results and Discussion

There was total of 737,337 acres of extant habitat within the Great Valley as of the 2018 NAIP imagery. This is down from 807,819 acres in 2005, a net reduction of 70,482 acres. Habitat actually was eliminated from 76,023 acres, but these losses were partially off-set by 2,135 acres of mitigation banks built since 2005, and by 3,406 acres that were missed in the 2005 or 2012 mapping. In the thirteen years since the Recovery Plan was adopted, some 5,848 acres per year have been converted to other land uses.

Figure 2 (page 6) is a map showing the results of the 2018 vernal pool habitat remapping. Some areas have been enlarged as examples to show the interspersion of extant and extirpated habitats and includes separate colors for newly created mitigation banks and habitat previously missed in earlier mapping efforts.

4.1 Comparison with Previous Mappings

This section is provided to document the overall level of changes between each of the mapping years. It is expected that a remapping project will include both more features and more area than the prior maps. Previous polygons may be cut into pieces to show land use changes over time. Additional polygons may be found due to earlier mapping errors or because new vernal pool habitat has been created. Table 1 (below) shows a general comparison between the maps.

Table 1: General comparison between mapping years.

Mapping Totals	Year of Aerial Imagery		
	2005	2012	2018
Number of Polygons	1,909	2,456	3,126
Total Acreage	807,819	812,173	813,360
Average Acres/Polygon	423	331	260
Extant Number of Polygons	1,909	1,954	1,986
Extant Acreage	807,819	764,868	737,337
Extant Average Acres/Polygon	423	391	371
Extirpated Number of Polygons	-	502	1,140
Extirpated Acreage	-	47,306	76,023
Extirpated Average Acres/Polygon	-	94	67
Percent Extirpated since 2005	-	5.82%	9.35%

More detailed analyses of various aspects of the 2018 remapping, especially pertinent to extirpated habitat, are provided in the sections below. However, one result illustrated by the table above is important to note here—the average size of extant polygons of vernal pool habitat have decreased from 423 acres in 2005 to 371 acres in 2018. The decrease of patch sizes is an indirect indication of increased fragmentation.

Table 2 (page 7) shows the extant habitat identified over the three mapping years by county. Average size of mapped extant habitat is also shown. Decreases in patch size are apparent in

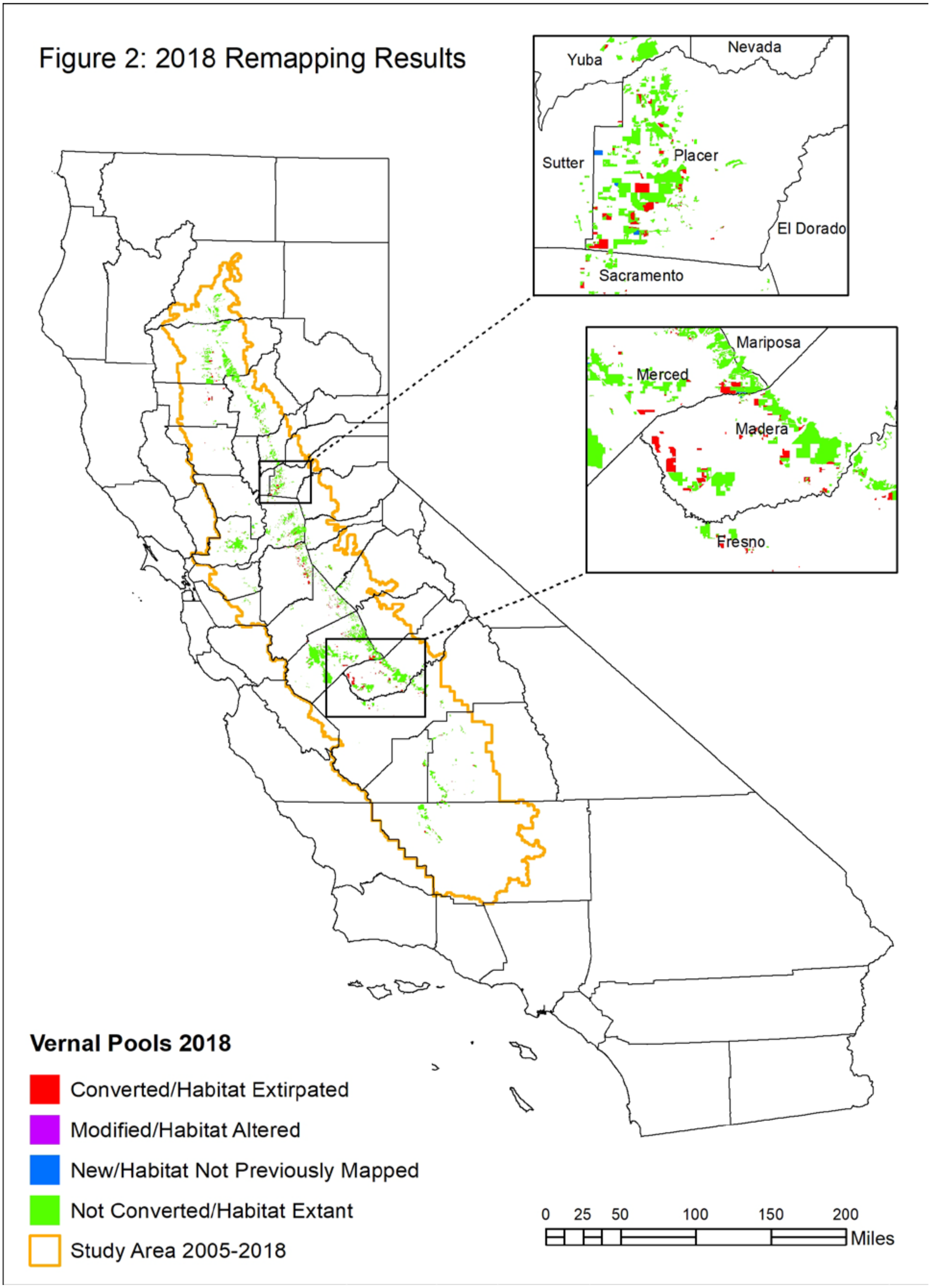


Figure 2: 2018 Remapping Results
Yuba
Nevada
Sutter
Placer
El Dorado
Sacramento
Mariposa
Merced
Madera
Fresno
Vernal Pools 2018
Converted/Habitat Extirpated
Modified/Habitat Altered
New/Habitat Not Previously Mapped
Not Converted/Habitat Extant
Study Area 2005-2018
0 25 50 100 150 200
Miles

most counties with significant decreases in Glenn, San Joaquin, Placer, Kern, and Madera Counties. Again, decreased patch size is an indirect indication of increased habitat fragmentation.

Table 2: Summary of extant habitat in 2005, 2012, and 2018 by county.

	2005 Extant Habitat			2012 Extant Habitat			2018 Extant Habitat		
County	Polygons	Acres	Avg Size	Polygons	Acres	Avg Size	Polygons	Acres	Avg Size
Alameda	10	1,976	198	10	1,966	197	10	1,920	192
Amador	12	3,729	311	14	3,664	262	15	3,575	238
Butte	96	54,857	571	103	54,228	526	117	52,559	449
Calaveras	28	5,942	212	28	5,942	212	26	5,523	212
Colusa	8	1,592	199	10	1,407	141	7	1,272	182
Contra Costa	18	3,499	194	19	3,465	182	20	3,505	175
El Dorado	7	903	129	6	852	142	7	713	102
Fresno	47	27,405	583	46	25,784	561	43	24,206	563
Glenn	17	6,020	354	14	3,848	275	14	2,489	178
Kern	32	31,202	975	37	29,719	803	41	29,335	715
Kings*	6	5,080	847	10	6,762	676	13	6,029	464
Madera	68	92,324	1,358	72	77,754	1,080	73	74,321	1,018
Mariposa	26	3,055	118	26	3,055	118	26	3,055	118
Merced	326	203,567	624	324	196,400	606	318	193,680	609
Placer	163	31,338	192	185	29,893	162	204	27,856	137
Sacramento	292	64,224	220	314	62,197	198	323	60,690	188
San Joaquin	143	31,692	222	141	25,557	181	136	20,359	150
Shasta	50	20,732	415	53	20,739	391	53	20,703	391
Solano	47	38,039	809	52	37,548	722	55	37,066	674
Stanislaus	216	23,464	109	189	20,489	108	179	18,700	104
Sutter	17	1,254	74	17	1,254	74	17	996	59
Tehama	154	101,196	657	155	99,101	639	156	97,007	622
Tulare	52	28,487	548	52	27,313	525	52	26,360	507
Tuolumne	27	5,174	192	27	5,161	191	27	5,145	191
Yolo	11	4,753	432	12	4,750	396	12	4,637	386
Yuba	36	16,315	453	38	16,020	422	42	15,634	372
TOTALS	1,909	807,819	423	1,954	764,868	391	1,986	737,337	371

*Includes significant acreage identified in 2012 which was under water in 2005 due to above ground water storage.

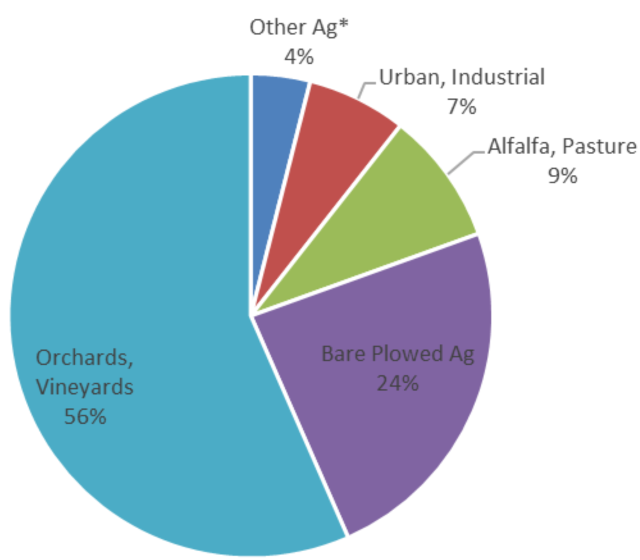
Additional analyses of the changes between mapping years may be found in Appendix C. The two tables provided in Appendix C detail by county the extent of changes over 2005-2012 and 2012-2018, respectively. They are provided to validate changes in acreage totals and polygon numbers between the mapping years. They also provide the general locations where additional natural habitat was found and where mitigation banks were created.

4.2 Types of Land Conversion

One of the fields included in the 2012 remapping geodatabase was a generalized list of land conversion types (refer to Appendix B). This allowed quantification of the land use to which the vernal pool habitat was being converted. A similar field was included for the 2018 remapping and is independent of what may have been mapped in 2012. These fields were kept separate to allow for future analyses of trends in habitat conversion. For example, a significant amount of the lands mapped as bare agricultural ground in 2012 were converted to orchards by 2018.

Figure 3 (below) details the disposition of the 76,023 acres that were converted between 2005 and 2018. Agricultural land uses are responsible for nearly all (93%) of the habitat conversion between 2005 and 2018. Over half of the conversions have been to orchards and vineyards. About a quarter of the acreage is in the transitional category of bare plowed ground. Urban and industrial development accounted for only seven percent of the conversions.

Figure 3: Disposition of 76,023 acres of vernal pool habitat converted between 2005 and 2018



*Includes conversion to agricultural residential, nurseries, dairies, permanent wetlands, etc.

Table 3 (page 9) provides tabular data on losses by conversion type by county. Madera County had the greatest amount of habitat loss (18,097 acres) of which over 99% was converted to agricultural uses. San Joaquin County showed the second greatest loss (11,432 acres) which was entirely agricultural conversion. Merced County had the third greatest loss (10,350), again with most losses due to agricultural conversion. Mariposa was the only county with no loss of vernal pool habitat between 2005 and 2018.

4.3 Wetted Acres Lost

The mapping conducted under this project (and prior mappings of 2005 and 2012) consisted of mapping the habitat matrix and not individual pools. However, it is possible to approximate wetted acres lost by multiplying acres converted in each cover class by the mid-point of the cover class range, then sum over cover classes.

Table 3: Losses of vernal pool habitat between 2005 and 2018 by conversion type and county.

	Urban, Industrial		Orchards, Vineyards		Alfalfa, Pasture		Bare Plowed Ag		Other Ag		Ag Residential		2018 Converted	
County	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres
Alameda							2	46	1	8	1	1	4	55
Amador			2	32	2	55	3	67					7	154
Butte	13	280	22	833	1	3	19	869	10	250	27	170	92	2,405
Calaveras			3	69			4	264	1	14	3	72	11	419
Colusa			4	208			2	56	2	77			8	341
Contra Costa							1	5	3	5			4	10
El Dorado	10	171					1	18					11	189
Fresno			14	760	2	219	17	1,588	8	494	14	139	55	3,200
Glenn			9	3,271			2	260					11	3,531
Kern			8	236	5	366	14	1,069	6	71	3	125	36	1,867
Kings	1	535					3	197					4	732
Madera	1	7	47	13,194	5	1,845	45	3,034	4	16			102	18,097
Mariposa														
Merced	10	288	49	5,795	13	2,689	26	1,410	8	167	2	1	108	10,350
Placer	54	1,842	1	75	2	18	23	2,743	2	4	3	13	85	4,694
Sacramento	29	933	26	1,261	4	40	63	1,930			31	121	153	4,285
San Joaquin			96	8,635	8	447	46	2,292	6	45	5	14	161	11,432
Shasta	1	1	1	1			5	61			3	3	10	67
Solano	11	349			1	156	6	599	2	59	1	4	21	1,167
Stanislaus			113	3,890	5	611	8	236	5	128			131	4,864
Sutter			2	51			3	206			1	2	6	259
Tehama	3	590	22	3,150	2	25	10	387	2	26	3	11	42	4,189
Tulare	1	1	17	1,420	5	277	14	435	10	329	2	69	49	2,533
Tuolumne	3	28											3	28
Yolo			1	97			2	174			1	5	4	276
Yuba	1	30	1	40			6	241	11	557	3	10	22	879
TOTALS	138	5,056	438	43,018	55	6,752	325	18,189	81	2,249	103	760	1,140	76,023

Table 4 (below) provides an estimate of the total wetted acres lost between 2005 and 2018. Over the 13-year period, a whopping 2,380 wetted acres are estimated to have been lost. As discussed in the section above, only around seven percent of the habitat matrix losses were to urban or industrial development and therefore subject to some amount of mitigation. Using a matrix cover class midpoint analysis like Table 4 reveals that urban and industrial development accounted for only 139 wetted acres of the total 2,380 lost to habitat conversion. The remaining 2,241 wetted acres of loss were due to unregulated, and therefore unmitigated, agricultural conversion.

Table 4: Estimate of wetted acres lost between 2005 and 2018.

Cover class range	Midpoint of cover class range	Total habitat acres converted 2005-2018	Calculated wetted acres lost 2005-2018	Average annual loss of wetted acres during 2005-2018
<2%	1.0%	32,741	327	25
2-5%	3.5%	34,633	1,212	93
5-10%	7.5%	7,961	597	46
>10%	12.5%	508	64	5
100%	100.0%	180	180	14
	Totals	76,023	2,380	183

4.4 Large Vernal Pools Lost

During the baseline mapping conducted using the 2005 NAIP imagery, the mappers added a point for every large vernal pool (or stockpond) encountered during the mapping exercise. All vernal pools greater than one acre in size were annotated and many prominent large pools less than one acre were also annotated. Some stockponds outside of mapped vernal pool matrix may also have been annotated. The 2005 baseline map included 770 individual large pool points and 223 stockpond points.

Table 5 (below) shows the large vernal pools extirpated between 2005 and 2018. The table was produced by extracting the original point file against the 2018 extirpated polygon file. It should

Table 5: Large pools extirpated.

	2018 Extirpated		
Feature size	Vernal Pools	Stockponds	Totals
<1 acre	11		11
1-3 acres	58	6	64
3-5 acres	11	3	14
5-10 acres	5	2	7
>10 acres*	3		3
Totals	88	11	99

be noted that while some large pools may remain within areas converted to orchards, those features have undergone (or are undergoing) conversion to a different wetland type and are unlikely to support typical vernal pool species.

4.5 Mitigation Banks

Table 6 (below) is a summary of the mitigation banks created between 2005 and 2018 by county. Only those counties with new mitigation banks mapped in 2012 or 2018 are included in the table. No mitigation banks created prior to the 2005 mapping are included in the table.

Table 6: New vernal pool habitat created between 2005 and 2018 by county.

	2012 New Banks*		2018 New Banks*		2018 Total Extant**		%Extant
County	Polygons	Acres	Polygons	Acres	Polygons	Acres	in Banks
Butte	1	107			117	52559	0.2%
Colusa	1	20			7	1272	1.6%
Contra Costa	1	16			20	3505	0.5%
Madera			1	61	73	74321	0.1%
Merced	1	9			318	193680	0.0%
Placer	10	573	3	373	204	27856	3.4%
Sacramento	17	708	3	23	323	60690	1.2%
Shasta	1	27			53	20703	0.1%
Solano	2	151			55	37066	0.4%
Sutter	1	1			17	996	0.1%
Yolo	1	1			12	4637	0.0%
Yuba	2	66			42	15634	0.4%
TOTALS	38	1679	7	456			

*Includes areas mapped as new banks created on other habitat types (often old alfalfa fields) and areas converted from low density to high density vernal pool habitat due to creation of additional vernal pools.
**Includes all extant vernal pool habitat including banks.

4.6 Protected Areas

The 2012 mapping report (Witham et al. 2014) included an analysis of vernal pool habitat under some form of protection. Of the 764,868 acres of habitat mapped as extant as of 2012, 229,637 acres (30%) are under some form of protection. The report outlined caveats for interpreting the data and concluded that actual acres of protection might be higher. The report also described numerous situations where the land may be protected, but land management is inconsistent with vernal pool conservation. Wildlife areas focused on waterfowl production are examples of protected lands not necessarily managed for vernal pool attributes.

Vollmar et al. (2017) built upon the initial analysis of protected areas in a comprehensive report and geodatabase prepared for the U.S. Environmental Protection Agency. For their study, preserve lands (or protected areas) include all public lands and all lands owned by private non-profit land trusts or other conservation groups whether or not they are protected under a formal conservation instrument (conservation easement or deed restriction) as well as all other private lands protected under a formal conservation instrument. Additionally, Vollmar et al. conducted a thorough review of all preserve lands which eliminated some of the inconsistencies and errors inherent in the preserved lands datasets used by Witham et al. (2014). They found that of the 764,862 acres of extant habitat mapped as of 2012, 270,329 acres (35%) were preserved within 724 individual preserves.

The Vollmar et al. (2017) report also analyzed multiple aspects of vernal pool habitat preserves including size and distribution by county, geologic formation, and ecoregion. The report also takes a deep dive into the types of landowners and funding sources for the protected areas. Readers are referred to that report for additional information on protected vernal pool landscapes.

4.7 Other Observations

The vernal pool habitat within the Great Valley continues to be fragmented by losses and degraded by disturbance. One example of degradation by disturbance is that 4,466 acres were mapped as bare agricultural lands in the 2012 mapping. These areas appeared to be plowed only once just prior to the 2012 imagery and the wetland signatures reappeared in the 2018 imagery. However, the sites are no longer pristine by virtue of having been plowed. Numerous other instances of increased level or area of disturbance are apparent in many of the mapped habitat polygons.

5 Summary and Comments

The primary objective of this project was to produce a new map of the vernal pool areas of the Sacramento and San Joaquin valleys as of the 2018 NAIP imagery. The new map used the 2012 map (Witham et al. 2014) as its basis. Areas lost to conversion were cut out of the original mapped polygons. Areas gained were added as new polygons. The resulting map contains 3,126 polygons encompassing 813,360 total acres. Of this total, 76,023 acres were lost to conversion from 2005 to 2018. Gained acreage included 456 acres of newly created habitat and 731 acres of habitat which was not evident in the 2012 imagery. Total extant habitat as of the 2018 imagery was 737,337 acres.

5.1 Minimum Mapping Units

Establishing a minimum mapping unit at the onset of the 2005 mapping project, particularly related to cutouts (ag residential, roads, canals), would have increased the internal consistency of the map. Because that was not done, that base map plus the 2012 and 2018 remapping efforts suffer from shortfalls related to economy of scale. In small polygons, the mappers were more likely to subtract small cutouts for buildings, corrals or staging areas. In larger polygons, the same size cutout was often overlooked simply because it was small in proportion to the landscape being mapped.

5.2 Attribute Field Validity

In preparing the 2018 remapping geodatabase, several attribute fields that were in the 2012 map were removed to eliminated confusion. Specifically, the number of large pools per unit area and information related to surround land use were removed. All prior acreage calculations were also removed. This was done to prevent possible misinterpretation of the data. While the attributes were clearly labelled by mapping year, they could be mistaken for current data by someone not understanding the geodatabase structure or not reading the entire report accompanying the geodatabase.

Following publication of the 2012 map, several individuals used the geodatabase for a variety of other analyses. In one case, the vernal pool map was intersected with (polygons cut up by using) soils data. The resulting file ballooned the number of polygons from 2,456 to 8,890. This action invalidated many of the attribute fields and yet all of the fields and their original data were carried into the new file with no explanations or caveats. This should serve as a caution to future users of the geodatabase for other analyses. Before publishing a new data set, the fields need to be carefully reviewed to determine their appropriateness (and validity) with respect to the new polygons in order to prevent potential misinterpretation of the data.

6 Recommendations

Again, the primary recommendation is to increase enforcement of Endangered Species Act and Clean Water Act violations occurring through unregulated agricultural conversion, primarily in Madera and Stanislaus counties. This might be accomplished through enforcement actions against the most recent conversions. Enforcement actions should be in coordination with the U.S. Environmental Protection Agency and the U.S. Army Corps of Engineers. In cases where state-listed species may be involved, the California Department of Fish and Wildlife also should be involved.

The primary purpose of this project was to map the current extent and recent losses of vernal pool habitat within the Great Valley, and to provide basic analysis of the sources of those losses (as well as some ‘gains’ from mitigation banking). The geodatabase accompanying this report contains information that can be used as a base layer for analyzing various attributes related to vernal pool conservation and impacts. This base layer can be overlaid with numerous other data layers such as documented special-status species occurrences, geology and soil type, vernal pool regions, vernal pool core recovery areas, critical habitat areas, etc. and analyzed to identify such elements as areas of highest conservation value, the most rare or vulnerable vernal pool habitat types in need of conservation, the success and trends in conserving vernal pool habitat, etc. All of these analyses are beyond the scope of this project, but the geodatabase developed through this project provides the key foundation for such analyses. These types of analyses will typically require both expert GIS analysts and expert vernal pool ecologists to accurately guide and interpret the GIS inputs and outputs.

7 References Cited

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Appendix B: Methods Used to Create 2005 Vernal Pool Habitat Map

Prior to beginning any mapping, the authors (Carol Witham, Robert Holland and John Vollmar) and key staff from Vollmar Natural Lands Consulting (Jake Schweitzer, Cassie Pinnell) held several meetings to help refine the scope, details and process to accomplish our goals. The team also met with Cheryl Hickman at USFWS and Todd Keeler-Wolf at DFG to solicit input on mapping methods and final data configuration. Together the team then worked out the structure of the geodatabase and a schedule for accomplishing the mapping.

We drew habitat boundaries on-screen using ESRI ArcMap 9.x GIS software. This software allows one to display air photos at any scale, and to superimpose additional information such as topography, soils, roads, precipitation, or any other environmental parameter that may be of interest. Unlike most other mapping projects of this scale, we chose to map double-blind. Each mapper (Holland and Witham) independently covered each county in turn. As counties were completed, we would meet and collaboratively reconcile our mapping. Once all the counties had been reconciled, the maps were collated into a single valley-wide file and subjected to various quality control reviews.

Create Mapping Geodatabase

While existing data were being compiled, the team met several times to discuss what attributes would describe each mapped polygon. We determined through review of the baseline 1 meter aerial photography that the aerial cover of vernal pools and aerial cover of disturbance were quantifiable using cover classes. Qualitative information on density of vernal pools, diversity of vernal pools, plus type and intensity of disturbance could also be determined from aerial interpretation. And finally, because large pools may have separate importance to certain vernal pool species, we chose to quantify–and separately map as points–the large pools in each of the mapped polygons.

A geodatabase was then designed to capture the information and attributes we believed could be assessed from aerial interpretation. Using the geodatabase ensured that both mappers were using the same cover classes, quantitative/qualitative categories and disturbance terminology in annotating the mapped polygons. We tried the geodatabase in a pilot study of part of Sacramento County and found several opportunities to improve its design and performance.

Conduct Double Blind Mapping

During the design and testing of the geodatabase, we decided to conduct the mapping on a county-by-county basis to maximize computing speed and for the purposes of tracking. For each county, all of the pertinent data layers were compiled into a project. Additionally, to facilitate tracking progress within each county, a 1 mile by 1 mile polygon grid was created. As each area was inspected and mapped, the overlying grid polygon was deleted.

Holland and Witham calibrated their mapping early in the project by choosing two areas to map and compare. These were southeast Sacramento County, where both mappers had extensive field experience, and Tulare County, which was relatively unknown to both mappers. After reviewing and discussing similarities and discrepancies between these maps, both Holland and Witham felt confident that their independent mapping efforts would be highly similar. They then proceeded to independently map the remainder of the Great Valley.

Elimination of unsuitable areas–such as intensive irrigated agriculture or metropolitan areas–usually was done at a scale of 1:24,000 which was the equivalent of about 15 square miles being visible on a 24-inch monitor. Where possible habitat was detected, the mapper would simply zoom in to a more appropriate scale. Most mapping of vernal pool areas was conducted at approximately 1:12,000 scale, which was the equivalent to having two square miles of aerial photography on the monitor. However, when appropriate the mapper may have zoomed to raster resolution of the image, which was approximately 1:4,000. For each mapped polygon, the geodatabase fields for all of the required attributes were completed, and habitat notes or mapping notes were added as appropriate.

No minimum mapping unit–for the polygons or cutouts–was determined in advance. Each mapper digitized what they interpreted from the aerial photography at whatever polygon size was appropriate for the setting. The benefits and limitations of this approach are discussed later in this report.

Reconciliation of Independent Mapping

As each county was completed, the two independent maps for each county were combined into a signal geodatabase. Holland and Witham then conducted a series of meetings to reconcile the mapping. This reconciliation was done on a polygon-by-polygon basis. Any discrepancies were discussed and the best fitting polygon shape and attribution were determined for each polygon. This reconciliation resulted in each polygon being reviewed at least three times (in the few cases where one of the mappers missed the feature), but usually four times. Reconciling each county usually took 2-5 hours, depending on how much habitat had been mapped.

The meetings to discuss the mapped polygons also allowed Holland and Witham to explore other information that might inform decisions about a particular polygon. For example, if a polygon was annotated “possibly just slope wetlands” by one mapper, and not mapped at all by the other, various additional data layers could be reviewed and discussed to inform the decisions to keep or discard the polygon, what its final shape would be, and how it’s attributes would be scored. Every single polygon we drew was subjected to the same review; each was considered and resolved before moving on to the next. These meetings also had the unanticipated benefit of continually calibrating both mappers.

Topology Checking and Quality Control Methods

Topology checking of the mapping was conducted in two phases. First each county was checked for internal topology issues (inadvertent overlaps and slivers). Then, once all the counties were compiled into a single geodatabase, additional topology checking was conducted along county lines to ensure that continuous mapped areas did not overlap or have slivers.

The topology-corrected “all counties” file was then carefully evaluated by inspecting each polygon that was adjacent to any county lines. In some cases, the cover, density or other attribution differed across a county line. These were checked to verify that the different condition was actually present and appropriately attributed.

Quality control on the final compiled map was conducted by Witham during the course of compiling tabular data results. All fields were checked for completeness and numerous queries were conducted for field entries which should be mutually exclusive with other entries. Once confident that the data set was as complete and accurate as possible, acreages were calculated for each polygon.

2005 MAPPING PRIMARY GEODATABASE (POLYGONS)		
OBJECTID	Object ID (auto renumbering)	
SHAPE	Geometry	
SHAPE_Length	Perimeter (auto recalculating)	
SHAPE_Area	Area (auto recalculating)	
FEATURE	Feature	
	0	Vernal pool matrix
	1	Individual vernal pool
COVER_VPs	Cover_VP	
	0	<2% cover of vernal pools
	1	2-5% cover of vernal pools
	2	5-10% cover of vernal pools
	3	>10% cover of vernal pools
	4	100% (individual pool / stockpond)
DENSITY_VPs (qualitative assessment based on observed density of pools in polygon)	Qualitative	
	0	Low
	1	Medium
	2	High
DIVERSITY_VPs (qualitative assessment based on the diversity of pool sizes)	Qualitative	
	0	Low
	1	Medium
	2	High
DISTURBANCE_Area	Dist_Area	
	0	<1% of polygon
	1	1-5% polygon
	2	5-25% of polygon
	3	25-50% of polygon
	4	50-99% of polygon
	5	100% of polygon
DISTURBANCE_Type	Dist_Type	
	0	None / unknown
	1	Plowing, disking or grading
	2	OHV use
	3	Ranch roads
	4	Paved roads
	5	Ag runoff (altered hydrology)
	6	Agricultural residential
	7	Managed wetlands (duck ponds)
	8	Mitigation banks (created vernal pools)
DISTURBANCE_Intensity	Qualitative	
	0	Low
	1	Medium
	2	High
HABITAT_Notes	Text	

MAPPING_Notes	Text	
COUNTY	Text	

2005 SECONDARY GEODATABASE (POINTS)		
OBJECTID	Object ID	
SHAPE	Geometry	
FEATURE_Type	Dot_Type	
	0	Vernal pool
	1	Stockpond
FEATURE_Size	Dot_Size	
	0	<1 acre
	1	1-3 acres
	2	3-5 acres
	3	5-10 acres
	4	>10 acres

2012 REMAPPING ADDITIONS TO PRIMARY DATABASE (POLYGONS)		
Converted_2012	2010_Conv	
	0	Not Converted/Habitat Extant
	1	Converted/Habitat Extirpated
	2	Modified/Habitat Altered
	3	New/Habitat Not Previously Mapped
Converted_To_2012	Conv_To	
	0	Not Converted
	1	Urban, commercial & industrial
	2	Orchards, vineyards, Eucalyptus
	3	Alfalfa and irrigated pasture
	4	Bare, plowed agricultural lands
	5	Other ag (rice, row crops, dairy, nurseries)
	6	Agricultural residential
	7	Mitigation banks / managed wetlands
	8	Not previously mapped
Converted_Notes_2012	Text	
Disturbance_Area_2012	Dist_Area	
	0	<1% of polygon
	1	1-5% polygon
	2	5-25% of polygon
	3	25-50% of polygon
	4	50-99% of polygon
	5	100% of polygon
Disturbance_Type_2012	Dist_Type	
	0	None / unknown
	1	Plowing, disking or grading

	2	OHV use
	3	Ranch roads
	4	Paved roads
	5	Ag runoff (altered hydrology)
	6	Agricultural residential
	7	Managed wetlands (duck ponds)
	8	Mitigation banks (created vernal pools)
Disturbance_Intensity_2012	Qualitative	
	0	Low
	1	Medium
	2	High
New_Notes	Text (notes from 2005 mapping)	

2018 RE-REMAPPING ADDITIONS TO PRIMARY DATABASE (POLYGONS)		
Converted_2018	2018_Conv	
	0	Not Converted/Habitat Extant
	1	Converted/Habitat Extirpated
	2	Modified/Habitat Altered
	3	New/Habitat Not Previously Mapped
Converted_To_2012	Conv_To_2018	
	0	Not Converted
	1	Urban, commercial & industrial
	2	Orchards, vineyards, Eucalyptus
	3	Alfalfa and irrigated pasture
	4	Bare, plowed agricultural lands
	5	Other ag (rice, row crops, dairy, nurseries)
	6	Agricultural residential
	7	Mitigation banks / managed wetlands
	8	Not previously mapped
Converted_Notes_2018	Text (notes from 2012 mapping)	
Disturbance_Area_2018	Dist_Area	
	0	<1% of polygon
	1	1-5% polygon
	2	5-25% of polygon
	3	25-50% of polygon
	4	50-99% of polygon
	5	100% of polygon
Disturbance_Type_2018	Dist_Type	
	0	None / unknown
	1	Plowing, disking or grading
	2	OHV use
	3	Ranch roads

	4 Paved roads 5 Ag runoff (altered hydrology) 6 Agricultural residential 7 Managed wetlands (duck ponds) 8 Mitigation banks (created vernal pools)
Disturbance_Intensity_2018	Qualitative 0 Low 1 Medium 2 High
F2018_Notes	Text (notes from 2018 mapping)
Acres_2018	Acres calculated for 2018 polygons

Appendix C: Tabulated Changes Between Mapping Years

Appendix C, Table 1 and Table 2 detail by county the extent of changes over 2005-2012 and 2012-2018, respectively. These tables are a cross-check of polygons and acres mapped in each of the primary categories:

- **Unmodified:** Habitat previously mapped and appearing unchanged in remapping.
- **Modified:** Areas previously mapped (usually at low density) which had been converted to high density and often highly disturbed mitigation banks in subsequent remapping.
- **Missed:** Areas of habitat found on aerial imagery during remapping that were not apparent in the earlier mapping imagery.
- **New Banks:** Areas in which vernal pool mitigation banks were built since the previous mapping effort. Many of these new banks were built on former agricultural fields.
- **Total Extant:** The sum of the previous four columns showing the total extant vernal pool acreage mapped.
- **Converted:** Habitat converted to other (incompatible) land uses since the previous mapping.
- **All Mapping:** The total polygons and acres contained in the geodatabase including extant and extirpated.
- **%Converted:** The percentage of all mapping that was converted to other land uses since the previous mapping.

Appendix C, Table 1: Changes in mapped vernal pool habitat between 2005 and 2012 by county.

County	2012 Unmodified		2012 Modified		Missed in 2005		2012 New Banks		2012 Total Extant		2012 Converted		2012 All Mapping		%Converted
	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	2005-2012
Alameda	10	1,966							10	1,966	2	10	12	1,976	0.5%
Amador	14	3,664							14	3,664	4	65	18	3,729	1.8%
Butte	100	54,056	2	65			1	107	103	54,228	23	737	126	54,964	1.3%
Calaveras	28	5,942							28	5,942			28	5,942	0.0%
Colusa	9	1,387					1	20	10	1,407	4	205	14	1,612	12.7%
Contra Costa	17	3,430	1	19			1	16	19	3,465	3	50	22	3,515	1.4%
El Dorado	6	852							6	852	3	51	9	903	5.6%
Fresno	46	25,784							46	25,784	18	1,621	64	27,405	5.9%
Glenn	14	3,848							14	3,848	7	2,172	21	6,020	36.1%
Kern	37	29,719							37	29,719	20	1,484	57	31,202	4.8%
Kings	7	5,080			3	1,682			10	6,762			10	6,762	0.0%
Madera	70	77,537	1	183	1	33			72	77,754	48	14,603	120	92,357	15.8%
Mariposa	26	3,055							26	3,055			26	3,055	0.0%
Merced	321	196,267			2	125	1	9	324	196,400	35	7,300	359	203,701	3.6%
Placer	168	27,768	4	1,444	3	108	10	573	185	29,893	56	2,126	241	32,019	6.6%
Sacramento	286	60,748	8	728	3	14	17	708	314	62,197	76	2,748	390	64,946	4.2%
San Joaquin	136	25,457			5	100			141	25,557	63	6,234	204	31,792	19.6%
Shasta	50	20,703			2	10	1	27	53	20,739	6	30	59	20,769	0.1%
Solano	49	37,020	1	377			2	151	52	37,548	14	642	66	38,190	1.7%
Stanislaus	187	20,423			2	66			189	20,489	72	3,041	261	23,530	12.9%
Sutter	16	1,253					1	1	17	1,254	1	2	18	1,256	0.1%
Tehama	155	99,101							155	99,101	15	2,095	170	101,196	2.1%
Tulare	50	26,908			2	405			52	27,313	24	1,579	76	28,892	5.5%
Tuolumne	27	5,161							27	5,161	1	12	28	5,174	0.2%
Yolo	11	4,749					1	1	12	4,750	1	5	13	4,754	0.1%
Yuba	35	15,822			1	131	2	66	38	16,020	6	493	44	16,513	3.0%
TOTALS	1,875	757,698	17	2,816	24	2,675	38	1,679	1,954	764,868	502	47,306	2,456	812,173	6.2%

2012 Unmodified: Habitat mapped in 2005 that appeared unchanged in 2012; 2012 Modified: Areas mapped in 2005 (usually at low density) which had been converted to high density and often highly disturbed mitigation banks by 2012; Missed in 2005: Areas of habitat found in the 2012 imagery that were not apparent in the 2005 imagery; 2012 New Banks: Areas in which vernal pool mitigation banks were built between 2005 and 2012; 2012 Total Extant: The sum of the previous four columns showing the total extant vernal pool acreage mapped in 2012; 2012 Converted: Habitat converted to other (incompatible) land uses between 2005 and 2012; 2012 All Mapping: The total polygons and acres contained in the 2012 geodatabase including extant and extirpated; Percentage Converted: The percentage of all mapping that was converted to other land uses between 2005 and 2012.

Appendix C, Table 2: Changes in mapped vernal pool habitat between 2012 and 2018 by county.

	2018 Unmodified		2018 Modified		Missed 2012		2018 New Banks		2018 Total Extant		2018 Converted		2018 All Mapping		%Converted
County	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	Polygons	Acres	2012-2018
Alameda	10	1920							10	1920	4	55	14	1976	2.8%
Amador	15	3575							15	3575	7	154	22	3729	4.1%
Butte	117	52559							117	52559	92	2405	209	54964	4.4%
Calaveras	26	5523							26	5523	11	419	37	5942	7.1%
Colusa	7	1272							7	1272	8	341	15	1612	21.1%
Contra Costa	20	3505							20	3505	4	10	24	3515	0.3%
El Dorado	7	713							7	713	11	189	18	903	21.0%
Fresno	43	24206							43	24206	55	3200	98	27405	11.7%
Glenn	14	2489							14	2489	11	3531	25	6020	58.7%
Kern	41	29335							41	29335	36	1867	77	31202	6.0%
Kings	13	6029							13	6029	4	732	17	6762	10.8%
Madera	72	74260					1	61	73	74321	102	18097	175	92418	19.6%
Mariposa	26	3055							26	3055			26	3055	0.0%
Merced	314	193351			4	330			318	193680	108	10350	426	204030	5.1%
Placer	199	27325			2	159	3	373	204	27856	85	4694	289	32550	14.4%
Sacramento	315	60388	3	273	2	5	3	23	323	60690	153	4285	476	64974	6.6%
San Joaquin	136	20359							136	20359	161	11432	297	31792	36.0%
Shasta	52	20702			1	1			53	20703	10	67	63	20770	0.3%
Solano	54	37023			1	43			55	37066	21	1167	76	38233	3.1%
Stanislaus	178	18666			1	34			179	18700	131	4864	310	23564	20.6%
Sutter	17	996							17	996	6	259	23	1256	20.7%
Tehama	156	97007							156	97007	42	4189	198	101196	4.1%
Tulare	52	26360							52	26360	49	2533	101	28892	8.8%
Tuolumne	27	5145							27	5145	3	28	30	5174	0.6%
Yolo	11	4478			1	159			12	4637	4	276	16	4914	5.6%
Yuba	42	15634							42	15634	22	879	64	16513	5.3%
TOTALS	1964	735877	3	273	12	731	7	456	1986	737337	1140	76023	3126	813360	10.3%

2018 Unmodified: Habitat mapped in 2005 and 2012 that appeared extant in 2018; 2018 Modified: Areas mapped (usually at low density) which had been converted to high density and often highly disturbed mitigation banks between 2012 and 2018; Missed in 2012: Areas of habitat found in the 2018 imagery that were not apparent in the 2005 or 2012 imagery; 2018 New Banks: Areas in which vernal pool mitigation banks were built between 2012 and 2018; 2018 Total Extant: The sum of the previous four columns showing the total extant vernal pool acreage mapped in 2018; 2018 Converted: Habitat converted to other (incompatible) uses between 2012 and 2018; All Mapping: The total polygons and acres contained in the 2018 geodatabase including extant and extirpated; %Converted 2012-2018: The perrcentage of all mapping htat was converted to other land uses between 2012 and 2015.