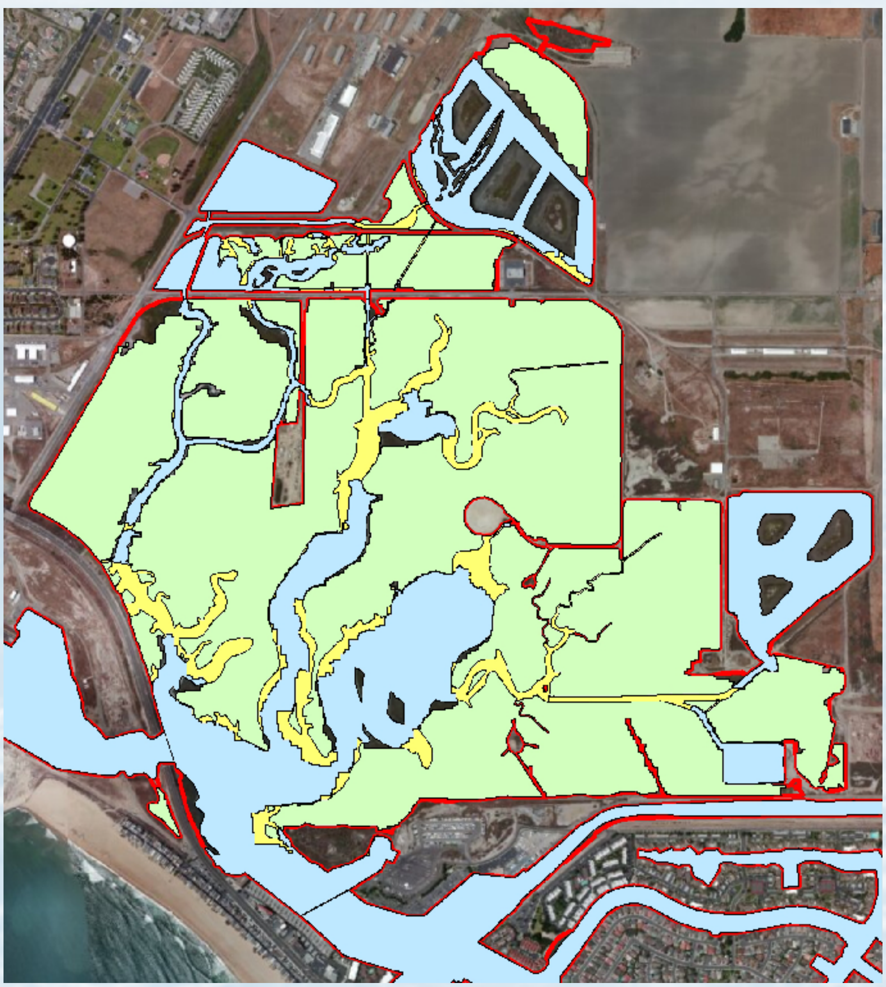
Demonstrating the California Wetland Status and Trends Program: A Probabilistic Approach for Estimating Statewide Aquatic Resource Extent, Distribution and Change over Time

Pilot Study Results



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Southern California Coastal Water Research Project

SCCWRP Technical Report 859

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INTRODUCTION

Motivation and Goals for California's Wetlands Status and Trends Program

Tracking the extent, distribution and change over time of wetlands (and other aquatic resources) statewide is a foundational element of California's wetland monitoring and assessment programs (CWMW 2010). It not only provides the basic information to report on wetland status and trends, but is also crucial for accurately assessing the Federal and State "no net loss" policies in terms of wetland quantity and evaluating the effectiveness of current regulatory and management programs (e.g., Porter-Cologne Water Quality Control Act, Clean Water Act §401, CA Fish and Wildlife Code §1600). Furthermore, monitoring trends and tracking net change provide a foundation for monitoring the long-term effects of climate change and other natural disturbances (e.g., fires, floods, and droughts) on wetland resources, and the effect of these trends on habitat and species conservation efforts.

Despite being a national leader in investment in wetland protection, management, and monitoring, California agencies cannot reliably answer essential questions about the extent and distribution of wetlands, streams, lakes, and estuaries and how these resources are changing over time (CNRA 2010). This knowledge gap precludes our ability to accurately evaluate the effectiveness of statewide investments in aquatic resources restoration, regulation, and management.

There are many factors that contribute to California's inability to answer fundamental questions about wetland status and trends, and principal among them is cost. Complete survey mapping of a state the size of California on a regular basis is cost-prohibitive and logistically challenging. A cost estimate to update mapping of streams and other aquatic resources is $3,000 per USGS quadrangle, and California has 2,800 quadrangles (CWMW 2010). Not only does the state of California lack the $8.5 million for comprehensive mapping, but also this cost would need to be incurred every 5 to 10 years in order to assess change over time.

The National Wetland Status and Trends (S&T) Program, administered by the U.S. Fish and Wildlife Service (USFWS), has addressed this challenge by adopting a probabilistic approach to wetland change assessment. Probabilistic mapping uses statistical estimation methods to produce extent and trend information in a practical, cost-effective manner. Because probability-based mapping requires significantly fewer resources, it allows for more frequent estimates of wetland extent and trends. Ideally, probability-based mapping would be combined with comprehensive mapping and project-based accounting to provide a robust understanding of wetland change over time and of the factors influencing changes. In addition to providing the foundation for a comprehensive status and trends program, probabilistically selected maps can contribute updates to the California Aquatic Resources

> **PROBILISTIC MAPPING**
>
> A probabilistic approach includes three basic elements:
>
> 1) random placement of sample points across the entire state
>
> 2) wetland mapping in small plots placed at each point
>
> 3) extrapolation from the random sample plot maps to a statewide estimate of wetland extent

Inventory (CARI), a standardized statewide map of wetlands, streams, and riparian areas that is used for Level 1 landscape assessment. The maps can also serve as a sample frame to support Level 2 or Level 3 condition assessments through the selection of locations for condition assessment from the status and trends plots.

Although sufficient for a national assessment, the National S&T plots by themselves are insufficient for assessing status and trends of California's wetland and riparian resources. The USFWS National S&T Program includes only 257 plots in California, covering approximately 0.6% of the land area, mostly concentrated along the coast. Furthermore, the national program is focused on wetlands and does not include streams, lakes and other aquatic resources. Even for wetlands, plots are selected based on older, vintage National Wetlands Inventory maps that omit many of the wetland and riparian areas of California.

California's wetland status and trends program builds on the national program by intensifying the number of plots and the type of resources mapped within each plot in order to provide statistically robust, statewide estimates of all aquatic resource types. The objectives of California's program are to:

- Report extent (status) and changes in extent (trends) at regular intervals.
- Include estimates for all surface aquatic resources, including wetlands, streams, and deepwater habitat.
- Support regional intensification through design flexibility.

Unlike the national program, the California status and trends program includes freshwater and tidal wetlands and streams (regardless of whether or not the streams include wetland areas) and is not limited by the seasonality of the resources (i.e., perennial, intermittent, and highly ephemeral resources are included). Furthermore, all natural and anthropogenic upland areas are also mapped within each plot to provide information about proximal influences on wetlands and aquatic resources that may affect trends, and to allow other resource mapping and monitoring programs to take advantage of the plots to fulfill part of their needs.

Objectives of the Pilot Demonstration

Design recommendations for implementation of the status and trends program were developed through a previous study that analyzed the effect of various options on bias, accuracy and cost (Stein and Lackey 2012). This study concluded that to balance statistical power and cost, the status and trends plots should be 4 km^2 in size (2 km x 2 km). A total of 2,000 non-stratified plots should be sampled through a static panel design (i.e., the same plots are revisited to assess trends vs. sampling 2,000 new plots). Standard procedures and quality assurance measures were also developed to help ensure consistency between mapping teams, minimize mapping and interpretation errors, and, in turn, maximize the confidence and reliability of the mapping results (CWMW 2014).

To facilitate transitioning the status and trends program from development to implementation by one or more state agencies, we conducted a pilot demonstration. The purpose of this demonstration was to:

1. Test application of the design methods and procedures in a limited number of plots in order to refine the overall approach.
2. Demonstrate potential analytical products that might be produced.
3. Ease the transition to implementation by completing a limited number of plots from the statewide sample draw.
4. Provide final recommendations to inform full-scale program implementation.

The goal of the demonstration is not to provide initial statewide estimates of extent and change, but to provide an initial template for program implementation that can be refined and expanded by the ultimate implementing agencies.

This document summarizes the outcomes of the demonstration project by providing an overview of preliminary findings, recommendations for transitioning to program implementation, and suggested revisions/clarifications to the Standard Operating Procedures previously developed (CWMW 2014).

APPROACH AND METHODS

The demonstration project consisted of mapping the first 110 plots from the overall statewide sample (Figure 1). The overall sample draw produced 2,000 randomly distributed plots across the entire state of California using a spatially balanced generalized random-tessellation (GRTS) design with equal probability and no stratification (Stevens and Olsen, 2004). The sample draw was done using the *spsurvey* package in R (Kincaid and Olsen 2013). The entire state was included in the sample draw, including offshore islands within State waters and interior open water bodies such as San Francisco Bay, Salton Sea, and Lake Tahoe. Plots adjacent to the state boundaries or on the coast were clipped to the state border and assigned a proportional weighting based on the area that is within California.

The 110 plots were split into three regions – northern, central and southern California – and each was mapped by one mapping team (Figure 1). All features within each plot were mapped and classified using the established status and trends protocols (CWMW 2014), including streams, wetlands, upland natural areas, upland developed, roads, and agriculture. Teams were intercalibrated prior to receiving the plots to ensure consistent interpretation and application of mapping and classification procedures. Intercalibration consisted of each of

GRTS SAMPLING

Generalized random tessellation stratified (GRTS) provides a spatially balanced sample that ensures that the spatial density pattern of the sample represents that of the overall resource being sampled. This reduces the chance of “clumping” that can occur when using simple random sampling.

the three teams mapping the same 20 plots, comparing results, and iteratively refining protocols to reduce areas that resulted in differences between teams. Data from the pilot plots were cross-checked by each team in a round-robin fashion after completion of the first 10 plots relative to the established quality control procedures and data quality objectives (CWMW 2014). If systematic errors had occurred (none did), plots would have been returned for remapping. A second round of quality control checks was performed upon completion of all 110 plots.

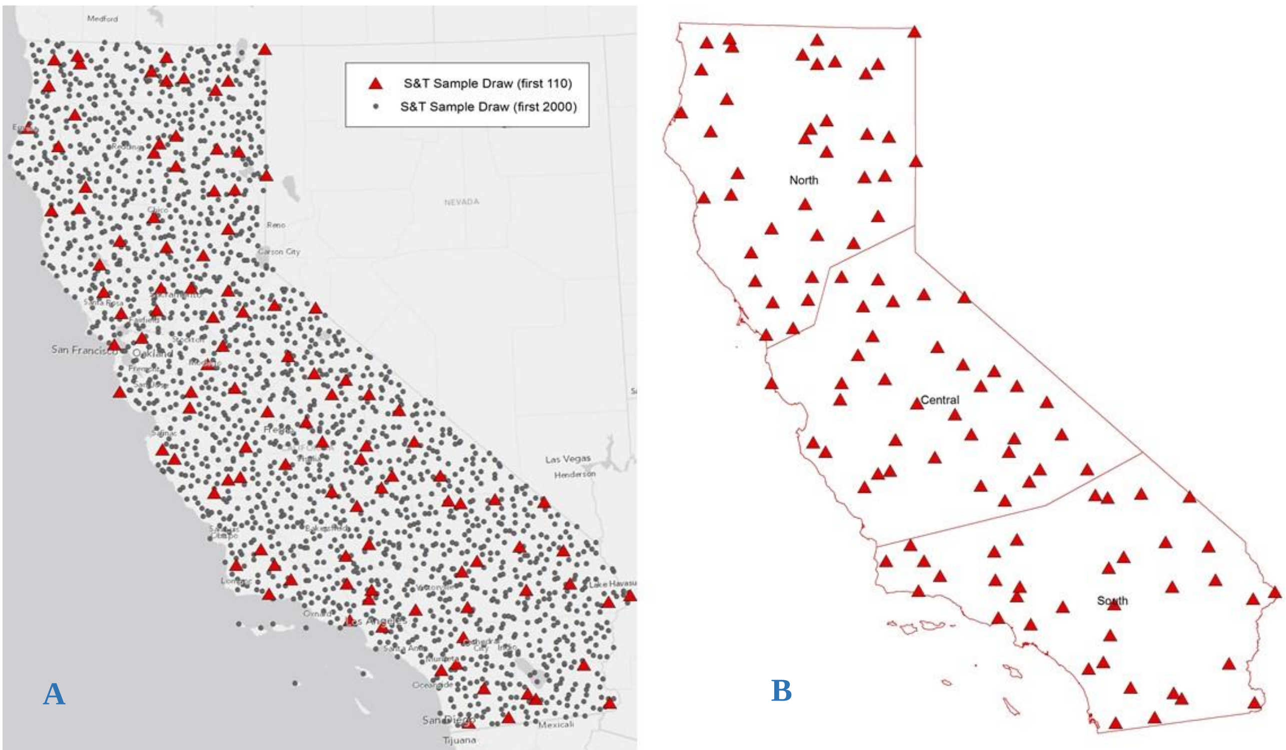

Figure 1. A - Location of 2,000 statewide sample plots (dots) and 110 plots used for the pilot study (triangles). B - Location of pilot study plots for each of the three regions of California.

To produce status and trends estimates, each plot was assessed using 2005 and 2010 NAIP imagery. To establish a baseline assessment of status, each aquatic resource polygon from the 2005 imagery was assigned a class and type value based on the California Aquatic Resource Classification System (Table 1), and each upland polygon was assigned a general land use classification (Table 2). Additional modifiers were assigned to all polygons as appropriate using the Status and Trends standard procedures (see Figure 2 for sample). Following the baseline assessment of status, the polygons derived from the 2005 image analysis were overlaid on the 2010 imagery. Differences between the two time periods were used to evaluate changes in the extent or classification of each polygon as an initial assessment of trends in aquatic resource extent (see Figure 3 for sample).

Table 1. California Aquatic Resource Classification System

Major Class	***Class***	***Type (required)***
Open Water (O)	Lacustrine (L)	
	Riverine (R)	Confined (c) Unconfined (u)
	Estuarine (E)	Lagoon/Dune strand (l)
		Bar Built estuary (r) Open embayment (b)
	Marine (M)	Intertidal (i)
		Subtidal (s)
Wetland (W)	Depression (D)	Depression, Other (d)
		Vernal Pool Complex (v)
		Playa (p)
	Lacustrine (L)	
	Slope (S)	Wet Meadow (w)
		Forested Slope (f)
		Slope, Other (s)
	Riverine (R)	Confined (c) Unconfined (u)
	Estuarine (E)	Lagoon/Dune strand (l)
		Bar Built estuary (r) Open embayment (b)

Table 2. Upland classifications

Upland Categories
Beach and dune (BD)
Developed (DEV)
Developed, Open Space/Recreation (DOS)
Cultivated Crops (CC)
Pasture, Rangeland, Ranchland (PRR)
Flooded agriculture (FLA)
Grassland/Herbaceous (GRS)
Forest (FST)
Rock Outcrop (RKO)
Ruderal/Barren (RUD)
Scrub/shrub (SSH)
Undeveloped Urban Open Space (UOS)
Roads (RDS)

Results from evaluation of initial aquatic resource status in 2005 and trends between 2005 and 2010 for the 110 pilot plots were tallied through simple summary graphics and used to illustrate how the data could be presented upon implementation of the full statewide survey. Given the small number of pilot plots, there is not sufficient statistical power to extrapolate results to the overall statewide scale in a meaningful way. Such extrapolation will occur once all 2,000 plots are mapped.

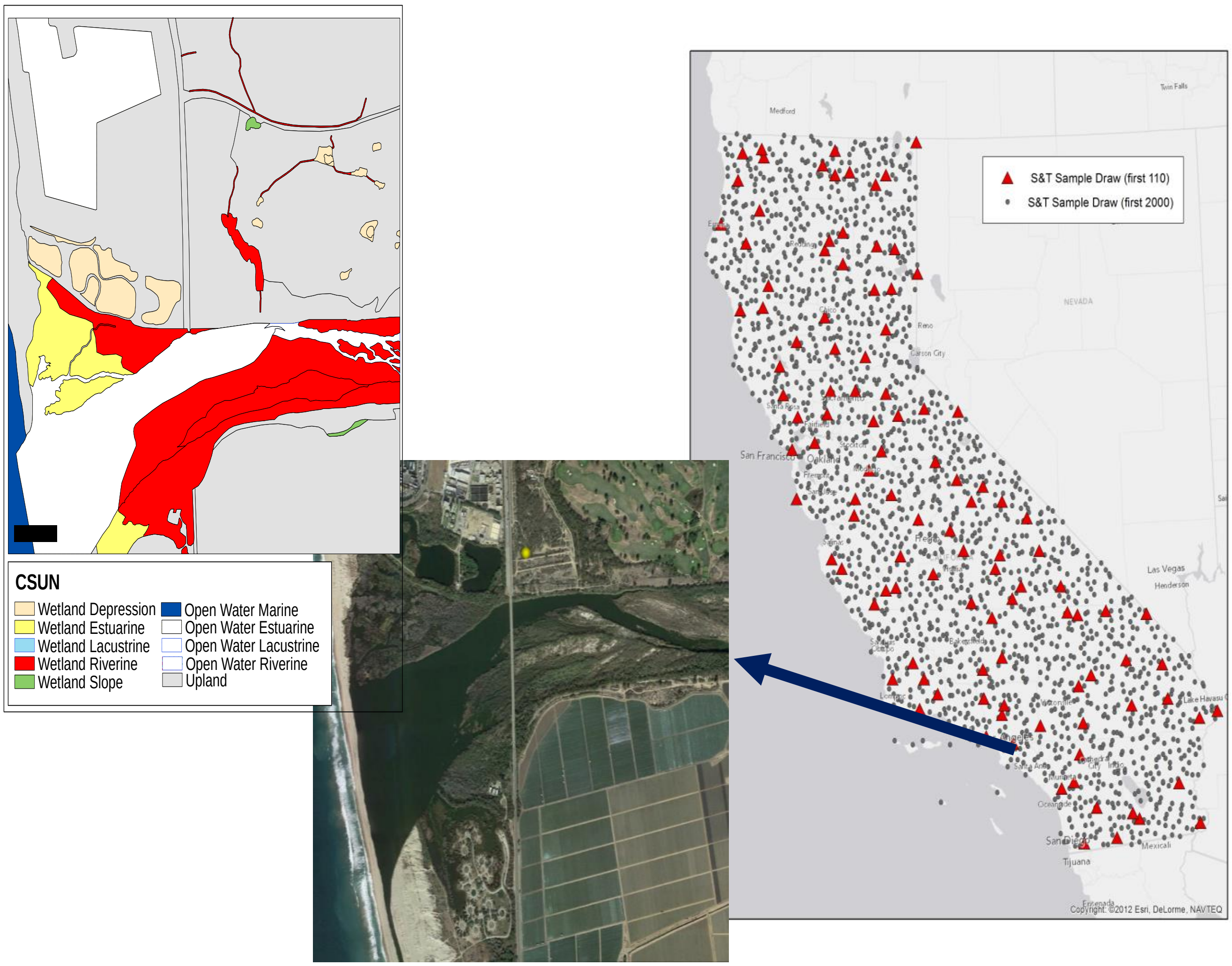

Figure 2. Example of how each plot was mapped and attributed

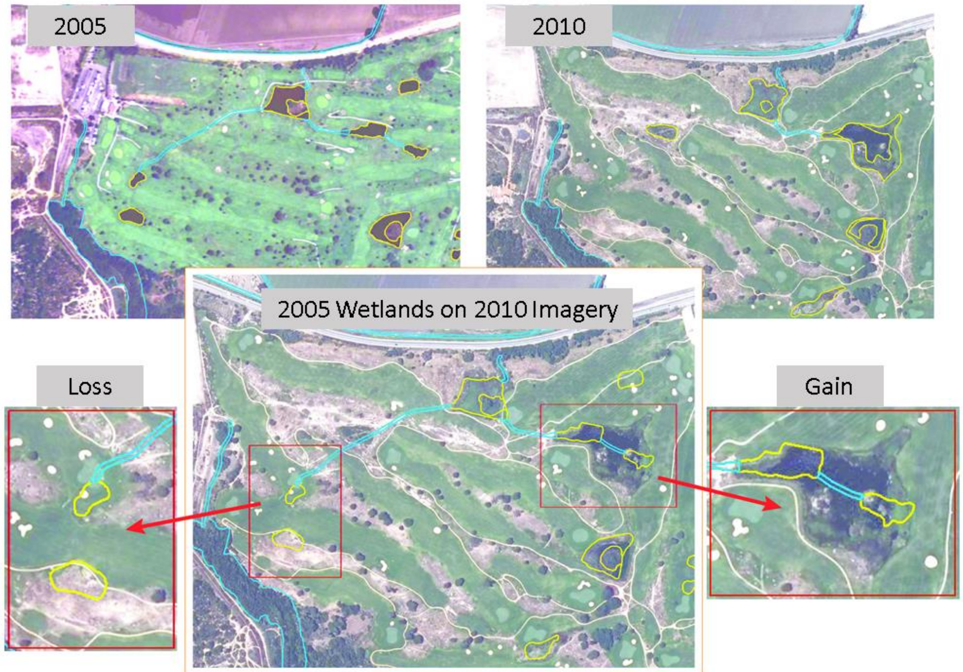

Figure 3. Example of trend assessment. 2010 imagery is overlaid on 2005 imagery to reveal changes in the extent of wetland polygons between the two assessment periods. Examples of wetland gains and losses are shown in the lower panels.

RESULTS FROM THE PILOT IMPLEMENTATION

Distribution and Performance of Pilot Plots

We successfully mapped 108 of the 110 pilot plots. Two plots along the state boundaries in the north coast region were excluded, but will be mapped during the full program implementation. The round-robin quality control process resulted in minor corrections to the initial plots, and all teams successfully achieved the specified data quality objectives of ±5% precision for overall mapping and ±20% precison for classification to the major class level. Only 2 of the 110 plots (1.5%) were null, meaning they contained no wetlands. This low percentage is consistent with the design assumptions that 4 km^2 plots would result in a relatively low number of null plots.

The distribution of the pilot plots among California's Omernick Level III Ecoregions was not completely representative of the overall distribution of the State's land area (Figure 4). The Cascades, Southern California Mountains, and Sierra Nevada ecoregions were over-represented, while the Mojave Basin and Range ecoregion was under-represented. This is not unexpected given that we only mapped 5% of the total sample draw. In contrast, the overall sample draw largely matched the statewide distribution of ecoregions. This demonstrates why we can report on extent and change within the pilot plots, but cannot extrapolate results to produce statewide estimates until all 2,000 plots are mapped.

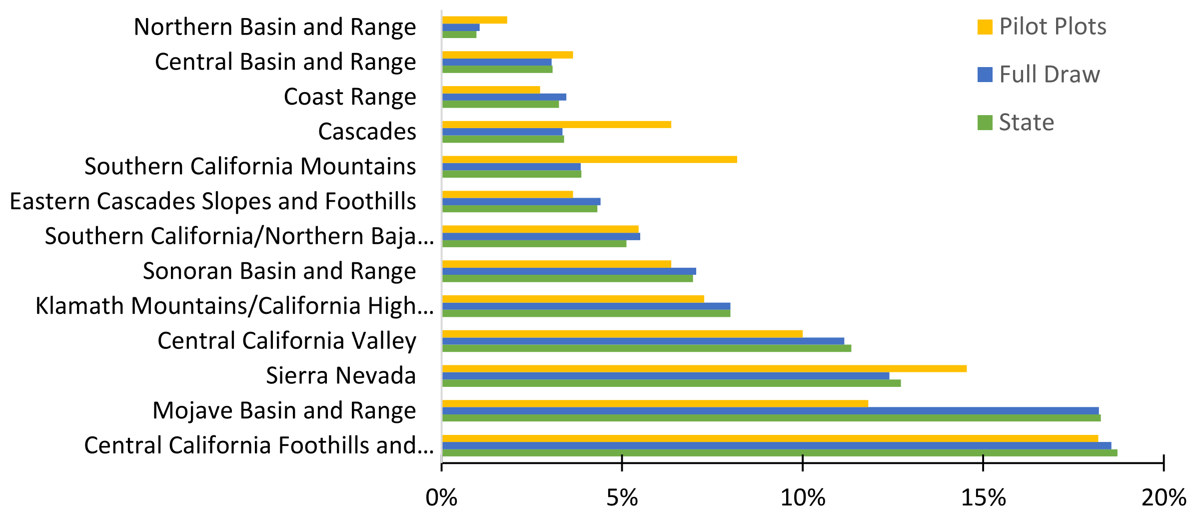

Figure 4. Distribution of Omernick Level III Ecoregions for the entire state of Californian, the full 2,000 plot sample draw and the 110 pilot plots

Extent of Wetlands in Pilot Plots in 2005

A total of approximately 4,000 ha of wetlands and 228 ha of open water were mapped in the pilot plots for the 2005 base year. If extrapolated to the entire state, this would represent a wetland density of approximately 9% and an open water density of approximately 0.5%. This density is substantially greater than the 3.5% reported in the 2010 State of the State's Wetland Report (CNRA 2010). This difference is most likely attributable to the fact that the State of the State's Wetlands Report did not include streams as part of the overall wetland inventory. If stream area were removed from our estimates, wetland density would be approximately 3% of overall state area.

Approximately 78% of total wetland area mapped is riverine (Figure 5). In terms of linear distance, we estimated 1,900 km of riverine features in the pilot plots, which translates to a density of approximately 17.6 km per plot. The riverine features are 30% unconfined and 70% confined. Of the non-riverine wetlands, 50% are comprised of slope wetlands and 25% each of depressional and estuarine wetlands. The 229 ha of open water habitat are associated primarily with estuarine and lacustrine wetlands, which each account for 35% of the total open water (Figure 6).

REGIONAL ANALYIS

No regional analysis was conducted as part of the pilot project. Plots were assigned to regions as a convenience for distribution among the mapping teams. This regional distribution has no ecological significance. Regional analysis may be conducted upon completion of all 2,000 plots.

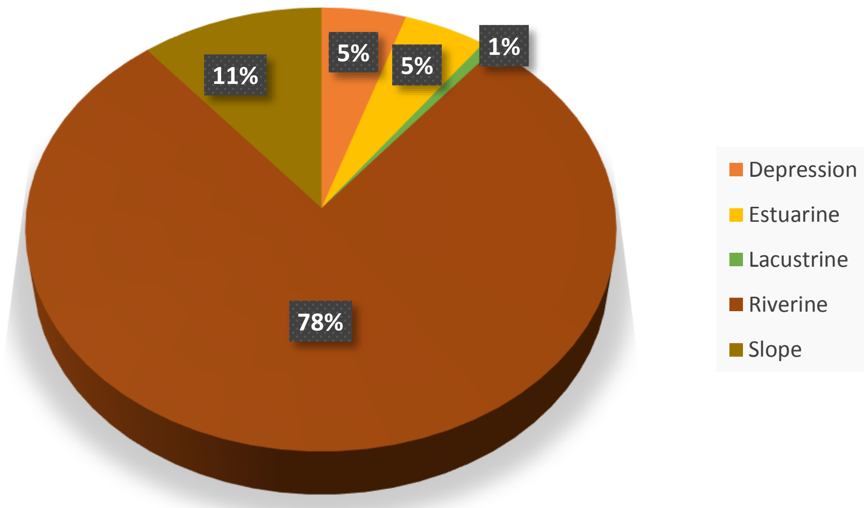

Figure 5. Distribution of wetland area in the pilot plots

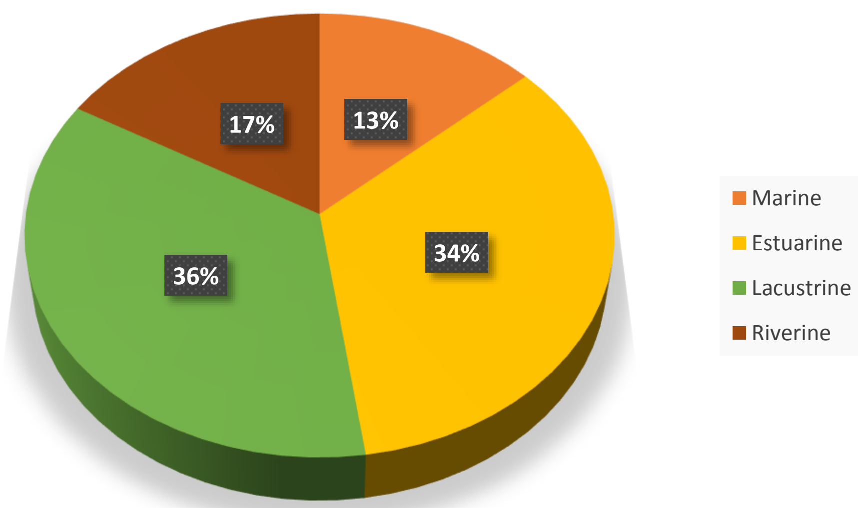

Figure 6. Distribution of open water area in the pilot plots

The proportions of wetland types within each major class provide additional insight into the diversity of wetlands in the state (Table 3). In all cases, one type dominates the total wetland area within a class. This suggests that additional subclassification may be warranted to improve our ability to document actual wetland diversity within the state.

Table 3. Distribution of wetland types for selected classes of wetlands

Wetland Class and Type	Percent of Total Area per Class
Slope	
Forested	4.6%
Wet Meadow	83.1%
Other	12.3%
Depression	
Playa	14.4%
Vernal Pool Complex	0.8%
Other	84.8%
Estuarine	
Bar-built	0.8%
Open Embayment	99.2%

Total wetland area within each plot is relatively small (Figure 7). Approximately 80% of the plots have less than 30 ha of wetland cover, and 67% have less than 15 ha. This does not necessarily represent the actual distribution of wetland size since a wetland may straddle a plot boundary and since only the portion of the wetland within the plot is mapped. Furthermore, the distribution is largely based on riverine wetlands, which comprise 78% of the total area. Estuarine wetland area ranged from 15 ha per plot to 160 ha per plot for each of the three plots that included this wetland class.

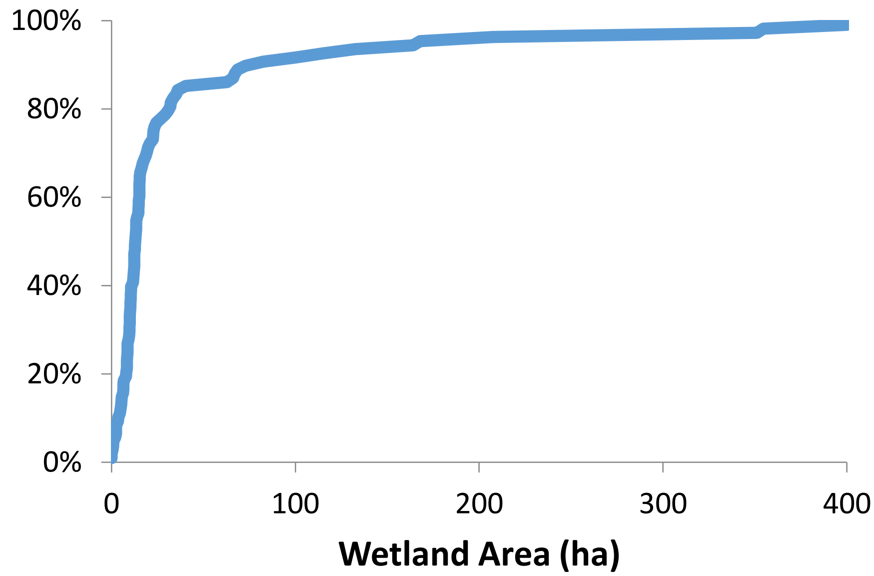

Figure 7. Frequency distribution of wetland area within each plot based on 2005 data

Change in Wetlands in Pilot Plots between 2005 and 2010

Overall wetland area in the 108 pilot plots decreased by approximately 72 ha (or 1.8% loss) between 2005 and 2010. Open water decreased by 14 ha (or 6%) over the same time period. These changes are within the expected error range of the status and trends methodology and must be interpreted with extreme caution.

The percent change in wetland area varies by class from a 14.5% gain for depressional wetlands to a 53% loss for estuarine wetlands. However, expressing percent change by total area per class can skew results based on the overall wetland distribution. For example, total estuarine area was low relative to riverine area; therefore, changes in a small number of plots can translate to large percent changes. In contrast, change in density is normalized to mapped area and is, therefore, a more appropriate way to express trends when using a probabilistic approach (Figure 8). Changes in wetland density show proportionately greater estuarine losses and modest gains in riverine and depressional wetlands (Figure 9).

TREND UNCERTAINTY

The status and trends methodology has a 6% rate of uncertainty for overall wetland area and a 15% rate of uncertainty for individual wetland classes due to expected differences between mapping team. Changes within these ranges should be interpreted with caution.

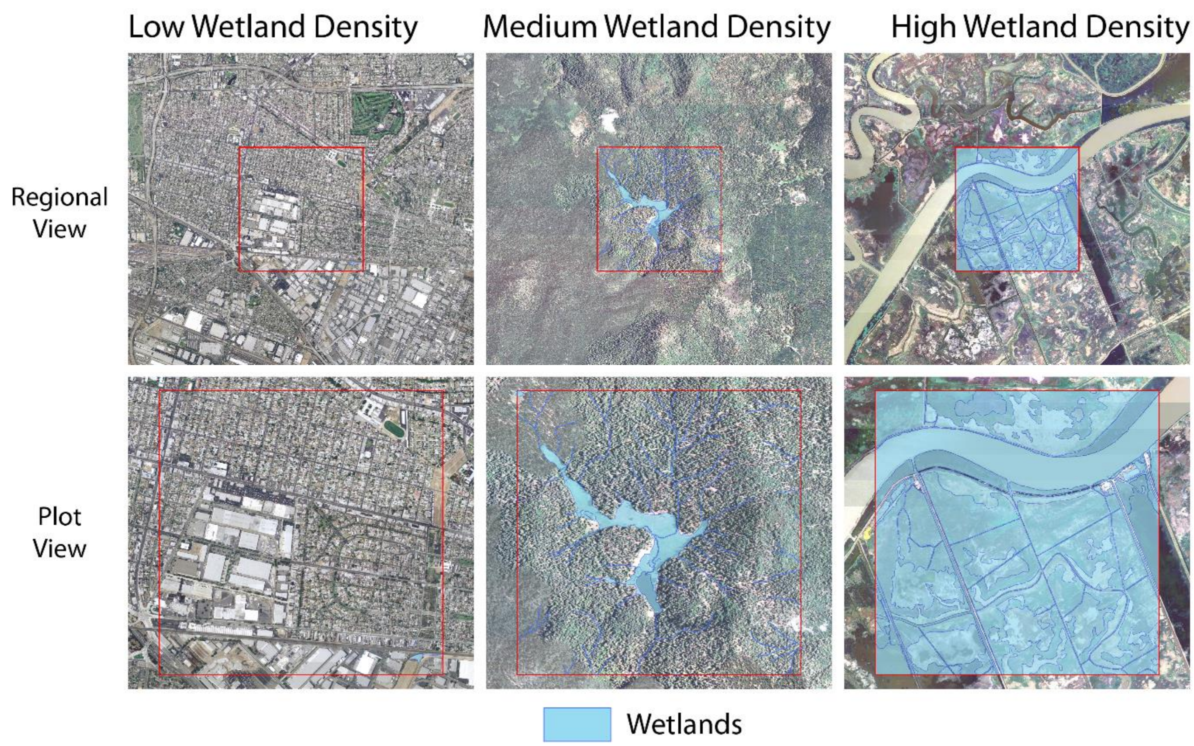

Figure 8. Example of differences in wetland density

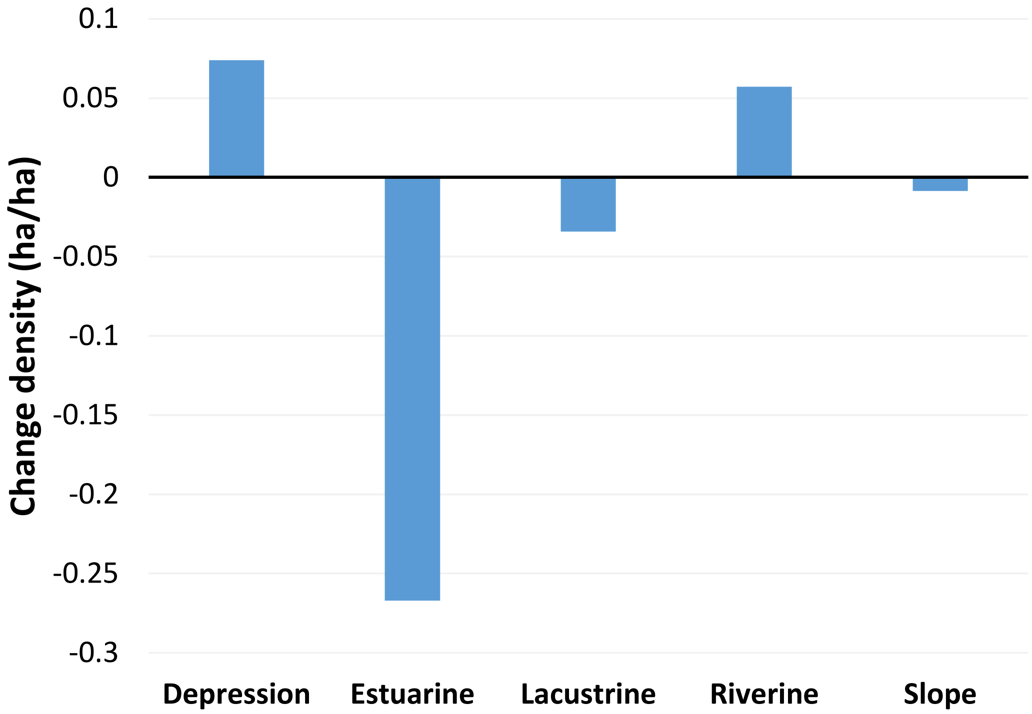

Figure 9. Change in wetland density in the pilot plots between 2005 and 2010

Most changes occurred in 22 of the 108 mapped plots and were associated with urban land uses adjacent to the wetlands (Figure 10). Wetland loss was over 3-fold greater when adjacent to urban areas vs. other land use types. Of the 27 anthropogenic modifiers evaluated, six were most commonly associated with wetland loss, most of which involved some type of hydrologic modification (Table 4). Gains in wetland density associated with natural areas may reflect either natural expansion or management activities; additional analysis is necessary to fully interpret the cause of this pattern.

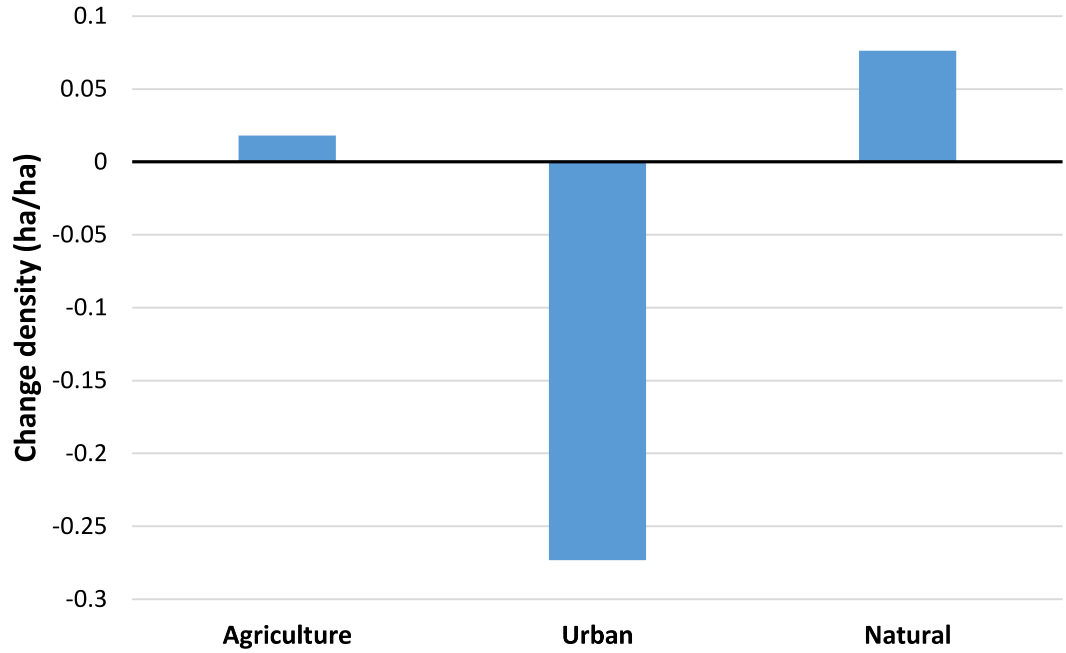

Figure 10. Change in wetland density associated with adjacent land use in the sample plot

Table 4. Possible anthropogenic modifiers. The modifiers most commonly associated with decreases in wetland density are highlighted.

Anthropogenic Influence	
Class	**Type**
Water Source/Hydroperiod	Agricultural Runoff (a)
	Constrained/Impounded (b)
	Diked (c)
	Ditched/Drained (d)
	Diverted (e)
	Infiltration (f)
	Wastewater Treatment Pond(x)
	Treatment Wetland (y)
	Stormwater Control (g)
	Urban Runoff (h)
Substrate and Bank	Armored (i)
	Excavated (j)
	Filled/Graded (k)
	Marine Control Structures (l)
	Realigned (m)
Agriculture or Other Use	Agricultural Storage Ponds (sp)
	Aquaculture (n)
	Flooded Agriculture (o)
	Flood Irrigation (p)
	Harbors/Marinas/Ports (q)
	Orchards (r)
	Ranchland (s)
	Rangeland (t)
	Recreation (u)
	Row or Sown Agriculture (v)
	Managed Hunting (w)
	Silviculture (z)

CONCLUSIONS AND RECOMMENDATIONS

This pilot project successfully demonstrates how the California Wetland Status and Trends Program may be implemented. The program's SOP proved to be a useful and valuable resource that allowed three independent mapping teams to map 108 plots at two time periods and achieve the specified data quality objectives. We provide example data products that can be used to synthesize findings on wetland status and trends over time. More in-depth analyses, such as analysis of the effects of anthropogenic stressors and extrapolation to state or regional estimates of extent and change, will be possible once all 2,000 plots are completed. Moreover, the 108 pilot plots represent the first phase of full-scale program implementation and can be seamlessly integrated into the larger mapping effort.

The initial training and intercalibration exercises took longer than anticipated, but were important to the success of the program. The upfront investment in training and quality control ensured that we were able to produce consistent results among teams that could be integrated into an overall data set. Subsequent intercalibration and quality assurance steps should be less time-consuming. The three mapping teams provided time estimates for mapping that should be useful for future planning purposes. These estimates are overall averages, and it is important to note that actual mapping times will vary widely depending on the complexity and difficulty of the individual plots:

> **NO STATE ESTIMATES**
>
> The 110 pilot plots are intended as a test and demonstration of how the Status and Trends program may be implemented. Their distribution is not representative of the state as a whole. Therefore, they cannot be used to extrapolate statewide status or trends.

- Mapping of the plot during the first time period: ***5-8 hours per plot***
- Mapping changes in extent during the second time period: ***2-3 hours per plot***
- Quality control checking and rectification: ***1-2 hours per plot***

Recommendations for Future Implementation

We offer the following recommendations based on our experience in the pilot project. If implemented, these measures will improve the efficiency and effectiveness of the overall program:

1. Improve the usability of the SOP document. The SOP is extremely detailed and comprehensive, making it a good resource. However, it can be cumbersome to use while mapping. A shorter, more step-by-step document written by experienced mappers would make it easier to use, would help in expediting the training of new mappers, and would likely further reduce inter-mapper variability.

2. Create more training and quality assurance resources. Building an online interactive mapping SOP with "frequently asked questions" and answers would improve consistency

and expertise among mappers. This could be augmented through a library of examples of challenging mapping situations along with recommended resolutions of those challenges.

3. Develop a training program and associated resources. There are currently three teams in the State of California with the necessary expertise to implement the Status and Trends mapping procedures. A formal training program and training materials will be essential to help the programs grow, expand to other natural resource programs, or transition to regional intensified mapping efforts. The training program should include "official" test plots that could be used to evaluate mapper aptitude. Routine inter-mapper calibration exercises will be important for ensuring the consistency among new teams and maintaining consistency among existing teams.

4. Develop recommended qualifications for Status and Trends mappers. The highest-quality and most consistent maps can only be produced by experienced mappers (or mapping teams) with the necessary expertise. A broad range of expertise is required to produce high-quality maps, including skills in digitization and photo-interpretation, GIS, basic wetland ecology, and plant community familiarity. A combination of geospatial and ecological knowledge is necessary and is best accomplished by teams of individuals. Furthermore, experienced mappers will be necessary to train and mentor more novice mappers. Recommendations for qualifications, knowledge and experience will help ensure production of high-quality maps consistent with established protocols.

5. Develop a process for updates, revisions and corrections. Mapping and assessment are never a static exercise. It is inevitable that previously mapped plots may need to be updated due to errors discovered later, improved imagery or data sources, or regional intensifications. Furthermore, the state wetland classification may change over time due to other programmatic needs. A process should be created to accommodate these changes, updates and corrections in a systematic way that ensures proper documentation (metadata) and version control.

6. Compile all base data sets in advance. A centralized place (e.g., an ftp server or web service) that contains all necessary base data sets would allow better version control and improve consistency between mapping teams. Key data sets could include the template geodatabases, Google Earth kmls, ArcHydro files, National Hydrography Dataset, state vernal pool layers, National Wetlands Inventory, etc. This repository would need to be updated routinely and could be expanded over time as other ancillary data sets are identified.

7. Re-evaluate the choice of the Status and Trends base-year. The pilot project used 2005 as the base-year for extent and trend estimates. However, the 2005 NAIP imagery appears to be less spatially accurate than more recent sources, which are derived from higher-quality imagery. In addition, there appears to have been a shift between the 2005 and 2010

imagery, making it difficult in some instances to overlay the images for change assessment. Prior to full program implementation, the 2005 and 2010 NAIP imagery should be compared and a decision made over the best choice for a base year in consideration of vintage (how old the plots are), legacy (the experience of past mapping efforts), and image quality. Transitioning to 2010 as the base-year would require some additional effort on the 110 pilot plots. This additional effort should be evaluated in consideration of potential improved resolution and quality associated with 2010 imagery.

8. Provide additional guidance for mapping "problematic areas." Several wetland types proved to be challenging to map given their subtle features or similarity to adjacent upland habitats. Additional guidance in the SOP (with examples) would improve consistency and accuracy in mapping these areas. Additional guidance would also be helpful for mapping roads and aqueducts. "Problem" wetland areas include:
    - Alluvial fans
    - Riparian habitat along streams, especially when juxtaposed with adjacent similar vegetation
    - Vernal pools
    - Playas

9. Establish a data management system. A formal data management system that allows mapping teams to easily submit, check and share mapping results will be important for long-term program implementation. This system should provide a repository for "official" Status and Trends data and provide an easy way to access the data. Such a system will facilitate use of the data, support regional intensifications, and facilitate a range of new applications.

LOOKING TO THE FUTURE

The Status and Trends program will allow the State of California to reliably estimate the extent and distribution of wetlands, streams, and deepwater habitat, as well as changes over time, in a cost-effective manner. This program, combined with other elements such as regional intensive maps, project-based accounting, and analysis of drivers of wetland loss, will allow California to meet the needs of a comprehensive strategy to assess wetland gains and losses, will support condition assessment, and will ultimately facilitate evaluation of the effectiveness of the state's wetland protection and restoration programs.

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