THE DISTRIBUTION OF EARLY-WINTER FLOODING IN THE CENTRAL VALLEY OF CALIFORNIA: 2000 – 2010

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Prepared for

The California Landscape Conservation Cooperative

May 2011

Recommended Citation:

Reiter, M. E., and L. Liu. 2011. The Distribution of Early-Winter Flooding in the Central Valley of California: 2000 – 2010. Report to the California Landscape Conservation Cooperative. PRBO Conservation Science, Petaluma, California.

Executive Summary

The Central Valley of California (CVC) is an important region for wintering shorebirds in the Pacific Flyway. Despite the importance of the CVC for Pacific Flyway shorebirds, currently there is no regular monitoring to quantify spatial and temporal variation and trends in shorebird populations using this landscape. Although the distribution shorebird habitat, including managed wetlands, vernal pools, and evaporation ponds, is mostly known and typically relatively stable over time, spatial and temporal variation in the distribution of flooded agricultural shorebird habitat is not well understood. Due to their ability to respond quickly to changing habitat conditions, shorebirds may shift their wintering distribution in response annual or even within season changes in the distribution of their habitat. In order to develop a robust monitoring plan for wintering shorebirds, it is important to understand the spatial and temporal distribution of their habitat during the chosen survey window. Remote sensing is a powerful tool to track habitat changes on a broad landscape and satellite based imagery is widely available. In this report we present: (1) GIS layers documenting the distribution of water and non-water areas during the early winter in the CVC between 2000 and 2010; (2) an aggregated GIS layer identifying the average probability of water presence for each pixel in the CVC; and (3) quantification of the spatial and temporal variability of water during early winter in the CVC. We acquired Landsat images of 3 scenes covering ~85% of the CVC and representing 10 winters (2000 – 2001 to 2009 – 2010). We classified image pixels into water and non-water. Overall, our classification summaries suggested that the total area of flooded habitat has been relatively stable through time in the CVC however there is significant year to year variation in the total amount of flooded habitat occurs in some basins. The Tulare Basin and the Delta Basin exhibited the largest year to year variation in flooded habitat. The largest extent of regular flooding (>30% of years) occurred in the north scene which largely represents flooded post-harvest rice as well as the extensive managed wetlands in this region. Overall, our approach was able to predict the spatial distribution of water in the CVC across many years using a simple classification technique. Our rapid assessment of water and non-water and evaluation of these data provided a broad spatial and temporal scale perspective on the distribution of surface water. These data provide needed habitat information for designing a robust monitoring program for wintering shorebirds in the CVC.

BACKGROUND

The Central Valley of California (CVC) is an important region for wintering shorebirds in the Pacific Flyway; with an estimated 200,000 to 300,000 birds, representing more than 30 species, overwintering annually (Shuford et al. 1998). Despite the importance of the CVC for Pacific Flyway shorebirds, currently there is no regularly monitoring to quantify spatial and temporal variation and trends in shorebird populations using this landscape. To obtain data to address these information needs and to inform the conservation of migratory shorebirds, PRBO Conservation Science is developing an annual Pacific Flyway Shorebird Survey (PFSS; http://data.prbo.org/partners/pfss/). The PFSS is a coordinated, multi-partner monitoring program led by PRBO Conservation Science to identify trends and habitat associations of wintering shorebirds in the Pacific Flyway to inform conservation and management. As part of the development of this larger program, we are developing a monitoring plan for wintering shorebirds in the CVC.

Shorebirds in the CVC generally use shallow water habitat that is free of vegetation, including managed wetlands, vernal pools, flooded agricultural fields, and evaporation ponds. Although the distribution of managed wetlands, vernal pools, and evaporation ponds are mostly known and typically relatively stable over time, spatial and temporal variation in the distribution of flooded agricultural habitat is not understood. Due to their ability to respond quickly to changing habitat conditions, shorebirds may significantly shift their wintering distribution in response to annual or even within season changes in the distribution of their habitat (Warnock et al. 1995). In order to develop a robust monitoring plan for wintering shorebirds, it is important to understand the spatial and temporal distribution of their habitat during the survey window. We are concerned primarily with identifying specific regions of the Central Valley with regular water availability and quantifying among year variability in the spatial and temporal distribution of water.

Remote sensing is a powerful tool to track habitat changes on a broad landscape and satellite based imagery is widely available. The Landsat Program initiated by NASA (http://landsat.gsfc.nasa.gov/) provides imagery of the earth at regular intervals (every 17 days) captured at a relatively fine resolution (30m pixels). These data can be used to delineate areas of standing surface water across a broad landscape. To facilitate the development of a monitoring plan for wintering shorebirds in the CVC, we examined Landsat images from early winter (November – early January; we have identified these months as the survey window for the PFSS) over the period 2000 – 2010 to delineate coarse patterns of spatial variability in water and non-water regions of the CVC using remote sensing techniques. Because there may be long-term temporal trends in water distribution, we only used data from the last 10 years to assess variability in the distribution of shorebird habitat. In this report we present: (1) GIS layers documenting the distribution of water and non-water areas during the early winter in the CVC between 2000 and 2010; (2) an aggregated GIS layer identifying the average probability of water presence for each pixel in the CVC; and (3) quantification of the spatial and temporal variability of water during winter in the CVC. We will use the results of this analysis to inform the sampling design of the Central Valley Shorebird Monitoring Plan; a forthcoming report to the CA LCC.

METHODS

We acquired 40 Landsat thematic-mapper (TM) satellite images of 3 scenes in the CVC from the Earth Resources Observation and Science Center webpage (http://eros.usgs.gov/) representing 10 winters (2000 – 2001 to 2009 – 2010; Table 1). We utilized both Landsat 5 and Landsat 7 images, as both satellites house comparable multispectral imaging sensors with 30m resolution which collect reflectance bands useful for distinguishing water (i.e. bands 5, 4, and 2). From the large pool of images, we selected images based on 2 criteria (1) the image was taken between 1 November – 31 January and (2) the image had <20% cloud cover (two scenes were used with >20% cloud cover but the cloud cover was not in the part of the image we classified). The 3 scenes used in this analysis covered >85% of the CVC survey region for shorebirds extending from the Butte and Colusa Basins in the north to the Tulare Basin in the south (Fig. 1).

We used the image analysis software eCognition (v. 8.0.1, © 1995 – 2008 Definiens AG) to process our images. We used the multi-resolution segmentation algorithm (Baatz and Schape 2000) to merge the pixels into groups based on spectral and shape criteria. The multi-resolution segmentation algorithm is an optimization routine that minimizes average local heterogeneity (and subsequently maximizes the homogeneity) creating groups of similar pixels (image objects). The segmentation

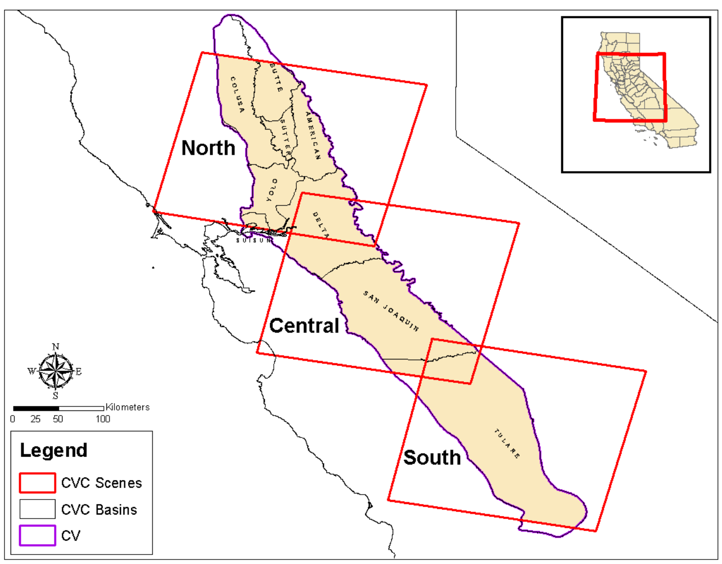
Table 1. Summary of Landsat TM scenes acquired and classified between winters 2000-2001 and 2009-2010 in the Central Valley of California. Images used in analysis in bold

Winter	North Date	Cloud Cover	Central Date	Cloud Cover	South Date	Cloud Cover
2000-01	**12/8/2000**	0.00	**11/7/2000**	4.76	**11/16/2000**	1.36
	12/24/2000	0.00	1/18/2001	0.00	12/26/2000	0.00
2001-02	**12/11/2001**	0.00	**12/4/2001**	10.00	**12/13/2001**	0.00
2002-03	**11/28/2002**	0.00	**12/23/2002**	0.00	**11/6/2002**	1.25
2003-04	**11/23/2003**	0.03	**11/16/2003**	1.31	**11/25/2003**	0.44
			1/3/2004	3.64	1/4/2004	10.00
2004-05	**12/3/2004**	0.00	11/2/2004	0.08	N/A	>20
			12/4/2004	4.07		
2005-06	**11/20/2005**	0.00	**11/21/2005**	0.26	**11/22/2005**	0.00
	1/23/2006	0.00				
2006-07	**11/23/2006**	0.00	**12/2/2006**	0.00	**11/9/2006**	0.00
	1/26/2007	0.00			1/12/2007	1.00
2007-08	**11/2/2007**	0.02	**12/13/2007**	0.68	**11/4/2007**	2.19
	12/20/2007	9.68				
2008-09	**1/15/2009**	2.00	**11/13/2008**	34.10	**11/14/2008**	4.00
					1/17/2009	3.00
2009-10	**11/15/2009**	0.00	**11/16/2009**	0.79	**12/3/2009**	25.00

process is defined by 3 parameters: (1) scale, (2) shape, and (3) color. The scale parameter determines the maximum allowable heterogeneity within an image object, with larger values typically resulting in larger image objects. The shape and color parameters dictate the relative importance of information about spectral reflectance homogeneity (i.e. color) or spatial homogeneity (i.e. shape) in the optimization process. Shape and color are values between 0 and 1 and are related as: *color = 1 – shape*. For our analyses, we weighted color (0.7) higher than shape (0.3) so that homogeneity of spectral reflectance would be prioritized over spatial homogeneity in the segmentation process.

Following segmentation, we iteratively separated the image objects into 2 classes, water and non-water using a nearest neighbor classification algorithm. We enhanced the visibility of water in each Landsat image by displaying bands 5, 4, and 2 representing red, green and blue, respectively. We then selected sample sets of image objects with known standing water (n = 15) and sets of image objects with no water (n = 15). Known flooded areas used to train the classification of each scene were derived from high resolution imagery, maps, historic data, and consultation with wetland managers and farmers. The rest of the image objects were then classified by the algorithm as water and non-water. We then selected image objects that were incorrectly classified and added them to the set of samples, and then repeated the classification. We continued this training process until all known sites were evaluated correctly by the classification algorithm.

Figure 1. Location of the Central Valley of California and the three Landsat TM scenes classified.



We determined that it was necessary to independently classify each scene in each year to account for differences among images (both between years and between locations) in the sensor returns for the spectral layers. However the processes for segmenting, classifying, and exporting to image files were automated and saved as a rule-set. Subsequently, it was only necessary to select positive and negative samples for each scene in each year. This streamlined the process of conducting 40 scene classifications. Areas of overlap among the scenes were also evaluated independently, although they represent only a small area of the classified region.

We stored the classified images in a geodatabase as both polygons and raster grid files derived from the classified polygons. We combined the classified water grids using raster math functions and the Spatial Analyst extension in ArcMap 9.2 (© 1999 – 2006 ESRI Inc.) to calculate the probability of water occurrence for each pixel in each scene. Regions with high probability of water values identified areas with regular water availability whereas areas with low values indicated little or no water presence. We also calculated the coefficient of variation of the probability of water occurrence in each pixel as a measure of variability. We evaluated spatio-temporal change by calculating the difference in the probability of water in each pixel between the winters 2005-2006 to 2009-2010 and 2000-2001 to 2004-2005. Values of this difference can range from -1 (decrease) to 1 (increase).

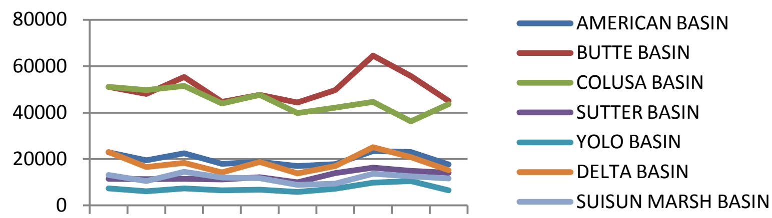
We used data collected as part of a separate project (PRBO unpublished data) to ground-truth our classification. To further test our classification approach, we also classified a north scene from December 1999 and compared our results to the classification developed for Fleskes et al. (2005)

RESULTS

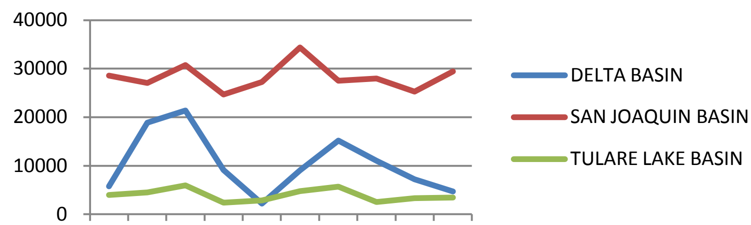
A total of 40 images from the north (*n* = 14), central (*n* = 13), and south (*n* = 13) scenes met our criteria for classification. We were able to classify at least one image for each scene in each winter except for the south scene during 2004-2005 (Table 1).

Figure 2. Summary of total flooded hectares by major hydrological basin in the Central Valley of California for each classified scene (North, Central, and South) in early winter between 2000-2001 and 2009-2010.

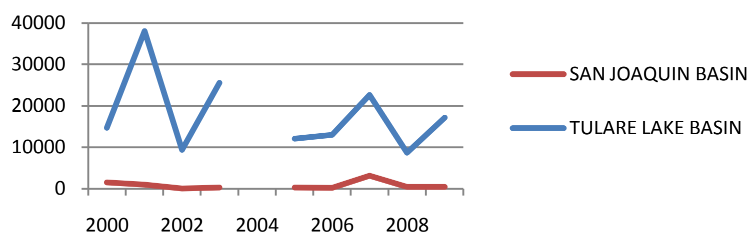
North



Central



South

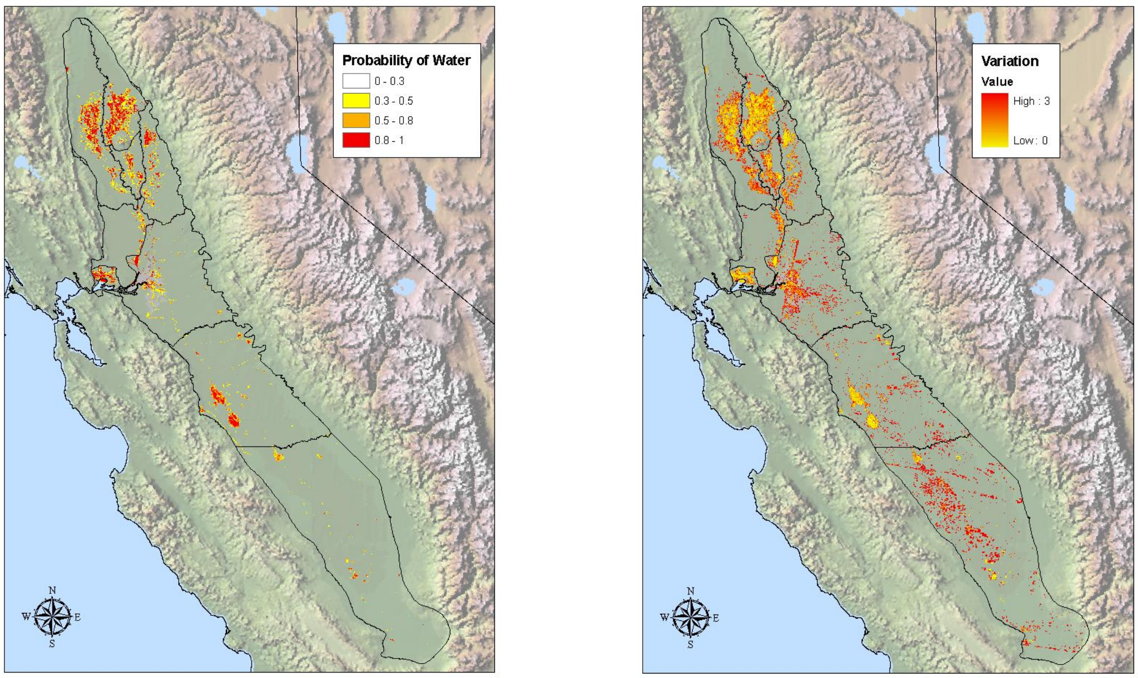


Overall, our classification summaries suggested that the total area of flooded habitat has been relatively stable through time in the CVC however there was significant year to year variation in the total amount of flooded habitat occurs in some basins (Fig. 2). The Tulare Basin and the Delta Basin exhibited the largest year to year variation in flooded habitat.

The largest extent of regular flooding (>30% of years) occurred in the northern scene which largely represents the winter flooded post-harvest rice as well as the extensive managed wetlands in this region. However, despite a large region of regular flooding there was still year to year variability in the flooding, particularly on the west side of the flooded region. In the central scene, regular flooding was localized and highly variable in areas near the Delta. Further south, near the Grasslands Ecological

Area, the North and South Grasslands stand out as large, localized areas having consistent water, while the remainder of the surrounding region has small highly variable patches of water. Only a few small areas appear to have regular water in the southern scene including the Mendota Wildlife Area at the northern edge of the Tulare Basin and the Kern National Wildlife Refuge in the southern portion of the region. There were also a large number of small, primarily agricultural, sites that have highly variable occurrence of water over the last 10 years.

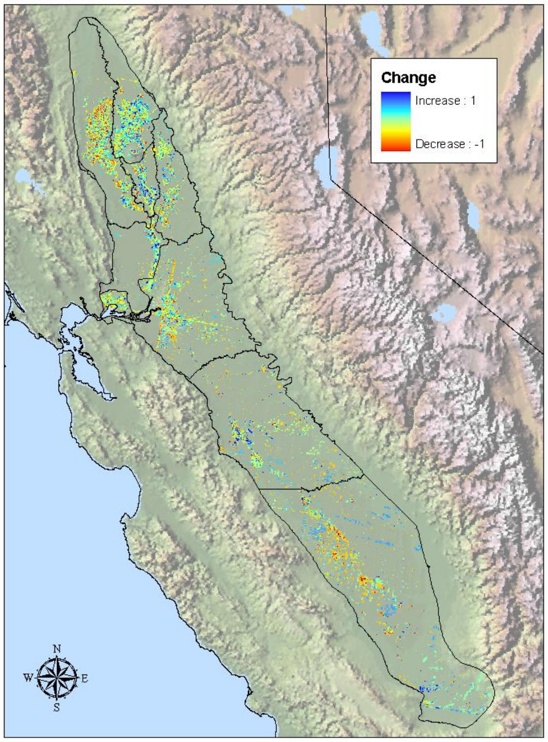
Figure 3. Probability of water occurrence and variability in flooded habitat in the Central Valley of California during the early winter between 2000 and 2010.



Between the early years of our analysis (winter 2000-2001 to 2004-2005) and the later years (winter 2005-2006 and 2009-2010) there were areas of increase and decrease in the probability of water in the CVC. In the north scene increases were primarily in the Butte Basin whereas there were decreases in the northwest regions of the Colusa Basin. In the central scene, there were some areas of increase in the San Joaquin Basin near the Grasslands Ecological Area. There were both localized areas of increase and decrease in the south scene. We will be further evaluating the specific locations of these changes in the south scene to inform our shorebird monitoring plan.

In the north scene, we ground-truthed our classification from December 2009 using data collected in rice fields from the same time period (PRBO, unpublished data). Our remote sensing classification correctly identified 96% of flooded fields (52 of 54) surveyed as part of this study in the Sacramento Valley.

Figure 4. Change in the probability of water in the Central Valley of California between winters 2000 – 2004 and 2005 – 2009.



To further test the classification technique we used in this study, we classified an additional image of the north scene from December 1999. Our results were very similar to those in the layer used by Fleskes et al. (2005). However, generally, our approach tended to over-predict the presence of water (Table 2). This was driven by our inclusion of a shape parameter which weighted spatial homogeneity as well as spectral homogeneity when grouping pixels. This tended to include entire wetland units and not just the open water portions. This was apparent in the comparison of the Suisun Marsh Basin, which is composed largely of managed wetlands. Our estimate was over double of that generated by Ducks Unlimited in Fleskes et al. (2005). For the goals of informing long-term monitoring of wintering shorebirds, which winter in large groups and respond over a broad landscape to changes in the distribution of habitat, we would rather over-predict the presence of water than regularly under-predict and miss important habitats.

Summary and Next Steps

Overall, our approach predicted the spatial distribution of early-winter (mid-November to mid-January) water in the CVC across many years using a simple classification approach. Our rapid assessment of water and non-water and subsequent evaluation of these data provide a broad spatial and temporal scale perspective on the distribution of surface water. These data provide essential information for designing a robust monitoring program for wintering shorebirds in this region. By understanding spatial and temporal variation in the distribution of water, we can develop an appropriate sampling design to efficiently target both managed wetlands and flooded agriculture as part of our monitoring efforts. Ultimately our results suggest that managed wetlands and rice in the Sacramento Valley had a high probability of providing flooded habitat and subsequently quite low year to year variability in whether an individual site was flooded. Large regions of agriculture in the San Joaquin Basin and Tulare Basin showed low levels of flooding and high spatial and temporal variability. Our results are consistent with other work that has documented regions of regular use by wintering shorebirds in the CVC (Shuford et al. 1998, Stralberg et al. 2010).

Our retrospective approach employed consistent classification methodology and generated unbiased assessments of spatio-temporal variability and trend in the distribution of water in the CVC,

Table 2. Comparison of ha classified as flooded using two different techniques using a Landsat TM image from the north scene in December 1999.

Basin	PRBO (ha)	Ducks Unlimited (ha)
AMERICAN	25000	21093
BUTTE	56454	46989
COLUSA	42916	34675
DELTA	21145	23657
SUISUN MARSH	13133	6152
SUTTER	9964	8457
YOLO	5658	4474

despite the absence of large amounts of ground-truthing data. One possible source of bias in our classification is that in each scene the image was not from the same date in all years. In fact we had a large amount of variation in the image dates among scenes and years, however the standard deviation of the classification date in the north, central, and south scenes was 18, 15, and 14 days, respectively. This suggests that the high variation observed in the south scene overtime, compared to the north and central scenes, was not likely the result of higher variation in the dates of the classified images.

The quantitative efficiency and effectiveness of long-term shorebird monitoring programs can be reduced due to changes in the distribution of habitat. This may become an increasingly common problem as the result of climate change. One approach to guard against potential bias in trend estimates that may result from changes in the distribution of habitat is to identify all areas where habitat could occur and sample broadly across that region. This approach may limit bias but will likely result in high variance in counts and require a large work force to complete across the large spatial-scale that is needed for wintering shorebirds. Our analysis of 10 years of imagery data provides a rigorous methodology for identifying regions of regularly occurring habitat for wintering shorebirds and quantifying the spatial variability in those locations over time. Our remote-sensing classification methodology could be applied regularly to track water distribution broadly throughout the CVC. If large patterns of change in the distribution of water were observed, these data could guide modifications of a long-term monitoring program to prevent biased results.

These data, along with other resources (e.g. Shuford et al. 1998), provide an excellent baseline to guide the development of a robust long-term monitoring program for wintering shorebirds in the CVC region of the California Landscape Conservation Cooperative (CA LCC). We will employ these data to inform our sampling design and to evaluate potential sources of bias that may limit competing designs. Currently, the GIS layers from this project are stored in a geodatabase at PRBO Conservation Science. Upon completion of our work with these data (i.e. Central Valley shorebird monitoring plan, publication of a water distribution manuscript), we will make these layers available to the public. We also plan to use the classifications from the north scene in analyses proposed to CA LCC as part of Phase II of this work.

ACKNOWLEDGEMENTS

We thank K. Strum (PRBO), C. Hickey (PRBO), J. Fleskes (USGS), and K. Petrik (Ducks Unlimited) for providing data and support for this project. This work was funded by the California Landscape Conservation Cooperative and the David and Lucile Packard Foundation.

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