THE USE OF REMOTELY SENSED DATA FOR THE DETECTION, MAPPING AND MONITORING OF SUDDEN OAK DEATH

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Abstract: The California Department of Forestry and Fire Protection (CDF) and the US Forest Service (FS), with cooperation of the California Oak Monitoring Task Force, are conducting a monitoring project for Sudden Oak Death (SOD) under the umbrella of the larger CDF/FS Land Cover Mapping and Monitoring Program (LCMMP). The objective of the SOD monitoring project is to evaluate the use of multi-scale remotely sensed data to identify "hot spots" of oak mortality and verify these areas with a combination of airborne imagery, aerial surveys and field verification.

INTRODUCTION

Tens of thousands of tanoak *(Lithocarpus densiflorus*), coast live oak *(Quercus agrifoli*a), California black oak *(Quercus kellogg*ii), Shreve oak *(Quercus parvula* var. *shreve*i), and madrone *(Arbutus menziesi*i) have been killed by a newly identified pathogen, *Phytophthora ramorum*. This pathogen, referred to as Sudden Oak Death (SOD), was first reported in Marin County in 1995 (McPherson et al., 2000). The pathogen also infects rhododendron species, huckleberry *(Vaccinium ovatu*m), bay laurel *(Umbellularia californic*a), and California buckeye *(Aesculus californic*a), but usually causes only leaf spot and twig dieback on these hosts. The host list is expected to expand as researchers at the University of California at Davis and University of California at Berkeley continue their investigations of affected ecosystems.

The known distribution of *P. ramorum* is expanding. According to the California Oak Mortality Task Force, there are, as of November 2001, ten counties with SOD; Alameda, Marin, Mendocino, Monterey, Napa, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma (Figure 1). The farthest north confirmed location of SOD is on Highway 128, between Boonville and Yorkville, in Mendocino County. The farthest south confirmed location is Pfeiffer Big Sur State Park, in Monterey County. The location farthest inland from the coast is in Solano County. The disease is widespread in Marin and Santa Cruz counties in redwood forests with tanoak in the understory, and in mixed hardwood forests of oaks, bay, madrone and other species (California Oak Mortality Task Force, 2002).

Currently, this outbreak of oak mortality has not been completely or accurately mapped. The California Department of Forestry and Fire Protection (CDF) and the U.S. Forest Service (FS) are using Landsat Thematic Mapper (TM) satellite imagery to determine the amount and extent of oak mortality in coastal counties affected with SOD. Imagery was acquired in 1996, prior to the onset of the syndrome, and in 2000. Change detection techniques are used to determine decline in oak canopy between the two image dates. Field efforts and high-resolution digital camera imagery collected randomly across the area will be used to verify SOD locations on the change map. This effort provides the baseline for future monitoring efforts that will evaluate the extent and spread of SOD.

The objective of the SOD monitoring project is to evaluate the use of multi-scale remotely sensed data to identify "hot spots" of oak mortality, and verify these areas with a combination of airborne imagery, aerial surveys and field verification. Multi-scale remote sensing, aerial survey expertise and on the ground sampling form baseline information to identify areas affected by SOD and facilitate identifying changes due to SOD. The scope of the SOD problem is expanding with every detection effort. Given the size of the affected land area, detection and monitoring of SOD would not be practical without the use of remotely sensed data.

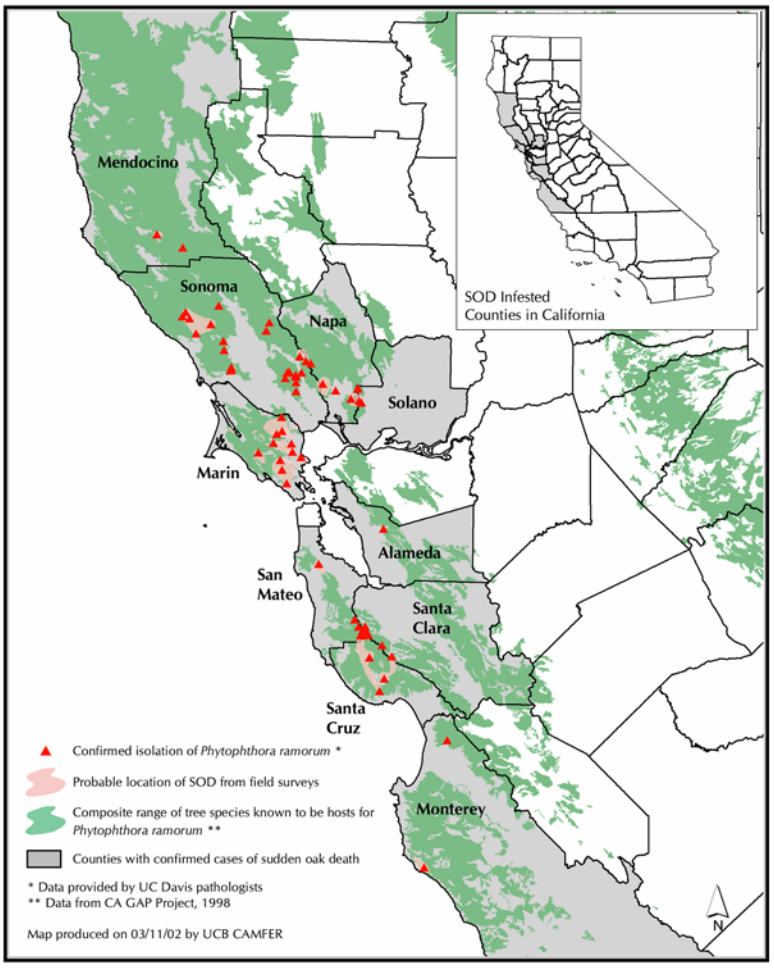

Figure 1. Distribution of Sudden Oak Death as of March 11, 2002
(www.suddenoakdeath.org / http://camfer.cnr.berkeley.edu/oaks/SODdistribution.html)

METHODOLOGY

The area of interest for this project covers approximately 10 million acres and portions of all of the 10 counties with current confirmed SOD sites and required the use of four different Landsat TM scene-pairs (Figure 2). Monitoring land cover change using remotely sensed data requires at least two different dates of imagery. For this project, late spring imagery dates were selected to capture changes in hardwood vegetation after leaf-out and to minimize confusion caused by drought-deciduous species in later months (Table 1). The differences in spectral reflectance, or the amount of sunlight reflected from surface features to the satellite in space, between the multi-date images determines whether or not change has occurred. The change detection process interprets these differences in spectral reflectance and produces an image depicting categories of change. These categories range from little or no vegetation change to large increase or decrease in vegetation cover. An additional decrease class, "Potential SOD", can be identified with the assistance of other remotely sensed data. Though SOD cannot be positively identified from remotely sensed data alone, with the assistance of ancillary data areas of hardwood decline that may be due to

SOD can be detected. These changes on the image can then be validated by ground truth information to determine accuracy and the actual causes of these changes.

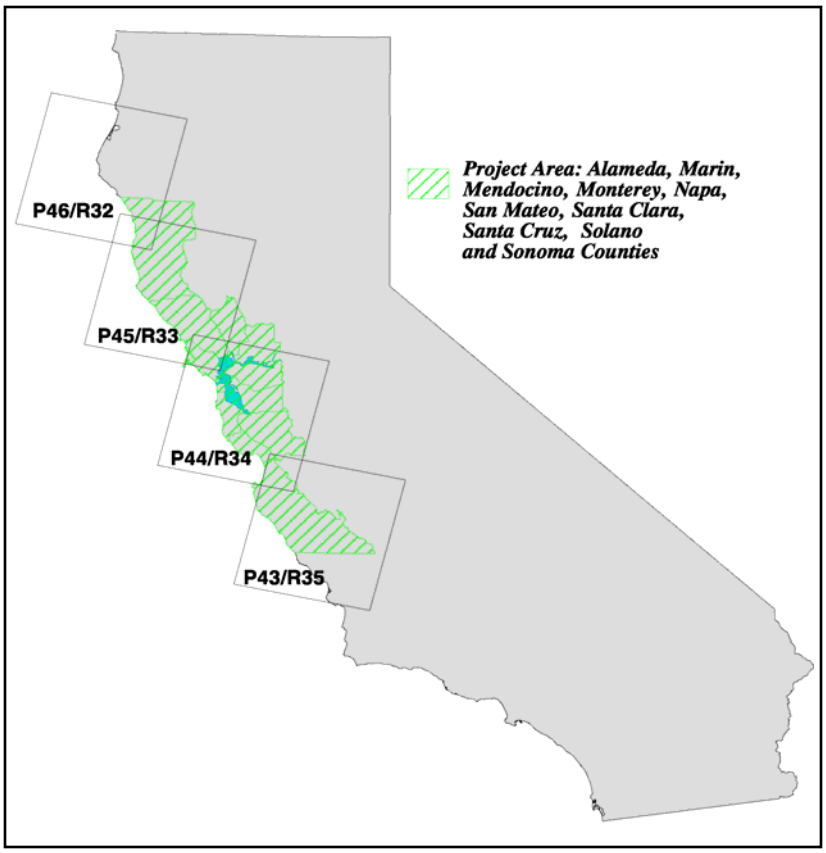

Figure 2. Project area and Scene Boundaries

Table 1. Imagery Dates

Path/Row	Dates	
4335	5/12/96	4/29/00
4533	5/10/96	5/29/00
4632	5/1/96	4/2/00
4434	5/3/96	4/20/00

Database Building

Before the actual change analysis can be completed the imagery must first be prepared for processing, and a seamless vegetation layer must be assembled. The first step in preparing the TM imagery is to co-register the early date TM image to the later date TM image of the same path/row. Registration begins by identifying common features throughout both images on-screen (e.g., road intersections). Approximately 50 to 100 features are located throughout each scene pair. These features are used in a nearest neighbor resampling technique to assign the early date pixel values to the later date pixel locations. Nearest neighbor resampling avoids altering pixel values, therefore maintaining spectral reflectance of ground features. These new pixel locations must be within ½ pixel of the later date pixels to eliminate any false changes. Next, the images are radiometrically corrected to account for differences in atmospheric conditions (e.g., haze and water vapor). This is accomplished by extracting invariant light (rock outcrops) and dark (water bodies) features from both dates of imagery and running a regression-based correction on the resulting pixels (Schott et al., 1988). The regression equation is applied to the early date TM image to derive normalized pixel values.

Because a single vegetation layer does not exist for the project area, the best available vegetation layers were obtained and mosaicked together. The USFS and CDF maintain vegetation layers for most of California's forested areas, both public and private. The LCMMP produces vegetation data using the Classification and Assessment with Landsat of Visible Ecological Groupings (CALVEG) (USDA Forest Service Regional Ecology Group, 1981) and Wildlife Habitat Relationships (WHR) (Mayer and Laudenslayer, 1988) classification systems. However, geographic extent is not complete for the state; thus other vegetation data sources are required to attain full project area coverage. Other data sources include a hardwood data layer (CDF layer updated in 1990) and a GAP data layer (created in 1990). Vegetation layers are mosaicked with precedence given to the LCMMP layers, then the updated hardwood layer and finally the GAP layer. GAP data is usually a small component of the seamless vegetation layer and mainly is used to cover the low elevation valley areas (Table 2).

Table 2. Vegetation Data

Name	Classification	Scale
LCMMP Vegetation Data	CALVEG/WHR	2.5 acre mmu
Hardwood Rangelands	WHR	25^2 meter pixels
GAP Analysis	WHR used	100 hectares (~250 acres)

Change Processing

Land cover change data are derived from the co-registered and radiometrically corrected TM imagery using image processing techniques. A multi-temporal Kauth-Thomas transformation (MKT) is applied to a 12-band image (bands 1-5 and 7 from each date) (Kauth and Thomas, 1976). This transformation applies coefficients to each TM band producing a new image depicting changes in brightness, greenness and wetness components (Crist and Cicone, 1984). These brightness, greenness and wetness components are calculated by the equation:

$$Bt1 = B1(TMb1)+B2(TMb2)+B3(TMb3)+B4(TMb4)+B5(TMb5)+B7(TMb7)$$

$$Gt1 = G1(TMb1)+G2(TMb2)+G3(TMb3)+G4(TMb4)+G5(TMb5)+G7(TMb7)$$

$$Wt1 = W1(TMb1)+W2(TMb2)+W3(TMb3)+W4(TMb4)+W5(TMb5)+W7(TMb7)$$

where Bt1 is the brightness value for time 1; Gt1 is the greenness value for time 1; Wt1 is the wetness value for time 1; Bx is the brightness coefficient for TM band x; Gx is the greenness coefficient for TM band x; Wx is the wetness coefficient for TM band x; and TMbx is the TM band x reflectance value.

Brightness is a measure of overall reflectance, greenness is related to the amount of green vegetation present in the scene, and wetness correlates to canopy and soil moisture (Crist et al., 1986). This transformation produces two new images, one for each date that depict brightness, greenness and wetness components (BGW). The two BGW images are then differenced to produce an image reflecting differences or changes in BGW (ΔBGW). Because of the vast amount of information in this differenced BGW image, and because each pixel contains values for changes in brightness, greenness, and wetness, this information can be effectively reduced by grouping similar BGW signatures. To group these signatures, first, an unsupervised classification for each vegetation lifeform type (e.g., hardwood, conifer, grass, etc.,) was performed, generating 75 discreet classes of spectral signatures of change in BGW per lifeform. Using a maximum likelihood classifier, these spectral signatures were then applied to the ΔBGW image to produce a final BGW change image.

Change Labeling

After image classification, categories of similar levels of brightness, greenness and wetness values are assigned to one of nine change classes that include large decrease, moderate decrease, small decrease, large increase, moderate increase, small increase, non-vegetation change and little to no change. Image appearance, bi-spectral plots (e.g., greenness vs. wetness), photo interpretation, vegetation and topographic maps aid in assigning the change

categories. Decrease and increase change classes represent relative changes in vegetation cover. For example, a small decrease will have less vegetation cover loss than a moderate or large decrease (e.g., a forest thinning compared to a clearcut). The little to no change class indicates that change did not occur or that change was so slight that it could not be detected. The non-vegetation change class accounts for variations in lake or reservoir water levels and snow pack in the higher elevations. A cloud and shadow class is added to account for clouds in the imagery and shadows in the mountainous areas that obscure ground cover making it impossible to determine whether the vegetation has changed or remained stable in these areas. Each individual lifeform change image is then mosaicked into one change image per scene.

Areas of small decrease are further evaluated to determine the potential for change due to oak mortality. Additional remotely sensed data of various scales, including ADAR photography of China Camp State Park and 2 meter digital camera data collected from flights over affected counties and adjacent areas, were examined in conjunction with the preliminary change data to evaluate hardwood mortality and its extent. Each digital photo was examined for signs of hardwood mortality that could not be attributed to a known cause (i.e. fire, harvest) and compared to change data for further confirmation of mortality. Point data of known infested sites, vegetation layers, and other ancillary data were also used to further isolate areas of change due to confirmed and potential SOD. If mortality due to SOD was suspected, the class was then labeled "Potential SOD"; known areas of infestation were labeled "Hardwood Mortality in an Area of Confirmed SOD".

In July 2001 an aerial survey was conducted by the USFS to identify areas of visible mortality within the project area. A combination of methods, including GPS, sketch-mapping, 35mm photography, and detailed notations were used to map and characterize mortality areas. The collected data were converted into a polygon coverage, which was used to assist in further evaluation of preliminary change data. Polygons were attributed with estimated acreage, species composition, percent mortality, and cause. Mortality polygons of indeterminate cause, as well as concentrated areas of "Potential SOD" are currently undergoing field verification.

Upon completion of analysis, individual change images were mosaicked together to form a complete change map of the project area. All classes other than decrease and SOD related classes were masked, and the three decrease classes (small decrease in vegetation, moderate decrease in vegetation, and large decrease in vegetation) were combined to form a single class. Decreases of known cause, such as fires or harvests, were masked, as was agriculture, urban areas and other nonessential data. The remaining data were then stratified by lifeform, masking out all but the hardwood and hardwood/conifer vegetation types. Because of the possibility that areas of "Potential SOD" and "Confirmed SOD" might be eliminated during an aggregation process, these classes were left at the pixel level. For data reduction purposes, the decrease class was aggregated to a minimum mapping unit of 2.5 acres, which is the standard mapping unit for all LCMMP change detection products (Figure 3).

RESULTS

Detection

Change detection methods using remotely sensed data can determine changes in vegetative canopy cover. These techniques can identify even subtle changes in canopy, such as those changes that might be caused by hardwood mortality due to SOD. Though image processing techniques may not be able to identify the exact cause of detected mortality, ancillary data sources, including other remotely sensed data such as digital photography and aerial surveys, can provide the detail necessary to highlight areas of potential SOD and give direction to field efforts. However, because of the landscape scale of this monitoring effort it cannot be expected that isolated individual trees affected by SOD will be correctly detected, but rather that "hot spots", or concentrated areas of hardwood mortality, will be more effectively detected. Additionally, the coarseness of these data (30m pixel size) along with the lack of aggregation in the SOD classes may overestimate changes due to mortality in vegetation.

Large concentrations of "Potential SOD" and other hardwood mortality were detected in the counties of Marin, Santa Cruz, and Monterey. Smaller concentrations were also present in Sonoma, Santa Clara, and Napa Counties. Since these counties already have known sites of infestation it is possible that much of the SOD related mortality, particularly within a distance of infected sites, has been correctly detected, though further field work is necessary to confirm these preliminary results. Aerial survey data also corroborates the change detection data. "Potential SOD"

and other hardwood mortality were detected in and around the majority of aerial survey polygons of indeterminate cause. Because of the possibility of locational offsets in aerial survey polygons, areas with detected hardwood mortality that surrounded mortality polygons were also considered to be sites of "Potential SOD". Field verification efforts are currently in progress and will be continued in the summer of 2002. At the present time, 5 aerial survey mortality polygons have been tested and confirmed positive for SOD, 4 were unable to be tested due to access difficulties, 13 were determined to have either no symptoms of SOD or mortality of another cause, and 16 were determined to be "likely SOD" due to their proximity to infested areas and general symptomology of inspected trees. Initial feedback from field verification teams regarding the change data has been positive and indicates that detected change is suspected SOD mortality.

Mapping & Monitoring

Field efforts focused on areas with high concentrations of "Potential SOD" in addition to the aerial survey mapped mortality polygons. Maps were created using the change data along with a GIS overlay of the mortality polygons and 100k topographic quads. These were then used in conjunction with DOQQ's and the 35mm photos from the aerial survey to navigate to specific sites. When possible, suspect trees were sampled and lab-tested to confirm or refute the presence of the phytophthora pathogen. These results were then used to update the change map to reflect the class labeled "Hardwood Mortality in an area of Confirmed SOD". Further field research will be completed in the summer of 2002, with the goal of verifying the causes of decrease and quantifying the results as well. Additional aerial surveys will also be conducted over the project area and adjoining counties, beginning in May 2002. Upon completion of field work, quantitative measurements will be obtained and an accuracy assessment will be performed.

CONCLUSION

Change detection methods can determine changes in hardwood canopy cover. Moreover, these techniques can identify even subtle changes in canopy cover, such as those that might be caused by SOD. The variety of multi-scale data used in this project was extremely helpful in identifying mortality. Digital camera data provided valuable reference information in areas of confirmed SOD and oak mortality and offered highly detailed information on both the extent of mortality and the identification of oak in particular. ADAR data of China Camp State Park also provided an essential visual tool for the appearance of SOD in imagery and helped guide labeling efforts. Aerial surveys assisted in the detection of oak mortality and helped to discriminate the various spectral reflectance values necessary for the change labeling process. Additionally, detailed notations and 35mm photographs taken during the aerial survey provided a valuable tool in verification of sketch-mapped polygons as well as offering on the ground reference information. Furthermore, the use of GPS in conjunction with sketch mapping greatly improved the spatial accuracies of the mortality polygons.

The use of ancillary data layers, such as vegetation data, forest resource photography, fire history, timber harvest records, and GIS layers of known SOD sites were critical in both the data interpretation and data reduction processes. Through the removal of non-essential data and stratification by vegetation type, areas of interest and concentrations of "Potential SOD" and other hardwood mortality of unknown cause are highlighted for future analysis. Though the pixel level may overestimate the actual hardwood mortality caused by SOD, an aggregation would certainly result in the loss of identified mortality. For field confirmation purposes then, it is more useful to leave all SOD-related classes at the pixel level.

Sudden Oak Death is affecting the state of California on a landscape scale. This multi-scale approach and these collaborative efforts are essential to a low-cost, long-term monitoring and sampling strategy for SOD. These data are prerequisite to the identification of future management opportunities, including allowing for more focused field efforts, and can also increase efficiency in future data acquisition. Over time these data can also be used to track the progress of hardwood mortality and identify the paths of spread of SOD. Additionally, the data collected in this project may also be of use in future risk mapping applications. These data form the baseline for any future monitoring efforts and provide a critical look at current SOD related mortality conditions. Without the use of change detection methodologies employing TM imagery, long term and low cost monitoring of the large area affected by SOD would be nearly impossible.

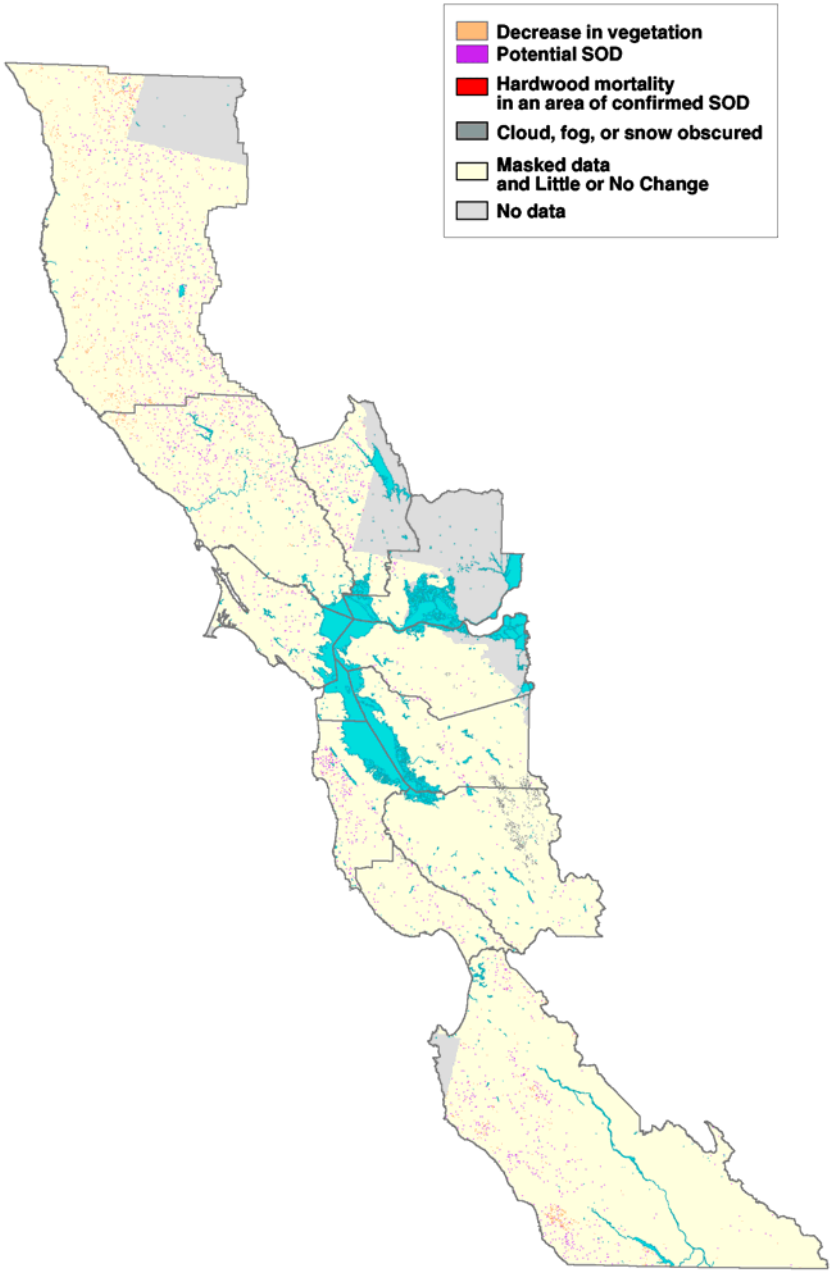

Figure 3. Final Change Map

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