CALIFORNIA LAND COVER MAPPING AND MONITORING PROGRAM: A COOPERATIVE

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Abstract: The California Land Cover Mapping and Monitoring Program (LCMMP), a cooperative program between the USDA Forest Service and the California Department of Forestry and Fire Protection, is addressing statewide vegetation mapping and long-term monitoring using Landsat Thematic Mapper (TM) satellite imagery. The LCMMP creates seamless data across California's landscape for multi-scale assessments across all ownerships and vegetation types. Vegetation data establish existing conditions from which impacts of changes over time are assessed and provide mid-scale vegetation information. The data are captured using automated, systematic procedures that can efficiently and consistently map large areas at a low cost. Monitoring addresses important issues at multiple scales. Regionally, monitoring can identify critical causes of change or provide an early warning system for habitat degradation. Locally, monitoring can assess county land use policies, identify areas of insects or disease problems, or assess the extent and impact of timber harvest in a watershed.

INTRODUCTION

The USDA Forest Service (FS) and California Department of Forestry and Fire Protection (CDF) have resource management and fire protection responsibilities across much of the non-irrigated land in California. Within the National Forests, the FS manages resource activities such as timber harvest, forest health monitoring, grazing, and fire protection. On private lands, CDF provides fire protection, regulates timber harvesting, and conducts wide area assessments of the extent and condition of natural resources in California. The Land Cover Mapping and Monitoring Program (LCMMP) provides a single, consistent source of current land cover data from which both CDF and FS (as well as other interested federal, state and local governments and private citizens) can make informed resource management decisions.

The FS (Ecosystem Planning, Forest Health Protection and Geometronics staffs) and CDF (Fire and Resource Assessment Program and Forest Pest Management staff) have developed a collaborative approach to land cover mapping and monitoring that includes coordinated acquisition of resource photography, satellite imagery, and geo-processing. The 5-year cycle covers approximately 65 million acres of mixed federal, state and private forestland. Project areas, Figure 1, cover approximately 13 million acres and are the basis for organizing mapping and monitoring work. At the beginning of the cycle for each project area, aerial photography and satellite imagery are acquired the summer before the monitoring work begins. This is followed by vegetation and surface fuel map updates, forest inventory re-measurements in changed areas, and finally, trend analysis and resource assessment.

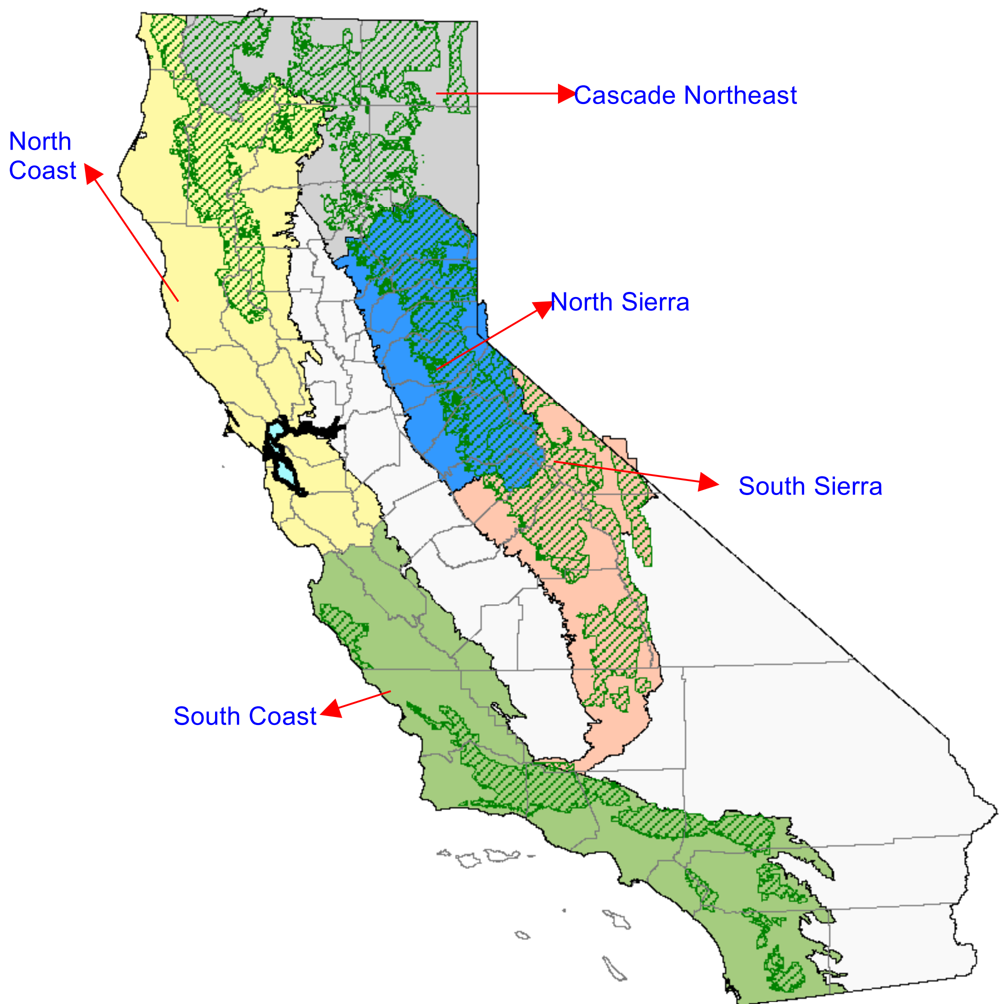

Figure 1. Coordinate project areas.

The objectives of the LCMMP are to 1) provide a single source of land cover data to assess the condition and extent of the State's forest and range resources; 2) monitor changes on the landscape; 3) identify the cause of these changes and; 4) assess their impacts. The strategy for achieving this is outlined in the 1990 Memorandum of Understanding (MOU) for Cooperative Forestland Mapping, which establishes common goals for vegetation mapping and monitoring between CDF and FS. This strategy identifies the need to maintain mapping and monitoring information on a 5-year cycle and includes cooperative mapping and monitoring, cost sharing, and common standards. The basic underpinning for this common strategy is to develop consistent vegetation maps for forest and rangeland areas that are within 5 years of each other. Vegetation maps are updated where changes have been identified through the monitoring program. The Land Cover Monitoring program utilizes satellite imagery and sophisticated methods to map changes in canopy cover over time. This monitoring not only provides critical information for map updating, it addresses important issues at multiple scales, serving a wide variety of interlocked objectives.

The LCMMP has taken an innovative approach to develop and maintain a long-term strategy that includes:

- Vegetation data standardized across broad ownerships
- Consistent, accurate and cost effective methods
- Monitoring of changes on a 5-year cycle

- Identification of the cause of changes
- Trend analysis

This cooperative effort has enabled efficient data collection and processing, sharing of resources and information, greater efficiency and use of public funds, greater access to data sources and standard methodologies.

METHODOLOGY

Vegetation Mapping Methods

A mapping methodology has been developed to capture forest vegetation characteristics using automated, systematic procedures that efficiently and cost-effectively map large areas with minimal bias. (Figure 2) Mapping work is currently done to the CALVEG system. The CALVEG system, which was originally developed by the Region's Ecology Program in 1978, is being maintained and updated by the FS and currently has 178 distinct vegetation and land use types. Vegetation layers are created in a hierarchical approach that focuses on building a foundation land cover / life form layer. The classification hierarchy of this layer is similar to one of the higher physiognomic units (i.e., Order) of the Federal Geographic Data Committee's National Vegetation Classification System (NVCS). CALVEG alliances are comparable to those in the uppermost floristic level (i.e., Alliance) of the NVCS hierarchy. Both CALVEG and NVCS are based on dominant and existing vegetation components in a given area, however mapping has always been an integral part of CALVEG's development and expansion process. It remains to be seen how well NVCS can be mapped on the ground. Other themes in the database include forest stand characteristics such as tree size and density and relative percentages of conifers and hardwoods in mixed stands. The CALVEG classification and mapping system involves the following steps and is described below:

- Life form classification
- Natural region delineation
- Data collection
- Terrain model development
- Field verification and editing
- Forest stand structure
- Accuracy assessment

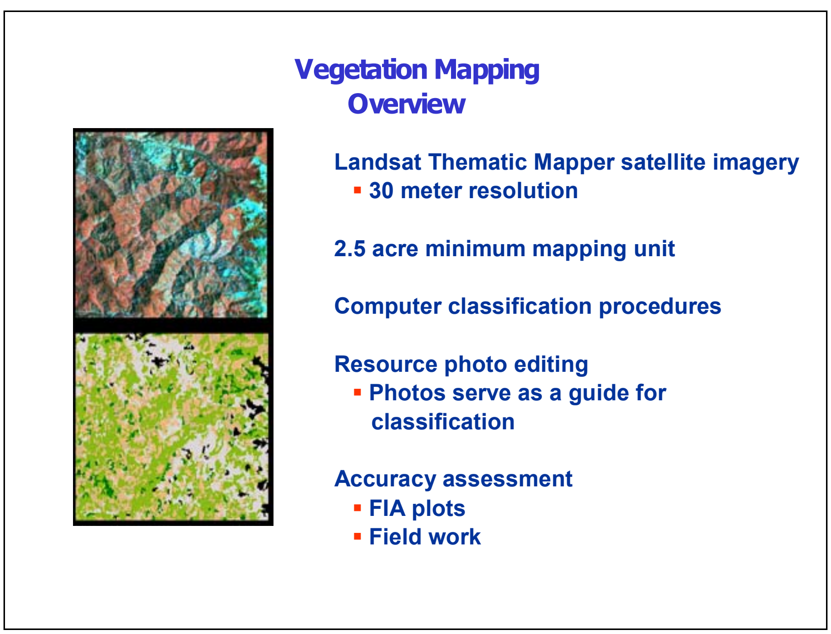

Figure 2. Vegetation mapping overview.

Life form classification: Prior to modeling ecological relationships for vegetation type, a Landsat Thematic Mapper image is classified into several life forms: conifer, hardwood, mixed, shrub, wet herbaceous, dry herbaceous, barren, water, snow, agricultural and urban. Other more specific vegetation types that have unique spectral properties may be mapped at this time as well. Image classification occurs on individual pixels, not stands. Therefore, an additional step utilizes an image segmentation procedure, which delineates stand boundaries based on spectral similarities (Ryherd and Woodcock, 1990). When combined with the pixel classification, a "stand based" land cover map is produced. This map is generated through a decision rule process, which utilizes analyst specified decision rules to label the stands or polygons, based on the membership of classified pixels. Editing is then carried out on these stands or polygons to resolve any ambiguous results for life form. This stand life form map is then used as input to the ecological terrain model.

Natural region delineation: Natural regions are defined as areas within which the elevation, slope, and aspect ranges of the major vegetation types remain constant. Initially, the National Hierarchical Framework of Ecological Units, Sections and Subsection of California are used to determine appropriate natural regions for classification.

Data collection: Field and existing data collection drive the classification system to enable the development of models that predict the occurrence of existing vegetation alliances. This process provides updated dominance types for the CALVEG classification system as areas across the state are systematically mapped within regional or Ecological Unit boundaries. Extensive field time is allocated to collect new information throughout the project's mapping boundaries, including, at the minimum, slope angle, elevation, slope aspect, and dominant species for each alliance in its varied expression throughout the mapping area. In many cases, areas are "masked" in the models to exclude alliances that are restricted in extent. Dominance types are then described for the general mapping area or CALVEG Zone, with the inclusion of a general dichotomous key to the types.

Terrain and model development: In addition to floristic information, terrain variables such as elevation, slope angle, slope aspect, soil and geologic or land form type, precipitation averages, fire history, etc. are addressed in the vegetation predictive models in ARC Macro Language scripts. Models are processed separately for each of four life form types - conifer, hardwood, mixed conifer/hardwood stands, and shrub. Herbaceous types are usually assessed from remotely sensed imagery corrected and edited by interpreting information from aerial photos. In cases where vegetation cannot be modeled, such as in serpentine or other edaphically defined vegetation types, ancillary data is used and supercedes the model's output. Model results are analyzed for conformance with new field data and field observations. A final "run" of the model merges output from the four life form models with land cover classifications derived from edited remotely sensed data to assure the labeling of all map areas.

Field verification and editing: Maps are provided for field reviewers and brought into the mapping area for comments and corrections that produce the final CALVEG data layers. The models are corrected and rerun, or the needed edits are made on the computer screen in ARC/INFO to produce a final CALVEG map product. The final completed map includes the incorporation of a plantations layer, the results of tree crown and density models and tree size estimate crosswalks to the California Wildlife Habitat Relationships (WHR) and regional descriptions of the vegetation alliances are supplied with the final map products.

Forest stand structure: In addition to mapping the floristic composition of a stand, the structural characteristics of canopy closure and overstory tree size are also mapped for the tree landcover types. Stands that have been mapped as conifer, hardwood, or conifer/hardwood mix are used as stratifications for independent canopy and size mapping approaches. Canopy closure is derived from a geometric optical canopy model that estimates canopy closure within each tree stand as a percent cover value. The resulting estimates of canopy closure in forested stands are evaluated using aerial photography and errors are subsequently corrected in a GIS environment. Overstory tree size estimates are generated from Landsat TM imagery using a combination of supervised and unsupervised image classification techniques in conjunction with aerial photography. As with canopy closure, size estimates are reviewed against aerial photography and anomalous errors are corrected.

Accuracy assessment: Accuracy assessment of maps improves their utility by providing the user of the maps with information about the nature, magnitude, frequency and source of errors. The two primary methods used are the Error Matrix and the Fuzzy Set. Forest inventory analysis (FIA) grid plots are used as reference data in the preparation of accuracy assessments. FIA grid plots are spatially coregistered to the vegetation map and map labels are assigned to each of the reference data plots through a point-map overlay. Map attribute labels are also calculated on the raw plot data to ensure comparable map and reference data. .

An error matrix is generated that compares mapped labels with the calculated reference labels for each plot.. Based on the classification system rules used in the mapping process, a computer determines whether a label is right or wrong. . If the mapped unit is labeled as "conifer" and the plot data lists only shrubs, it counts as an error. A matrix table is constructed using mapped labels on one axis, and observed conditions on the other axis. The higher the proportion of "matches" there are, the more accurate the map is. The error matrix is also referred to as a "Confusion Table" because it highlights the types that are confused in the map. Fuzzy Set theory goes a step beyond looking at right vs. wrong and confusion. It requires an analyst, without knowledge of the map label, to make an unbiased evaluation of the site and rate all possible labels on a relative scale from "absolutely right" to "absolutely wrong". For example, if the observer was evaluating a pure red fir stand, a label of "hardwoods" would be rated as absolutely wrong, but a map label of "mixed conifer-fir" would be rated as wrong, but close. A shrub/hardwood site on the ground might get an OK rating for either the "shrub" or "hardwood" label, but would receive "absolutely wrong" for a "conifer" label. A summary of total map accuracy and accuracy by map class is generated for each of the map attributes. These summary tables depict both fuzzy set and absolute accuracy percentages, allowing the user flexibility in determining map utility for a specified analysis objective.

Change Detection Methods

The LCMMP uses two dates of TM imagery to derive land cover changes. A difference in spectral reflectance (the amount of sunlight reflected from surface features to the satellite in space) between these image dates indicates where change probably occurred. The change detection process interprets these spectral reflectance differences and produces an image depicting various levels of vegetation change. Processing for quantifying canopy cover change is accomplished in three steps, database building, change processing and labeling. (Figure 3).

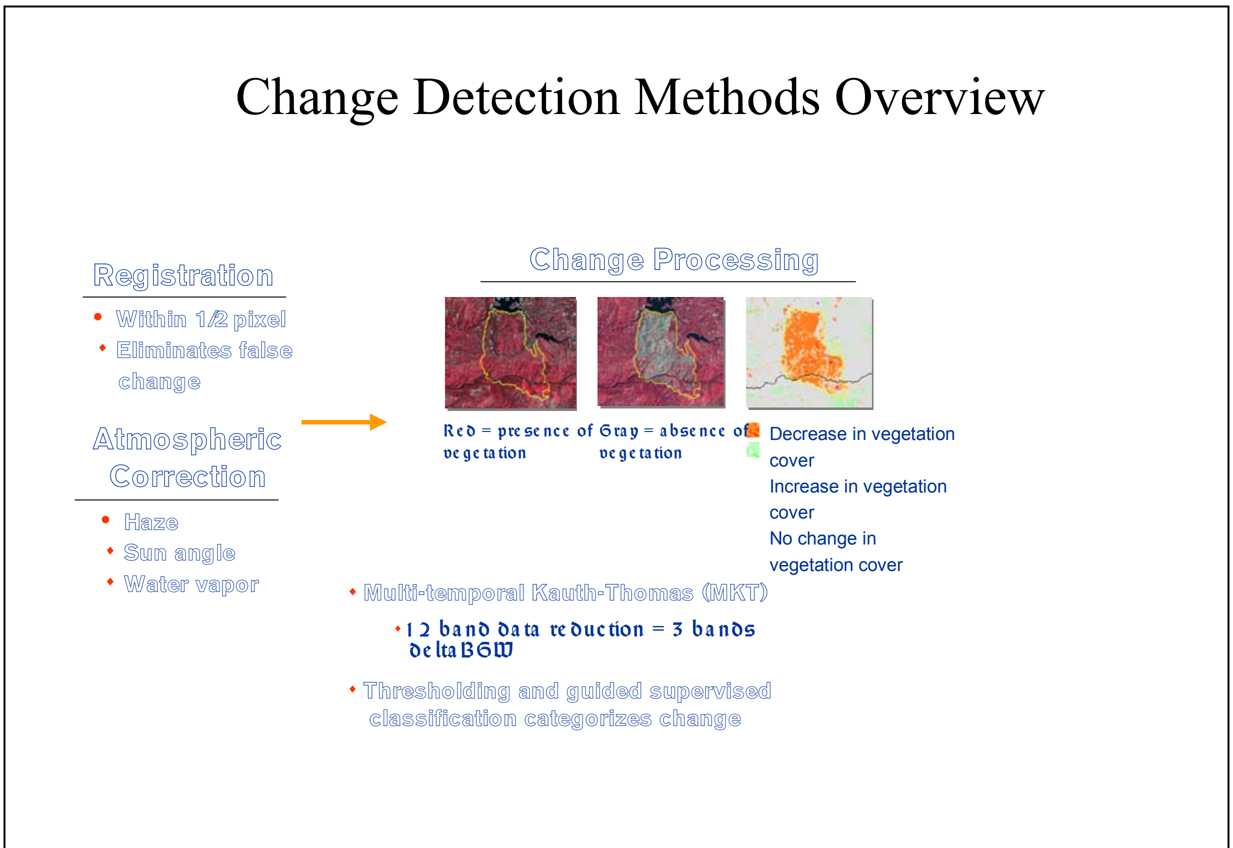

Figure 3. Change detection methods

Database Building: A time one (early date) image is registered to a time two (later date) image in the same path and row. Registration begins by identifying common features throughout both images on-screen (e.g., road intersections). These features are used in a nearest neighbor resampling technique to assign the early date pixel values to the later date pixel locations. These new pixel locations must be within ½ pixel of the later date pixels to eliminate any false changes. The images are then radiometrically corrected to account for differences in atmospheric conditions (e.g., haze and water vapor). This process selects dark and light groups of pixels in each image date and applies a regression-based correction to the early image date to effectively remove differences in atmospheric conditions (Schott et al., 1988).

Another part of database building includes assembling a single vegetation layer. This involves gathering data from various sources but the majority of the data comes from the cooperative vegetation mapping program. The WHR classification system is used for the final vegetation layer. Vegetation layers not in this classification system, such as CALVEG (USDA Forest Service Regional Ecology Group, 1981), are classified to it. WHR types are crosswalked from the CALVEG system.

Change Processing: The change processing begins by applying a Kauth-Thomas (KT) transformation to both dates of co-registered imagery (Kauth and Thomas, 1976). This transformation uses model coefficients to produce a new image depicting changes in brightness, greenness, and wetness components (Crist and Cicone, 1984). Brightness identifies variation in reflectance, greenness is related to the amount of green vegetation present in the scene, and wetness correlates to canopy and soil moisture.

Change Labeling: Change labeling is a multi-step process that converts the change image to a change map that identifies decreases and increases in vegetation cover. The change image is subset into individual lifeform type (e.g., conifer, hardwood and shrub) by overlaying the vegetation layer and selecting those areas in the change image that have the same lifeform. An unsupervised and guided supervised classification is performed on the individual lifeform change images resulting in groups of similar levels of brightness, greenness and wetness. These groupings are assigned to one of nine change classes. Image appearance, photo interpretation, vegetation and topographic maps and bispectral plots (e.g., greenness vs. wetness) aid in assigning the change classes. Each individual lifeform change image is then assembled into one project area change map.

The decrease and increase categorical change classes represent measured changes in vegetation cover. For example, a small decrease (15%-40%) will have less vegetation cover loss than a moderate (41%-70%) or large decrease (> 70%), e.g., a thinning compared to a clearcut. The little or 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. The cloud or shadow class accounts for clouds in the imagery and shadows in the mountainous areas that obscure ground cover and make it not possible to determine whether the vegetation had changed or remained stable in these areas.

Training and Accuracy: A random stratified sample of the change image is performed to gather selected points for quantifying canopy cover change. Digital infra-red imagery is acquired over a number of randomly selected sites in a project area at 2 foot resolution. Digital orthophotographic quads are used as a time 1 estimate and the digital imagery is used as the time 2 estimate for canopy cover classification. A photo interpretation key is used for aerial photography to count percent canopy in time 1, and an automated software program called ForestEye is used for the digital camera and DOQQ's to quantify canopy. These values are used to label the classes into change categories. A portion of the randomly selected sites is used for accuracy assessment. An accuracy assessment is performed and an error matrix is constructed to determine the accuracy of the classified change map.

Cause Verification: Once the final change map is complete, the attempt is made to verify cause on all change areas. GIS overlay, fieldwork and photo interpretation are used to determine the causes of change areas. The CDF forest practices database, the FS stand record system database and the CDF fire history database are overlaid onto the change map to attribute changes caused by harvests, regeneration and wildfires. FS resource managers interpret change maps by applying local knowledge and fieldwork to identify sources of change on national forest lands. Similarly, UC Integrated Hardwood Rangeland Management Program (IHRMP) personnel consult private landowners to identify sources of change in hardwood rangelands. Areas without a causal agent identified through the above processes become the focus of further field efforts and aerial photo interpretation. Despite all these efforts, full coverage of cause verification is not always possible due to the large number of change areas, insufficient information and inaccessible lands.

Field verification: A number of randomly selected sites are saved for field verification. Crews go into the field with aerial photos and DOQQ's and run transects through the polygon of change. Along these transects a densitometer is used to quantify canopy cover. Canopy cover percent is then compared to in-house estimates to calibrate the photo interpreters.

APPLICATIONS

The LCMMP supports diverse priorities and responsibilities from various cooperators. The Forest and Rangeland Resources Assessment and Policy Act of 1977 (Public Resource Code 4789) requires CDF to periodically assess California's forest and rangeland resources. The LCMMP supports this function by developing and maintaining a baseline data set quantifying the amount and extent of California's forest and range resources and monitoring changes to these resources over time. The FS and CDF use these data to track forest health trends, evaluate watershed cumulative impacts, model wildlife habitat, identify the hazardous build up of fuels, and examine the effectiveness of existing policies. Both agencies also use the LCMMP data to monitor the effects of sudden oak death, pitch canker disease and others (Mahon et.al., 2002). The FS ecosystem planning staff uses LCMMP data to update land management plans for National Forests in California and to conduct multi-forest analyses such as the North-west Forest Plan Amendment, California Spotted Owl EIS Sierra Nevada Framework and others. Land cover maps are also used in conjunction with resource inventories to meet resource reporting requirements set at the Congressional level.

Major applications of these data include:

- Vegetation Mapping
- Fire/Fuels Mapping
- Timber Harvest Plans
- Urban
- Examining effectiveness of existing policies

Vegetation Mapping

Vegetation map revision using the change detection data is an integral part of the LCMMP. By overlaying the change data onto the vegetation map, only areas that intersect are revised. This procedure generates a vegetation map that reflects current conditions in a more cost-effective and time-efficient manner than traditional re-mapping of an entire area. This process also results in an assessment tool for determining accurate changes in vegetation extent. By comparing the original vegetation map to the updated vegetation map, it is easy to determine where cover type changes exist.

Fire / Fuels Mapping

Incorporating change detection data into California's statewide fire history mapping project can enhance the ability to correctly map missing fire perimeters in the hardwood and coniferous vegetation types. To detect fire perimeters, a comparison is made between existing perimeters and the change detection data. Although not identical, there is strong agreement between known fire perimeters and the change data. This indicates that in areas where there is no fire perimeter in the database or the existing fire perimeter is of questionable accuracy, the change detection data can assist in identifying and delineating a new fire perimeter.

Timber Harvest Plans

Monitoring Timber Harvest Plans (THP) and evaluating silvicultural practices with change detection data is also being examined. Preliminary results show that various levels of canopy removal are detectable by the current change detection methodology. For example, clearcuts are detected as large, moderate and small vegetation decreases, and selection harvests as moderate and small vegetation decreases. There is also an agreement between the boundaries of various silvicultural systems and change detection polygons. Clearcut boundaries align most accurately with the change polygon boundaries. Lighter canopy removal boundaries, such as thinnings and selection harvests, do not always align properly with the change polygon boundaries because the vegetation removal is below our threshold to detect change. Further research will enhance the thresholds between change classes and silvicultural practices resulting in a representation of quantitative changes in canopy reduction and growth.

Urban

As the landscape and technology continue to change, so will future change detection developments and applications. When the cause of landscape change is evaluated, one issue that comes to the forefront is urbanization. Change detection data can interface with current urbanization models to help predict build-out and to validate the models' predictive ability. As populations in the Sierra foothills and conifer belt continue to grow, so will the need for efficient fuels management and fire protection strategies. Change detection data can provide information for fuels map updating and for monitoring and measuring post-fire effects and rehabilitation prescriptions. Higher resolution satellites, which are becoming operational, and other technological advancements will provide greater landscape detail and potentially move satellite-based change detection to a more site-specific level.

Effectiveness of existing Policies

The IHRMP is one mechanism to promote effective education in assessing voluntary compliance with hardwood resource protection standards, hardwood resource management results and trends in hardwood resource use. Recognizing the value of monitoring data over large areas and its ability to provide various degrees of change, counties have begun to explore the utility of these data. In Fresno County, the change data were presented to private landowners and the Fresno Resource Conservation District as an educational tool for assessing local voluntary guidelines for hardwood rangeland conservation. Napa County, in collaboration with the IHRMP, is assessing the utility of the change data for local planning issues, including identifying changes in riparian and wetland cover, mapping patterns of urban development, locating conversion of agricultural land and open space to urban uses, and monitoring habitat fragmentation. Future efforts focus on analyzing policy issues and trends in land cover over time using these data.

The LCMMP produces other benefits by providing monitoring data to other agencies, private interest groups and stakeholders. These data can answer the different question these entities may have at different spatial scales. At regional scales, ecosystem characteristics or function can be investigated by examining the cause of change over time, the balance of vegetation increase and decrease, and whether changes are temporary or permanent (e.g., fire versus development). Examining changes in vegetation at a more sub-regional or local scale can help resource managers evaluate the impacts of disturbances on natural resources of local interest. This information is useful to assess the effectiveness of existing policies, programs, management activities and regulations, and to develop alternatives as needed (e.g., county voluntary guidelines for oak woodland management). Finally, these data provide a valuable tool for the IHRMP to work with landowners and state and local governments in resolving hardwood issues.

SUMMARY

The Land Cover Mapping and Monitoring Program (LCMMP) is a collaborative approach between CDF and the USFS. This program provides seamless and consistent land cover data for all ownerships within the forest and range resource areas in California. Land cover data establish existing conditions from which impacts of changes over time can be assessed. The data are captured using automated, systematic procedures that can efficiently and consistently map large areas at a low cost. This approach provides consistency between State and Federal estimates of existing resources and facilitates communication about these resources between agencies. This collaborative approach to land cover mapping and monitoring leverages limited financial and technical resources and provides a cost effective methodology to fill critical information needs. This program is open to new participants, and solicits collaboration from users interested in land cover mapping and monitoring data. Briefings, meetings, and workshops are held throughout each project area to encourage cooperation and share information. Cooperators can provide existing data, review draft products and/or cost-share. For more information or to download products please visit our website at http://frap.cdf.ca.gov/projects/land_cover/index.html.

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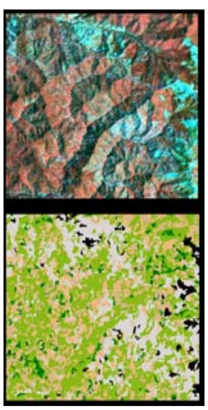
Vegetation Mapping Overview



- Landsat Thematic Mapper satellite imagery
  - 30 meter resolution
- 2.5 acre minimum mapping unit
- Computer classification procedures
- Resource photo editing
  - Photos serve as a guide for classification
- Accuracy assessment
  - FIA plots
  - Field work