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Revealing Land Cover Change in California With Satellite Data

The conversion of natural land cover into human-dominated cover types continues to be a change of global proportions with many unknown environmental consequences. Noteworthy conversions of this type include tree stand harvests in forested regions, urbanization, and agricultural intensification in former woodland and natural grassland areas. Determining where, when, and why natural ecosystem conversions occur is a crucial scientific concern [*Foley et al.*, 2005]. Characteristics of the land cover can have important impacts on local climate, radiation balance, biogeochemistry, hydrology, and the diversity and abundance of terrestrial species [*Randerson et al.*, 2006]. Consequently, understanding trends in land cover conversion at local scales is a requirement for making useful numerical predictions about other regional and global changes. It is urgent that accurate, timely, and economical tools be made available to document these conversions and aid in the management of their impacts.

Land cover alterations can be assessed by comparing imagery taken at different dates over the same locations. The launch of NASA's Terra satellite platform in 1999 with the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board has enabled the collection of daily images of the entire Earth land surface, with promising implications for land cover change research. Operational MODIS algorithms have been used to generate the Enhanced Vegetation Index (EVI) at 250-meter spatial resolution from 2000 to the present [*Huete et al.*, 2002]. EVI is a spectral measure of the amount of vegetation present on the ground, whereby the vegetation properties in red and near-infrared spectral bands are designed to approximate vegetation biophysical properties derived from canopy radiative transfer theory. Global MODIS EVI data sets are available free of charge from NASA-supported data centers (http://earthobservatory.nasa.gov/Observatory/Datasets/evi.modis.html).

Regions experiencing rapid population growth and changing economic activities, such as California, are logical places to evaluate the MODIS time series for characterizing land cover changes. The population of California increased by 75% between 1970 and 2005, resulting in rapid and extensive urbanization and loss of natural cover types [*Beck and Kolankiewicz*, 2001]. For example, of all land urbanized in 42 of the state's 58 counties between 1984 and 1990, an estimated 13% occurred on irrigated prime farmland, whereas 48% occurred on wildlands or fallow marginal farmlands [*Charbonneau and Kondolf*, 1993].

Clustering MODIS Data for Land Cover

The complete MODIS 250-meter resolution time series of EVI data (2001–2005) covering the majority of California were obtained to assess the usefulness of this satellite imagery for land cover change detection. Quality control filter methods were applied to the MODIS 250-meter EVI data set used in this analysis. This EVI usefulness index is a high-resolution quality indicator whose value for a pixel within a MODIS image is determined from several conditions: aerosol quantity, atmospheric correction conditions, cloud cover, shadow, and Sun-target-viewing geometry. A specific score is assigned to each condition, and a sum of all the scores gives a usefulness index value for the pixel. For the present analysis, if the two leading MODIS quality indicator scores were reported as equal to 0, then the data were considered good quality and included in our regional analysis. About 80% of the EVI values in this California data set were found to have indicator scores equal to 0.

MODIS EVI time series examined over individual January–December yearly periods showed that natural vegetation cover in California has a characteristic seasonal profile of greenness levels that is influenced strongly by precipitation and temperature variations over an annual cycle [*Potter et al.*, 2005]. A large portion of the state's forested land cover reaches maximum greenness levels (EVI_{max}) during the period of June–August when temperature is highest, whereas rangelands and mixed grassland-woodland areas reach maximum EVI levels earlier in the calendar year, typically during the period of January–April when rainfall is highest. As regional examples, April was most commonly identified as EVI_{max} in the Sacramento and San Joaquin Valleys and the Sierra Nevada Foothills, whereas June was most commonly identified as EVI_{max} in the Sierra Nevada mountain range and the Coast Redwood forest belt (Major Land Resource Areas; source, U.S. Geological Survey).

Large contiguous areas of the state were found to display temporally consistent timings of annual green-up and green-down cycles in the EVI profiles. Time series cluster analysis by K-means [*Jain and Dubes*, 1988] of the 250-meter EVI time series was carried out to produce a minimum number of distinct centroids—in this case, five centroids or center points in the multidimensional data space—that could be characterized uniquely according to the EVI_{max} level during a year (i.e., maximum green biomass density) and the variability of EVI_{max} from one year to another (Figure 1a). An example of this temporal EVI cluster analysis for the San Francisco Bay area of the state is shown in Figure 1b. This type of time series land cover map represents a new mapping

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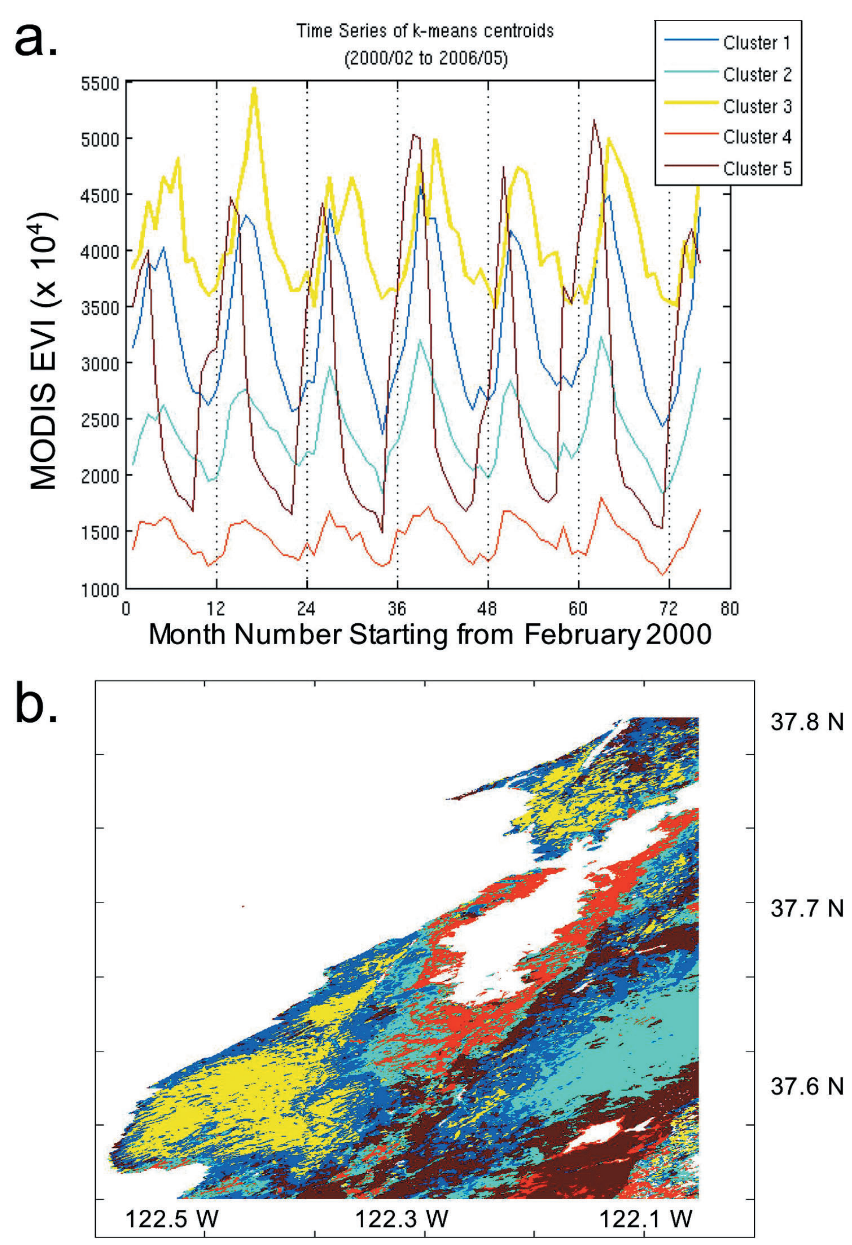

Fig. 1. (a) Moderate Resolution Imaging Spectroradiometer (MODIS) Enhanced Vegetation Index (EVI) time series separated as K-mean cluster centroids. Attributes of biomass density and interannual variability are defined as follows, with a corresponding land cover type assigned: Cluster 1 is high seasonal biomass density, moderate interannual variability (shrub cover). Cluster 2 is moderate annual biomass density, moderate interannual variability (grass cover). Cluster 3 is high annual biomass density, low interannual variability (evergreen tree cover). Cluster 4 is low annual biomass density, low interannual variability (urbanized cover). Cluster 5 is high seasonal biomass density, high interannual variability (agricultural cover). (b) Map of MODIS EVI time series clusters for the San Francisco Bay area, defined by the centroid lines and corresponding colors from Figure 1a.

About AGU

An Appeal to the AGU Membership

The American Geophysical Union invites nominations for new members to its distinguished Fellows program. Each year, about 100 nominations reach the selection committee through the AGU scientific sections, and about half are elected. The number of Fellows is limited to at most .1% of the membership, which makes this honor very prestigious. The Union Fellows are distinguished scientists who have made important contributions to one or several fields of geophysical sciences. While such people often are at high positions at universities or institutions, the selection committee feels very strongly that the scientific merits are the most important criterion for fellowship. AGU has a significant number of non-U.S. members, who at present are underrepresented in the Fellows program. I would like to invite you to consider suitable candidates amongst your colleagues and to make nominations following the instructions included in this issue.

—Tuija Pulkkinen, AGU Fellows Committee Chair

Fellows Nominations

To be elected a Fellow of AGU is a special tribute for those who have made exceptional contributions to the Earth and space sciences.

Any AGU member, whether or not a Fellow, may nominate another member for Fellow. The process is simple and very satisfying.

First, review "Guidelines to a Successful Fellow Nominations" online at http://www.agu.org/inside/fellguides.html

Membership Eligibility for Fellows: A nominee must have been an AGU member in each of the three years immediately preceding nomination and may not be a Section president or president-elect for the 2006–2008 term. If you are unsure about the membership status of the nominee, check the online membership directory or contact Member Services.

Nomination Package: Each item must be not more than two letter-sized pages.

- Nominating letter—In the last sentence very briefly summarize the reason for Fellowship, using the following format: "(Nominee's name) should be elected a Fellow for (state the essence of the scientific contributions in 150 characters or less)."
- Concise curriculum vitae, including candidate's name, address, history of employment, degrees, research experience, honors, memberships, and service to the community through committee work, advisory boards, etc.
- Selected bibliography, which is representative of the significant contributions made by the nominee and begins by briefly stating the total number and types of publication and specifying the number in AGU journals.
- At least three but no more than five supporting letters whose authors have been chosen to provide the best coverage of the nominee's contributions and achievements.
- Cover sheet if package is sent by post. Include name of nominee, name, and e-mail address of nominator, and all Sections and Focus Groups to which the nomination should be directed.

Nomination packages can be sent by post to AGU headquarters or submitted via a web form at http://www.agu.org/inside/fellnom.html

The deadline for Fellows nominations is 15 July 2007.

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approach to understanding how ecosystems within a region differ from one another in terms of green cover variations during a year.

Detecting Land Cover Changes

Annual cycles of vegetation greenness can be characterized further by examining the changes in seasonal amplitude of EVI during a year. This attribute was computed as the EVI difference (EVI_{diff}), which is defined as the difference between the maximum (EVI_{max}) and minimum (EVI_{min}) greenness values measured over each of the single calendar years that compose the entire 2001–2005 time series available to date. By identifying areas where both the annual EVI_{diff} and the EVI_{max} values changed continuously over the MODIS time series, locations of potential land cover change could be extracted from the statewide data set.

Over the entire period 2001–2005, locations that showed continuous 3-year decreases in both the EVI_{diff} and the EVI_{max} made up more than 5170 square kilometers within the MODIS image area (Figure 2). These locations were distributed across land cover types [*U.S. Geological Survey*, 1999] categorized mainly as forest (46%), followed by shrublands (29%) and herbaceous cover (7%). Forest and shrubland areas together remained the predominant land cover types over which most of the locations (60–70%) of continuous decreases in both the EVI_{diff} and the EVI_{max} were detected, regardless of which 3- or 4-year subperiod of the 2001–2005 MODIS time series was extracted for analysis. In contrast, locations that showed continuous increases in both the EVI_{diff} and the EVI_{max} made up only 366 square kilometers within the MODIS image area analyzed for this study.

More detailed examination of localized land use change records at locations where EVI_{diff} and EVI_{max} both decreased over the MODIS time series was conducted by visual analysis of high-resolution satellite images available, for example, in Google Earth. The 50 largest contiguous areas of concurrent EVI_{diff} and EVI_{max} decrease (as mapped in Figure 2) were examined for independent visual evidence of disturbance in the land cover. In 15 of these 50 cases, the satellite imagery at spatial resolution of less than 10 meters revealed a recent area burned by wildfire. In another seven cases, the satellite imagery revealed extensive cutting of the forested land cover. An example of what appears to be extensive forest harvest is shown in high-resolution imagery as a patchwork of land cover types near Lower Bear River Reservoir in Amador County, Calif. (Figure 3). Extensive forest cutting patterns similar in appearance to Figure 3 were readily identified from areas of concurrent EVI_{diff} and EVI_{max} decrease locations (Figure 2) in Mendocino, Butte, and Pulmas counties.

Land use change records in California counties with the highest rates of farmland conversion and urban development were also compared with changes in EVI_{diff} and EVI_{max} over the MODIS time series. These records include the state's Farmland Mapping and Monitoring Program (FMMP), which produces maps and statistical data for use in analyzing impacts of land conversion on California's natural resources [*California Department of Conservation*, 2004]. The FMMP covers 45.9 million acres, representing 91% of the state's private agricultural lands. Analysis of FMMP trends from 2002 to 2005 in the counties with the highest areas of cropland conversion—Kern, Santa Barbara, Tulare, and Ventura counties—revealed that the most common pattern of change (between 40% and 70% of land use change areas) in the annual EVI_{max} was an increase followed by a decrease and then another year of EVI_{max} increase. This comparison suggests that the extensive agricultural land conversion that took place in California over the past 5 years cannot be detected as a permanent loss of vegetation greenness in most cases. Instead, even areas converted to housing and business developments tend to increase in greenness cover, as observed by MODIS EVI patterns, probably due to seasonal irrigation of replanted lots and parklands.

MODIS observations, such as those used in this report for California, cover the entire Earth surface, and there are many more locations of interest worldwide for studying land cover from satellites. Areas affected by forest management and encroachment of residential developments into natural vegetation zones should be prime locations to apply and further study these satellite methods of land cover change detection.

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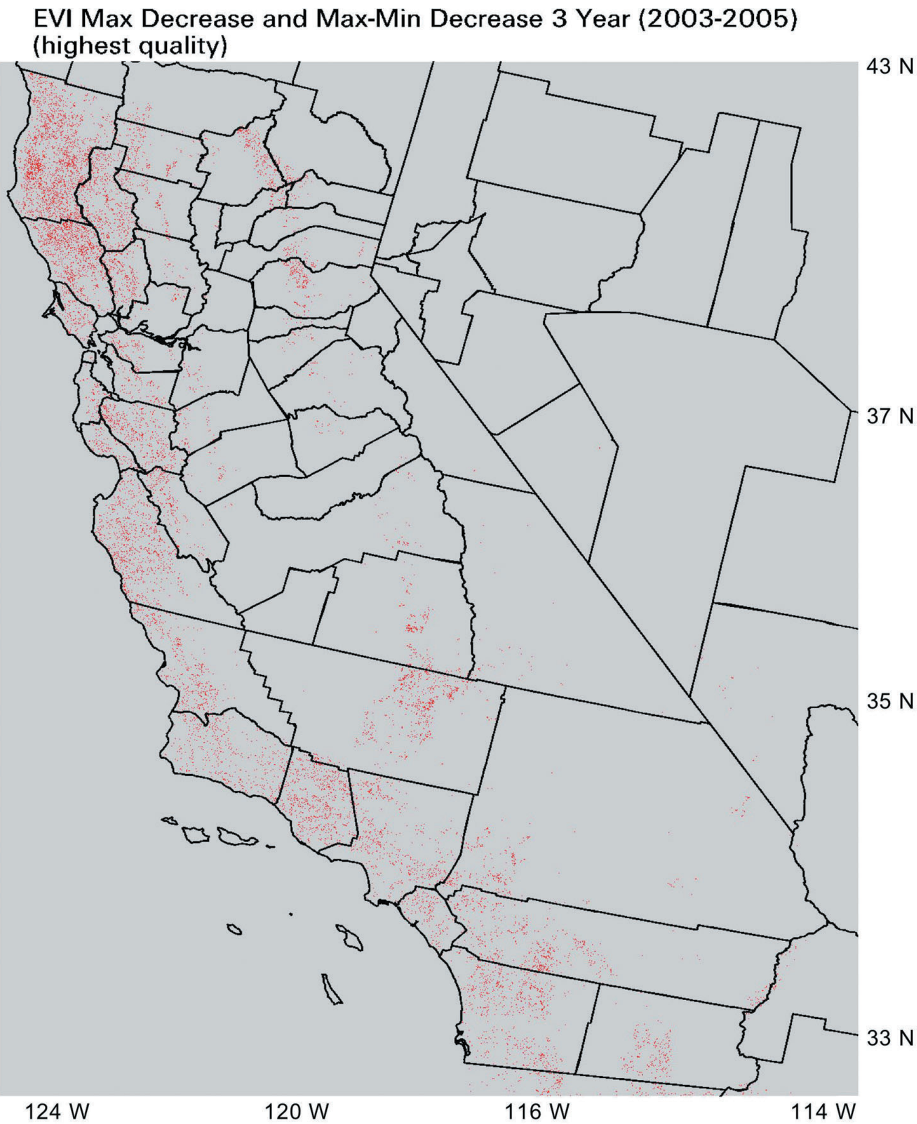

Fig. 2. Map of the locations (in red) where MODIS 250-meter time series showed continuous decreases in both EVI_{diff} and the EVI_{max} over the period 2003–2005.

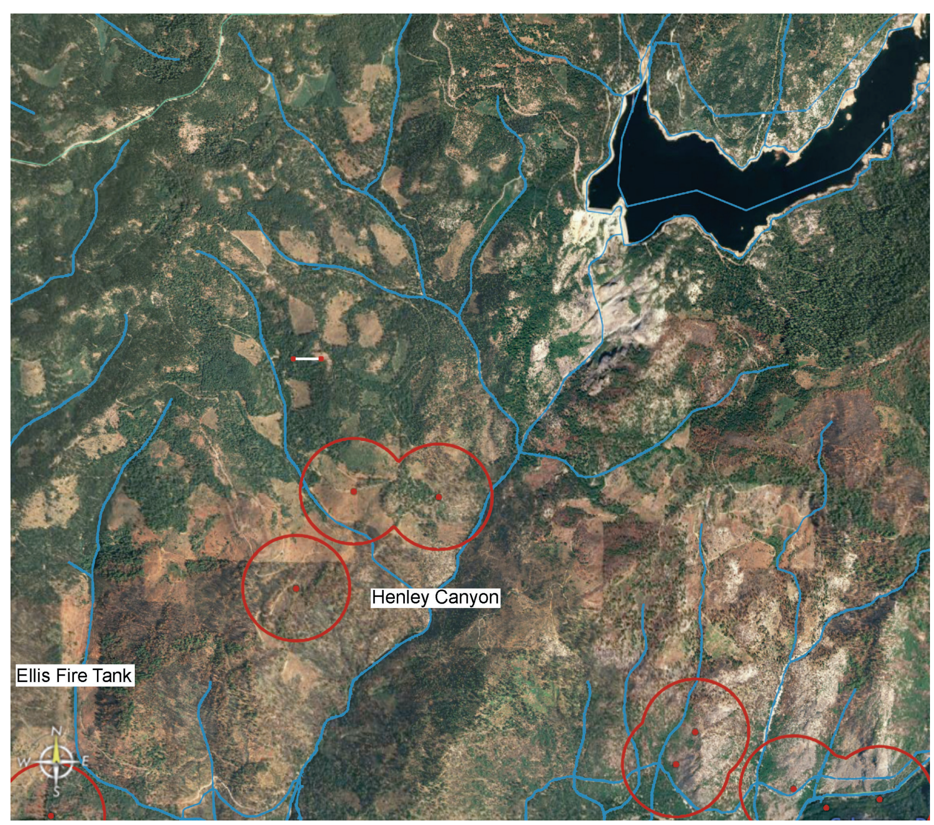

Fig. 3. High-resolution satellite image showing cleared patches of land near Lower Bear River Reservoir in Amador County, Calif. For scale, the white line at the left center of the image is 250 meters in length. Rivers and streams are displayed as blue lines. Red circles identify the center location of MODIS 250-meter areas where the most recent land cover change as been detected. Google Earth imagery © Google Inc. used with permission.