Estimating the loss of perennial woody vegetation to cropland in California using 20 years of Landsat image analysis

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ABSTRACT

The progressive loss of perennial woody vegetation to cultivated land use throughout California has the potential to compromise native wildlife habitats and natural bio-control agents for cropland pests. In this study, satellite image products from the NASA Landsat sensor were compared from 1992 to 2012 to map the full spatial extent and the detailed geographic patterns of woody vegetation loss in all valley growing regions of the state. Counties the highest woody cover area converted to cropland were led by Riverside and Imperial in southern-most California and Siskiyou in northern-most California. On a statewide basis, the most common crop types into which woody cover was converted were alfalfa and hay, fallow, grapes, wheat, and almonds. Spatial autocorrelation analysis carried out within a 15-km diameter circular buffer zone centered on selected growing areas showed strongly clustered patterns of converted woody cover, indicting that entire woodland and scrubland corridors and connectors have been lost to cultivated land uses over the past two decades.

Keywords: woody vegetation, Land sat, croplands, biodiversity, California

1. Introduction

The large-scale conversion of California's native oak woodlands and shrublands to intensive agricultural land uses has been linked to diminished landscape biodiversity (Heaton and Merenlender, 2000), soil nutrient losses (Jackson et al., 1990), impaired surface water quality (Hinckley and Matson, 2011), and groundwater deletion (Grismer and Asato, 2012). The progressive loss of tree and shrub cover in what are already crop-dominated landscapes may make farming more difficult for growers and the environment more unhealthy for rural communities.

For example, Morandin et al. (2011) reported that hedgerows in the Sacramento Valley attracted more beneficial insects than pest insects, while weedy areas showed the opposite trend, attracting significantly more pest insects than beneficial insects. Hannon and Sisk (2009) found that flowering shrubs in cropland hedgerows were important in attracting bees that were otherwise uncommon in the landscape, including some species that are potentially valuable pollinators of field crops and trees. Planting of cover crops in California vineyards can provide well-documented benefits (Nicholls et al., 2001), namely enhancement of natural enemies of crop pests. Selection of non-crop plants grown as strips around (or islands within) fields can support flowers that host beneficial predators species (Gurr et al., 2004).

There have been no statewide, long-term studies of woody vegetation loss to intensive agricultural land uses in California. Cameron et al. (2014) used the Department of Conservation's Farmland Mapping and Monitoring Program (FMMPP) database from 33 of the state's 58 counties to estimate that 77,486 ha of rangeland in central California had been converted to cropland between 1984 and 2009. New cropland types resulting from the recent

conversion of these rangelands were mostly to vineyards and orchards. This study excluded the northern and southern counties of the state and defined "rangeland" broadly as grassland, shrubland, and woodland cover combined. It is worth noting that the area converted to cropland was only 40% of total rangeland lost over the 25-year study period in these 33 counties, with the other 60% converted mainly to residential and commercial developments.

The purpose of the present study was to determine the area of perennial woody vegetation cover (woodlands and shrublands) in California that has been lost to cropland conversion over the past 20 years. Satellite image products from the NASA Landsat sensor were compared from 1992 to 2012. This is the first study of its kind to show the full spatial extent and the detailed geographic patterns on the landscape of woody vegetation loss in different valley growing regions of the state, broken down by specific cropland types that have today replaced woody cover.

2. Material and methods

2.1 Woody vegetation cover in the early 1990s

The 1992 National Land Cover Database (NLCD1992) is a 21-class land cover classification scheme that has been applied consistently across the lower 48 United States at a spatial resolution of 30 meters (Vogelmann et al., 2001). NLCD1992 is based primarily on the unsupervised classification of the National Aeronautics and Space Administration's (NASA) Landsat Thematic Mapper (TM) image data acquired in the early 1990's. Other ancillary data sources used to generate the NLCD1992 included topography, census, and agricultural statistics, soil characteristics, and other types of land cover maps.

Four of the 21 NLCD1992 land cover classes were identified as comprising California's perennial woody vegetation cover. Three of these were forest classes (deciduous, evergreen, and mixed), characterized by tree cover greater than six meters tall. Deciduous forest areas are dominated by trees where 75% or more of the tree species shed foliage simultaneously in response to seasonal change, whereas evergreen forest are areas dominated by trees where 75% or more of the tree species maintain their leaves all year. The fourth class was shrubland (both deciduous and evergreen), characterized by natural or semi-natural woody vegetation with aerial stems less than six meters tall, with individuals or clumps not touching nor interlocking.

2.2 Cropland cover in 2012

All locations of cultivated cropland types in California were determined from the USDA National Agricultural Statistics Service (NASS), California Cropland Data Layer (CDL) from 2012 (available at http://nassgeodata.gmu.edu/CropScape). The CDL is a raster, crop-specific land cover data layer with a ground resolution of 30 meters. The CDL is produced using satellite imagery from the Landsat 5 TM sensor, Landsat 7 ETM+ sensor, and the Disaster Monitoring Constellation (DMC) DEIMOS-1 and UK2 sensors collected during the current crop growing season. Additional satellite imagery and ancillary inputs are used to supplement and improve the CDL classification, including the United States Geological Survey (USGS) National Elevation Dataset (NED), the imperviousness and canopy data layers from the USGS National Land Cover Database 2006 (NLCD 2006), and the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) 250 meter resolution 16-day Normalized Difference Vegetation Index (NDVI) composites.

The selection of CDL2012 as the most recent and representative cropland cover year was intended to precede the historic drought years in California of 2013 and 2014, during which a higher proportion of farmland was fallowed statewide, mainly of feed and other annual crops (Howitt et al., 2014). Calendar year 2013 was the driest on record in California, with a total of just 30% of long-term average statewide precipitation (Hanak et al., 2014). The previous statewide record low was 56% of average precipitation in 1976. This extreme lack of rainfall during 2013 and 2014 wet seasons created an unprecedented level of stress on natural ecosystems and agricultural production systems throughout the central and southern regions of state (Howitt et al., 2014).

3. Statistical analysis

All 30 meter pixel areas that have changed from perennial woody vegetation in the early 1990s to cultivated cropland by 2012 were identified by comparison of the NLCD1992 raster layer to the CDL2012 raster layer. Areas of woody vegetation converted were totaled by county and cross-referenced to the major crop types mapped in the CDL2012 data set.

Spatial autocorrelation using the Global Moran's I index method (Goodchild, 1986) was applied to converted woody cover areas as an inferential statistical test, the results which can be interpreted within the context of its null hypothesis. For the Global Moran's I statistic, the null hypothesis states that the attribute being analyzed was randomly distributed among the features in the study area; In other words, the observed pattern of values is the result of random chance (Getis and Ord, 1992). The method computes the mean and variance for the attribute being evaluated, in this case the polygon areas of converted woody cover. For each attribute value, the algorithm subtracts the mean, creating a deviation from the mean. Deviation values for all neighboring features within the computed distance band are multiplied together to create a cross-product.

From a cross-product computation, the spatial autocorrelation method evaluates whether the spatial pattern expressed is clustered, dispersed, or random. The method generated a z-score and p-value to indicate whether or not one can reject the null hypothesis. When the z-score or p-value of the Global Moran's I index indicates statistical significance, a positive index value indicates tendency toward clustering while a negative Moran's I index value indicates tendency toward dispersion. Given a z-score of greater than 2.6, there is a less than 1 percent likelihood that this clustered pattern could be the result of random chance. Comparisons of statistically significant z-scores provide a measure of the intensity of spatial clustering or spatial dispersion. The Distance Threshold value is the Euclidean distance that ensures every feature has at least one neighbor. A series of increasing Distance Threshold values indicates the distance/scale at which the processes promoting spatial clustering were most pronounced.

4. Result and conclusion

A total of 88,300 ha (883 km^2) were detected as having been converted from perennial woody cover to cropland in California between 1992 and 2012. The top 22 counties (that together comprised over 87 percent of all woody cover area converted to cropland) were led by Riverside and Imperial Counties in southern-most California and Siskiyou County in northern-most California, each with more than 8900 ha converted between 1992 and 2012 (Table 1). The woody area converted to cropland as a proportion of the entire county area

averaged 0.43 percent for the leading counties listed in Table 1, and averaged 0.22 percent of the total state land area.

Table 1: Top 22 counties of California according to the largest area of perennial woody cover converted to cropland between 1992 and 2012 (all > 10 km^2 per county). The area converted to cropland as a proportion of the entire county area was provided, followed by the predominant cropland classes into which woody cover was converted.

County	Area (km^2)	Percent county area	Predominant cropland classes into which converted (with percent of total area converted)
Riverside	138	0.73	Wheat (24%), Alfalfa and Hay (23%), Fallow (15%)
Imperial	89	0.77	Fallow (17%), Alfalfa and Hay (9%)
Siskiyou	89	0.54	Fallow (46%), Alfalfa and Hay (41%)
Lassen	64	0.53	Alfalfa and Hay (45%), Fallow (16%), Wheat (7%)
Fresno	60	0.39	Fallow (26%), Alfalfa and Hay (19%),
Kern	58	0.27	Fallow (45%), Alfalfa and Hay (17%), Almonds (6%)
Tulare	35	0.28	Alfalfa and Hay (20%), Fallow (17%), Oranges (14%)
Shasta	27	0.27	Fallow (53%), Alfalfa and Hay (21%)
Modoc	23	0.21	Alfalfa and Hay (49%), Fallow (16%), Wheat (5%)
Kings	21	0.59	Fallow (48%), Alfalfa and Hay (12%), Almonds (4%)
Sonoma	21	0.50	Grapes (69%), Alfalfa and Hay (11%)
Butte	19	0.44	Fallow (28%), Alfalfa and Hay (20%), Walnuts (12%)
San Luis Obispo	18	0.21	Grapes (26%), Alfalfa and Hay (21%), Fallow (14%)
Yuba	17	1.04	Fallow (23%), Alfalfa and Hay (17%), Walnuts (10%)
Yolo	17	0.63	Fallow (41%), Alfalfa and Hay (20%), Walnuts (10%)
Monterey	15	0.17	Grapes (29%), Alfalfa and Hay (28%), Fallow (9%)
Tehama	11	0.15	Alfalfa and Hay (31%), Fallow (8%), Almonds (6%)
Napa	11	0.54	Grapes (63%), Alfalfa and Hay (13%)
Sacramento	11	0.43	Fallow (28%), Alfalfa and Hay (18%), Walnuts (6%)
San Bernardino	11	0.02	Alfalfa and Hay (50%), Fallow (14%), Wheat (5%)
Merced	10	0.20	Alfalfa and Hay (29%), Almonds (15%), Fallow (9%)
Sutter	10	0.63	Fallow (29%), Walnuts (21%), Alfalfa and Hay (10%)

On a statewide basis, the most common crop types into which woody cover was converted were alfalfa and hay (25%), fallow (23%), grapes (6%), wheat (6%), almonds (3%), walnuts (2%), citrus (2%), barely (1%), and cotton (1%). In Riverside County, winter wheat was the most common crop type into which woody cover was converted (Table 1), whereas in Imperial, Siskiyou, Fresno, Kern, Shasta, Kings, Butte, Yuba, Yolo, and Sacramento counties, fallow and hay croplands made up the majority into which woody cover was converted. In Sonoma, San Luis Obispo, Monterey, and Napa counties, grapes made up the majority of crop area into which woody cover was converted. In Kern, Kings, Butte, Yuba, Yolo, Tehama, Sacramento, and Merced counties, almonds and/or walnuts made up > 5% of crop area into which woody cover was converted.

The spatial patterns of woody vegetation converted to cropland cover were extracted for a representative subset of county growing regions listed in Table 1. The most obvious clusters of converted woody cover were located in Siskiyou, Fresno, Riverside, and Imperial counties (Figure 1). Spatial autocorrelation analysis carried out within a 15-km diameter circular buffer zone centered on each growing area (shown in Figure 1) all showed positive Moran's I

index values for the examples listed in Table 2. The z-scores in all these cases were greater than 2.6, indicating a far less than 1 percent chance that these strongly clustered patterns could be the result of random chance. Converted woody cover areas were most tightly clustered in Siskiyou, Riverside, and Imperial counties, followed by Fresno and Monterey counties.

Table 2: Spatial autocorrelation results for a representative subset of county growing regions listed in Table 1, corresponding to maps shown in Figure 1.

County	Moran's I index	z-score	p-value	Distance threshold (m)
Siskiyou	0.23	185.9	0	1652
Monterey (Watsonville)	0.18	14.9	0	2335
Fresno	0.07	44.8	0	2280
Riverside	0.22	110.3	0	959
Imperial	0.27	120.4	0	1351

Several counties stand out in this analysis of woody cover conversion as important indicators of agro-ecosystem change in California. Starting in the northern-most portion of the state, Siskiyou County is an example of a growing region where field crops such as alfalfa and wheat persist as the most common systems of production (Siskiyou County Department of Agriculture, 2013). Nursery crops such as strawberries have recently become one of the county's most valuable crops, with harvests exported worldwide. The Siskiyou County Department of Agriculture reports that cropland in the county is most commonly fallowed for the purposes of soil fumigation, crop rotation, integrated pest management, or water delivery cutoffs.

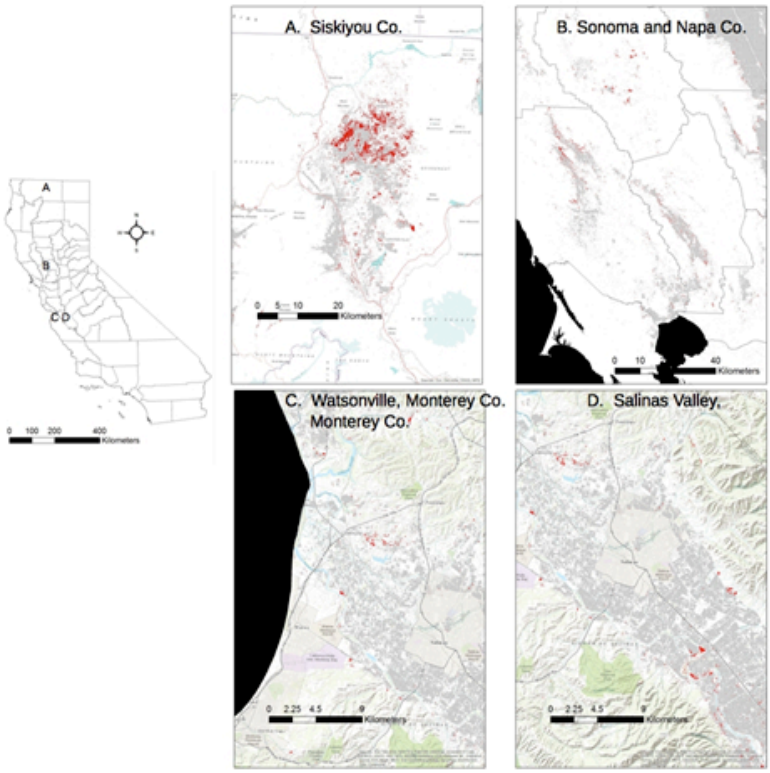
In the Central Valley, specifically western Fresno County, the number of acres planted to trees and vines more than doubled between 1993 and 2003, while the number of acres planted in cotton declined by about 50 percent (Westlands Water District, 2003). Today, perennial almond and other nut trees occupy more acreage than either cotton, tomatoes, or wheat crops, which have been historically important annual production systems in this part of the San Joaquin Valley. In addition to generating improved farmer incomes, permanent tree crops tend to provide stable employment at higher wages for seasonal farm workers.

The San Jacinto River watershed drains the major agricultural valleys of western Riverside County in the southern part of the state, and remains covered by about 120,000 ha of natural forest and shrubland, at 60% of the total watershed area (San Jacinto River Watershed Council, 2007). For comparison, this county was detected with the highest total area (13,800 ha) of woody cover converted to cropland of any in the state between 1992 and 2012. Small grains and hay crops today cover about 9,115 ha of the entire San Jacinto watershed (Riverside County Agricultural Production Report, 2013).

Imperial County cropland today is dominated by field crops of alfalfa and wheat covering roughly 150,000 ha and vegetable crops covering an additional 48,000 ha (Imperial County Agricultural Crop and Livestock Report, 2013). In comparison, this county was detected by Landsat analysis with 8,900 ha of woody cover converted to cropland between 1992 and 2012. The highest percentage of this converted woodland was classified presently by comparative Landsat image analysis as fallowed cropland, which is consistent with reports

that the local water district recently designated around 10% of farmland to be unplanted as a temporary measure to help meet the Imperial Valley's commitments transfer more water to growing urban centers.

The strong clustering of woody cover conversion since the early 1990s in the county areas (as listed in Table 2) indicates that entire woodland and shrubland corridors and connectors have been lost to cultivated land uses over the past two decades. These patterns raise concerns about the rates of native vegetation loss around cropped fields throughout California that may be slowly compromising pest suppression by natural bio-control agents. On the research side, improvement of farm habitat for natural predators of crop pests and other beneficial native wildlife has been realized by restoring the vegetation diversity of agricultural landscapes.



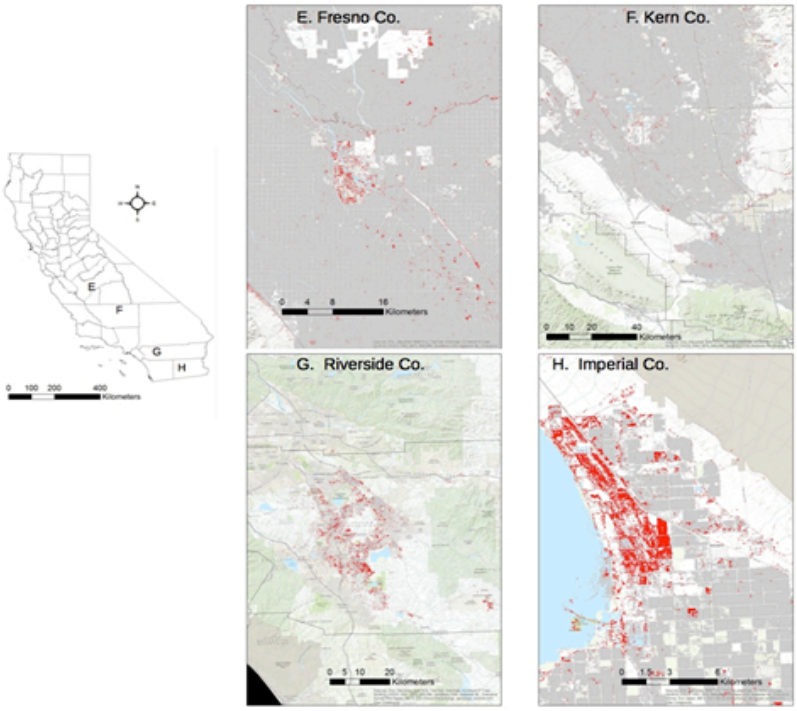


Figure 1: Maps of valley cropland areas in counties detected with the highest total areas of woody vegetation cover converted to cropland between 1992 and 2012. Woody cover converted was displayed in red shades, overlaid on cultivated land (2012) in gray shades.

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