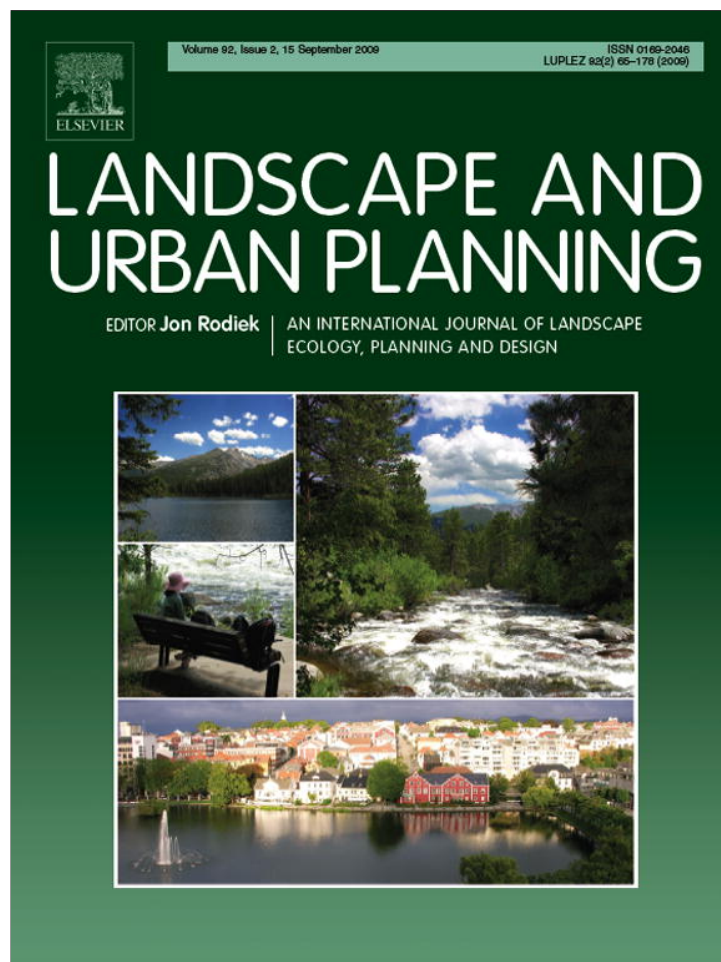




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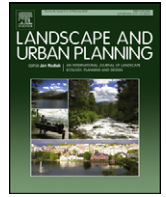
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Impacts of conservation easements for threat abatement and fire management in a rural oak woodland landscape

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ABSTRACT

Rural residential development can impact habitat and complicate fire management. Conservation easements are created to prevent development but are rarely assessed for their influence on development patterns. In the Lassen Foothills, California, The Nature Conservancy (TNC) holds over 37,000 ha of mostly public-funded conservation easements on ranchland dominated by blue oak (*Quercus douglasii*) woodland. For this region we modeled land use through 2050 under two scenarios, with and without conservation easements, using a rule-based growth model. We mapped development footprints on 760 rural residential parcels through automated remote sensing. From calculated footprint sizes we projected site-level habitat loss for each scenario. We also projected the influence of development patterns on fire management. With easements present the Lassen Foothills would gain about 184 new homes, compared with 223 homes if easements were absent. With an average residential footprint size of 0.34 ± 0.25 ha (mean $\pm$ SD), we found that easements slightly reduce vegetation conversion, protecting an additional 16.8 ha than were protected by the general plan alone. Without easements, scattered development may alter fire management on 12,370 ha (17.5% of undeveloped wildfire containment areas) by requiring more fire suppression and reducing options for prescribed burning. Low development pressure and county land use policies maintain very low residential densities in the Lassen Foothills. The easement program may increase options for fire management by preserving large landscapes. This case illustrates the limited effectiveness of land acquisition in preventing development in a low-threat landscape, and demonstrates the utility of growth models for prioritizing conservation investments.

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1. Introduction

Rural residential development is the fastest growing land use type in the United States (Brown et al., 2005). This low density development impacts biodiversity and ecosystem processes and fragments habitat (Hansen et al., 2005). Many conservation efforts to reduce development and protect habitat rely heavily on conservation easements (Merenlender et al., 2004), but the extent that conservation easements effectively alter development levels and reduce habitat conversion has not been fully examined.

Seeking the “natural amenities of rural landscapes” such as open space, outdoor recreation, and a clean environment, people

have chosen to live in low density areas on small “ranchettes” or subdivisions in rural areas or at the urban fringe (Rasker and Hansen, 2000; Rudzitis, 1999). Rural residential development, or exurban development, is low density housing on large parcels (Brown et al., 2005; Theobald, 2005) outside of urban service boundaries, which requires a reliance on septic systems and well-water. Exurban area increased five-fold since 1950 (Brown et al., 2005), occupies five to ten times more area than urban and suburban land use, and is expanding by 10–15%/year (Theobald, 2000, 2001).

Despite calls for research on the impacts of human settlement (Miller and Hobbs, 2002) particularly beyond the urban fringe (Fraterrigo and Wiens, 2005; Theobald, 2005), attempts to quantify exurban development and assess its impacts are only just beginning. Low density development is difficult to map and monitor using existing land cover data because tree canopy cover often remains dense in the surrounding area (Sutton et al., 2006). Exurban landscapes tend to be heterogeneous (Bock et al., 2006) and support a wide variety of land use activities such as horse grazing and small scale agriculture. These dispersed activities and related

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low density developments modify the landscape and complicate land management, especially adjacent to protected areas (Cole and Landres, 1996; Theobald, 2004).

Rural residential development has particularly influenced fire management in California. The highest fire frequency and greatest area burned occur at intermediate population densities (~35 to 45 people/km²) where development intermingles with wildland vegetation (the Intermix Wildland-Urban Interface) (Syphard et al., 2007). Human-caused fire ignitions have increased with population and wildland recreation, while fire suppression efforts have prevented total burn area from increasing (Stephens, 2005). The dollar amount of damage caused by wildfires and suppression costs have increased dramatically. Suppression costs from the 2004 to 2005 fire season were \$170.1 million and the average annual financial loss from 2001 to 2005 was \$288.3 million (California Department of Forestry and Fire Protection, 2007).

The threat of development drives many initiatives to protect open space on private land, including local ballot initiatives, private and public fundraising campaigns, acquisition of land and conservation easements, and regulatory land use planning. Conservation easements have emerged as a dominant tool for land trusts and government agencies to protect natural resources (Hansen et al., 2005; Land Trust Alliance, 2006). Conservation easements are individually negotiated agreements used frequently on working landscapes (Rissman et al., 2007) in which a landowner agrees to limit subdivision, development, and other land use, usually in perpetuity. In exchange, landowners may receive a direct payment or reduction in income, estate, and property taxes (Gustanski and Squires, 2000).

Since the 1980s the use of conservation easements has increased sharply, funded by millions of dollars in private donations, federal and state tax deductions, public grants, and local and statewide ballot initiatives (Fairfax et al., 2005; Land Trust Alliance, 2006). Yet the effectiveness of conservation easements for preventing development and protecting habitats is relatively unquantified (Merenlender et al., 2004; Rissman et al., 2007). Conservation easements are designed to prevent development permanently, so their effectiveness is related to the likelihood of future development. Their effectiveness is also linked to the amount of development permitted in the conservation easement, which is often a compromise agreement and can permit new residential dwellings (Rissman et al., 2007). Build-out models are one method of projecting future development with estimates of population growth allocated into land use classes that can be used to compare alternative protection scenarios (Johnston and Shabazian, 2003).

We examined how effectively conservation easements protect against rural residential development threats in a Northern California blue oak (*Quercus douglasii*) woodland landscape dominated by large, unfragmented cattle ranches. We explored the effectiveness of conservation easements in the context of county land use planning, and assessed the capacity of conservation easements to protect oak woodland habitat and permit fire management and planning. We employed a novel remote sensing approach to quantify and map the development footprint on low density residential parcels.

Our study addressed three main questions. (1) What is the expected low density development pattern in our study area based on a county build-out model, and how does the presence of conservation easements alter that development pattern? (2) How much does low density development contribute to direct habitat conversion, and do conservation easements minimize these impacts? Finally we ask, (3) to what extent is fire planning and management influenced by conservation easements? This study represents a novel approach to assessing conservation easement outcomes by projecting future development and forecasting the effects on habitat conversion and fire management across a greater rural landscape.

2. Methods

2.1. Study area

Starting in the 1990s, The Nature Conservancy (TNC) has been conserving land in the Lassen Foothills, one of the largest unfragmented landscapes in California, which spans the eastern half of Tehama County and extends into Shasta County to the north and Butte County to the south (Fig. 1). The Lassen Foothills project area covers over 364,000 ha, and extends from Mount Lassen to the Sacramento River. Blue oak woodlands in the project area are mostly held in large privately owned cattle ranches. TNC's primary conservation strategy is the purchase of conservation easements that limit development, woodcutting, and other extractive uses, and allow the landowners to continue ranching.

TNC invested in conservation easements here to protect a relatively unfragmented blue oak woodland landscape, extensive vernal pool complexes, California's largest migratory deer herd, and Federally listed anadromous fish (The Nature Conservancy, 2007). Easements were established on over 37,000 ha of land between 1997 and 2007. The total amount of public funding used for these easements was \$12,970,000.00, or \$349.80/ha. One of TNC's primary land management strategies is fire management aimed to reduce the cover of invasive non-native plants, and enhance deer habitat and forage quality (Hujik, 2000).

We developed a build-out model for Tehama County since the county covers most of the Lassen Foothills project area and necessary input data are aggregated at the county level. Tehama County encompasses 7770 km² with a strong east–west topographic gradient from the Pacific Coast Range to the Sacramento River Valley to the ridgeline of the Sierra Nevada Mountains.

Tehama County's landscape reflects its rural character, with over half its land area designated as cropland (valley agriculture) or grazing land (upland agriculture) according to the county general plan (Tehama County Planning Department, 2000). Urban and commercial centers and most of the county's population [61,424 in 2006 (State of California Department of Finance, 2006)] are located in the Sacramento Valley near Interstate 5 and Highway 99. To the east and west of these transportation corridors, the land is dominated by large ranches and federal and state government land holdings.

Tehama County's population density was 17.3 people/km² in 2000, compared to the state average of 83.9 people/km². Only about 15% live in the incorporated cities of Red Bluff, Corning, and Tehama. The remaining population lives in small, unincorporated communities or in residences scattered throughout the county (PMC, 2006).

2.2. Rural residential build-out scenarios

UPlan is a rule-based urban growth model that operates in ESRI's ArcView 3.1 or higher (Johnston and Shabazian, 2003). The model allows the user to change parameters in order to test future development scenarios, which has made it a popular tool for county planning agencies in California (Johnston et al., 2003; Merenlender et al., 2005). In UPlan population and employment projections determine the extent of development in seven land use classes. The general plan plus user-defined weighted development attractions (e.g. highways), discouragements (e.g. slope), and masked areas (e.g. public lands), determine spatial allocation of development. The user inputs a general plan (recoded in UPlan general land use categories, Fig. 2A) and attraction, discouragement, and mask data as 50-m grids. The model projects development within high-, medium-, low-, and very low density residential, high- and low density commercial, and industrial land use classes. While many urban-growth models are available (U.S. Environmental Protection Agency, 2000), we chose UPlan because

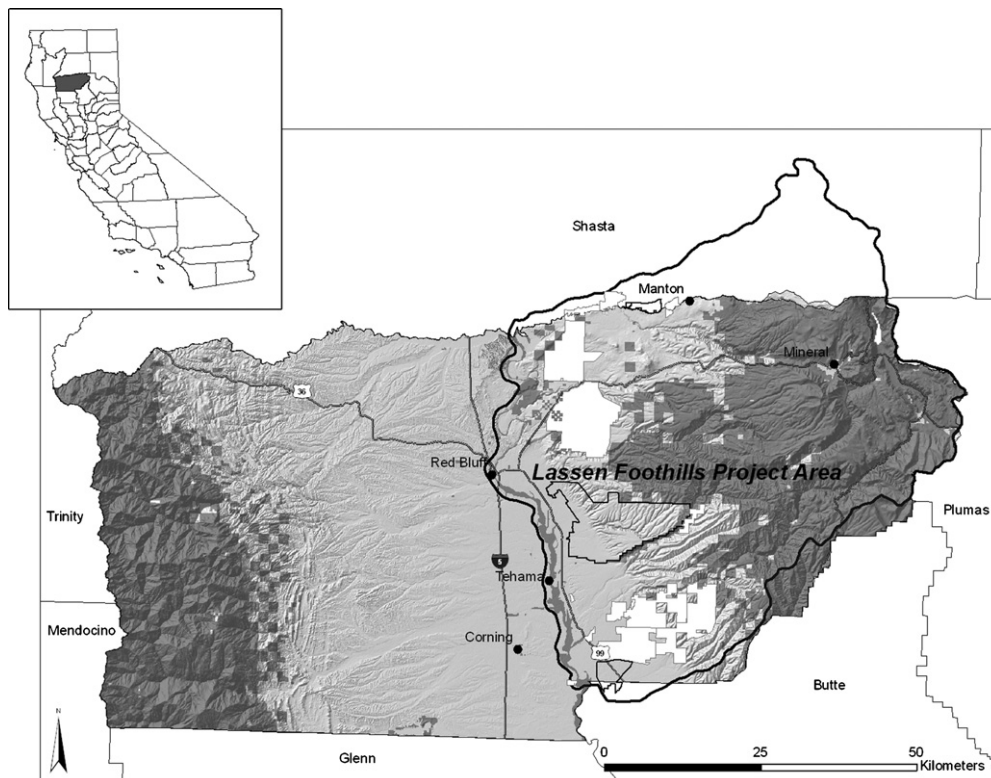


Fig. 1. Tehama County and the Lassen Foothills Project Area. TNC conservation easements are shown in white, TNC fee title and managed lands are outlined, and public lands are shown in dark gray. This study focused on easements in Tehama County, though the Lassen Foothills Project Area extends into Butte and Shasta Counties as well.

it can project very low density residential growth, the development type most likely to affect the Lassen Foothills region. Unlike the other land use classes, very low density residential development is allocated randomly throughout rural areas (Johnston and Shabazian, 2003). Attractions and discouragements do not influence the distribution of this land use type in the UPlan model but development masks continue to apply. This random allocation represents the noncontiguous patterns of rural development because attractions for exurban development can include a variety of landscape features including ridgetops, valleys, proximity to roads, or remote lots. It also reflects observations that rural households tend to be built away from existing ones (Irwin and Geoghegan, 2001).

To project residential development, the UPlan model requires the present-day number of households within four density classes, average lot size of each density class, and the areas in the general plan coded for each class. The low density residential class (RL) was defined as detached dwellings including mobile homes and recreational vehicles with an average lot size of 0.8 ha in rural areas designated residential small lot, residential large lot, or suburban according to the Tehama County Draft Existing General Plan. The model also allowed RL development in areas designated for cropland and valley grazing. The very low density residential class (RVL) was defined as detached dwellings including mobile homes and recreational vehicles in rural areas with average lot size of 64.7 ha (160 acres) designated for foothill grazing (64.7 ha minimum lot size) or resource lands according to the Tehama County Draft Existing General Plan.

To calculate the current number of RVL households, a key input parameter for the model, we used parcel data obtained from the Tehama County Assessor's Office. We selected parcel data for all parcels within the RVL land use category, including areas zoned for foothill grazing with a minimum lot size of 64.7 ha, and areas

zoned for resource lands. The parcel data contained a use code, year structure was built, and number of bedrooms. According to the Assessor's Office, all parcels with a residential use code contained at least one dwelling. We checked the parcel data for errors and re-coded vacant parcels as residential when they also contained data on the number of bedrooms in a structure. We tabulated all parcels with residential use codes and added one additional residence for all parcels coded for two or more residences.

Attractions, discouragements and masks were selected based on communication with Tehama County land use planners (personal communication with Robert Halpin, Planner II, Tehama County Planning Department, July 6, 2006). For industrial, high and low density commercial, and high and medium density residential classes, the attractions were city spheres of influence (SOI), the I-5 corridor extending north of Red Bluff to the county border, and other major roads. Cities and developments that served as attractions included Red Bluff, Tehama, Corning, Lake California, the Del Webb development, and Los Molinos. These towns and developments were chosen based on their potential for future development. The Draft County General Plan (Tehama County Planning Department, 2008) calls for new residential development to be concentrated along the I-5 corridor north of Red Bluff to the county border. Because the county intends to cluster low density development in this region, the north I-5 corridor attraction was weighted more heavily than other road attractions. Attractions and buffers for the residential low density class were similar to those above and included water bodies, streams, and the Sacramento River. The only discouragements were the 100-year floodplain and slope classes ranging from 10% to 50% (Johnston and Shabazian, 2001). We used the following layers to mask out development completely in the Tehama UPlan model: urban areas, as defined by the 2000 U.S. Census, developed residential parcels in RL and RVL classes as defined in parcel data use codes, all land with slope >50%, all water bod-

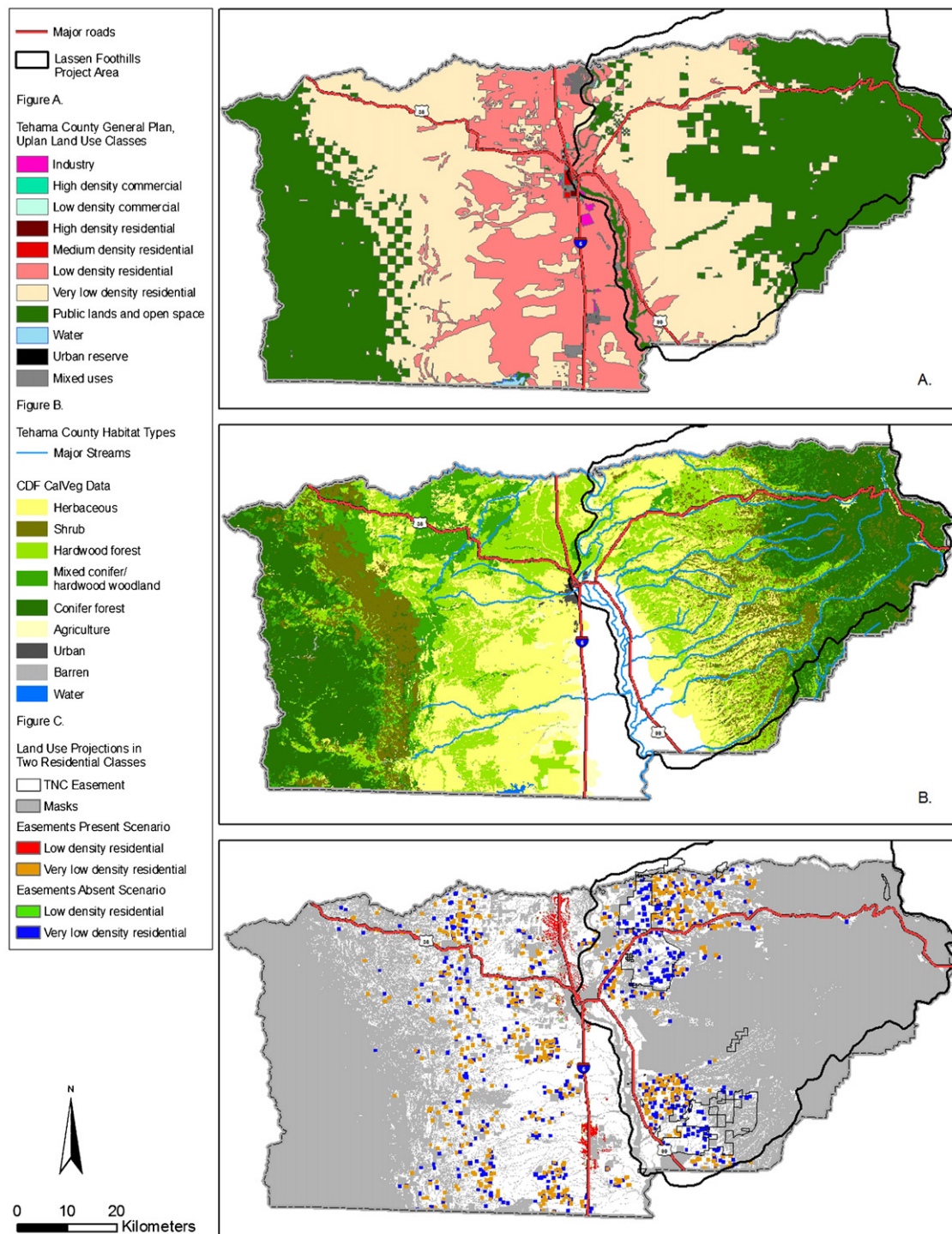


Fig. 2. Tehama County UPlan Results. A shows the land use designations in the UPlan Tehama County General Plan. B shows habitat types based on CDF CalVeg data. C shows UPlan results for two residential land use classes under the easements absent and the easements present scenarios. The low density residential (RL) land use distribution is approximately the same under both scenarios. Very low density residential (RVL) development was allocated in 250-m grid increments to represent the typical 64.7 ha lot size. All other land use classes were allocated in 50-m grid increments. The gray areas in C represent the UPlan mask, or places where development was excluded under the easements absent scenario.

ies including the Sacramento River, public lands, the Dye Creek Preserve managed by TNC and all properties owned in fee title by TNC.

We ran two UPlan scenarios. In the first scenario, TNC easements in the Lassen Foothills project area, totaling 32,375 ha at the time of analysis, were masked from development (easements present scenario). This scenario modeled RVL development given TNC's cur-

rent easement holdings. In the second scenario, we assumed that the TNC easements were abandoned as of 2000, given that easement boundaries may have shaped development patterns prior to the start date of our model run, and we allowed development on easement properties (easements absent scenario). After running the two scenarios we tallied the area of land allocated to each of the seven land use classes calculated in UPlan.

To better estimate the number of homes that would be developed within the Lassen Foothills under each scenario, we ran the UPlan model a total of 10 times per scenario. We limited our model repetitions to 10 because, for each scenario, the variance in the number of new households in the Lassen Foothills calculated from 5 and 7 model runs was the same as the variance from 10 model runs based on a variance ratio test ($p < 0.05$) (StataCorp LP, 2004).

We averaged the number of projected RVL homes within the Lassen Foothills project area per scenario. Finally we calculated the probability of development occurring on each easement, and we calculated the average number of new homes projected for each easement under the easements absent scenario based on 10 model runs. We then compared this to the number of homes allowed on each conservation easement property by reading and coding conservation easement documents.

2.3. Site-level habitat loss

We classified remotely sensed imagery to estimate direct habitat loss from the typical rural residential development footprint within the oak woodlands of Tehama County. A habitat map of Tehama County is presented in Fig. 2B. We defined the development footprint to include any structures, bare ground, paved areas, roads and driveways, and irrigated land (primarily lawns) within a parcel boundary. The footprint did not include surrounding infrastructure such as roads and utilities. We selected sample parcels from all developed rural residential parcels in Tehama County according to parcel use codes. Sample parcels were further selected if the dominant vegetation type was hardwood based on CalVeg data from the California Department of Forestry and Fire Protection's (CDF) Land Cover Mapping and Monitoring Program (California Department of Forestry and Fire Protection, 2006a), and the parcel had not burned in the past 20 years, based on the fire perimeter data from CDF's Fire and Resource Assessment Program (California Department of Forestry and Fire Protection, 2006b). The final parcels were limited to those with a size range of 1 ha to 129.5 ha (2.5 acres to 320 acres), and fell within a study region characterized by oak woodlands and rolling hills located northwest of Red Bluff.

These 843 parcels were classified into 6 size classes: 1) 1–4 ha (2.5–10 acres); 2) 4.1–8.1 ha (10.1–20 acres); 3) 8.2–16.2 ha (20.1–40 acres); 4) 16.3–32.4 ha (40.1–80 acres); 5) 32.5–64.7 ha (80.1–160 acres); and 6) >64.7 ha (160 acres). A subset of 120 parcels was chosen from this list, with 20 in each size class. Ground-truth field data of these sites was collected *in situ* with a Garmin GPSmap® 60CSx (accuracy 2–10 meters) to train data classifiers (algorithms) in order to conduct a supervised classification of a 1-m 2005 National Agriculture Imagery Program (NAIP) true color digital aerial photo (Farm Service Agency-U.S. Department of Agriculture, 2005) of Tehama County in ERDAS Imagine 8.7 (Leica Geosystems GIS & Mapping, 1991–2003). Each parcel was viewed from the road and the following information was collected: dominant vegetation type, presence and number of dwellings, other land uses, and presence of irrigated land (lawns). The classified image included four classes: oaks, grassland, irrigated land, and the development footprint. The footprint class contained any paved areas, roads, driveways, rooftops, and other man-made structures.

Object-based image analysis software Definiens Professional 5.0 (eCognition) (Definiens, 2006) was used to partition the NAIP imagery into objects in order to improve classification results. Rooftop objects were manually classified as such and added to the footprint class. A 5×5 majority filter was applied to the final product. We generated 243 stratified random reference data points for use in an accuracy assessment in ERDAS Imagine 8.7. Reference data were obtained from photointerpretation and ground-truthing. We computed a standard error matrix (Lillesand and Kiefer, 2000) as part of the assessment. Ten percent of the parcels found to be poorly

classified or to contain no development footprint were removed from the sample to create a final sample size of 760 parcels.

The footprint and irrigated land classes were combined to produce the total development footprint for rural residential development. The area of footprint for each parcel was then calculated using "Tabulate Areas" in Spatial Analyst extension in ArcGIS 9.2 (ESRI, 1999–2006). Summary statistics (count, mean and standard deviation) on footprint size were calculated for each of the six size classes in Intercooled Stata 8.2. We also calculated the regression of parcel area against log footprint size. Three outlier samples out of 760 were removed to create a normal distribution. The regression model residuals were checked for normality with the Shapiro-Wilk test and for variance heterogeneity by examining a plot of residuals vs. fitted values.

New development in the Lassen Foothills would occur on large parcels (around 64.7 ha) based on requirements in the Draft County General Plan (Tehama County Planning Department, 2008). As a result we used the value of footprint size for the largest classified parcels [(90th percentile, >49 ha (120 acres))] along with the number of new RVL households projected in the Lassen Foothills to estimate the total footprint area of new development. For each UPlan model scenario, we multiplied the average number of new RVL households by the sample of footprint sizes for the largest classified parcels, and ran a t-test to compare the means of the total footprint area.

2.4. Fire management

After projecting the number of new rural homes along with their development footprint in the Lassen Foothills, we examined whether managers' ability to allow for reduced fire suppression and to implement prescribed fires would be affected by development in our study region. The Tehama County Resource Conservation District (TCRCD) and TNC have developed the Tehama East Fire Plan (TCRCD, 2008). As part of this plan the TCRCD identified natural and man-made resources in the area, local assets at risk from wildfire, and projects in place to protect these assets. A major component of the Fire Plan is the development of defensible polygon areas (TNC and TCRCD, 2007). These are areas of natural fire containment based upon topography and existing firelines that include roads, streams and rock fences. Polygon boundaries generally follow TIGER roads, rock walls, and ridgelines. Many of these polygons were already-existing Fire Management Units developed by TNC to aid in prescribed burning plans for the Dye Creek Preserve, the Denny Ranch conservation easement, and the Vina Plains Preserve.

We applied the Defensible Polygon GIS data in analyzing the effects of future rural development on fire management. Our objective was to determine differences between the two build-out scenarios within each of the 140 defensible polygons located in the Lassen Foothills project area. Initially we ran a diagnostic test to determine whether 10 UPlan model runs were sufficient to study differences between the two scenarios. Based on a paired *t*-test we found no difference in the variance in projected new homes per polygon from 5 model runs compared to 10 model runs.

First we calculated the average number of new homes developed over all polygons from 10 model runs for each scenario, and compared these averages with a paired *t*-test, paired by polygon. Second we determined how many polygons currently undeveloped were likely to be developed by 2050. A polygon was classified as developed if at least one new household occurred within its boundaries in at least six out of ten UPlan model runs. We then calculated the area of these newly developed polygons for each scenario. We also studied which polygons were most likely to become developed, and the development patterns under each scenario. We ranked polygons according to number of projected new homes, then tallied the number of most-developed polygons needed to contain 50% of the projected new households.

3. Results

3.1. Rural residential build-out scenarios

For the UPlan model parameters, we calculated that the present-day total number of residences in the RL class was 8964, or 42.7% of all residences in the county. The total number of residences in the RVL class was 969, or 4.6% of all residences in the county.

The UPlan model generated data on the land area allocated to new development in seven land use classes: industrial, high density commercial, low density commercial, and the four residential density classes (RH, RM, RL, and RVL). For each model run, UPlan generated a GIS map showing where development in each class would occur (Fig. 2C). The model allocated development in 50-m grid cell increments for all classes, with the exception of the RVL class, which was allocated in 750-m grid cell increments to better visualize the typical RVL 64.7 ha (160 acre) lot size.

Based on average residential lot sizes, this growth translates into 1737 new attached dwellings, 4684 new detached homes in urban areas, 5207 new detached homes in the RL class, and 561 new detached homes in the RVL class in Tehama County by the year 2050. The area of land allocated to development is the same for both easements present and easements absent scenarios, the difference being the location of development across the county.

Our results for both scenarios indicated that future low density residential growth (RL) will be primarily located in the Sacramento Valley. The allocation of this growth will be highly influenced by development attractions, especially the I-5 corridor between Red Bluff and the Shasta County border, which was weighted heavily in the model, and the City of Corning. Our UPlan model allowed RL development to occur on land zoned as cropland and composite cropland according to the Tehama County Draft Existing Zoning Map. Model results show a small amount of industrial and commercial development spilling into cropland as well. Overall, based on our model, the acreage of cropland or composite cropland lost to development by 2050 will be 2509 ha. Most of this loss will be attributed to low density residential growth, at 2488 ha.

The area of available land for RVL development differs slightly between the two scenarios: 125,766 ha in the easements present scenario and 143,995 ha in the easements absent scenario. However in both scenarios, the area of available land for RVL development

greatly exceeds the demand. As a result the number of new residences county-wide would be the same for both scenarios. Within the Lassen Foothills project area, approximately 184 (σ 5.8) new RVL homes would be developed under the easements present scenario, and with more land available, 223 (σ 5.6) RVL homes would be developed under the easements absent scenario. These results are based on averages from 20 model runs (10/scenario) ($t = 15.1$, $df = 18$, $p \ll 0.05$). With the easements present RVL development becomes more prevalent in the Sacramento Valley and is spread more throughout the western portion of the county.

At the time of the study, 14 TNC conservation easements were located within the Tehama County portion of the Lassen Foothills project area (three are located primarily in Shasta County). Eight of these properties are not likely to be developed even without easement restrictions, based on averages of 10 model runs (probability of development 10% or less) (Table 1). Their easement agreements currently allow anywhere from 1 to 4 residences on a property. These eight properties are generally smaller and contain a large proportion of land masked from development because of steep slopes. Three other properties would likely see considerably more development than is currently allowed under easement restrictions. In one case (easement "B") 40 new residences would be projected on a property that currently allows five.

3.2. Site-level habitat loss

Classification of aerial photography successfully created a map of development footprints on rural residential parcels in northwestern Tehama County. Overall classification accuracy was 87.2% for the final classified image with four classes: oaks, grassland, irrigated land, and development. The final development footprint class (a combination of irrigated land and development classes) had a producer's accuracy (1-omission error) of 90.0% and a user's accuracy (1-commission error) of 93.9%. The development footprint generally consists of a driveway, one or more structures, and a small area around those structures. On large parcels, much of the land remains undeveloped (Fig. 3).

The distribution of footprint area according to parcel size class reveals an increase in footprint size with increasing parcel size. Footprint area ranged from an average of 0.09 ha in class 1 (parcels 1–4 ha) to 0.56 ha in class 6 (parcels greater than 64.7 ha) (Fig. 4).

Table 1

Conservation easement residential allowances and 2050 very low density rural residential development (RVL) projections under UPlan scenario 2, easements absent. Average projected residences and development probability were calculated from 10 model runs. Area masked from development was calculated from UPlan mask grid. Easement names were coded to protect privacy of property owners. Total number of residences permitted by each easement includes residences in existence when the easement was established and new residences permitted by the easement.

Conservation easement	Area (ha)	% Area masked from development	Total number of residences permitted by each easement	Easements absent: 2050 average projected residences	Easements absent: 2050 probability of development
A ^a	612	N/A	2	N/A	N/A
B	4	0	2	0	0
C	14 598	22	5	40	100
D	4121	8	2	11	100
E	5344	66	4	6	100
F	20	20	0	0	10
G	16	13	0	0	10
H	10	80	2	0	0
I	660	93	0	0	10
J	155	21	2	0	40
K	749	11	5	1	70
L	4215	50	3	9	100
M ^a	813	N/A	2	N/A	N/A
N ^a	400	N/A	2	N/A	N/A
O	67	12	1	0	10
P	446	42	4	0	0
Q	4	25	1	0	0

^a These properties are mostly located outside of the Tehama County study area. As a result the masked area was not calculated and there are no projections for new residences.

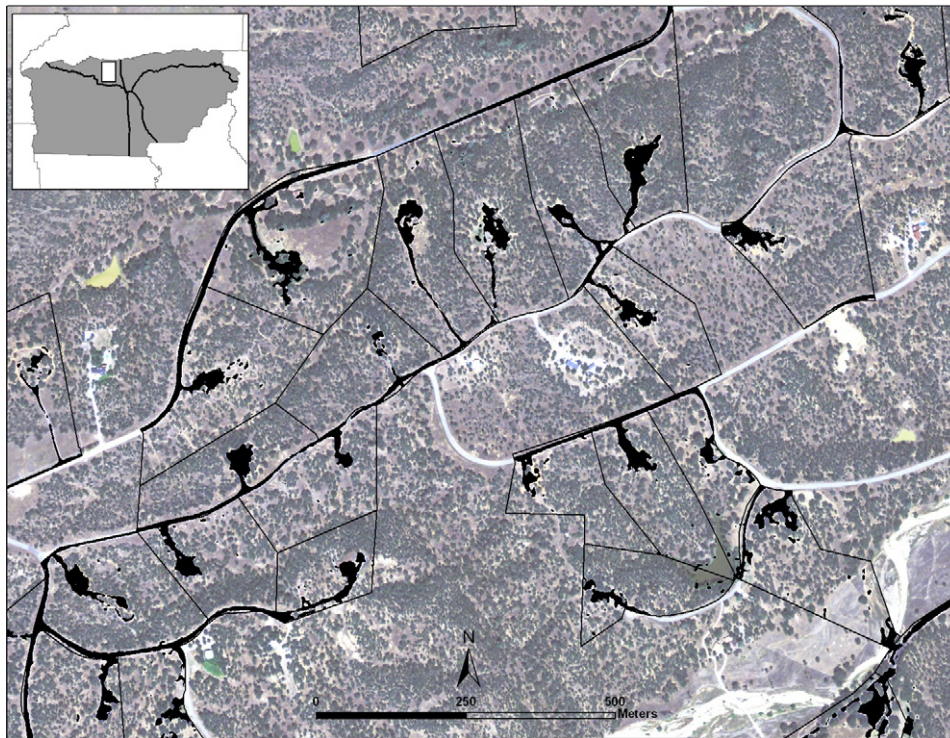


Fig. 3. Rural residential development footprint. The development footprint on rural residential parcels includes irrigated land, paved areas and structures. The footprint was produced through automated classification of 1-m true-color 2005 NAIP imagery.

An increase in variance corresponded with an increase in footprint area. After log transformation of the footprint data, a significant but small relationship was found between footprint area and parcel area ($R^2 = 0.22$; $F_{(1, 755)} = 208.1$, $p \ll 0.05$).

The median footprint size of the largest classified parcels [(90% percentile, >49 ha (120 acres))] was 0.34 ha, with a standard deviation of 0.25 ha. Within the Lassen Foothills, we estimated a cumulative development footprint of 79.1 ha under the easements present scenario, and a cumulative footprint of 95.9 ha under the easements absent scenario. These means were not significantly different based on t-test results ($t = 1.39$, $df = 172$, $p = 0.17$).

3.3. Fire management

In a pairwise comparison of defensible polygons, there were significantly more residences projected per defensible fire polygon in the easements absent scenario than the easements present scenario (1.53 vs. 1.25; $n = 140$, $t = 2.56$, $p = 0.01$). Under the easements present scenario, 17 currently vacant polygons totaling 31,239 ha would be considered developed due to additional very low density residential development (Fig. 5). Thirteen of these polygons have a 90% or greater probability of being developed, based on 10 model runs. Under the easements absent scenario, 29 currently vacant

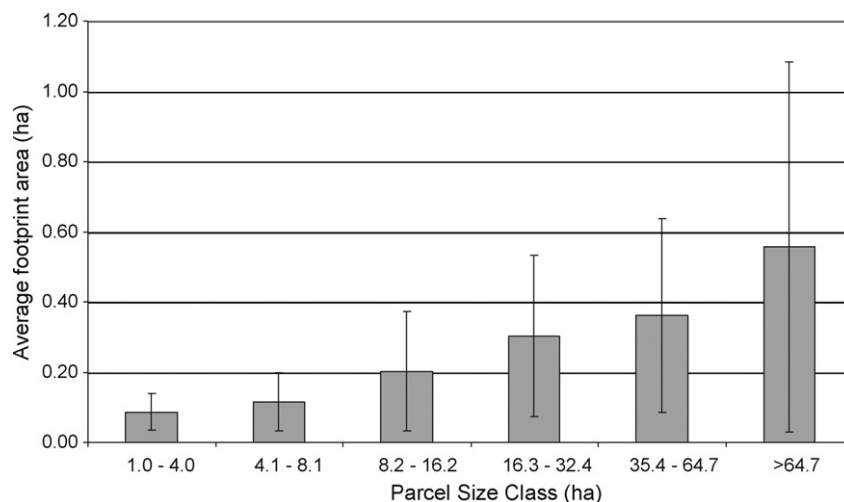


Fig. 4. Relationship between parcel size class and average footprint area. As parcel size class increases, the average footprint area increases accordingly. Error bars represent standard deviations. Regression formula: $\text{Log}(\text{footprint area}) = 0.021 (\text{parcel area}) - 2.19$; $R^2 = 0.22$; $F_{(1, 755)} = 208.1$, $p \ll 0.05$.

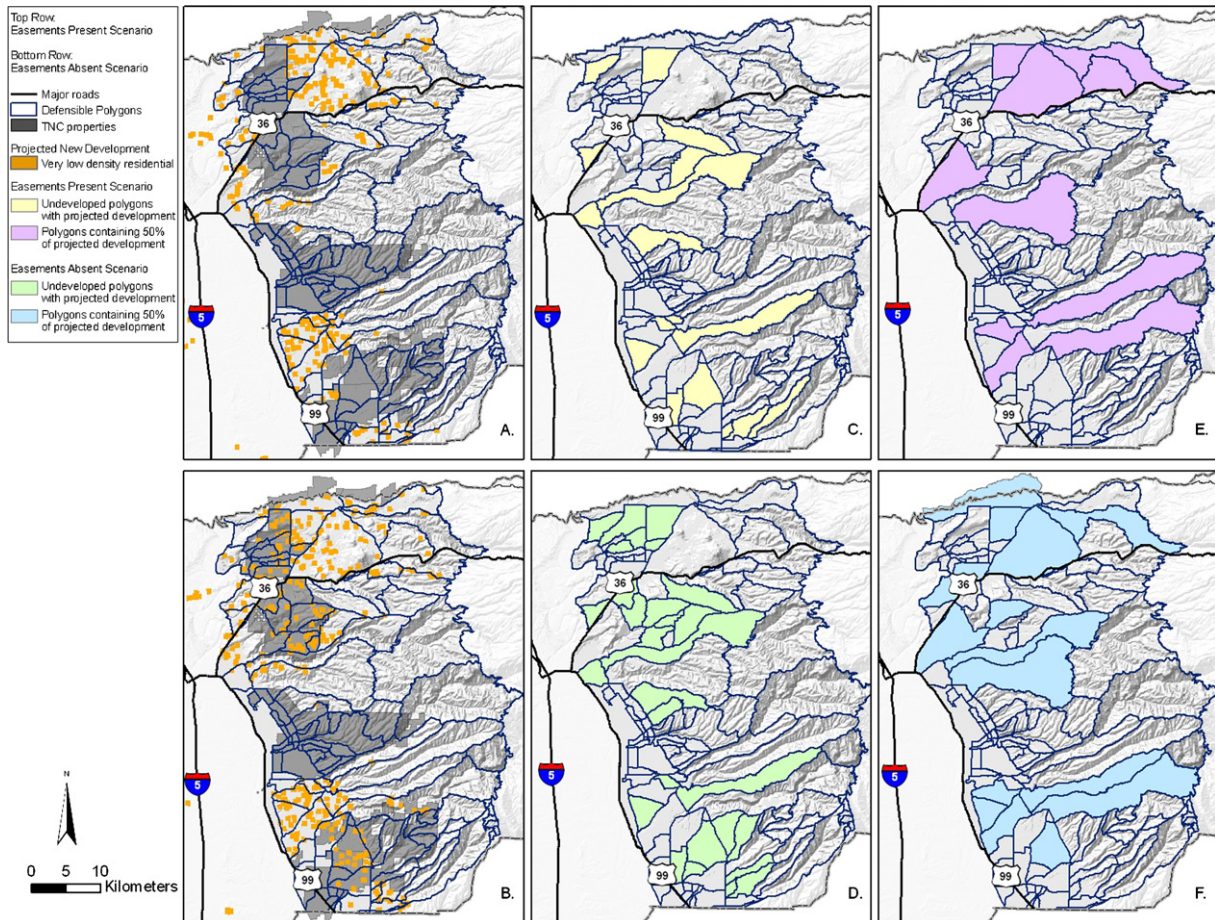


Fig. 5. Development projections for Tehama East Fire Plan Defensible Polygons (TNC and TCRCD, 2007). The top row of figures represents the easements present scenario and the bottom row of figures represents the easements absent scenario. A and B display UPLAN model results overlaid with the Defensible Polygons. C and D display the currently vacant polygons likely to be developed under each scenario ($\geq 60\%$ probability). Under the easements present scenario, 17 currently vacant polygons would likely be developed (13 have a 90% or greater probability of being developed, based on 10 model runs). Under the easements absent scenario, 29 currently vacant polygons would likely be developed (21 have a 90% or greater probability of being developed, based on 10 model runs). E and F display polygons projected for the most development that together would contain 50% of new homes (10 polygons with easements present and 15 polygons with easements absent).

polygons would become developed totaling 43,609 ha. Twenty-one of these polygons have a 90% or greater probability of being developed, based on 10 model runs. In total, without easements 12 additional vacant defensible polygons would likely be developed, covering an additional 12,370 ha more than if easements were present. With easements present, 10 of the most heavily developed polygons would contain half of all new homes, and with easements absent, half of the new homes would be scattered among 15 polygons.

4. Discussion

As land trusts and government agencies increasingly rely on conservation easements, there is a growing need to demonstrate conservation outcomes (Ferraro and Pattanayak, 2006). Land managers need to evaluate the extent that easements alter development patterns and preserve native habitat. Modeling scenarios of future development over time with tools like UPLAN is one important approach to evaluating easement effectiveness, and can be used to help prioritize future acquisitions.

This research demonstrates that the extent of rural residential development in a low-threat region is only altered slightly by the acquired conservation easements, which therefore do not result in measurable reduction of habitat loss from site-specific development. Based on demographic and economic projections, the county general plan does not constrain development, but instead accom-

modates all projected growth. Changes to the plan would not alter the number of projected new homes, but instead their distribution throughout the county, which could impede effective fire management. Conservation easements would enable managers to allow for prescribed fires and unsuppressed wildfires by preserving large unfragmented areas.

Our model projected over 5000 new low density residential (RL) units with an average lot size of 0.8 ha located mostly along the I-5 corridor north of Red Bluff and around Corning. With the strong development attractions in these areas, the easements located far from these population centers did not affect the distribution of these homes. In contrast most easements are located on grazing land designated for very low residential (RVL) development in our UPLAN model with an average lot size of 64.7 ha. Many fewer homes, 561, are projected in this land use category throughout the county. The easements influence the distribution of these homes, pushing them out of the Lassen Foothills project area and into the Sacramento Valley and Tehama County's western slopes.

Conservation easements are not the only factor protecting the Lassen Foothills. The Draft Tehama County General Plan aims to preserve land capable of supporting grazing and other agriculture, conserve open space, and accommodate commercial recreation, resource protection and habitat management (Tehama County Planning Department, 2008). The objectives and goals of the Tehama County Planning Department mirror those of The Nature Conservancy for the foothills region of eastern Tehama County.

Both intend to preserve large working ranches and protect blue oak woodlands. Through these independent but consistent efforts it is unlikely that significant development will occur in the Lassen Foothills over the next four decades, especially given the little amount of development predicted for the region. As long as the County Plan remains in effect, most of the ranchland in the Lassen Foothills zoned for foothill grazing will have a 64.7-ha minimum lot size and will be restricted to one dwelling per parcel. Instead, to accommodate growth, the Draft County Plan encourages high density and in-fill development. This will be achieved by encouraging future residential development to be located adjacent to existing communities.

Rule-based growth models such as UPlan are based on existing knowledge that a general plan provides, but unpredictable changes to land use restrictions can occur in the future for which our model would not account. Several mechanisms might allow for local development in excess of general plan restrictions. Historic parcels that existed before the California Subdivision Map Act was established are grandfathered in and are eligible for certificates of compliance. These antiquated subdivisions are widespread and not subject to current planning constraints (Johnson, 2002). Developers may also obtain variances that provide exceptions to zoning. General plans are updated and subject to change over time. Even when counties impose open space restrictions, they are vulnerable to fiscal pressures to permit development (Pincetl, 1999). These pressures are intensified by reduced property tax revenues to cities and counties as a result of California's Proposition 13 (Fulton, 1999). In contrast conservation easement restrictions may prove less subject to change than general plans. Modeling a longer time horizon would increase the likelihood of changes to the general plan, which could increase the difference in the scenario outcomes.

To our knowledge we are the first to use automated remote sensing classification methods to quantify the development footprints of rural residential parcels. The recent availability of object-based image classification software and affordable color aerial photography make these methods feasible for many other locations. We found that the developed area of rural residential parcels is likely to be small, around 0.34 ha/parcel. Residential development can influence wildlife beyond its immediate boundary (Odell et al., 2003). However the small footprint calculated here suggests a low level of habitat conversion expected without conservation easements. The footprint tends to increase with parcel size, though there is a high level of variation around this relationship. While the footprint includes irrigated land and completely cleared areas, it does not capture other types of vegetation clearing like tree thinning that is difficult to interpret from aerial photos. Our footprint measurement was applied to parcels dominated by oak woodland. Chaparral vegetation, which is highly flammable, is also likely to be impacted by residential development in the Lassen Foothills.

This measurement of the development footprint only includes what falls within each parcel, and does not include infrastructure such as roads and power lines that surround the parcels and support rural residential communities (Hawbaker et al., 2004). Further, UPlan model results display probable locations of new development under different scenarios, but do not project associated infrastructure. Research in road ecology demonstrates that roads fragment the landscape, and may cause habitat degradation and loss of habitat connectivity (Forman, 2006; Saunders et al., 2002). In future assessments of conservation easement effectiveness, research should consider the effect of easements on development of roads and infrastructure necessary to access rural residential homes.

At the landscape scale we found that easements served to cluster development and protect large landscapes that could allow for unsuppressed fires and prescribed burns. Some defensible polygons in the Tehama East Fire Plan are used for implementing prescribed

burns while other large, rugged units are used for containing wild-fires escaping initial attack (Callenberger and Lunder, 2003). A more scattered development pattern under the easements absent scenario affects more fire management units, which is likely to increase the costs of fire suppression, impede efforts to implement prescribed fires and impede efforts to control wildfires.

Fire fighting logistics become more challenging in a region with scattered homes. According to the Tehama East Fire Plan, scattered development requires fire fighting forces to disperse, which prevents protection resources from organizing, and allows fires to spread and build in intensity more rapidly. Scattered development also makes rescue and evacuation efforts more difficult, heightening risk to those involved (TCRCD, 2008).

If the season of burn, fire intensity and post fire conditions are managed appropriately, prescribed fire may reduce non-native annual grasses, increase native annual grasses, and possibly increase native species richness (Reiner et al., 2007). However different plant communities in the Lassen Foothills respond variably to prescribed fire and more information is needed on the complex relationship between changing fire regimes and ecological response in the study area. Prescription fire would likely be more of a priority in the undeveloped units (Peter Hujik, former Dye Creek preserve manager, personal communication July 11, 2007). While prescribed burning would not be prohibitive with lot sizes around the general plan minimum of 64.7 ha, more tactics, resources, money, and planning are needed to reduce risk associated with prescribed burns near developed areas (Adam Wyman, Cal Fire Tehama-Glenn Unit Vegetation Management Program Coordinator, personal communication July 11, 2007). Fire suppression would become a priority for any defensible polygon with a residence, and prescription fire opportunities would be more limited (Peter Hujik, personal communication July 11, 2007). Allowing a defensible polygon to burn is not likely to be an option if a residence is present.

Under the easements present scenario, most vacant defensible polygons found within easements will remain undeveloped. As shown in Table 1, many easement agreements allow for a limited number of new homes. However this scenario does not assume that all of the easement-permitted residences will be built. Homes could be built in up to two vacant polygons contained within easement boundaries, depending on site selection and TNC approval. Taking fire planning into account when permitting new homes on easements could help preserve undeveloped defensible polygons.

5. Conclusion

Many conservation organizations focus on land acquisition because of uncertainty about natural resource protection under land use planning and regulation (Daniels and Lapping, 2005). The Nature Conservancy has articulated the importance of threat abatement in prioritizing land protection (The Nature Conservancy, 2006), but we found only minor differences in development projections resulting from the establishment of conservation easements in the Lassen Foothills. These results demonstrate that when setting land investment priorities, cost-effectiveness should be considered along with biological value, likelihood of land use change, and land use planning restrictions that aid in conservation (Newburn et al., 2005). At the landscape scale we found that easements serve to cluster development and protect large landscapes needed to implement fire management programs.

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References

- Bock, C.E., Jones, Z.F., Bock, J.H., 2006. Grasshopper abundance in an Arizona rangeland undergoing exurban development. *Rangeland Ecol. Manage.* 59, 640–647.
- Brown, D.G., Johnson, K.M., Loveland, T.R., Theobald, D.M., 2005. Rural land-use trends in the conterminous United States, 1950–2000. *Ecol. Appl.* 15, 1851–1863.
- California Department of Forestry and Fire Protection, 2006a. CalVeg, Land Cover Mapping and Monitoring Program. <http://frap.cdf.ca.gov/projects/land-cover/mapping/index.html>, November 15.
- California Department of Forestry and Fire Protection, 2006b. Fire perimeter data, Fire and Resource Assessment Program. <http://frap.cdf.ca.gov/projects/fire-data/fire-perimeters/>, November 15.
- California Department of Forestry and Fire Protection, 2007. Statistics and Events. <http://cdfdata.fire.ca.gov/incidents/incidents.stateevents>, August 18.
- Callenberger, B., Lunder, Z., 2003. Fire management plan for Inks Creek, Tuscan Buttes, Dye Creek and Vina Plains. Northtree Fire International, Marysville, California.
- Cole, D.N., Landres, P.B., 1996. Threats to wilderness ecosystems: impacts and research needs. *Ecol. Appl.* 6, 168–184.
- Daniels, T., Lapping, M., 2005. Land preservation: an essential ingredient in smart growth. *J. Plann. Lit.* 19, 316–329.
- Definiens, 2006. Definiens Professional 5 (eCognition). Denver, Colorado.
- ESRI, 1999–2006. ArcMap 9.2, ArcInfo. Redlands, California.
- Fairfax, S.K., Gwin, L., King, M.A., Raymond, L., Watt, L., 2005. Buying Nature: The Limits to Land Acquisition as a Conservation Strategy, 1780–2004. Massachusetts Institute of Technology, Cambridge, Massachusetts.
- Farm Service Agency–U.S. Department of Agriculture, 2005. Tehama County, 1-meter true color digital ortho photography, National Agriculture Imagery Program.
- Ferraro, P.J., Pattanayak, S.K., 2006. Money for nothing? A call for empirical evaluation of biodiversity conservation investments. *PLoS Biol.* 4, 482–488.
- Forman, R.T., 2006. Good and bad places for roads: effects of varying road and natural pattern on habitat loss, degradation, and fragmentation. In: Irwin, C.L., Garrett, P., McDermott, K.P. (Eds.), *Proceedings of the 2005 International Conference on Ecology and Transportation*. North Carolina State University, Raleigh, NC, pp. 164–174.
- Fraterriro, J.M., Wiens, J.A., 2005. Bird communities of the Colorado Rocky Mountains along a gradient of exurban development. *Landsc. Urban Plann.* 71, 263–275.
- Fulton, W.B., 1999. Guide to California Planning, 2nd ed. Solano Press, Point Arena, California.
- Gustanski, J.A., Squires, R.H., 2000. *Protecting the Land: Conservation Easements Past, Present, and Future*. Island Press, Washington, D.C.
- Hansen, A.J., Knight, R.L., Marzluff, J.M., Powell, S., Brown, K., Gude, P.H., Jones, A., 2005. Effects of exurban development on biodiversity: patterns, mechanisms, and research needs. *Ecol. Appl.* 15, 1893–1905.
- Hawbaker, T.J., Radeloff, V.C., Hammer, R.B., Clayton, M.K., 2004. Road density and landscape pattern in relation to housing density, land ownership, land cover, and soils. *Landsc. Ecol.* 20, 609–625.
- Hujik, P., 2000. Lassen foothills project strategic fire plan. Unpublished report to The Nature Conservancy of California.
- Irwin, E.G., Geoghegan, J., 2001. Theory, data, methods: developing spatially explicit economic models of land use change. *Agric. Ecosyst. Environ.* 85, 7–24.
- Johnson, E.J., 2002. Comment: the effect of historic parcels on agriculture—harvesting houses. *San Joaquin Agric. Law Rev.* 12, 49–86.
- Johnston, R.A., McCoy, M., Kirn, M., Fell, M., 2003. Streamlining the NEPA process through cooperative local-state-federal transportation and land use planning. In: *Transportation Research Board Annual Meeting*, January, 2004, Washington, D.C.
- Johnston, R.A., Shabazian, D.R., 2001. A detailed description of the UPlan model. <http://www.des.ucdavis.edu/faculty/johnston/pub7.htm>, February 1, 2006.
- Johnston, R.A., Shabazian, D.R., 2003. UPlan: a versatile urban growth model for transportation planning. *Transport. Res. Rec.* 1831, 202–209.
- Land Trust Alliance, 2006. 2005 National Land Trust Census. Land Trust Alliance, Washington, DC.
- Leica Geosystems GIS & Mapping, L. L. C., 1991–2003. ERDAS Imagine 8.7. Norcross, Georgia.
- Lillesand, T.M., Kiefer, R.W., 2000. *Remote Sensing and Image Interpretation*, 4th ed. John Wiley and Sons, Inc., New York, New York.
- Merenlender, A.M., Brooks, C., Shabazian, D., Gao, S., Johnston, R., 2005. Forecasting exurban development to evaluate the influence of land-use policies on wildland and farmland conservation. *J. Conserv. Plann.* 1, 64–88.
- Merenlender, A.M., Huntsinger, L., Guthey, G., Fairfax, S.K., 2004. Land trusts and conservation easements: who is conserving what for whom? *Conserv. Biol.* 18, 65–75.
- Miller, J.R., Hobbs, R.J., 2002. Conservation where people live and work. *Conserv. Biol.* 16, 330–337.
- Newburn, D., Reed, S., Berck, P., Merenlender, A., 2005. Economics and land-use change in prioritizing private land conservation. *Conserv. Biol.* 19, 1411–1420.
- Odell, E.A., Theobald, D.M., Knight, R.L., 2003. Incorporating ecology into land use planning—the songbirds' case for clustered development. *J. Am. Plann. Assoc.* 69, 72–82.
- Pincetl, S.S., 1999. *Transforming California: A Political History of Land Use and Development*. The Johns Hopkins University Press, Baltimore, Maryland.
- PMC, 2006. Draft Background Report for the County of Tehama General Plan Update. Chico, California.
- Rasker, R., Hansen, A.J., 2000. Natural amenities and population growth in the Greater Yellowstone region. *Hum. Ecol. Rev.* 7, 30–40.
- Reiner, R.J., Hujik, P.M., Pollock, J.F., 2007. Assumptions used to justify prescribed fire as a restoration tool in California annual grasslands. In: Schlising, R., Alexander, D. (Eds.), *The Vernal Pool Complexes of the Northstate: Biology, Conservation and Management Conference: Proceedings from a Conference*. Butte Environmental Council, Chico, CA, March 2006, pp. 167–174.
- Rissman, A.R., Comendant, T., Lozier, L., Kareiva, P., Kiesecker, J.M., Shaw, M.R., Merenlender, A.M., 2007. Conservation easements: private use and biodiversity protection. *Conserv. Biol.* 21, 709–718.
- Rudzitis, G., 1999. Amenities increasingly draw people to the rural West. *Rural Dev. Persp.* 14, 9–13.
- Saunders, S.C., Mislivets, M.R., Chen, J., Cleland, D.T., 2002. Effects of roads on landscape structure within nested ecological units of the Northern Great Lakes Region, USA. *Biol. Conserv.* 103, 209–225.
- StataCorp LP, 2004. *Intercooled Stata 8.2*. College Station, Texas.
- State of California Department of Finance, 2006. California County Population Estimates and Components of Change by Year, July 1, 2000–2006. <http://www.dof.ca.gov/HTML/DEMOGRAP/ReportsPapers/Estimates/E2/E-2.2000-06.asp>, February 10.
- Stephens, S.L., 2005. Forest fire causes and extent on United States Forest Service lands. *Int. J. Wildland Fire* 14, 213–222.
- Sutton, P.C., Cova, T.J., Elvidge, C., 2006. Mapping exurbia in the coterminous United States using night time satellite imagery. *Geocarto Int.* 21, 39–45.
- Syphard, A.D., Radeloff, V.C., Keeley, J.E., Hawbaker, T.J., Clayton, M.K., Stewart, S.L., Hammer, R.B., 2007. Human influence on California fire regimes. *Ecol. Appl.* 17, 1388–1402.
- Tehama County Planning Department, 2008. Draft Tehama County General Plan. Red Bluff, California.
- Tehama County Planning Department, 2000. Tehama County General Plan. Adopted March 1, 1983, Amended March 21, 2000, Red Bluff, California.
- Tehama County Resource Conservation District (TCRCD), 2008. Tehama East Community Wildfire Protection Plan and Risk Assessment With Recommendations for Fire and Pre-Fire Fuels Treatment Opportunities, Technical Review Draft. Red Bluff, CA.
- The Nature Conservancy, 2006. Conservation by design: a strategic framework for mission success. <http://www.nature.org/aboutus/howwework/cbd/files/cbd.brochure.en.pdf>, July 1.
- The Nature Conservancy, 2007. The Lassen Foothills. <http://www.nature.org/wherewework/northamerica/states/california/preserves/art6320.html>, January 20.
- The Nature Conservancy (TNC) and Tehama County Resource Conservation District (TCRCD), 2007. *Defensible Polygons*. Chico, California.
- Theobald, D.M., 2000. Fragmentation by inholdings and exurban development. In: Knight, R.L., Smith, F.W., Buskirk, S.W., Romme, W.H., Baker, W.L. (Eds.), *Forest Fragmentation in the Southern Rocky Mountains*. University Press of Colorado, Boulder, Colorado, pp. 155–174.
- Theobald, D.M., 2001. Land use dynamics beyond the American urban fringe. *Geographic. Rev.* 91, 544–564.
- Theobald, D.M., 2004. Placing exurban land-use change in a human modification framework. *Front. Ecol. Environ.* 2, 139–144.
- Theobald, D.M., 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. *Ecol. Soc.*, 10.
- U.S. Environmental Protection Agency, 2000. Projecting land-use change: A summary of models for assessing the effects of community growth and change on land-use patterns. EPA/600/R-00/098, U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

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