Habitat and open space at risk and the prioritization of conservation easements

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Abstract: Funds available to purchase land and easements for conservation purposes are limited. This article provides a targeting strategy for protecting multiple environmental benefits that includes heterogeneity in land costs and probability of land-use conversion, by incorporating spatially explicit land-use change and hedonic price models. This strategy is compared to two alternative strategies that omit either land cost or conversion threat. Based on dynamic programming and Monte Carlo simulations with alternating periods of conservation and development, we demonstrate that the positive correlation between land costs and probability of land-use conversion affects targeting efficiency using parcel data from Sonoma County, California.

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Voters passed 801 referenda in state and local ballot initiatives between 1998 and 2003 within the United States, committing more than $24 billion to fund land acquisition and easements for open space, habitat protection and other conservation objectives (Trust for Public Land 2003). Non-governmental organizations, such as The Nature Conservancy and local land trusts, have become increasing popular due to their investments in private land conservation (Merenlender et al. 2004). Nonetheless, conservation budgets are typically far less than the cost of protecting all the remaining desirable lands, and tradeoffs must be made when targeting available sites for protection.

The literature in conservation biology has focused much attention on reserve site selection (Margules, Nicholls and Pressey 1988; Pressey et al. 1993). Conservation biologists often frame the selection of reserve sites as covering the maximum number of species when constrained to select only a specified number of reserve sites. In this “site-constrained” optimization framework, a species is considered protected if it is represented at any of the chosen sites (Church, Stoms and Davis 1996).

Two extensions for the site-selection framework have been to incorporate heterogeneity in either the land costs (Ando et al. 1998) or in the vulnerability to future land-use conversion (Abbitt, Scott and Wilcove 2000; Myers et al. 2000; Margules and Pressey 2000). In the latter targeting strategy, priority sites for protection possess high benefit value and are also highly vulnerable to future land-use conversion. For instance, Abbitt, Scott and Wilcove (2000) evaluated benefits for a set of species with restricted ranges and developed a vulnerability index based on projected increases in human population and development for each county in the coterminous United States. Their “hot spots of vulnerability” are areas near major urban centers, including counties in coastal California (e.g. San Francisco, San Mateo, Contra Costa, and Los Angeles) and southeastern Florida (e.g. Broward, Dade, and Palm Beach).

In contrast, Ando et al. (1998) compared traditional “site-constrained” (benefit maximization) versus “cost-constrained” algorithms (benefit-cost maximization). They utilized county-level data on endangered species listings and agricultural land values for the coterminous United States and demonstrate that program costs for preserving species are significantly less when targeting also considers land costs. In fact, the major advantage of the “cost-constrained” solution is avoiding the enormously high cost for sites such as San Francisco County; and instead, this solution prioritizes more sites in the remote Inner Mountain West (e.g. rural counties in Idaho, Montana, and Nevada). In sum, Ando et al. (1998) and Abbitt, Scott and Wilcove (2000) provide contrary site rankings when analyzing similar data sets. The underlying reason is that land costs and likelihood of future land-use conversion are typically positively correlated. These two targeting approaches, which alternatively omit either vulnerability or land costs, will therefore lead to extreme and opposite solutions.

Costello and Polasky (2004) develop a theoretical model for dynamic reserve site selection that incorporates the benefits, land costs and vulnerability to future land-use conversion. Conservation decisions are framed in a dynamic setting since all available sites are neither immediately conserved nor developed. The authors compare targeting efficiency for several common heuristic algorithms and the optimal solution using stochastic dynamic integer programming. In all cases, they find that greater targeting efficiency can be achieved when conservation decisions are made prior to development, relying on the fact that the probability of development is non-negative for any unprotected site. Their simulation and empirical examples consider only heterogeneous benefits and probability of development, while land costs are considered homogeneous. Hence, they do not consider whether and when to conserve more vulnerable, expensive sites versus less vulnerable, inexpensive sites.[1]

This article provides a targeting strategy for protecting multiple environmental benefits that takes into account heterogeneity in both land costs and in probability of land-use conversion. This proposed strategy is compared to two alternative strategies that assume either homogeneous land costs or homogeneous probability of land-use conversion. The purpose of the study is to demonstrate how the positive correlation between land costs and probability of land-use conversion affects the efficiency of reserve site selection in a dynamic setting. Based on dynamic programming and Monte Carlo simulations with alternating periods of future conservation and development, we compared the targeting efficiency for the three site-selection rules.

The analysis was conducted for the unincorporated area of Sonoma County in California, for which developable parcels (e.g. mainly pasture and forest areas) with environmental benefits are being rapidly converted to residential use and vineyards. An environmental benefit index was formulated based on the conservation priority areas for habitat, open space and rangeland, which were designated by a local publicly funded open space district. Targeting simulations also required site-specific estimates of land costs and vulnerability for all available parcels. Tax assessor records, linked to a digital parcel map within a geographic information system (GIS), provide the necessary data on recent property sales, land use and other site information. Spatially-explicit models were used to estimate, and then predict, the conservation easement value and likelihood of land-use conversion for all developable parcels. The land-use change model was developed to estimate recent land-use transitions as a function of parcel site characteristics (e.g. land quality, accessibility to urban centers, zoning, and neighboring land use) (Bell and Irwin 2002). The value of development rights was estimated using hedonic price models on both recent sales of developable parcels and existing-use value assessments. The payment made for the conservation easement compensates the landowner for restrictions on future development (e.g. residential and vineyard uses in this example).[2]

We formulate the reserve site-selection problem as a constrained Markov decision process. For all simulations, the conservation planner receives a limited budget at the beginning of each period. Developable parcels are selected for protection, according to one of the targeting strategies, until the budget is expended. Any developable parcel that is left unprotected in each period has a probability of land-use conversion. Land-use conversion causes a loss in environmental benefits and precludes future protection. The planner's objective is to maximize the total benefits remaining at the end of the planning horizon.

The structure of the remainder of this article is as follows. In the first section, we derive the selection rules for the three targeting strategies in the single-stage case. We then generalize the targeting framework for the multi-stage case with alternating periods of conservation and development. The second section outlines the methods for the case study, including a description of the region, environmental benefits index, techniques to obtain estimates of conservation easement costs and land-use conversion probabilities, and methodology for the conservation targeting simulations and assessment. The third section provides the main results and discussion for the targeting simulations. Lastly, we provide the summary and concluding remarks.

Modeling framework for prioritizing conservation easements

Comparison of three targeting strategies for single-stage problem

In this subsection, we initially outline the targeting strategy for protecting multiple benefits that incorporates the components for both heterogeneous land costs and likelihood of conversion. The other strategies alternatively omit either one of the two latter components. The purpose here is to derive the selection rule for each targeting strategy in the single-stage problem. Then, we discuss the implications of the positive correlation between land costs and likelihood of future land-use conversion.

The conservation planner (e.g. land trust, public resource agency) prioritizes conservation easements among a set of *I* developable parcels, given a limited budget. Parcels may vary in lot area, and the benefits and costs are assumed to be homogeneously distributed within each parcel. There are multiple types of environmental benefits, which are compatible with parcels in either developable or protected status. Land-use conversion causes a full or partial loss in benefits, depending on the subsequent developed state. The planner's objective is to maximize the total benefits remaining at the end of the planning horizon.

Each developable parcel *i* has the same initial land-use state. A developable parcel may occupy only one of *K* land-use states in the following period, including: protected with a conservation easement, remain unprotected and developable, or converted into one of $K-2$ developed states. For parcel *i* at time *t*, the state vector A_t^i. The first element is the fraction developable, the last element protected, and the intermediate elements represent the developed states. In expectation, the state vector represents the proportion of the parcel in each state. The realization is that a parcel can only occupy one state. There are two developed states in the empirical analysis, residential and vineyard use respectively. Thus, the state column vector for developable parcel *i* at the initial time *t* = 1 is $A_1^i = (1,0,0,0)'$.

The planner decides which developable parcels to protect from future development. Let x_t^i be a control variable, representing the proportion of the developable parcel *i* protected in period *t* prior to future development. Let *Z* be a *K x K* matrix that changes the parcel status from developable to protected with a conservation easement. The matrix *Z* is an identity matrix except that the first column has a zero for the first element and a one for the last element. Thus, if $x_t^i = 1$ for a protected parcel, then the state after the conservation decision becomes ZA_t^i. If $x_t^i = 0$ for a parcel that is not protected, then the parcel remains in developable status.

If no conservation action is currently taken to protect a developable parcel, it may remain developable or transition into either of the two developed states. Let p_k^i represent the probability that developable parcel *i* in the current period will be in land-use state *k* in the following period. These transition probabilities differ for different parcels because of site-specific characteristics, such as land quality, accessibility to urban centers, public services and zoning. The transition to any developed state is taken to be irreversible, due to the large up-front costs necessary for conversion. Protected status on any parcel is also assumed to be irreversible, since the conservation easement is considered to be held in perpetuity.

The state equation for the two periods *t* and *t+1* is:

(1) $$A_{t+1}^i = \left(1 - x_t^i\right)\psi_{t+1,t}^i A_t^i + x_t^i \psi_{t+1,t}^i Z A_t^i,$$

where $$\psi_{t+1,t}^i = \begin{bmatrix} p_1^i & 0 & 0 & 0 \\ p_2^i & 1 & 0 & 0 \\ p_3^i & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}.$$

Hence, conditional on parcel *i* being developable and unprotected ($x_t^i = 0$), the probability of remaining developable in the following period is $p_1^i = 1 - p_2^i - p_3^i$.

Land-use conversion causes a full or partial loss in environmental benefits, depending on the relationship between the benefit type *j* and subsequent developed state *k*. There are *J* types of environmental benefits to represent the different conservation objectives. The value of benefit type *j* is denoted b_{jk}^i, given the parcel *i* is in state *k*. In the empirical analysis, there are five benefit types, respectively: two greenbelt types, two habitat types, and one rangeland type.[3] Hence, the total initial benefits on developable parcel *i* in state *k=1* are $b_1^i = \sum_{j=1}^{J} b_{j1}^i$. The benefit endowment is fully maintained on any parcel that either becomes protected or remains in developable status, so $b_4^i = b_1^i$. Any parcel converted to residential use has a complete loss in all benefit types, $b_2^i = 0$. Any parcel converted to vineyard use has a complete loss in habitat and rangeland benefits, $b_{j3}^i = 0$ for benefit types *j=3,4 and 5*. However, a parcel in vineyard use does fully maintain the greenbelt benefits, $b_3^i = b_{13}^i + b_{23}^i$. Let $B^i = \left(b_1^i, ..., b_4^i\right)$ be a row vector that represents the total benefit remaining for parcel *i* for each of the *k* land-use states.

The planner's objective is to maximize the total benefits remaining at the end of the planning horizon. For a single decision stage, the horizon is simply from *t* = 1 to *t* = 2. The planner receives a budget *M* in the current period, which is spent prior to future development. Let c_t^i denote the site-specific cost of protecting the developable parcel *i* with a conservation easement at time *t*. The cost of the conservation easement is considered to be the value of the development rights, including restrictions on future residential and vineyard development.[4] The budget constraint equation is $\sum_{i=1}^{I} x_t^i c_t^i A_t^i \le M$. The site-selection problem may be formulated as a stochastic dynamic program with only one stage remaining. In this case, the backwards induction can be solved by Lagrangian methods:

(2) $$L = \sum_{i=1}^{I} \left(\left(1 - x_t^i\right) B^i \psi_{t+1,t}^i A_t^i + x_t^i B^i \psi_{t+1,t}^i Z A_t^i \right) + \lambda \left(M - \sum_{i=1}^{I} x_t^i c_t^i A_t^i \right).$$

Maximizing *L* with respect to x_t^i gives the criterion for protecting parcel *i* in terms of the optimal shadow value λ^*:

(3) $$B^i \psi_{t+1,t}^i \left(Z - I\right) / c_t^i \ge \lambda^*.$$

Because of the linearity in the benefit and cost distributions, there is at most one parcel that will be partially protected. The numerator in (3) is the difference between the total benefits with protection and expected benefit remaining when no protection is provided. It is the expected loss in benefits and is expressed as $b_4^i - \left(b_1^i p_1^i + b_2^i p_2^i + b_3^i p_3^i\right)$. Hence, the targeting rule prioritizes parcels according to the highest expected loss in benefits per unit cost. The objective to maximize the total benefits remaining is equivalent to prioritizing parcels to minimize expected benefit loss per unit cost. This strategy is called "expected-benefit-cost" (EBC) targeting.

Now consider targeting strategies that omit either the component for land costs or likelihood of land-use conversion. The "benefit-cost" (BC) targeting strategy considers the initial endowment of benefits and land cost without taking into account the likelihood of land-use conversion. The problem formulation is to maximize the initial total benefits b_1^i, subject to the budget constraint. Thus, the Lagrangian is:

(4) $$L = \sum_{i=1}^{I} x_t^i b_1^i + \phi\left(M - \sum_{i=1}^{I} x_t^i c_t^i\right).$$

The shadow value ϕ^* is the threshold ratio, such that parcel *i* is selected for $b_1^i / c_t^i \geq \phi^*$. BC-targeting ranks parcels according the highest ratio of initial benefits to land costs. By ignoring the influence of land-use conversion, BC-targeting has implicitly set the relative conversion probability to be constant for all parcels. This presumes that high and low cost areas have the same likelihood of development. However, due to the positive correlation that exists between conversion probabilities and easement values, low cost parcels typically also have low likelihood of future conversion. BC targeting preferentially protects low cost parcels without weighting the decreased likelihood of future land-use conversion.

In contrast, "expected-benefits" (EB) targeting considers the initial benefits and likelihood of land-use conversion without taking into account the heterogeneity in land costs. The parcels are selected according to the highest expected loss in benefits, $B^i \psi^i_{t+1,t}(Z-I)$, until the budget is expended. Hence, there exists a threshold value η^*, such that parcel *i* is selected for $B^i \psi^i_{t+1,t}(Z-I) \geq \eta^*$. Because the selection rule omits the cost component, it has no mechanism to screen out parcels with extremely high cost. Since land costs and probability of conversion are highly correlated, EB targeting selects too many high costs parcels, thereby expending the budget on a small number of land parcels.

Expected-benefit-cost targeting for multi-stage problem

There are $t = 1, 2, \ldots, T$ rounds of alternating conservation and development. Conservation decisions, x^i_t, are made prior to development. The conservation budget allocated in each time period *t* is M_t. Since not all parcels can be protected in current period, the likelihood that a parcel will still be available to protect in a later period must be considered. The objective is to maximize the total benefits remaining at the end of the planning horizon in time *T+1*. The value of the objective function is $\Omega_{T+1} = \sum_{i=1}^{I} V^i_{T+1} A^i_{T+1}$, where the value of benefits remaining on parcel *i* at time *T+1* are evaluated using $V^i_{T+1} = B^i$. The four-vector V^i_t is the value of benefits on parcel *i* at time *t* for each of the four corresponding land use states.

The optimal policy with multiple stages is solved by backwards induction using the recursion relationship:

(5)
$$\sum_{i=1}^{I} V^i_t A^i_t = \max_{x^i_t} \sum_{i=1}^{I} \left\{ \left(1 - x^i_t\right) V^i_{t+1} \psi^i_{t+1,t} A^i_t + x^i_t V^i_{t+1} \psi^i_{t+1,t} Z A^i_t \right\}$$
$$s.t. \quad \sum_{i=1}^{I} x^i_t c^i_t A^i_t \leq M_t$$

Equation (5) defines V_t^i in terms of V_{t+1}^i. For developable parcels, it says that the value at time *t* is the maximum of the value at time *t+1* in two different circumstances: (1) the parcel is protected, where it will have the value of V_{t+1}^i for the protected status, and (2) the parcel is unprotected, and therefore its value is the sum over the expected land-use transition probabilities times the corresponding values of V_{t+1}^i for the other three states.

The solution to (5) yields the optimal shadow value λ_t^*, such that parcel *i* is protected if:

(6) $$\left[V_t^i \psi_{t+1,t}^i \left(Z - I\right) - c_t^i \lambda_t^*\right] A_t^i \geq 0 .$$

For each stage *t*, let G_t^i be the expression in the brackets [.] on left-hand side of (6), and let λ_t^* be the corresponding shadow value for the budget constraint M_t. If $G_t^i > 0$ then parcel *i* is protected at time *t*, indicating that $x_t^i = 1$ and $V_t^i = V_{t+1}^i \psi_{t+1,t}^i Z$. If $G_t^i < 0$ then parcel *i* is not protected at time *t*, indicating that $x_t^i = 0$ and $V_t^i = V_{t+1}^i \psi_{t+1,t}^i$. One parcel, of course, will be partially protected $x_t^i \in [0,1]$ for $G_t^i = 0$, and $V_t^i = \left(1 - x_t^i\right) V_{t+1}^i \psi_{t+1,t}^i + x_t^i V_{t+1}^i \psi_{t+1,t}^i Z$.

While value of the objective function is straightforward to compute, the optimal policy cannot be feasibly enumerated for a large number of sites. In the empirical analysis, there are more than 16,000 developable parcels with four land-use states and multiple stages. Using the recursion relationship above, the dimensionality of the problem has been reduced to a set of optimal shadow values λ_t^* for *t=1,2,…, T*. The shadow value in stage *t*, however, depends on which parcels have already been protected and developed prior to this stage. In other words, the state vector A_T^i is needed to determine λ_T^* and solve the problem by backward induction, but the optimal set of λ_t^* for all stages is needed to find A_T^i. Numerical methods were used to approximate the set of optimal shadow values.

Equation (6) provides intuition for the multi-stage problem. Consider the problem with three stages, *t=1,2,3*. When parcel *i* is left unprotected for all three stages, then $V_1^i = V_4^i \psi^{i(3)}$, where $\psi^{i(3)} = \psi_{4,3}^i \psi_{3,2}^i \psi_{2,1}^i$. Meanwhile, if the parcel *i* is protected in the second stage then $V_1^i = V_4^i \psi^{i(2)} Z \psi^{i(1)}$, signifying that the parcel was unprotected during the first round of development and protected for the final two rounds. The $\psi^{i(1)}$ term determines the expected likelihood of land-use conversion for the first period. After the first period, however, the parcel *i* either remains in developable status with the initial benefit endowment or it has already been developed. Therefore, this term determines the expected probability that the parcel would still be available to protect in the second period. Now consider two parcels *i* and *j*, where the ratio of initial benefits to land costs is equal for both parcels. However, parcel *i* has low benefits and low land costs, while parcel *j* has high benefits and high land costs. Because higher cost parcels typically have higher probability of development, assume that parcel *j* has higher probability of future land-use conversion. Since $\psi^{j(1)}$ indicates a higher expected probability of land-use conversion than $\psi^{i(1)}$, parcel *j* is less likely to be available to protect later and should be prioritized ahead of parcel *i*.

Empirical procedure

Research study area

Data from Sonoma County in California are used to demonstrate the efficiency and implications of the three targeting strategies. The region is situated roughly 50 miles north of San Francisco. Sonoma County, together with neighboring Napa County, is the premium wine grape-growing region in the United States. There is a strong local economy centered on the wine industry, tourism and, until recently, a growing high-tech industrial base.

The empirical analysis was done for Sonoma County, leaving out the nine incorporated cities. This mostly rural area represents 94 percent of the county's total area (~ 4,000 km^2) and is characterized by relatively high rates of land conversion to vineyard and low-density residential uses. Residential use is considered here as any parcel with the housing density greater than or equal to 1 housing unit per 5 acres. As of 2000, almost one-quarter of the study area had been converted to residential (12 %) and vineyard (11 %) uses. The remaining "developable" land is defined to include the following land uses: pasture (30 %), chaparral/shrub (13 %), timber (12 %), vacant residential (5%), and very-low density residential (4%).[5] Most land is held in private ownership (>90%), and vineyards and residential uses compete for developable parcels. For this reason, the main land uses are separated into three groups – residential, vineyard, and undeveloped.

Environmental benefits index

The multiple conservation objectives being considered are priority habitat, greenbelt, and rangeland areas. The Sonoma County Agricultural Preservation and Open Space District (SCAPOSD) has prioritized these environmental benefits in their Acquisition Plan 2000.[6] Hence, this study is framed as one of choosing parcels such that when the parcel is located within one of these priority areas, then the environmental benefit value is equal to one for this benefit type and otherwise set to zero if located outside. Forested areas are divided into two main priority habitat types – oak woodlands and conifer – which are mutually exclusive. These habitat areas were designated by scientists and local forestry experts using a GIS and a set of landscape criteria (SCAPOSD Acquisition Plan 2000).

Two priority greenbelt zones were established by the SCAPOSD to preserve open space adjacent to cities and for scenic landscape units, such as Sonoma Mountain. These "priority" and "expanded" greenbelt categories are also mutually exclusive. Lastly, priority rangeland is specified by grass land cover in a region known for its high site productivity for livestock grazing and dairy farming. In sum, the maximum number of overlapping benefit types is three; for example, a parcel that is located in the priority conifer habitat, rangeland, and a greenbelt zone.

A more generalized benefit function could potentially incorporate more complex factors where appropriate, such as additive benefits from protecting adjacent parcels. Reserve site-selection models that incorporate spatial attributes and connectivity for protected areas has been studied, particularly by conservation biologists, who recognize the need for viable core habitat areas and species migration (Briers 2002; Williams, Revelle and Levin, forthcoming). The current benefit data set, as provided by the SCAPOSD, has limited information to evaluate these additive effects without employing ad hoc weighting factors for spatial connectivity, which we did not want to employ.

Land-use change model

A spatially explicit land-use change model is constructed using parcel-level data (Bell and Irwin 2002). The model is conditioned on the initial land-use state, taken as "developable" parcels in 1990. This excludes those lands protected in parks and reserves and parcels already converted to residential, vineyard or other high-intensity land uses prior to 1990 based on existing land-use maps. Land-use conversion is defined as transitions from developable parcels in 1990 to either residential or vineyard use during the period 1990-2000. Residential and vineyard uses have much higher revenues relative to extensively managed land uses, such as grazing. The conversion decision is considered irreversible due to the substantial up-front fixed costs.[7]

Given the three possible land-use outcomes over the period 1990-2000, a multinomial logit model was employed to explain land-use transitions as a function of parcel site and neighborhood characteristics. The Sonoma County Tax Assessor's Office database provides the land-use data source, which was linked to the digital parcel map within a GIS.[8] Parcel boundaries permitted the overlay and extraction with GIS layers to obtain many site and neighborhood characteristics on land quality, accessibility to urban centers, public water and sewer services, zoning and neighboring land use. For example, average percent slope and elevation in meters was calculated for each parcel. Growing-degree days, summed over the April to October vineyard growing season, serves as a proxy for microclimate. A dummy variable was used to represent whether a given parcel is situated within the 100-year floodplain. An optimal routing algorithm within the GIS was used to calculate the minimum travel time in minutes between each parcel and San Francisco along the road network, utilizing weighted travel speeds of 55 mph on major highways and 25 mph on county roads.

Two types of zoning regulations were taken from the 1989 Sonoma County General Plan – land-use designations and zoned minimum lot size. The 1989 General Plan was used since these zoning designations were set prior to the period utilized to model land-use change in 1990-2000. This reduces the potential for endogeneity between land use and zoning. The six zoning designation categories are (in order from highest to lowest residential density): urban residential, rural residential, diverse agriculture, land intensive agriculture, land extensive agriculture, and resource and rural development. Zoned minimum lot size is included as another proxy for potential residential development, represented in natural log form. A dummy variable was used to specify whether a given parcel is located within the existing 1989 urban service area (e.g. sewer and water utilities). Residential development is expected to be more likely in places with access to public water and sewer service. However, it should be noted that rural residential homes built in the unincorporated areas are often privately serviced by groundwater wells and septic tanks.

A set of explanatory variables was used to assess the amenities (or disamenities) created by the neighboring land uses that surround each developable parcel. The percentage of neighboring land uses were calculated within a given radius of the parcel for three categories: protected open space, vineyards, and urban development. Protected open space consists of parks, reserves, and easements. Meanwhile, urban development includes higher-intensity uses, such as residential, commercial and industrial parcels. Land use data in 1990 was used to obtain temporally-lagged development patterns, which exist prior to the 1990-2000 period used to model land-use change.

The land-use change model was estimated with multinomial logit. Logit parameters are potentially biased in the presence of spatially autocorrelated errors. Full spatial error correction for discrete-choice models using Gibbs sampling or EM algorithm are too computationally intensive for data sets larger than several hundred observations (Fleming 2004). For a similar land-use change model, Carrion-Flores and Irwin (2004) implemented a "workaround" method, originally proposed by Besag and Moran (1975). This method creates a subsample by removing nearest neighbors within a fixed distance. The justification is that the spatial autocorrelation in the residuals is likely to be lower if the samples used for estimation are farther apart. We repeated this "workaround" method on our parcel-data set and found that it induced severe sample-selection bias by preferentially removing smaller sized parcels that tend to be closer together. In the spirit of Besag and Moran, we estimated logit on random stratified bootstrapped samples taken from the full data set. These samples did not have sample-selection bias and had less spatial autocorrelation than the full sample, because the parcels were farther apart. Cross-validation techniques showed that the "workaround" method produced markedly inferior predictions when compared to random stratified bootstrapped samples, 62 % and 68 % overall prediction accuracy, respectively. This bootstrapped subsampling technique did not have noticeably different parameter estimates or prediction errors as compared to standard logit estimation. Hence, the estimated model, reported in table 1, is the standard multinomial logit based on the full sample.

Estimation results for the land-use change model in table 1 indicate that conversion to vineyard use is more likely on areas with lower slope and higher growing-degree days (warmer microclimate). Steeper slopes raise expected vineyard establishment costs and lower grape yields, while cooler coastal microclimates are less likely to allow grapes to reach maturity. Vineyards are also more likely in areas designated for “land intensive agriculture” or “diverse agriculture” under the 1989 General Plan. These zoning designations correspond to the prime agricultural areas within the County, and future residential development is highly restricted.

Residential conversion is more likely in areas zoned for rural or urban residential, the baseline zoning category in table 1, and more likely on parcels zoned for smaller minimum lot sizes. The importance of zoning for residential conversion is clear since higher density zoning increases rents per acre associated with residential uses. Areas with access to urban services are estimated to be more likely to be developed for residential use, whereas residential conversion is less likely on steeper slopes and within the 100-year floodplain. Residential use was expected to have higher likelihood in the southern region of Sonoma County; however, the estimate coefficient for travel time to San Francisco is positive. The percentage of neighboring 1990 urban development increases the likelihood of residential conversion, whereas the percentage of protected open space did not appear to significantly affect residential conversion.

For all targeting simulations, developable parcels remaining in 2000 serve as the complete set of sites with environmental benefits to be targeted for protection. Estimated coefficients from the multinomial logistic regression in table 1 are employed to predict the relative probability of land-use change, since the site characteristics for all parcels are known within the GIS. For this prediction phase, explanatory variables for percentages of neighboring land uses are updated from 1990 to 2000. The model output is the relative probability of future residential and vineyard development for each of the 16,773 developable parcels.

Valuation of development rights model

The value of development rights (VDR) is the amount by which the value of developable land exceeds its value restricted to its current use. The valuation of developable land is estimated from recent sales of developable properties in 2000. The Sonoma County Tax Assessor's Office database provides the necessary information on individual parcels for the land value, existing-use value assessment, and other property characteristics.[9] A hedonic price model for the developable land value is determined as a function of heterogeneous parcel site characteristics. The hedonic model is specified with a semilog functional form, in which the dependent variable is taken as the natural log of the land value per acre. The same explanatory variables affect both land values and land-use conversion probabilities.

The hedonic analysis was initially modeled using ordinary least squares estimation. The OLS residuals were tested for spatial autocorrelation using the Moran I statistic (Cliff and Ord 1981). The null hypothesis (i.e. no spatial autocorrelation) was rejected by the Moran I statistic ($p < 0.001$). Therefore, a spatial autoregressive (SAR) model was used (Anselin 1988). Formally, the vector of error terms ε is written as:

$$\varepsilon = \rho W \varepsilon + u \,, \tag{7}$$

where ρ is the spatial autoregressive parameter, W is a nearest neighbor weights matrix, and u is a vector of i.i.d. errors with variance σ^2. The SAR residuals had no further spatial autocorrelation. Hedonic estimation results for the SAR model are reported in table 2a.

Developable land value per acre is significantly lower for areas in which land quality, accessibility, or zoning regulations, limit the economic returns to higher-intensity uses (table 2a). Steeper slopes on developable parcels raise conversion costs and reduce the number of potential home sites. Areas within the 100-year floodplain have lower land values, due to risk of property loss and restrictions on future development. Remote areas, particularly in northwestern Sonoma County, have longer travel times to the greater Bay Area metropolitan region, which lowers developable land values. Land extensive agriculture zoning typically restricts residential development, thereby reducing land values. Regions of the County zoned for large minimum lot sizes have significantly reduced land values. Land values are higher in areas with access to urban services, namely public water and sewer. There is also a significant and positive amenity effect for coastal properties that are within 1 kilometer of the Pacific Ocean. The amenity effect associated with spatial externalities from neighboring protected areas, vineyards and urban development were all found to be insignificant.

Existing-use value assessments, obtained from developable parcels enrolled in the Williamson Act, provide the baseline for the land value restricted from future development. The Williamson Act, a tax differential program for rural landowners, changes the basis of property tax liability to the existing-use value rather than the full assessment value, in exchange the state government holds the lease on development rights for a 10-year contract period.[10] Similar to the method applied to developable land values, the SAR model is used to estimate the existing-use value per acre as a function of site characteristics. Site characteristics include land quality factors and travel time to urban centers, the latter serving as a proxy for accessibility to output and input factor markets. Zoning and neighboring land-use variables are omitted here since they should not be important for farm-based returns.

Hedonic estimation results for existing-use value assessments are presented in table 2b. Existing-use value, mainly from either grazing or forestry, is reduced significantly on parcels with steeper slope and in higher elevation areas, another proxy for steepness. Farm-based returns are also lower in remote areas, presumably due to higher transaction costs for poor market accessibility. While the existing-use value assessments vary somewhat throughout the County, developable land values vary to a much greater degree.

For the purposes of targeting analysis, hedonic coefficient estimates in table 2a and parcel site characteristics in the GIS both are used to estimate the expected land value for each developable parcel remaining in 2000. The same procedure is used to predict the expected existing-use value from the hedonic coefficient estimates in table 2b. Finally, the expected VDR is determined for each of the 16,773 developable parcels in 2000, calculated as the difference between the estimated values for developable land and existing-use value.

Targeting scenarios and assessment

Dynamic programming and Monte Carlo simulations are performed to compare the efficiency of the selection rules for the three strategies: EBC, EB, and BC targeting. For all targeting simulations, the set of initial sites is always the developable parcels in the year 2000. The time horizon is always thirty years divided into three periods, and each period is one decade because the land-use change model is based on 1990-2000. The conservation budget is the approximately $10 million that the SCAPOSD raises annually from the ¼ percent sales tax levied by a 1990 Sonoma County ballot initiative. Thus, the conservation budget per decadal period is $100 million. Conservation decisions always precede development in each period. For simplicity, the state transition matrix and relative land costs are assumed here to be constant in each time period. Later, we relax this assumption to allow the probability of land-use conversion to increase proportionally on unprotected parcels, due to the land supply restrictions from protected parcels.

The optimal way to choose parcels for conservation is the dynamic EBC procedure. As described above, the optimal control is characterized by the value of the three λ_t parameters. To find these values, we solved the dynamic program as a linear program. The solution yields the values of λ_t for an open-loop control. We used these values in a dynamic simulation and discovered that the values for the closed-loop control are extremely close to the solution for the open-loop control. With these values of λ_t from the open loop control, we computed G_t^i as described in (6) and the following text. The values of G_t^i gives the ranking rule for the dynamic EBC procedure. That is, parcels with higher *G* values are protected before those parcels with lower *G* values. The ranking rules for the other two procedures can be viewed as modifications of *G*. For EB targeting, set $\lambda_t = 0$ so that ranking is only based on the highest expected loss in benefits, and costs are not used to determine rankings. For BC targeting, set the state transition matrix $\psi_{t+1,t}^i$ to have equal state transition probabilities for all parcels, and hence, the probability of land-use conversion does not affect the rankings. These procedures provide the multi-period ranking rules for each of the three selection criteria.

The dynamic simulations were performed separately according to each of the three targeting strategies. First, one of the three ranking rules was used to select parcels for protection until the budget in the first period was expended.[11] Then, each unprotected, developable parcel was either left to remain in developable status or assigned to vineyard or residential use, based on a draw from a random number generator and the site-specific conversion probabilities determined in the land-use change model. This completes one period of conservation and development for the targeting simulation. For the remaining developable parcels, the procedure was repeated two more times, for a total of three decadal periods. The simulations were repeated 1000 times for each strategy to obtain averages for all variables used in targeting assessment.

The targeting strategies were assessed according to the total benefits remaining after three periods of conservation and development. Each targeting strategy was compared relative to the same "business as usual" (BAU) scenario, in which no conservation purchases occur. Parcels protected under each targeting strategy were also compared for characteristics, including the percentage of total initial benefits acres protected, average residential, and vineyard conversion probabilities and average easement cost per acre.

Results and discussion on targeting simulations

The objective of SCAPOSD is to maintain land in non-developed uses within the designated conservation priority areas. Even after simulations for a thirty-year period of development and a $300 million conservation easement program, most of the land in the conservation priority areas is neither conserved nor developed. Hence, it is important to consider not only what is protected, but also what land remains undeveloped when no conservation action is taken. The advantage of the EBC selection criteria over the standard BC criteria and the non-economic EB criteria is that EBC targeting adroitly balances the tradeoffs between the probability of land-use conversion and cost of land protection. Because these three targeting methods evaluate the tradeoffs among costs and probability of land-use conversion in a different manner, they select different types of parcels for protection.

Table 3 summarizes the benefits for parcels protected under each targeting strategy after three periods, and table 4 provides the average conservation easement costs and probability of land-use conversion for these corresponding parcels. BC targeting protects the largest percentages of both land area and total initial benefit acres, 11.0 and 14.3 percent, respectively. In fact, BC targeting protects a higher percentage of benefit acres than EBC targeting for all benefit types. EB targeting protects dramatically lower percentages of benefit acres for all types in comparison to either BC or EBC targeting. The reason is that EB targeting initially protects the most vulnerable parcels on the urban fringe without consideration of land costs. The average probability of residential conversion per period is 0.273 for protected parcels under EB targeting; however, the corresponding land values are too expensive with an average easement cost of $212,045/acre (table 4). The inset on figure 1a shows protected parcels for the region surrounding the incorporated cities of Petaluma, Cotati and Rohnert Park. These parcels are within the expanded greenbelt and rangeland conservation priority areas. They are also the most vulnerable and expensive parcels due to the site characteristics, including flatter slopes, access to urban services, and zoning regulations permitting urban and rural residential development.

BC targeting takes the contrary approach to EB targeting, initially protecting large tracts of the low cost land. The average easement cost for the protected parcels after three periods is only $4,573/acre (table 4). In particular, BC targeting selects a much higher percentage of the conifer habitat type than either EBC or EB targeting, respectively 19.7, 7.2 and 0.0 percent (table 3). Priority conifer habitat is located mainly in the remote, mountainous area of northwest Sonoma County (figure 1b). The vast majority of parcels in this area have average slopes exceeding 30 percent and greater than 100-acre minimum lot size zoning regulations. Steeper slopes and cooler microclimates within this coastal region typically create unsuitable conditions for vineyard production. Additionally, future residential development is much less likely due to steeper slopes and stricter zoning regulations. EBC targeting takes into account the very low development potential and prioritizes fewer parcels with conifer habitat benefits. Rather it allocates a higher proportion of the conservation funds to initially protect parcels with oak habitat benefits, located in the northeastern region of Sonoma County (figure 1c). Oak woodland parcels protected under EBC targeting are more suitable to land-use conversion as a result of moderate slopes, warmer microclimates, and proximity to the main highway corridors. These parcels have moderate likelihood of conversion, particularly for vineyard development (p = 0.057), but relatively low easement values $7,881/acre (table 4). In sum, parcel maps shown in figures 1a, 1b and 1c demonstrate that the targeting strategies protect unique sets of sites with different benefits distributions. EBC targeting protects 277 parcels as compared to 437 protected by BC targeting, but the two targeting strategies protect only 108 parcels in common. Even more dramatically, EB targeting protected 626 parcels, but only one parcel is protected in common with EBC targeting and none with BC targeting. The reason is that the land cost and probability of land-use conversion are positively correlated, specifically with a 0.88 correlation coefficient.

Table 5 provides the total remaining benefits after three periods, reported as the difference between each targeting strategy and the same business as usual scenario. EBC targeting achieves higher total benefit remaining after three periods than either BC targeting or EB targeting, respectively 5289, 3965, and 1299 benefit acres. While table 5 only reports the results after three periods of conservation and development, we performed additional simulations that used different time lengths for the planning horizon, including simulations with one and five periods. For all simulations, EBC targeting has a higher total remaining benefits than the other two strategies, and the absolute difference increases through time. EB targeting achieves higher benefits remaining in expanded greenbelt and rangeland benefit types, but at the expense of much lower oak and conifer habitat protection (table 5).

There are two main reasons why EBC targeting achieves higher total remaining benefits than BC targeting. First, BC targeting initially protects the least vulnerable, inexpensive sites, without considering that some desirable and more vulnerable sites will not be available in later periods. EBC targeting initially protects the parcels with greater, but still moderate, vulnerability as compared to BC targeting. For instance, the average probability of vineyard conversion is more than three times higher for parcels protected under EBC targeting versus BC targeting after five periods, p=0.057 and p=0.016 respectively (table 4). Average easement costs for EBC targeting meanwhile are only 72 percent higher than BC targeting, $7,881/acre and $4,573/acre. Hence, the EBC targeting strategy is more likely to protect the less vulnerable parcels in later periods, or perhaps even decide to leave them unprotected.

Second, BC targeting protects some parcels with poor land quality or strict zoning regulations which have *de facto* conservation, and thus do not warrant being targeted despite the low costs of protection. For example, BC targeting protects a slightly higher percentage of oak habitat benefits than does EBC targeting, 20.4 and 18.9 percent, respectively (table 3). However, EBC targeting achieves almost twice the total remaining oak habitat benefits in comparison to BC targeting, 4244 versus 2306 benefit acres respectively (table 5). The reason is that BC targeting initially selects the parcels in the oak habitat conservation priority area that are located on the steepest slopes. Hence, targeting strategies should consider that the majority of benefits typically will exist outside of protected areas, since most land is neither protected nor developed even after several periods. This concept is not fully appreciated by a targeting strategy using static benefit-cost maximization (Ando et al. 1998).

It is also important to understand that easements typically only have a marginal impact on land development for any type of targeting strategy. Conservation easements are parcel-by-parcel land-supply restrictions, but they may not be an effective way to shape future regional growth patterns. EB targeting, for instance, tends to protect land within urban fringe areas, a strategy recommended by some conservation biologists (Abbitt, Scott and Wilcove 2000). To some extent, land-supply restrictions will increase the probability of land-use conversion on the remaining developable and unprotected parcels. For instance, Wu (2000) demonstrated that the slippage effect may result in a 9 to 14 percent loss of environmental benefits achieved for land retirement payments under the Conservation Reserve Program.

Consider an upper bound estimate on the slippage effect. This case would occur when regional demand for land is perfectly inelastic, and the land supply is highly elastic. For this case, the amount of land converted under the business as usual scenario is held constant, despite land protection on some parcels. It is now assumed that the probability of land-use conversion would increase proportionally on the remaining unprotected parcels. The upper bound estimates on slippage reduces the total benefits remaining for the three strategies by 51 percent for EB targeting, 39 percent for EBC targeting, and 33 percent for BC targeting. Hence, EB targeting originally had the lowest level of total benefits remaining in table 5, and after considering slippage, it also has the largest percentage loss in program efficiency. In comparison, EBC and BC targeting protect parcels with relatively low probability of land-use conversion. However, both strategies have notable slippage due to the moderately large percentage of land supply protected. Overall, EBC targeting still achieves a higher total remaining benefits than BC targeting after considering slippage, but the difference is somewhat reduced.

It should be noted that these estimates on the slippage effect are the upper bound, and there are several reasons to expect less significant efficiency losses. For instance, when the land supply is restricted within the unincorporated region, land prices will increase and some future residential development will shift to the incorporated cities or to other neighboring regions. Additionally, Sonoma County wine grapes are sold for the premium wine market that includes other domestic and foreign wine-growing regions. The amount of land supply restricted under a local conservation easement program is unlikely to cause a major price effect in the global premium wine grape market, and hence there is likely no upward shift in demand for vineyard acreage.

Another notable topic to consider is the connectivity of protected areas and how land development causes fragmentation within the priority conservation areas. The parcel maps in figures 1a, 1b and 1c show that protected parcels are often clumped, even when the environmental benefit index does not weight for spatial connectivity. If the environmental benefits index were to include additive weights for spatial agglomeration, then of course, the parcels selected for protection would be even more clumped. The main reason for the currently observed clumping is that land characteristics that influence the conservation priorities, such as steep slopes, distance to urban centers, or zoning designations, are often similar across areas that are much large than parcel boundaries. It is revealing to consider the urban fringe area (inset on figure 1a). This is most challenging area to achieve connectivity since it has a significant amount of prior land development. Hence, the EB targeting strategy is operating in a heavily fragmented area, and moreover, the high probability of future residential conversion leads to a higher rate of future fragmentation.

Conclusion

Results from targeting simulations demonstrate that conservation strategies to protect environmental benefits must consider the positive correlation between land costs and likelihood to future land-use conversion. The expected-benefit-cost targeting strategy proposed here aims to minimize the expected loss in benefits per unit cost, resulting in a more efficient allocation of conservation funds. The two targeting strategies that alternatively assume either homogeneous land costs or likelihood of future conversion result in contrary and inefficient site rankings. Benefit-cost targeting, which ignores the vulnerability of benefits to future land-use conversion, is biased toward initially protecting low-cost sites (figure 1b). Some parcels with poor land quality or strict zoning regulations are under *de facto* conservation due to their very low probability of conversion, and therefore do not warrant being targeted despite the low cost of protection. Timing of conservation decisions is also crucial. The benefit-cost strategy initially protects the least expensive parcels in the hinterlands and does not consider that some desirable and more vulnerable parcels may not be available to protect in later periods.

In contrast, expected-benefits targeting, which assumes homogeneous land costs, is biased toward initially protecting the most vulnerable sites on the urban fringe (figure 1a). However, the corresponding selection rule does not have a threshold on land costs to screen out the extremely expensive parcels. Parcels on the urban fringe with greenbelt benefits are most expensive to protect because these areas have better access to urban services, flatter slopes, and zoning permitting urban and rural residential development. Since land is very expensive only a small amount of land area may be protected, and to some extent, development will shift to unprotected parcels. This slippage effect is larger for expected-benefits targeting than for either of the other two targeting strategies. Expected-benefits targeting also has the greatest challenge in achieving spatially connected protected areas, because the urban fringe area has the largest amount of prior development and highest rate of future land-use conversion.

In conclusion, easement programs are not typically suited for containing development on the urban fringe. Public-infrastructure projects and land-use plans are necessary to guide regional development patterns. For instance, Irwin, Bell and Geoghegan (2003) demonstrate that extending public sewer and water infrastructure may guide urban growth to designated target areas more effectively than placing easements on existing rural areas. Nonetheless, programs to purchase development rights are an important component for protecting areas with high environmental benefits, particularly in areas with historic rights for rural residential development.

Footnotes

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[1] It should be noted that the relationship between land costs and vulnerability is not expected to be perfectly linear. Otherwise, land costs and vulnerability components would negate each other, and priority setting could focus exclusively on benefits.

[2] These programs to purchase easements are increasingly being used to protect environmental quality and landscape amenities, since they are less costly than outright land acquisition (Buist et al. 1995).

[3] This formulation is analogous to the environmental benefit index employed in the Conservation Reserve Program, administered by the United States Department of Agriculture.

[4] The full costs to acquire the easement may include additional management and transaction costs, which are not included here.

[5] Other "developable" land uses include dairy (2.8 %), field crops (1.6 %), orchard (0.4 %) and horse farms (0.2 %). The remainder of the study area contains mainly state and local parks, private energy-producing facilities (e.g. hydroelectric dam, geothermal area), and non-residential urban development (e.g. industrial, commercial, etc.).

[6] SCAPOSD, a local conservation agency, was established through a 1990 Sonoma County voter ballot initiative. This publicly funded agency meets its conservation objectives via land acquisitions, and more often, easement contracts (for details on the SCAPOSD: Acquisition Plan 2000 see their website at http//:www.sonoma-county.org/opensp).

[7] The number of vineyards replaced by residential development is negligible, due to large establishment costs and high annual revenue for vineyards (mean annual revenue = $9,237 per acre in year 2000).

[8] There are cases in which vineyard and residential uses occur on the same parcel. The tax assessor land use classification attempts to clarify this issue by defining the dominant land use with a list of sub-land uses where appropriate.

[9] In order to ensure that land value data reflects market value for developable land, the following rules were used to screen transactions prior to analysis: 1) parcel must be in the "developable" land use state and no residential structures exist on the property in 2000; 2) all transactions occurred in 2000 to represent market conditions during the time the study was conducted; and 3) a full change in ownership had to take place so that the transaction indicates the sale price. Land value is derived from the total value at the sale date minus structural value (e.g. non-residential farm buildings) and other improvements.

[10] Since the contract is a lease on development rights, rather than conservation being guaranteed in perpetuity, the properties remain at risk of land use conversion in the future. Thus, parcels enrolled in the Williamson Act are considered "developable" for targeting purposes.

[11] If exact expenditure of the budget required the purchase of a partial parcel, that parcel was not purchased and the remaining balance was rolled over to the next period.

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Table 1: Multinomial Logit Model for Land-Use Change in 1990-2000: Sonoma County, California (Baseline Land Use Category = Developable Parcels)

Variable	Coefficient	Std. error	Pr(>|t|)
Vineyard			
Slope	-0.0596	0.0065	0.0001
Growing-degree days	1.2418	0.1545	0.0001
Elevation	-0.0003	0.0005	0.6180
Within 100-year floodplain	-0.4844	0.2472	0.0500
Travel time to San Francisco	0.0118	0.0038	0.0020
Zoning type (1989 General Plan) [1]			
Resource and rural development	0.3611	0.2452	0.1410
Land extensive agriculture	0.5267	0.3035	0.0830
Land intensive agriculture	1.3902	0.2171	0.0001
Diverse agriculture	1.0061	0.1615	0.0001
Ln(zoned minimum lot size)	0.1034	0.0811	0.2020
Within urban service areas	-1.5443	0.4270	0.0001
Neighboring land use in 1990			
% Protected open space within 500m	-0.0253	0.0067	0.0001
% Developed within 500 m	-0.0241	0.0042	0.0001
% Vineyard within 500 m	0.0025	0.0046	0.5880
Constant	-3.4039	0.2779	0.0001
Residential			
Variable	**Coefficient**	**Std. error**	**Pr(>|t|)**
Slope	-0.0306	0.0032	0.0001
Growing-degree days	-0.1167	0.0963	0.2260
Elevation	-0.0001	0.0005	0.7720
Within 100-year floodplain	-1.5115	0.2262	0.0001
Travel time to San Francisco	0.0101	0.0024	0.0001
Zoning type (1989 General Plan) [1]			
Resource and rural development	-0.7389	0.1807	0.0001
Land extensive agriculture	-0.3483	0.2947	0.2370
Land intensive agriculture	-0.5493	0.2526	0.0300
Diverse agriculture	-0.3161	0.1118	0.0050
Ln(zoned minimum lot size)	-0.3201	0.0348	0.0001
Within urban service areas	0.3688	0.0847	0.0001
Neighboring land use in 1990			
% Protected open space within 500m	0.0009	0.0029	0.7430
% Developed within 500 m	0.0123	0.0020	0.0001
% Vineyard within 500 m	0.0110	0.0050	0.0270
Constant	-2.0401	0.1734	0.0001
N = 17,130 parcels			
Likelihood ratio = 2734.04			

[1] Zoning baseline type = rural and urban residential

Table 2a: Hedonic Coefficient Estimates for Developable Land Value in 2000 using Spatial Autoregressive (SAR) Error Model

Variable	Coefficient	Std. error	Pr(>|t|)
Slope	-0.0295	0.0036	0.0001
Growing-degree days	0.0768	0.1216	0.5278
Elevation	-0.0012	0.0005	0.0103
Within 100-year floodplain	-1.3373	0.2781	0.0001
Within 1 km to coastline	0.9694	0.1825	0.0001
Travel time to San Francisco	-0.0061	0.0032	0.0563
Zoning type (1989 General Plan) [1]			
Resource and rural development	-0.1568	0.1804	0.3851
Land extensive agriculture	-0.6536	0.2788	0.0194
Land intensive agriculture	-0.0302	0.3013	0.9203
Diverse agriculture	0.0651	0.1632	0.6902
Ln(zoned minimum lot size)	-0.2652	0.0479	0.0001
Within urban service areas	0.5318	0.1331	0.0001
Neighboring land use in 1990			
% Protected open space within 500m	-0.0005	0.0042	0.8978
% Developed within 500 m	-0.0001	0.0032	0.9665
% Vineyard within 500 m	0.0055	0.0092	0.5487
Constant	11.8923	0.2325	0.0001

ρ = 0.201 (Spatial correlation coefficient)

N = 628 parcels   Log-likelihood = -1967

R-squared = 0.675

Dependent variable = Ln(land value per acre)

[1] Zoning baseline type = rural and urban residential

Table 2b: Hedonic Coefficient Estimates for Existing-Use Value using Spatial Autoregressive (SAR) Error Model

Variable	Coefficient	Std. error	Pr(>|t|)
Slope	-0.0199	0.0023	0.0001
Growing-degree days	-0.5406	0.0650	0.0001
Elevation	-0.0015	0.0002	0.0001
Within 100-year floodplain	0.0372	0.1495	0.8036
Travel time to San Francisco	-0.0204	0.0015	0.0001
Constant	6.7273	0.0791	0.0001

ρ = 0.438 (Spatial correlation coefficient)

N = 887 parcels   Log-likelihood = -2487

R-squared = 0.776

Dependent variable = Ln(existing-use value per acre)

Table 3: Percentage of Initial Benefit Acres Protected under each Targeting Strategy after Three Periods of Conservation and Development

	Protected benefit acres (% of initial benefit acres)			**Initial benefit acres** (acres)
Benefit type	**Expected-benefits-cost targeting**	**Benefit-cost targeting**	**Expected-benefit targeting**	
Total benefits	9.7	14.3	0.6	592,029
Oak habitat	18.9	20.4	0.4	187,496
Conifer habitat	7.2	19.7	0.0	165,043
Rangeland	1.3	2.3	1.2	82,827
Priority greenbelt	4.2	4.7	0.2	93,044
Expanded greenbelt	8.6	11.8	2.2	63,619
Land area	7.2	11.0	0.3	654,104

Table 4: Average Conservation Easement Costs and Probability of Land-Use Conversion for Protected Parcels under each Targeting Strategy after Three Periods of Conservation and Development

	Protected parcels		
	Expected-benefits-cost targeting	**Benefit-cost targeting**	**Expected-benefit targeting**
Easement cost ($/acre)	7,881	4,573	212,045
Pr(vineyard)	0.057	0.016	0.012
Pr(residential)	0.010	0.007	0.273

Table 5: Total Remaining Benefits for each Targeting Strategy with respect to Business as Usual Scenario: After Three Periods of Conservation and Development

Benefit type	**Expected-benefit-cost targeting** (acres)	**Benefit-cost targeting** (acres)	**Expected-benefit targeting** (acres)
Total benefits	5289	3965	1299
Oak habitat	4244	2306	294
Conifer habitat	691	1266	59
Rangeland	107	167	357
Priority greenbelt	111	106	87
Expanded greenbelt	137	121	503

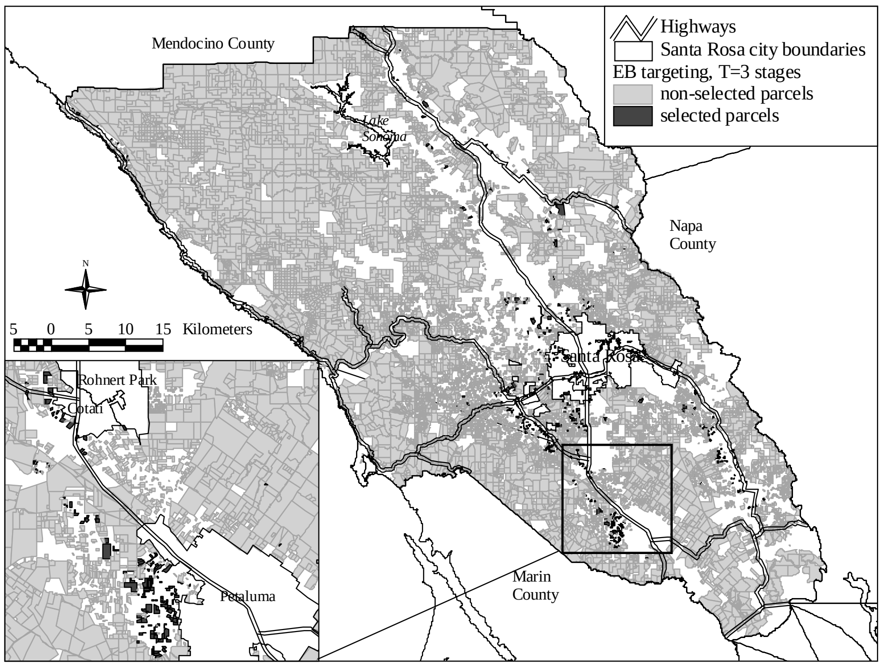

Figure 1a: Parcels protected under expected-benefits (EB) targeting after three periods
Note: Parcel boundaries are masked out in white for non-developable areas.

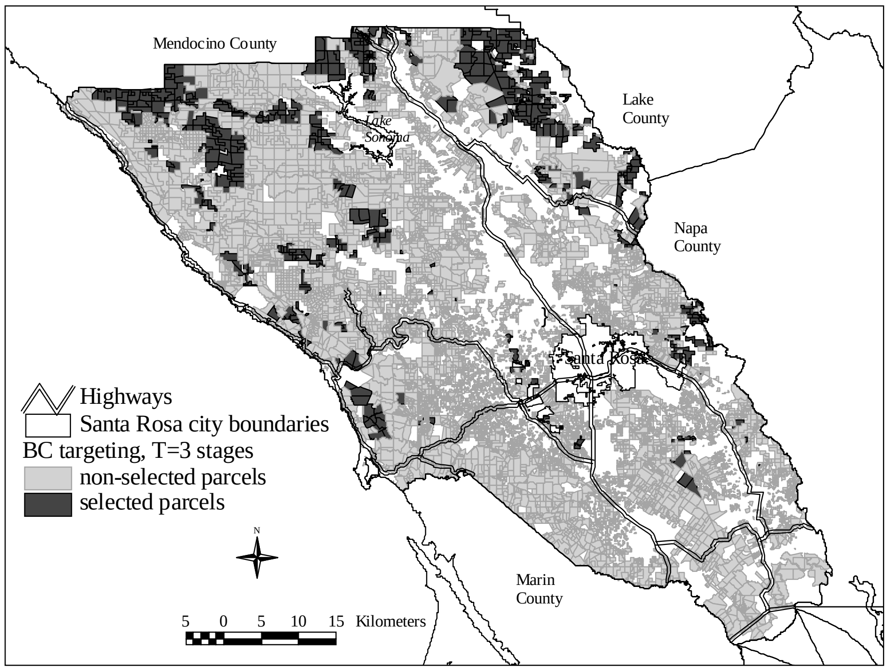

Figure 1b: Parcels protected under benefit-cost (BC) targeting after three periods
Note: Parcel boundaries are masked out in white for non-developable areas.

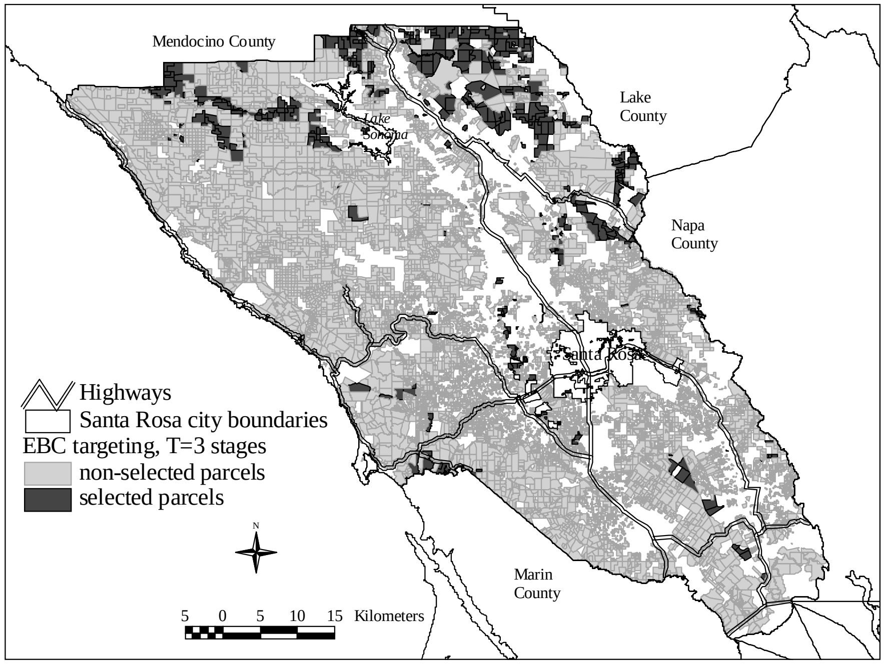

Figure 1c: Parcels protected under expected-benefit-cost (EBC) targeting after three periods

Note: Parcel boundaries are masked out in white for non-developable areas.