Spatial Targeting Strategies for Land Conservation

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Voters passed 529 referenda in state and local ballot initiatives between 1998 and 2001, committing more than $19 billion to fund land acquisition and easements for open space, habitat protection and other conservation objectives (Trust for Public Land).[1] Nonetheless, conservation budgets are typically far less than the cost of protecting all the remaining desirable lands. Tradeoffs must be made when targeting available parcels with multiple benefits and heterogeneous land costs. Similarly, the demand for ecosystem restoration exceeds the available support for such activities. Efficiency of restoration programs has been improved in several ways, particularly from studies on alternative targeting schemes for the Conservation Reserve Program (CRP) (Babcock et al. 1996; Babcock et al. 1997; Wu; Wu, Zilberman and Babcock). Babcock et al. (1997) demonstrate that the optimal allocation of restoration funds seeks to maximize net benefits achieved per unit cost. This benefit-cost approach is more efficient than targeting approaches based solely on either lowest opportunity costs or highest environmental benefits. Targeting for preservation of existing benefits (i.e. forested habitat or open space) differs from restoration because the former must consider whether development is likely if no protection is guaranteed on a given parcel. The inclusion of the probability of land use conversion in the targeting rule is the major contribution of this paper.

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 (Pressey et al.). In this "site-constrained" optimization framework, the species is considered protected if it is represented at any of the chosen sites (Church, Stoms and Davis). Ando et al. demonstrate that program costs for preserving species are significantly less when targeting also considers land costs. They utilize county-level data on endangered species listings and agricultural land values for the entire United States. This benefit-cost optimization algorithm is still suboptimal; it selects sites for reserve inclusion with lower cost of protection, but it does not consider that these areas typically also have lower likelihood of future development. Costello and Polasky incorporate land use change into a complete theoretical model of reserve site selection, employing dynamic stochastic programming and other optimization techniques. However, they consider only the probability of development, but not land costs, in their empirical regional model.

This paper provides a targeting strategy for protecting multiple environmental benefits that takes into account land costs and probability of land use conversion. We compare the proposed strategy aiming to minimize the benefit loss expected from future land use conversion versus another strategy based on benefit-cost maximization. The former approach integrates the positive relationship between the likelihood of land use change and the value of the development rights.

Unlike previous targeting studies which employ counties or other aggregated units, we examine targeting strategies utilizing parcel-level data.

THEORY: PRIORITIZING CONSERVATION EASEMENT ACQUISTION

The conservation organization (i.e. land trusts, public resource agencies) prioritizes easements among developable parcels, given a limited budget. Each developable parcel is endowed with predefined environmental benefits, which are compatible with the initial land use state. Land use conversion causes the environmental benefits to be fully or partially lost, depending on the subsequent land use state. The objective is to minimize the expected loss in environmental benefits. The budget is spent in one period prior to future development, and the budget constraint is binding.

Targeting multiple goals requires identifying relative weights between conservation objectives to assess the potential tradeoffs. Thus, the benefit type *i* at parcel *j* is denoted as B_i^j, and therefore the total benefits for parcel *j* is equal to:

$$B^j = \sum_{i=1}^{I} \alpha_i B_i^j \tag{1}$$

for *I* conservation objectives and α_i is a weighting factor for each benefit type.[2]

The spatial land use change model is constructed with respect to the set of developable parcels that are observed at two time periods. All developable parcels have the same initial land use state. Land use transitions are indexed on the final land use state k = 0, 1, ..., K, including the outcome of a parcel remaining in the initial state $k = 0$. The conversion decision is modeled as a discrete choice, where P_k^j represents the probability that parcel *j* will be converted to final land use state *k*. Irreversibility is assumed due to the large up-front costs necessary for conversion to any developed state with higher-intensity use. If the parcel is converted to a developed state $(k \neq 0)$, then the parcel remains in this state and does not convert to any other developed state.

Individual landowner decisions to convert are partly influenced by the relative land values in alternative states. The expected value of converting land to state *k*, V_k, is assumed to be the present value of future returns minus conversion costs. Land is considered to embody spatially-varying characteristics for land quality, accessibility to urban centers, public services and zoning. For each parcel *j*, the vector of site-specific characteristics, z^j, underlies the spatial variation in conversion costs and returns from existing and higher-intensity uses, such that V_k is expressed as a function of z^j. The spatial land use change model utilizes a random utility framework, since some unobserved factors also affect land use decisions, represented here by the error term ε_k^j (Bockstael). Thus, the probability of parcel *j* with initial state *0* will be converted to final state *k*, P_k^j, is stated as the probability that $V_k\left(z^j\right)$ is greater or equal to $V_m\left(z^j\right)$ for all possible final land use states $m \in K$.

Land use conversion probabilities can also be expressed in terms of the value of development rights. The value of development rights for conversion to state *k*, E_k, equals the amount that land value in state *k* exceeds the existing use value $\left(E_k = V_k - V_0\right)$. Hence, after subtracting the existing use value from the land value in each state, probability of conversion to state *k* is expressed as:

$$P_k^j = \Pr ob\left[E_k\left(z^j\right) + \varepsilon_k^j \geq \max_{m \in K}\left\{E_m\left(z^j\right) + \varepsilon_m^j\right\}\right] \tag{2}$$

The easement value is stated here for the condition to restrict all possible developed land use states (any final state other than the initial state). Easement value, *E*, for parcel *j* is the maximum value of development rights for all *K+1* states $E^j = \max\left\{E_0^j, E_1^j, ..., E_K^j\right\}$, which includes the lower bound $E_0^j = 0$ for remaining in the initial state. When the easement value is large, the probability of conversion to some developed state is expected to be high as well. In contrast, parcels that have low likelihood of future development should have an easement value that is close to zero. These unsuitable parcels may have conversion costs that far exceed the present value of future returns, as a result of low land quality, poor accessibility, strict zoning regulations or other factors. The conversion probability to some developed state $\left(k \neq 0\right)$ as a function of the easement value should satisfy the limit conditions that $P(E)=0$ as $\lim E \to 0$ and $P(E)=1$ as $\lim E \to \infty$. The expected probability of conversion to some developed state is assumed to be strictly increasing in the value of development rights $P'(E)>0$. The importance being that value of development rights and expected probability of conversion are implicitly linked, and hence both factors need to be addressed to improve targeting strategies for land protection.

Comparison of targeting methods

Benefit cost (BC) targeting selects parcels based on the benefits B^j and easement value E^j evaluated for each parcel j. Assuming a budget M, the Lagrangian for the benefit-cost approach is:

$$L = \sum_{j=1}^{J} \delta^j \sum_{i=1}^{I} \alpha_i B_i^j + \lambda \left(M - \sum_{j=1}^{J} \delta^j E^j \right) \tag{3}$$

The choice variable $\delta^j = 1$ when the parcel j is targeted for an easement from the J available parcels of developable land (for non-targeted parcels $\delta^j = 0$). In the solution to this problem, the optimal shadow value λ^* indicates the critical threshold B / E ratio for which parcels will be selected, conditional on the budget amount. In other words, the conservation organization targets easements on all developable parcels with $B/E \geq \lambda^*$ to set aside from potential development, while parcels with $B/E < \lambda^*$ are not targeted.

Benefit loss minimization (BLM) targeting is similar to BC targeting, but it also incorporates the relative probability of land use change into the site selection problem. For each parcel j, the product of initial benefit value and expected conversion probability is considered to determine the expected loss of benefits if the parcel remains unprotected.

The most important sites to protect would possess high benefit value and also be highly vulnerable to future land use conversion. Let $\gamma_{ik} \in [0,1]$ be the loss in initial benefit type *i* if the parcel is converted to state *k*. In our empirical work, we restrict γ_{ik} to be binary. Expected loss of benefits with respect to benefit type i and relative conversion probability to final state *k* on parcel *j* is expressed as $\gamma_{ik} P_k^j B_i^j$. Hence, total expected loss of benefits on parcel *j* is:

$$S^j = \sum_{i=1}^{I} \alpha_i \sum_{k=0}^{K} \gamma_{ik} P_k^j B_i^j \tag{4}$$

considering all combinations of *K+1* final land use states and *I* benefit types. For BLM targeting, the Lagrangian is:

$$L = \sum_{j=1}^{J} \delta^j S^j \quad + \quad \lambda' \left(M - \sum_{j=1}^{J} \delta^j E^j \right) \tag{5}$$

In this case, the solution selects parcels based on the highest ratio of total expected loss of benefits S^j to the easement value E^j. Site prioritization is the same applying either relative or absolute land use conversion probabilities, since ranking according to the S / E ratio is invariant for a scalar multiple between relative and absolute probabilities. The optimal shadow value $\lambda'^* = S / E$ defines the critical threshold, such that parcels satisfying $S / E \geq \lambda'^*$ are targeted for easements.

BC targeting, which ignores the influence of land use conversion, has implicitly set the relative conversion probability $P = 1$ for all parcels. This presumes that relative probability of land use change is constant for all easement values. The assumption contradicts the relationship stated earlier, in which relative conversion probability is expressed as an increasing function in the value of the development rights, $P'(E) > 0$. 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 selects low cost parcels without weighting the decreased likelihood of future land use conversion.

EMPIRICAL PROCEDURE

Research study area

Data from Sonoma County, CA demonstrates the implications of BLM as compared to BC targeting strategies. The study 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. Thus, there is a strong local economy centered on the wine industry, tourism and until recently a growing high-tech industrial base.

The focus of the study is the exurban area, which includes the entire county except the nine incorporated cities (~ 4,000 km^2 in area). Typically, the rural-urban interface is an important zone for conservation within many regions of the United States. This zone is characterized by relatively high rates of urban conversion, and in this case vineyard conversion as well. However, there exists a significant amount of remaining developable land. As of 2000, roughly one-quarter of the exurban area had been converted to residential (14 %) and vineyard (11 %) uses. Developable land, taken as "extensive use" parcels, comprises the majority of the land uses, including pasture (30 %), chaparral/shrub (13 %), and timber (12 %).[3] Most land is held in private ownership (>90%), and vineyards and residential uses compete for "extensive use" parcels. For this reason, the main land uses are separated into three groups – residential, vineyard, and "extensive use".

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) values these environmental benefits for all developable parcels through the designation of priority conservation areas.[4] Forested areas are divided into two main priority habitat types – oak woodlands and conifer – designated using a geographic information system (GIS) and a set of landscape criteria developed by scientists and local technical experts (SCAPOSD Acquisition Plan 2000). Habitat benefit values are continuous on the range [0,1], according to the ratio of each type of priority habitat contained within each developable parcel's area.

Two priority greenbelt zones were designed by the SCAPOSD to preserve open space adjacent to cities and for scenic landscape units, such as Sonoma Mountain. Environmental benefit values for "core" and "expanded" greenbelt categories equals one if the parcel is located in one of these greenbelt zones and otherwise set to zero if located outside.

Priority rangeland is specified by grass land cover in a region known for its high site productivity for livestock grazing and with dairies. Similarly, the rangeland value equals one when the parcel is located within the priority rangeland area, and otherwise set to zero. In sum, the maximum number of overlapping benefit types is three; for example, a parcel completely covered with oak woodland, which is located in the priority rangeland and greenbelt zone. A more generalized benefit function could potentially incorporate more complex factors where appropriate, such as off-site benefits and a non-constant marginal benefit function. The current benefit data set, as provided by the SCAPOSD, has limited information to test these additional factors without ad hoc definitions. Both targeting methods, in any case, are compared for the same definition of the benefit distribution.

Land use change model

A spatially-explicit land use change model is developed in two phases – modeling phase and prediction phase. For the modeling phase, developable land is the "extensive use" parcels in 1990, taken as the initial land use state. 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 taken from base maps. Land use conversion is defined as transitions from "extensive use" parcels in 1990 to either residential or vineyard use during the period 1990-2000. Residential and vineyard uses have much higher revenues relative to extensive uses, and the conversion decision is considered irreversible due to the substantial up-front fixed costs.[5]

Given the three possible land use outcomes over the 1990-2000 period, 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 via the unique parcel identification code.[6] Parcel boundaries permitted the overlay and extraction with GIS layers to obtain many site and neighborhood characteristics on land quality, travel times to urban centers, and zoning restrictions. For example, average percent slope and elevation in meters was calculated for each parcel, utilizing a digital elevation model at 30-meter resolution. Warmer microclimatic conditions, particularly needed for grape maturity, are measured using temperature data layers from the Oregon State University's Spatial Climate Analysis Service. Growing-degree days, summed over the April to October vineyard season, serves as a proxy for microclimate. Soil quality is represented using the dominant farmland category from the California Farmland Mapping and Monitoring Program on each parcel. The farmland categories are (in order of highest to lowest soil quality): prime, statewide importance, unique, local importance, grazing and other.

Travel time to the central business district was measured for the accessibility to employment opportunities. An optimal routing algorithm within the GIS calculated the minimum travel time 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. Zoning restrictions were taken from the digital map of the 1989 Sonoma County General Plan. The five zoning designation categories are (in order from highest to lowest residential density): rural residential, diverse agriculture, land intensive agriculture, resource and rural development, and land extensive agriculture. Lastly, the lot size is included as a variable to proxy the potential for residential density, represented in natural log form.

In the prediction phase, "extensive use" parcels remaining in 2000 form the complete set of developable sites with environmental benefits to be targeted for protection. The estimated coefficients from the multinomial logistic regression are employed to forecast the relative probability of land use change, since the site characteristics for all parcels are known within the GIS. The model output is relative probability of future residential and vineyard development for each of the 5,467 developable parcels. Expected loss in benefits, utilized for BLM targeting, requires solely the relative conversion probabilities to be estimated rather than absolute conversion probabilities or predicted events. The latter would require more information on the amount of future land to be developed and optimal timing decisions.

Valuation of development rights model

The value of development rights (VDR) is estimated for the "extensive use" parcels in 2000, which similarly has both modeling and prediction phases. The VDR is the price differential by which the value of developable land exceeds the present value from existing returns. For targeting at the regional scale, the land trust is taken to compete with developers in the land market. Thus, the market value for the conservation easement is regarded as the landowner's opportunity cost in permanently forgoing the option to build future residential structures or convert to vineyard use.

The valuation of developable land is performed on recent sales of "extensive use" parcels unrestricted from future development. The Sonoma County Tax Assessor's Office database provides the necessary information on individual parcels for the land value and other property characteristics.[7] A hedonic price model for the developable land value is determined as a function of spatially-varying parcel site characteristics, as described above. These same explanatory variables logically may affect both land values and land use conversion probabilities. The reduced-form land use change model is underlain by the latent variable of the land value in alternative uses. The econometric model utilizes least squares estimation and a semilog function form with the dependent variable as the natural log of the land value per acre. Hedonic coefficient estimates are employed to determine the expected land value for each "extensive use" parcel in 2000, since site characteristics are known for all parcels within the GIS. The result is the mapped surface of predicted land values for all 5,467 developable parcels across the entire region.

Existing use value assessments, obtained from "extensive use" parcels enrolled in the Williamson Act, provides the baseline for the land value restricted from future residential or vineyard 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.[8] Similar to the method applied to developable land values, the existing use value per acre is estimated 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 variables are omitted here since they should not be important for farm-based returns. Finally, the expected VDR is determined for each "extensive use" parcel in 2000, calculated as the difference between the estimated values for developable land and existing use value.

Targeting scenarios and assessment

Parcels with "extensive use" in 2000 were utilized as the set of developable parcels being targeted for conservation easements. BLM targeting requires definitions for relationships between five benefit types and three final land use states in order to evaluate the expected benefit loss. For the purposes of this exercise, we assume vineyard conversion causes a complete loss in priority habitat and rangeland benefits ($\gamma_{ik} = 1$); however, greenbelt benefits are fully retained ($\gamma_{ik} = 0$). Residential development is assumed to cause a complete loss in all environmental benefits. Meanwhile, parcels remaining in "extensive use" fully retain the initial endowment of all environmental benefits.

BLM and BC targeting are examined under two different scenarios for the environmental benefit index. The first scenario investigates the five benefit types individually. In the second scenario, the five benefit types are combined into a total benefit index, summing the value when multiple overlapping benefits exist on a given parcel. Benefit types are given equal weighting as a baseline ($\alpha_i = 1$ for all types within Equation (1)) in this second formulation.

BLM targeting is compared to BC targeting to assess differences in targeting efficiency, using Lorenz curves and Gini coefficients. Targeting efficiency is measured as the expected loss in benefit on acres protected, rather than simply acres of benefits protected. Each targeting approach selects a different subset of parcels for protection amongst the *J* developable parcels, conditional on the budget expenditure M. Spatial heterogeneity in *S/E* values across parcels is governed by the underlying distributions of environmental benefits, conversion probabilities, and easement values. The Gini coefficient is a summary statistic for the Lorenz curve. In this application, the Gini coefficient measures the difference between the cumulative expected loss in benefits protected and cumulative budget expended, integrated over the entire budget range: $G = 2\left[\int_0^1 \left[S^c\left(M\right) - M^c\right] dM\right]$. The maximum budget is defined as the purchasing cost at current easement values summed for all J parcels, $M_{\max} = \sum_{j=1}^{J} E^j$, which is normalized to equal one when expressed as a cumulative distribution. The complete set of J available parcels includes only those parcels with non-zero benefit value.

RESULTS AND DISCUSSION

Spatial land use change and value of development rights models

The land use change model results, shown in Table 1, indicate that land use conversion to vineyard use is more likely on areas with lower slope and higher growing-degree days (warmer microclimate). Residential conversion is more likely on parcel zoned for rural residential, the baseline zoning category in Table 1, and more likely on parcels with smaller lot sizes. The importance of slope and microclimate in connection with vineyard conversion is consistent with the fact that steeper slope raises expected vineyard establishment costs and lowers grape yields, meanwhile cooler coastal microclimates are less likely to allow grapes to reach maturity. The importance of zoning and parcel size to residential transitions is clear since higher density zoning increases rents per acre from residential uses. Furthermore, residential use has higher likelihood in the southern region of Sonoma County, in response to the increasing land rent gradient as one travels south toward San Francisco. California FMMP data on farmland type does not provide high explanatory power for vineyard and urban development since these data are coarsely measured, as compared to the spatial resolution needed to determine site specific soil limitations. Spatial heterogeneity in parcel site characteristics dictates that expected probability of land use conversion is far from uniform across the landscape in Sonoma County. Model accuracy assessment was 74 percent overall when comparing the maximum expected probability to actual land use transitions for a random set of parcels not used in the model (73 % vineyard, 67 % extensive and 81 % urban for respective parcel land use transitions). These results highlight that variation in land use conversion probabilities is an essential factor for efficient targeting of conservation funds.

Land values for recently sold properties vary according to parcel site characteristics, similar to the factors influencing land use conversion probabilities.

Developable land value per acre for these "extensive use" parcels is greatly reduced in areas where land quality, accessibility or zoning constraints limit the economic returns to higher-intensity uses (Table 2a). For instance, "extensive use" parcels with steeper slopes raise conversion costs and reduces the number of potential home sites. Remote areas, particularly in northwest Sonoma County, have longer travel times to the greater Bay Area metropolitan region, which lowers the developable land values. Land extensive agriculture zoning typically restricts residential development, thereby reducing land values.

Likewise, hedonic regression results for existing use value assessments as a function of land quality and accessibility are presented in Table 2b. Existing use value, mainly from grazing lands, is slightly lower on steeper slope and higher elevation (another proxy for steepness). Farm-based returns are additionally lower in remote areas with poor accessibility, presumably due to higher transaction costs for outputs and input factor markets. While the existing use value assessments vary somewhat throughout the County ($\bar{x}$ = \$ 241/acre and σ_x = \$401/acre), developable land values vary to a much greater degree($\bar{x}$ = \$ 19,853/acre and σ_x = \$ 23,862/acre). Not surprisingly, variation in expected VDR is mainly attributable to the developable land values, as compared to existing use values, since the former is more spatially variable across the region than the latter.

Targeting for individual benefit categories

In this first scenario, targeting of conservation easements is conducted on the five benefit categories individually. Budget expenditures are compared for each targeting approach to avoid 20 percent of expected benefit loss (Table 3). Target inefficiencies are most pronounced for greenbelt benefit categories. BC targeting requires \$76.3 million to meet the specified goal for "core" greenbelt benefits, whereas BLM targeting needs only \$10.9

million for the same objective. Habitat and rangeland benefit categories exhibit less extreme differences in budget expenditures, but substantial improvements are still made with BLM targeting.

Gini coefficients for BLM targeting are large for the "core" and "expanded" greenbelt categories, 0.67 and 0.68 respectively (Table 3). In contrast, the Gini coefficient for rangeland is only 0.23, reflecting much less heterogeneity in S/E values. Spatial heterogeneity in parcel site and neighborhood characteristics leads to estimated easement values and conversion probabilities that both vary by several orders of magnitude. Priority greenbelt conservation areas span the widest array of site conditions, mainly situated in flatter slope parcels near incorporated cities (high suitability) but also including parcels in remote, steep regions such as Sonoma Mountain (low suitability). Meanwhile, the priority rangeland area, while still exhibiting large variation, spans a more homogeneous region relative to the greenbelt priority zones.

In sum, when two conditions are met, the difference in Gini coefficients, $\Delta G = G_{BLM} - G_{BC}$, will be large, and hence BC targeting is inefficient. First, there must be a high degree of heterogeneity in S/E values, such that G_{BLM} is large, in order for targeting to be an important consideration. Second, BC targeting must obtain site selection that deviates substantially from BLM targeting, resulting from ignoring the large variation in the likelihood of future land use conversion among developable parcels.

Targeting for total benefit index

In the second scenario, both targeting approaches now are applied to all five benefits when combined into a total benefit index. The purpose is to explain how each targeting approach will make tradeoffs when allocating the budget between the five benefit categories.

Furthermore, it provides insight into how benefit acres protected may differ from meeting the objective to avoid a specified level of expected loss in benefit acres. In Table 4, BLM and BC targeting are compared for the same objective, namely to avoid 20 percent of the expected loss in total benefits.

It should be noted first that budget expenditures to meet this objective for BC targeting are much higher than BLM targeting, \$213 million versus \$122 million (Table 4). This result is analogous to the higher budget expenditure for BC targeting reported in Table 3 for each individual benefit category, but presently applied to the total benefit index. BC targeting protects more than twice the number of benefit acres, 95,841 versus 36,853 benefit acres. In fact, BC targeting protects a higher percentage of benefit acres within each benefit category.

Interestingly, BC targeting protects more benefit acres in oak habitat and rangeland categories, while it correspondingly obtains a lower percent of the expected loss in benefit acres protected. The underlying reason being that BC targeting preferentially selects low cost parcels. However, many of these parcels are less likely to be converted, due to the positive correlation between easement values and likelihood of land use conversion.

Tradeoffs between benefit categories are apparent, since both targeting approaches are required to meet the same objective for expected loss in total benefit acres. BC and BLM targeting obtain 2458 versus 1386 expected loss in benefit acres for conifer habitat, respectively. BLM targeting contrastingly chooses a larger number of expected loss in benefit acres for parcels within oak habitat and rangeland benefit categories. In sum, BC targeting preferentially selects parcels in priority conservation areas associated with lower easement values, primarily remote conifer forest areas for this case study. As a result, BC targeting prioritizes low cost parcels, with a low probability of conversion, resulting in higher expenditures to reach any specified level of expected loss in benefit acres protected.

The same goal is achieved with substantially different subsets of the 5,467 developable parcels under the BC and BLM criteria. BLM targeting selects 740 parcels as compared to 1104 parcels chosen by BC targeting, but the two targeting methods selected only 481 parcels in common.

It is informative to investigate the underlying parcel site characteristics (i.e. land quality, accessibility to urban areas, zoning), which influence land use decisions and land values. For example, priority conifer habitat is located mainly in the remote, mountainous area of northwest Sonoma County. Steep slopes and cooler microclimates within this coastal region typically create unsuitable conditions for vineyard production. Additionally, longer commute times to major employment centers and large lot zoning make future residential development much less likely. Since easement values are very low in these areas, BC targeting preferentially chooses parcels with conifer habitat. BLM targeting considers the very low development potential, and allocates fewer funds for the conifer benefit category than BC targeting. Rather BLM targeting utilizes more funds to purchase easements with oak habitat and rangeland benefits, respectively located in north/eastern and southeastern Sonoma County. These areas are more suitable to vineyard or residential development, as a result of moderate slope, warmer microclimates and proximity to the main highway corridors. Oak and rangeland parcels selected under BLM targeting have moderate likelihood of conversion but relative low easement values. Parcels in both greenbelt categories typically are ranked lowest under either BC or BLM targeting. BC targeting does not prioritize greenbelt parcels primarily due to high costs. These areas often possess flatter slopes and proximity to urban areas, which make them suitable to vineyard and residential development. However, the expected loss in greenbelt benefits only considers residential conversion, since vineyards are assumed not to displace the greenbelt benefits. Therefore, the relative conversion probability to residential solely is too low to justify the high purchasing cost for easements on greenbelt parcels, even under BLM targeting. In priority conservation areas with high easement values, the easement value will approach the land value for full property title. This would mean that purchasing the property in fee would be a more effective conservation tool for these types of lands, a result we have observed in Sonoma County.

CONCLUSION

Protection of environmental benefits, as compared to restoration, requires a different targeting approach. Restoration efforts are efficiently targeted for the highest ratio of net benefits achieved to opportunity costs for enrolled parcels. However, protection of existing benefits also must consider the likelihood of benefit loss resulting from future land use change on all unprotected parcels.

Site selection performed according to benefit-cost maximization is biased toward low cost parcels, since it ignores variation in likelihood in future land use conversion. This bias arises from the positive correlation that typically exists between easement values and conversion probabilities. For instance, some parcels with poor land quality or remote accessibility to urban centers would have *de facto* conservation, and therefore do not warrant the targeting of conservation funds, despite the low cost of protection. Contrastingly, conservation biologists recently have developed reserve site selection algorithms based on habitat benefits and a vulnerability index, a proxy for the likelihood of land use conversion (Abbitt, Scott and Wilcove; Pressey and Taffs). Targeting approaches utilizing solely benefits and conversion probabilities, without accounting for land costs, would bias selection toward the most threatened sites. Benefit loss minimization targeting attempts to balance the countervailing factors of land values and likelihood of land use conversion. Furthermore, benefit-cost targeting preferentially selects parcels with conservation benefit categories geographically associated with low-cost areas. In the present example, conifer habitat is over protected, while oak woodland habitat and rangeland are under protected.

Spatially-explicit models for land use change and valuation of development rights may substantially improve efficiency of conservation programs on private lands. These spatial models have the advantage of being calibrated based on individual landowner actions. Both land use conversion decisions and land values from recent property transactions are estimated according to spatially-varying parcel site characteristics and current market conditions. Future research collaboration is needed between economists and natural scientists to improve methodology for the disaggregated valuation of environmental benefits. For instance, species habitat suitability models could provide the likelihood of species occurrence on developable parcels, and then by using the methods described here, provide the disaggregated level of analysis needed to help decision-makers balance the protection of threatened species with future human demands for agriculture and urban uses.

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Endnotes

[1] Non-governmental organizations, such as The Nature Conservancy and local land trusts, have gained in popularity in recent decades, adding a complementary effort to address these issues (Merenlender et al.).

[2] This formulation is analogous to the environmental benefit index employed in the CRP.

[3] Other land uses also grouped into "extensive use" include dairy (2.8 %), field crops (1.6 %), orchard (0.4 %) and horse farms (0.2 %). The remaining exurban area contains mainly state and local parks, private energy-producing facilities (i.e. hydroelectric dam, geothermal area), and non-residential urban development (i.e. industrial, commercial, etc.).

[4] SCAPOSD, a local conservation agency, was established through a 1990 Sonoma County voter ballot initiative and funded with a ¼ percent increased sales tax. This mechanism raises approximately $15 million annually to meet the 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).

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

[6] 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. For example, "irrigated vineyard with residence" category signified a parcel that is mainly a vineyard operation, but there is a residential structure for the vineyard owner or workers. The "rural residence" category had most of the land value attributable to the home site value in residential use, but there may be a few vineyard acres on the property for hobby growing. These small hobby vineyards represent much less than ten percent of the vineyard acreage in the County.

[7] 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) land use must be "extensive use" in 2000; 2) all transactions took place 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 assessment was based on the sale price. Land value is derived from the total value at the sale date minus structural value and other improvements.

[8] 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.

Table 1: Spatial land use change model results using multinomial logit regression (Baseline land use category = Extensive use)

Vineyard

Variable	Coefficient	Std. Error	Pr(>|t|)
Slope	-0.0823	0.0117	0.000
Growing degree-days	1.8548	0.2651	0.000
Ln(lot size)	-0.0604	0.0779	0.438
Travel time to San Francisco	0.0274	0.0082	0.001
Elevation	-0.0008	0.0007	0.266
Farmland type[1]			
Other	-0.1371	0.2173	0.528
Unique	1.8144	0.4369	0.000
Urban	-0.1163	1.3182	0.930
Prime	0.5304	0.4121	0.198
Local	-0.5196	0.2573	0.043
State	1.0058	0.6570	0.126
Zoning type[2]			
Rural resource & development	-0.6905	0.2995	0.021
Land extensive agriculture	-0.7083	0.3457	0.041
Land intensive agriculture	0.6572	0.3176	0.039
Diverse agriculture	-0.2530	0.2575	0.326
Constant	0.4838	0.3904	0.215

Urban

Variable	Coefficient	Std. error	Pr(>|t|)
Slope	0.0109	0.0117	0.352
Growing degree-days	-0.7513	0.2440	0.002
Ln(lot size)	-1.3876	0.1048	0.000
Travel time to San Francisco	-0.0224	0.0104	0.031
Elevation	0.0012	0.0008	0.126
Farmland type[1]			
Other	-0.4767	0.2470	0.054
Unique	-0.0612	0.5447	0.911
Urban	-0.6451	1.6191	0.690
Prime	-0.5224	0.5212	0.316
Local	-1.0651	0.3001	0.000
State	-1.6910	1.2176	0.165
Zoning type[2]			
Rural resource & development	-1.6351	0.3172	0.000
Land extensive agriculture	-2.1982	0.4857	0.000
Land intensive agriculture	-0.9781	0.3962	0.014
Diverse agriculture	-1.6938	0.2957	0.000
Constant	5.3205	0.4479	0.000

N = 1500 parcels (500 parcels from each land use state)

Likelihood ratio = 1451.65 Pseudo-R2 = 0.4404

[1] Farmland baseline type = Grazing [2] Zoning baseline type = Rural residential

Table 2a: Hedonic coefficient estimates for developable land value in 2000
Dependent variable = Ln(land value per acre)

Variable	Coefficient	Std. error	Pr(>|t|)
Constant	12.2249	0.3261	0.0000
Ln(lot size)	-0.2637	0.0597	0.0000
Travel time to San Francisco	-0.0140	0.0042	0.0010
Elevation	-0.0012	0.0006	0.0363
Slope	-0.0424	0.0063	0.0000
Growing-degree days	0.065	0.1631	0.6908
Farmland type[1]			
Unique/Local	-0.3176	0.2391	0.1860
Prime/Statewide	-0.2504	0.3889	0.5206
Zoning type[2]			
Diverse agriculture	0.0905	0.2531	0.7211
Land extensive agriculture	-0.7382	0.3227	0.0236
Rural residential	-0.1008	0.2325	0.6654
Land intensive agriculture	0.0645	0.2849	0.8213

N = 158 parcels R-square = 0.720

[1] Farmland baseline type = Grazing/Other
[2] Zoning baseline type = Resource and rural development

Table 2b: Hedonic coefficient estimates for existing use value
Dependent variable = Ln(land value per acre)

Variable	Coefficient	Standard error	Pr(>|t|)
Constant	7.8473	0.5176	0.0000
Slope	-0.0704	0.0219	0.0019
Elevation	-0.0021	0.0008	0.0074
Travel time to San Francisco	-0.0439	0.0127	0.0009
Ln(lot size)	0.0727	0.0575	0.2096
Farmland type[1]			
Prime/State	-0.4202	0.4810	0.3852
Local/unique	-0.9272	0.4057	0.0252
Growing degree-days	-0.0004	0.0002	0.0627
Travel time to SF*Slope	0.0008	0.0003	0.0058

N = 85 parcels R-squared = 0.697

[1] Farmland baseline type = Grazing/Other

Table 3: BLM versus BC targeting performed by individual benefit type: Gini coefficients and budget expenditures to avoid 20 percent of expected benefit loss

	Budget expenditures (in $ millions)		Gini coefficient	
Benefit category	**BLM targeting**	**BC targeting**	**BLM targeting**	**BC targeting**
Rangeland	60.9	83.4	0.23	0.17
Core greenbelt	10.9	76.3	0.67	0.08
Expanded greenbelt	12.2	85.0	0.68	-0.01
Oak habitat	40.7	47.9	0.55	0.49
Conifer habitat	15.9	31.9	0.53	0.36

Table 4: BLM versus BC targeting performed on the combined benefit index: Measured for the same objective to avoid 20 percent of expected loss in total benefits

Budget expenditure to meet this objective:
BLM targeting = $122 million
BC targeting = $213 million

	Expected loss in benefit acres [1]					Benefit acres [2]				
Benefit category	**BLM**	**(%)**	**BC**	**(%)**	**Total**	**BLM**	**(%)**	**BC**	**(%)**	**Total**
Rangeland	2684	(16)	2008	(12)	16905	9032	(14)	18360	(27)	66069
Core greenbelt	149	(9)	184	(11)	1631	1954	(3)	8092	(13)	60713
Expanded greenbelt	67	(6)	111	(9)	1215	1301	(3)	11417	(29)	38636
Oak habitat	4025	(26)	3517	(22)	15688	15490	(29)	18452	(35)	53336
Conifer habitat	1386	(23)	2458	(41)	5943	9077	(13)	39521	(58)	68394
Total	**8312**	**(20)**	**8277**	**(20)**	**41382**	**36853**	**(13)**	**95841**	**(33)**	**287148**

[1] Expected loss in benefit acres by category signifies the number of benefit acres selected multiplied by the estimated probability of land use conversion on each parcel.

[2] Benefit acres by category indicates the number of acres selected within the designated conservation priority area.