Economics and Land-Use Change in Prioritizing Private Land Conservation

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Abstract: *Incentive-based strategies such as conservation easements and short-term management agreements are popular tools for conserving biodiversity on private lands. Billions of dollars are spent by government and private conservation organizations to support land conservation. Although much of conservation biology focuses on reserve design, these methods are often ineffective at optimizing the protection of biological benefits for conservation programs. Our review of the recent literature on protected-area planning identifies some of the reasons why. We analyzed the site-selection process according to three important components: biological benefits, land costs, and likelihood of land-use change. We compared our benefit-loss-cost targeting approach with more conventional strategies that omit or inadequately address either land costs or likelihood of land-use change. Our proposed strategy aims to minimize the expected loss in biological benefit due to future land-use conversion while considering the full or partial costs of land acquisition. The implicit positive correlation between the likelihood of land-use conversion and cost of land protection means high-vulnerability sites with suitable land quality are typically more expensive than low-vulnerability sites with poor land quality. Therefore, land-use change and land costs need to be addressed jointly to improve spatial targeting strategies for land conservation. This approach can be extended effectively to land trusts and other institutions implementing conservation programs.*

Key Words: conservation easements, land economics, land-use change, protected-area planning, reserve design, spatial models

Economía y Cambio en el Uso de Suelo en la Priorización de la Conservación de Tierras Privadas

Resumen: *Las estrategias basadas en incentivos, como los derechos de conservación y los acuerdos de manejo a corto plazo, son herramientas populares para conservar la biodiversidad en tierras privadas. Las organizaciones conservacionistas gubernamentales y privadas gastan billones de dólares para financiar la conservación. Aunque la mayor parte de la biología de la conservación se centra en el diseño de reservas, estos métodos a menudo no son efectivos para la óptima protección de los beneficios biológicos de los programas de conservación. Nuestra revisión de la literatura reciente sobre planificación de áreas protegidas identifica algunas de las razones de lo anterior. Analizamos los procesos de selección de sitios en función de tres componentes importantes: beneficios biológicos, costo de las tierras y la probabilidad de cambio en el uso de suelo. Comparamos nuestro enfoque en el beneficio-pérdida-costo con métodos más tradicionales que omiten, o abordan inadecuadamente, el costo de las tierras y/o la probabilidad de cambio en el uso de suelo. La estrategia que proponemos trata de minimizar la pérdida esperada del beneficio biológico debido a la conversión del uso de suelo en el futuro al tiempo que considera los costos parciales o totales de la adquisición de tierras. La correlación positiva implícita entre la probabilidad de conversión en el uso de suelo y el costo de la protección de tierras significa que los stios altamente vulnerables con tierras de buena calidad típicamente son mas caros que los sitios de baja vulnerabilidad con tierras de baja calidad. Por lo tanto, se requiere que el cambio en*

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el uso del suelo y el costo de las tierras sean atendidos conjuntamente para mejorar las estrategias para la conservación de tierras. Este método se puede extender con efectividad a consorcios y otras instituciones que llevan a cabo programas de conservación.

Palabras Clave: cambio en el uso de suelo, derechos de conservación, diseño de reservas, economía, modelos espaciales, planificación de areas protegidas,

Introduction

Incentive-based strategies such as conservation easements and short-term management agreements are increasingly popular tools for conserving biodiversity on private lands (Merenlender et al. 2004). These voluntary contracts compensate landowners for restrictions placed on property rights, and they offer a greater degree of permanence than environmental regulation or land-use zoning plans. Between 1998 and 2001, more than $19 billion of public funds were appropriated through state and local initiatives for conservation objectives on private land in the United States (Trust for Public Land and Land Trust Alliance 2001). There will, however, never be enough money to protect all the biologically valuable areas that exist on private lands.

We analyzed three important components of the site-selection process: distributions of biological benefits, economic costs of conservation, and probability of land-use conversion. We surveyed the recent literature in protected-area planning to determine the extent to which these components are included in targeting methods and how often the resulting analysis was implemented. Then we compared four conservation targeting strategies to demonstrate how the selection process is influenced by exclusion or poor assessment of cost or probability of land-use change. Most important, we examined the importance of accounting for the implicit positive correlation between the probability of land-use conversion and land values.

There are only a handful of examples where models developed by conservation biologists are actually implemented by organizations and individuals who set priorities and enact conservation land transactions. This is in part because the process of land conservation is influenced by financial and politically based decisions made at multiple scales of control, including the willingness of private landowners to participate, desire of local interest groups, and short-lived government priorities. It is important to recognize that although scientists try to provide the best possible prioritization methods, decision makers will want to capitalize on future political and economic adjustments that will influence what sites are ultimately conserved. Therefore it is important that decision-support tools are flexible enough to allow for these influences and are developed in collaboration with the end user.

Based on our experience working with one of the 10 largest land trusts in the United States to set acquisition priorities, we outline practical steps that may help with implementation in the real world. Lastly, we discuss the need for conservation programs to better understand how land-use planning influences future development patterns.

Survey of Protected-Area Planning Literature

We surveyed research papers published in the journals *Conservation Biology*, *Biological Conservation*, and *Landscape & Urban Planning* over 5 years (1999–2003). We limited our search because of the immense body of literature in this field and because we wanted to represent contemporary advancements. Our guiding question was, Do conservation biologists currently offer effective methods to prioritize spending for conservation programs on private lands? To address this issue, we selected papers that focused on a specific reserve design or land priority scheme for the biological benefit of an individual species, group of species, biodiversity, habitat, or ecosystem type. This selection process yielded a set of 74 papers on 71 different plans. We assessed these plans on the basis of whether they incorporated the following factors: explicit consideration of private lands, land-use change, costs, stakeholder involvement, and plan implementation.

Several researchers have pointed out the need for conservation biologists to focus more attention on private lands. Indeed, 83% of protected-area plans included in our review were implicitly situated in a matrix of private lands. Yet only a small proportion (14%) offered explicit strategies for private land conservation. Although it is clear that implementation of ideal reserve designs on private lands will be constrained by existing patterns of property ownership, we found only two protected-area plans that incorporate the boundaries of individual land parcels in spatial models (Lunney et al. 2000; Cox & Engstrom 2001).

All protected-area plans are designed to protect habitat from land conversion to alternate uses. Less than half (48%) of plans, however, cite potential land conversion to residential, agricultural, or forestry uses as a justification for conservation, and even fewer (21%) include development threat in their calculation of relative conservation priorities. Most of these plans rely on coarse indicators of relative vulnerability across the landscape, such as the spatial distribution of existing threats (Kremen et al. 1999). Only two research groups (Menon et al. 2001; Rouget et al. 2003) use spatially explicit, predictive, land-use change models to assist in the efficient allocation of conservation funds.

When working on private lands, conservation programs must realistically consider the economic costs of alternative reserve-design strategies. Effective incorporation of land economics, however, remains relatively rare in the contemporary protected-area planning literature. Only 13% of the plans we reviewed discuss economic costs of conserving habitat as a component of implementation. Even fewer (9%) explicitly incorporate costs of land acquisition, conservation easements, or management agreements into prioritization schemes. When costs are incorporated into plans, they are generally aggregated mean or median land values (Haight et al. 2002), and costs are principally used post hoc to evaluate rather than derive alternative reserve designs. Two groups of researchers working in South Africa estimate acquisition and management cost estimates through expert knowledge and existing use values to compare costs of different conservation strategies (Frazee et al. 2003; Pence et al. 2003). Although these efforts are encouraging, none of the plans reviewed uses a hedonic model approach, the most common technique that economists use for land valuation.

Perhaps the most telling indicator of reserve-design theory's relevance to contemporary conservation practice is the rate of application of published protected-area plans. As Prendergast et al. (1999) predicted, a very low percentage (13%) of the plans reviewed show evidence of implementation at the time of publication, which may be related to the low level (12%) of stakeholder involvement in the reserve designs. Six of the eight plans that involved stakeholders and decision makers ultimately informed practical planning processes, in contrast to only 5% of those plans that did not involve stakeholders.

In practice, land trusts and agencies often try to take economics and land-use change into consideration. They typically, however, have limited expertise or resources to formulate landscape-level models of land-use change or acquisition cost. For example, in partnership with several organizations, the Vermont Land Trust balances ecological and cultural values with development threats and funding opportunities to prioritize parcels for conservation in eastern Chittenden County (R. O. Link & R. M. Heiser, personal communication). The group has formulated a complex and sophisticated scoring system to meet its conservation objectives. Their assessments of threat, however, are based on anecdotal evidence and existing development patterns and priority scores are restricted to approximately 50 properties previously identified by participant organizations.

In recent years several organizations have developed tools and services to support a geographic information system (GIS)-based approach to expand conservation prioritization capacity in local communities. For example, the Orton Family Foundation's CommunityViz program (http://www.communityviz.com) has created GIS-based software packages that allow communities to visualize and quantify the impacts of alternative conservation and development scenarios. NatureServe, a spin-off program of The Nature Conservancy, will soon release a decision-support system designed to map and integrate scientific data for conservation prioritization (http://www.natureserve.org/prodServices/vista.jsp; Stoms et al. 2005). Although both tools are supported by extensive digital databases, they provide solely ad hoc methods for assessing economic and land-use change components. Spatial models for these components must be constructed separately or imported from independent sources and may not be readily available for many regions.

A Unified Approach for Conservation Targeting

Working under the assumption that the ultimate objective of conservation decision making is to minimize the expected loss of biological benefits due to future land-use conversion, subject to a limited budget for protection, we compared four conservation targeting strategies. We sought to demonstrate how the targeting process is influenced by the inclusion or exclusion of three model components: distributions of biological benefits (B), land costs (C), and probability of land-use conversion (P). We also describe common techniques used to estimate these three components with particular emphasis on the link between economic costs and land-use conversion.

To simplify the targeting discussion, we assumed there are only two types of land use—developed or developable—and that biological benefits are not found on developed sites. The conversion process from developable to developed was considered to be irreversible and to result in a complete loss of biological benefits rather than a partial loss (e.g., a reduction in habitat quality). We assumed acquisition decisions for only one time period and with no spatial interactions among sites. Targeting methods that are iterative over time (Costello & Polasky 2004) or consider the spatial configuration of protected lands (Briers 2002), however, are important advancements that could be incorporated in the development of more complex models. Also, we considered only the initial costs of acquisition, although there can be considerable costs of monitoring and land management.

Benefits-Only Targeting

Conservation biologists have made significant progress in reserve-selection techniques that maximize representation of biodiversity across space and ensure species persistence over time. Representativeness of a reserve network is typically measured by an index of species richness or habitat diversity. Operations research methods are often applied to optimize representation of a set of target taxa or habitat types by comparing all possible combinations of sites given a constraint on the number of sites or minimum area for conservation.

When the persistence of an individual species or group of species over time is considered in reserve-site selection, then population dynamics and habitat area and quality requirements are often included. Population viability analysis (PVA) can be used to determine the minimum reserve area necessary to support viable populations of focal species (Allen et al. 2001) or to optimize habitat protection (Haight et al. 2002). Recently, goals of representation and persistence have been integrated in reserve designs (Araujo & Williams 2000; Roberts et al., 2004), and valuation of ecosystem services and function (Costanza et al. 1997) has emerged as an important justification for conservation actions.

If biological benefit value (B) is the only criterion for targeting land acquisitions, sites may be ranked from highest to lowest benefit value and then selected until the budget is fully expended. For a given budget amount M, there will exist a critical benefit value B^*, such that sites with $B \geq B^*$ will be selected for protection. Benefits-only targeting will select sites in regions 1 and 2 above the critical benefit value, whereas sites in regions 3 and 4 are not selected (Fig. 1).

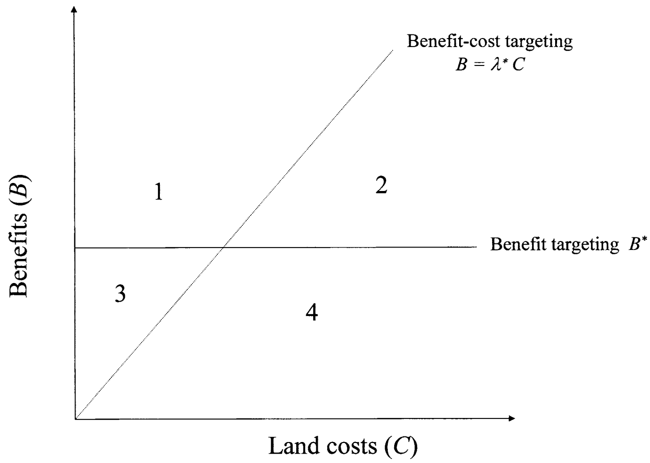

Figure 1. Benefit targeting versus benefit-cost targeting. Benefit targeting ranks sites from highest to lowest benefit value and selects sites in region 1 and 2 above the critical benefit value B* *(horizontal line). This critical benefit value* B* *is always positive because the budget cannot protect all available sites. Given the same budget, benefit-cost targeting selects sites based on the highest ratio of biological benefit value to land costs. It selects sites in regions 1 and 3 situated above the critical line* B = λ* C *(diagonal line), where* λ* *is the slope of the line and critical benefit-cost ratio. If the budget increases, the critical threshold ratio* λ* *decreases, lowering the slope of the critical line.*

Benefit-Cost Targeting

Spatially explicit methods to estimate the acquisition cost of parcels should be a key component in any reserve plan. The most common technique for land valuation is the hedonic approach, which uses observed market transactions to infer the market value of parcel characteristics (Rosen 1974). Heterogeneous land-supply characteristics may include physical land quality (e.g., slope), locational attributes (e.g., proximity to urban centers), and land-use regulations and other factors influencing the returns to land (e.g., zoning). Recent property transactions are used to estimate sales price as a function of the land characteristics, in addition to any property improvements (e.g., buildings). Coefficients in the hedonic equation are interpreted as the marginal implicit value of a unit change in the explanatory variable. For example, the hedonic coefficient on proximity to urban center estimates the gradient in land values as one travels away from the central business district. For more details on the hedonic approach, Palmquist (1991) provides a rigorous explanation of the theory and application, and Garrod and Willis (1999) offer a simpler discussion with less mathematical detail.

Availability of parcel databases and advancements in GIS technology have made spatially explicit land-valuation models increasingly feasible for practical applications. Parcel records, collected for tax assessment purposes by local and state governments, provide detailed information on property sales, existing-use value assessments, land use, and other characteristics. These records can be linked to a digital parcel map and integrated with site-specific characteristics to estimate the developable land value per acre as a function of parcel characteristics.

A separate hedonic model needs to be performed for existing-use value assessments (e.g., value from solely forestry or rangeland activities) to obtain the land value restricted from future development. Tax differential programs such as the California Williamson Act can provide the data on restricted-use value. The conservation easement value can be estimated as the value of developable land minus the restricted-use value and predicted for each developable parcel with a GIS database of parcel characteristics (Newburn et al. 2006).

Benefit-cost targeting selects sites based on the highest ratio of biological benefit value to land costs. Given the same budget M, there will exist a critical threshold ratio λ^*, such that sites with $B/C \geq \lambda^*$ will be selected for protection. Benefit-cost targeting selects sites in regions 1 and 3 situated above the critical line $B = \lambda^* C$, and sites in regions 2 and 4 are not selected (Fig. 1). Benefit-cost targeting justifies protecting lower value benefit areas if the critical ratio $B/C \geq \lambda^*$ is satisfied (region 3), thus permitting a much larger amount of land to be purchased with the same budget. Benefit-cost and benefit targeting are analogous to Ando et al.'s (1998) "cost-constrained" and "site-constrained" targeting algorithms, respectively.

Benefit-Loss Targeting

Conservation targeting should also consider the likelihood of biological benefit loss if the site is not protected from future land-use change. Benefit-loss targeting is analogous to the example Margules and Pressey (2000) provide, which has model components for irreplaceability (biological benefits) and vulnerability (conversion probability). Typically, ad hoc ranking or rule-based classification is used to formulate a proxy for vulnerability (Abbitt et al. 2000; Pressey & Taffs 2001). We advocate that vulnerability should be calibrated based on actual land-use transitions and the underlying parcel characteristics.

"Reduced-form" models may be used to estimate land-use outcomes as a function of the underlying biophysical and socioeconomic characteristics (Chomitz & Gray 1996). Consider a simple land-use-change model constructed with respect to a set of developable parcels observed at two time periods. For each developable parcel, there is a binary outcome—remain in the initial developable land use (e.g., forest habitat) or be converted to a more intensive type of land use (e.g., agriculture). Mapped biophysical and socioeconomic characteristics derived from a GIS serve as explanatory variables in a logistic regression to estimate the relative probability of each land-use alternative. For example, forest conversion to agricultural use will be more likely on areas with suitable soil quality, slope, access to water or precipitation, and access to markets. Coefficients from the logistic regression then can be used to predict the relative probability of land-use conversion for remaining developable sites.

Veldkamp and Lambin (2001) highlight the distinction between the spatial pattern and extent of land-use conversion. Heterogeneity in land-supply characteristics strongly influences the spatial pattern for current and future land uses. Spatial extent and rate of land converted depends on regional demand factors (e.g., employment growth, commodity prices). It is more challenging to forecast economic growth cycles and implications of policy changes and, in turn, to predict the actual spatial extent of future land conversion.

In the California Urban Futures model, Landis and Zhang (1998) simulate the quantity and spatial pattern of future urban growth for San Francisco Bay Area counties. This model relies on regional projections of future population, households, and employment by jurisdiction. Then, a spatial land-use change model allocates households and jobs to available sites based on the site-specific land-use change probabilities (e.g., the probability that a specific vacant or previously developed site will be developed or redeveloped in residential, commercial, or industrial use). Our own spatial models for residential and vineyard expansion in Sonoma County, California, follow this framework. We use parcel-level data on land use, which is publicly available from the county tax assessor. First, we forecast regional demand for housing units and vineyard acreage with time-series analysis. Then, we use multinomial logistic regression to estimate spatial allocation models for land-use transitions at the parcel level. Developable forest or rangeland parcels can be converted to either intensive agriculture or residential use, and these past land-use transitions are calibrated as a function of parcel site characteristics. Vineyard conversion is more likely in areas with flat slopes and warmer microclimate (growing degree-days). Residential development is more probable for parcels close to existing cities, on flat slopes, and within zoning areas permitting higher housing densities. Finally, we forecast development scenarios by stochastically allocating future regional demand for future housing units and vineyard acres in space based on the relative conversion probabilities of developable parcels. These examples demonstrate one approach to modeling land-use change, and a broader discussion of land-use change models is available (Angelsen & Kaimowitz 1999; Irwin & Geoghegan 2001; Agarwal et al. 2002; Parker et al. 2003).

The expected benefit loss (S) can be estimated as the product of the initial biological benefit value and expected conversion probability. Trade-offs between benefits and conversion probabilities will define a set of indifference curves, such that $S = BP =$ constant. Benefit-loss targeting selects sites for protection based on the highest values of S to minimize the expected benefit loss. Hence, sites with the highest expected benefit loss are selected until the budget is fully expended. For a fixed budget M, benefit-loss targeting defines the critical level S^*, and all sites with $S \geq S^*$ are selected. Benefit-loss targeting selects sites in regions $2'$ and $4'$ situated in the upper right corner of Fig. 2.

Benefit-Loss-Cost Targeting

Conservation biologists frequently neglect the implicit positive relationship between expected probability of land-use conversion and land costs for protection. Vulnerable parcels with high land quality for development are typically more expensive than less vulnerable parcels with poor land quality because the relative values in alternative land uses strongly influence landowner conversion decisions. As an intuitive example, consider the probability of urban conversion on a forest or rangeland parcel. When the land value in urban use is high, the probability of urban conversion is expected to be high as well. In contrast, parcels with poor access to urban centers, low land quality, or strict zoning regulations will have much lower land value in urban use. Hence, the expected probability of land-use conversion typically is expressed as an increasing function of the value of developable land. The underlying reason is that land-supply characteristics,

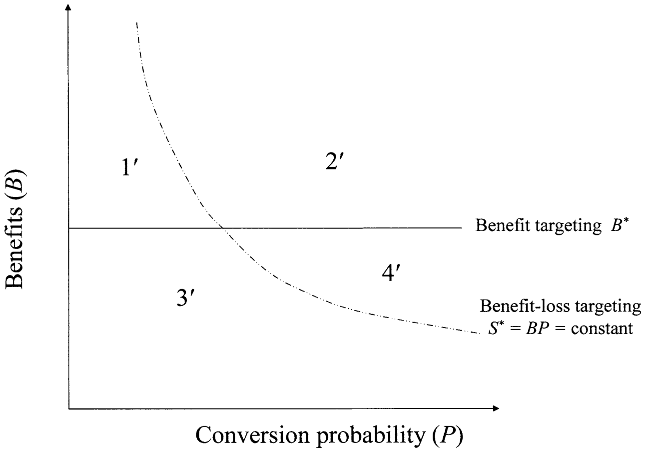

Figure 2. Benefit targeting versus benefit-loss targeting. Benefit targeting selects sites in region 1′ and 2′ above the critical benefit value B* *(horizontal line). Benefit-loss targeting selects sites in regions 2′ and 4′ above the critical level of expected benefit loss* S* *(curve). Benefit-loss targeting prioritizes sites situated in the upper right corner, which possess high benefit value and are highly vulnerable to future land-use conversion.*

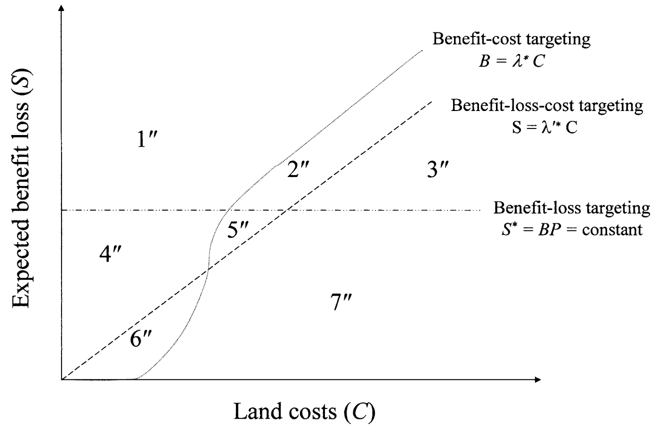

*Figure 3. Benefit-loss-cost, benefit-loss, and benefit-cost targeting. For graphical convenience, the product of initial benefit value and probability of conversion is represented as a single measure (*S*) on the y-axis. Benefit-loss-cost targeting selects sites in regions 1″, 2″, 4″, and 5″ with a ratio of expected benefit loss to costs (*S/C*) greater than the critical slope* λ'^* *(diagonal line). Benefit-loss targeting selects sites in regions 1″, 2″, and 3″ above the critical level of expected benefit loss* S* *(horizontal line), whereas benefit-cost targeting selects sites in regions 1″, 4″, and 6″ above the critical benefit-cost curve.*

serving as explanatory variables for land-valuation models, are also used in land-use change models.

Bockstael (1996) formally demonstrates this relationship in a structural economic model for residential conversion in suburban Maryland. The two-stage process models the explicit relationship between land-use conversion and the relative land values in two alternative uses (forest/farmland or residential). First, a hedonic model for residential transactions is estimated as a function of locational and zoning parcel characteristics. Next, a discrete-choice model of land-use change is constructed with the estimated residential value, agricultural-use value, and other explanatory variables acting as proxies for conversion costs. As expected, model results indicate that the relative probability of urban conversion is positively related to the estimated land value in residential use.

Unifying the methods described above, we propose benefit-loss-cost targeting, which aims to minimize the expected loss of biological benefits due to future land-use conversion and takes acquisition costs into account. Benefit-loss-cost targeting selects sites with the highest ratio of expected benefit loss (S) to land costs (C). The benefit-loss-cost selection rule can be restated in terms of all three components as the highest *PB/C* ratio, where *P* is the probability of conversion. For the same budget *M*, benefit-loss-cost targeting selects sites satisfying the condition $S/C \geq \lambda'^*$, where λ'^* is the critical threshold value for the expected benefit loss per unit cost. Benefit-loss-cost targeting selects sites in regions 1″, 2″, 4″ and 5″, which lie above the critical line $S = \lambda'^* C$ (Fig. 3).

Recall that benefit-loss targeting selects sites above the critical level set for S^* (Fig. 2). This constant level set for S^* would be represented as a horizontal line within S–C space in Fig. 3. Benefit-loss targeting selects sites above this horizontal line in regions 1″, 2″, and 3″. Benefit-loss targeting is less cost-effective than benefit-loss-cost targeting to the degree that it may overallocate the conservation budget toward the most costly sites at the expense of lower cost sites with moderate vulnerability. Benefit-loss targeting selects sites in region 3″, and it does not select sites in regions 4″ and 5″. Region 3″ represents sites with high expected benefit loss, $S \geq S^*$, but these highly vulnerable sites also possess much higher land costs, such that $S/C \leq \lambda'^*$. In sum, the benefit-loss targeting selection rule omits the component for land costs and, hence, does not provide a mechanism to screen out sites with extremely high land costs.

Benefit-cost targeting omits the component for land-use conversion, implicitly assuming that all sites have the same probability of land-use conversion ($P = 1$ for all sites). The assumption contradicts the relationship stated earlier, in which the relative conversion probability is expressed as an increasing function of the land value. Heterogeneity in land-supply characteristics creates spatial variation in land values; hence, sites with lower land values typically also have lower likelihood of future conversion. By neglecting the likelihood of conversion, benefit-cost targeting may be less efficient in that it preferentially selects low-cost sites without weighing the decreased likelihood of future land-use conversion. To map the critical line $B = \lambda^* C$ into Fig. 3, we multiplied this linear function by the expected conversion probability at each corresponding land value. Benefit-cost targeting selects sites above this critical curve in Fig. 3, defined as regions $1''$, $4''$, and $6''$. Benefit-cost targeting is less efficient than benefit-loss-cost targeting to the degree that it selects sites in region $6''$, and it does not select sites in regions $2''$ and $5''$. Region $6''$ represents sites with $B/C \geq \lambda^*$; these low cost sites, however, typically have decreased conversion probability such that $S/C < \lambda'^*$. In sum, benefit-cost targeting overallocates the conservation budget to protect the hinterlands and to maximize available biological benefits. Meanwhile, it underallocates the budget on sites more likely to be developed. Benefit-loss-cost targeting balances the countervailing factors of land costs and probability of land-use conversion.

Given the same fixed budget, each targeting strategy will result in a different amount of land protected—another implication of the positive correlation of likelihood of land-use conversion and land costs. Consider the two strategies based on either lowest-cost or highest-vulnerability targeting. Selecting the lowest-cost sites will result in a larger area protected because of lower acquisition costs per acre, but the more vulnerable sites will not necessarily be protected. In contrast, selecting the highest-vulnerability sites results in a smaller area protected because of higher acquisition costs per acre. Hence, benefit-cost targeting results in a larger area protected than either benefit-loss or benefit-loss-cost targeting, but it preferentially selects the least vulnerable sites. Relative land costs affect site ranking, whereas budget and absolute land costs determine the total number of acres protected.

Although lowest-cost or highest-vulnerability targeting appear to be extreme strategies in theory, they are being implemented in real conservation programs. For example, the Costa Rican government has implemented a national payment for a forestry environmental services program. Starting in 1997, the program offered a fixed payment of roughly \$200/ha to landowners who do not deforest their property for a 5-year contract period (Chomitz et al. 1999). The program structure is analogous to a management agreement based on a lowest-cost targeting strategy. Landowners preferentially enroll in the program if they have poor-quality land characteristics (e.g., steep slopes, far from town). These landowners' economic opportunity costs are typically much less than the fixed payment. In many cases, the cost of forest conversion exceeds the expected returns from alternative uses (pasture, agriculture), meaning these landowners have no intention of forest clearing during the contract period and the opportunity costs are effectively zero. The result may be that the Costa Rican government was allocating funds largely to protect forestlands that are not at immediate risk of deforestation.

Applications for Conservation Programs

In 1999 we initiated collaboration with the Sonoma County Agricultural Preservation and Open Space District to develop a plan for open-space acquisition in Sonoma County, California. The district was created by voters in November 1990 and funded with a local sales tax. We worked with district planners and decision boards to identify and prioritize desirable conservation benefits. Initially, we compiled available digital data on open space and agricultural and natural resources of Sonoma County from available databases. The district authority defined four categories of benefits: agriculture, greenbelts, natural resources, and recreation. The available mapped information related to these topics was reviewed, critiqued, and updated by a broad spectrum of local agricultural, planning, and natural resource professionals. It quickly became clear that the benefits categories were primarily not overlapping in space and each benefit type had distinct supporters. Therefore, separate funds were established to address each benefit type individually.

We developed parcel-level models of land-use change and easement values using the methods described above (Newburn et al. 2006). We were fortunate to have a digital parcel map for Sonoma County, and many other local governments are now in the process of putting their parcel boundaries into digital format. These models allow staff planners to make trade-offs for the relative development threat and acquisition cost for each available parcel. Finally, we helped county computer programmers design a user-friendly GIS interface that allows district staff to query any number of parcels and generate a report of all the mapped benefits included in each site.

Our approach to date in making the district's interactive GIS planning tool useful for the planners is to provide them with information on benefit types, acquisition cost, and relative threat for each parcel and allow them to weigh these in setting priorities. We recognize that conservation planners can best integrate this information and adjust the analysis required depending on changing demands from the district and partnering institutions and other political realities. For example, the district staff use the information to solve diverse problems, from identifying the best places to implement a fast-track easement program for riparian-corridor setbacks to selecting upland sites that meet California's criteria for allocation of bond funds for oak woodland conservation. The district's acquisition priority areas create a landscape-level plan but still provide the flexibility to respond to unexpected conservation opportunities. This flexible, interactive acquisition plan has eased public concern over subjective decision making, allowed transparent exploration of alternative conservation strategies, and reduced the time it takes for project approval in what was formerly a heavily politicized process.

These types of collaborative efforts take time that most conservation biologists do not have and some resources that many smaller land trusts do not have. Conservation biologists, however, are often in a position to influence conservation organizations, or in some cases work for these organizations. To improve the chances that these ideas will be incorporated into the decision-making process by land conservation institutions, we offer the following practical suggestions:

1. Initiate an early collaboration with the conservation organization and work toward explicit conservation objectives. Then, examine the distributional relationships (e.g., correlation and relative variation) among biological benefits to determine whether benefit types should be targeted jointly or individually. If benefit distributions rarely overlap or the relative weights between benefit types are difficult to quantify, then consider allocating the budget into separate funds for each conservation objective.
2. Allocate effort for biological data collection and to increase the spatial resolution of land-use and land-cover information to better address the conservation objectives and landscape context. If a particular component (benefit, cost, threat) exhibits high spatial variability, then greater effort should be allocated to that component to reduce uncertainty in predictive modeling.
3. Model scenarios of land-use change and assess the expected loss of benefits for each conservation objective across the landscape.
4. Estimate the relative economic costs for conservation easements and/or fee title acquisition across the landscape.
5. Provide a simplified user interface that overlays model results for available land parcels. This allows the user to weigh this information and make informed trade-offs depending on their purchasing options, funding partners, and political realities.

Discussion

Economic models have the simplicity of a common currency in dollar terms for evaluating trade-offs between sites. For instance, one site may have five times the economic land value per hectare compared to another site. The valuation of biological benefits, however, remains a major challenge for conservation biologists, particularly when there are multiple conservation objectives (e.g., species, habitat types). To set land acquisition priorities, conservation planners must define the relative weights between benefit types. What is the trade-off between conserving a hectare of wetland and a hectare of montane forest? Even if one had complete and accurate information on all species distributions and habitat requirements, this question of relative conservation value would remain. Moreover, different wetland areas may not be uniform in habitat quality, and relative weights must be assigned as a proxy for habitat quality within a single habitat type. Setting regional conservation goals such as conserving 10% of common habitat types and 20% of rare habitat types is another method for weighting areas. In this case, the measures of irreplaceability or complementarity depend on the extent of remnant habitat and modeler's choice of regional conservation goals.

In practice, protected-area plans are typically determined by regional goals and ad hoc scoring procedures, and site ranking depends on the choice of relative weights within and between benefit types. Consider a benefits-only targeting approach with two benefit types and, for the moment, assume that costs and land-use change components are both uniform across space. The sensitivity of site ranking depends fundamentally on the correlation and relative variation between the two benefit distributions. Positive correlation signifies co-occurrence of the priority species or habitats, whereas negative correlation indicates that the two distributions rarely overlap in space. If the biological benefit value function were redefined to increase the ratio of weights between two distinct habitat types (e.g., montane forests vs. wetlands), the set of priority sites would include more parcels from one habitat type at the expense of the other habitat type. This substitution effect of site selection increases with the strength of negative correlation among multiple distributions of benefit types. This may result in a see-saw effect, where site rankings shift primarily as a function of the relative weights defined by the modeler.

Valuation of biological benefits will increase in complexity as one considers the spatial relationships between sites. The benefit function will be nonlinear because the benefits of a given site depend on the status of adjacent sites. Because habitat requirements vary for each species, the benefits are also typically defined by the modeler's choice of scoring procedures for reserve site connectivity.

Valuation of biological benefits is also a primary limiting factor in achieving optimal solutions with operations research algorithms. Operations research has made important contributions toward solving complex reserve selection problems, but we need to recognize that even with the best available data our objective functions are products of their particular social, economic, and political contexts. A decision maker unfamiliar with the optimization algorithms may not clearly see the link between spatial data on benefit distributions, relative weights as model inputs, and optimal solutions.

Correlations between the three main components, together with poor assessments of the relative variation, may exacerbate inefficiency in conservation targeting. For example, the positive correlation between the likelihood of land-use conversion and costs of land protection requires a trade-off between high-vulnerability, high-cost sites and low-vulnerability, low-cost sites (Fig. 3). Consider the case of a strong negative correlation between land costs (C) and expected benefit loss (S). Many sites would be situated in regions 1″ and 7″; hence, the three targeting approaches would perform similarly. In contrast, when strong positive correlation exists between costs and expected benefit loss—as it typically does—many sites would be situated either slightly above or below the critical line for benefit-loss-cost targeting. This results in greater differences in the set of selected sites among the three targeting methods. Conservation efficiency increases with the application of realistic economic and ecological models. Spatial economic models should elucidate the trade-offs between vulnerability and costs. Spatial ecological models, although they may not be put into economic terms, should compare the biological value of remaining habitat according to different future scenarios of land-use change.

Future Directions: Land-Use Planning and Conservation Programs

No matter how efficient the theory and practice of conservation targeting become, we will not be able to acquire all the conservation benefits that private lands provide. We must seek a comprehensive approach to conservation that integrates incentive-based tools with land-use planning. It is important to recognize how our conservation programs operate within a larger context of property rights and land-use policies.

Conservation easements and zoning restrictions have essentially the same function. The difference between the two is the distributional effects between the public and private landowners (Coase 1960). Conservation easement or full purchase is used when the landowner has the right to develop, and the public must compensate the landowner to protect the public resources. Land-use regulations such as zoning say that the public can limit future development to protect public interests and compensation is not necessarily provided.

Zoning represents the "police power" of the public to reduce externalities from private landowner decisions (Fischel 1995), and it is a critical tool for private land conservation. More often, zoning regulations act as a partial restriction to development by limiting the size and intensity of future development. These regulations may reduce the cost of purchasing development rights. Conservation programs can take advantage of this partial restriction because the developable land value is generally lower than it would be without regulation.

Conservation easements and fee title acquisition amount to parcel-by-parcel land-supply restrictions. Protecting land from development may prevent habitat conversion locally, but these restrictions on land supply may not be an effective way to shape future regional growth patterns. The regional demand for land remains despite conservation acquisitions, and growth will shift to other unprotected locations. Land-use plans and public infrastructure projects are necessary to redirect and concentrate regional development and can serve conservation objectives as well. For example, Irwin et al. (2003) demonstrate that extending public sewer and water infrastructure may guide urban growth to designated target areas more effectively than placing easements on existing farmland.

Conclusion

We compared four simple targeting strategies to conceptually demonstrate the important relationship between economics and land-use change. Any targeting approach that ignores either vulnerability or costs will result in suboptimal targeting. Often land trusts have a general idea of these factors but lack the expertise to formulate accurate spatial models of land-use change or acquisition costs. We hope our experiences on how to construct and extend these models to land trusts implementing conservation programs will be useful. We believe more attention should be placed on the relationship between conservation programs and local zoning plans. Comprehensive conservation planning on private lands should identify the best areas to protect but must also envision the best spatial configuration to accommodate future growth.

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