Title
The power of information for targeting cost-effective conservation investments in multifunctional farmlands

Journal
Environmental Modelling & Software, 26(1)

ISSN
1364-8152

Authors
Stoms, David M
Kreitler, Jason
Davis, Frank W

Publication Date
2011

DOI
10.1016/j.envsoft.2010.03.008

Peer reviewed

Elsevier Editorial System(tm) for Environmental Modelling & Software
Manuscript Draft

Manuscript Number:

Title: The power of information for targeting cost-effective conservation investments in multifunctional farmlands

Article Type: Special Issue: NRM Investment Decisions

Keywords: spatial targeting; farmland preservation; marginal value; benefits; costs; Great Central Valley; California; threats; additionality; ecosystem services; urban growth management

Corresponding Author: Dr David Stoms, Ph.D.

Corresponding Author's Institution: University of California Santa Barbara

First Author: David Stoms, Ph.D.

Order of Authors: David Stoms, Ph.D.; Jason Kreitler, PhD candidate; Frank W Davis, Ph.D.

Abstract: Decisions about which places to conserve are based upon the geographic heterogeneity of three types of information: public goods or benefits, their vulnerability to threats, and the costs to avert those threats. The choice of public goods depends on the mission of the conservation organization (e.g., biodiversity, open space, cultural values, or farmland). For spatial targeting of conservation at the regional scale, practitioners must estimate the values of these types of information. The quality of the estimations will vary by the primary data used, the assumptions made, and the practitioner's technical ability to analyze complex data. This paper contributes to the growing literature by presenting a systematic evaluation of effect of the quality of the estimation on the cost-effectiveness of the set of sites selected for conservation based upon those estimates. The specific case study targets farmland for preservation from urban development in California's Central Valley where a new land trust was recently established to purchase conservation easements. In one analysis, we compared the cost-effectiveness of farmland benefits using our most sophisticated estimation procedures to those that ignored costs and/or potential loss (i.e., assumed they were equal among sites). Excluding information about the potential loss of resources caused only a slight decrease in cost-effectiveness. On the other hand, ignoring cost information was extremely inefficient. The second analysis compared the performance of the sophisticated estimated to increasingly simpler estimates, such as those that are representative of the methods used by many American farmland preservation programs. The simplification of the estimates caused a 5- to 20-fold decline in the benefits that could be retained for a given budget. To make more cost-effective targeting strategies accessible to farmland preservation programs, we recommend that researchers develop new spatial targeting tools to overcome obstacles in data processing.

1. Introduction

Conservation practitioners, whether protecting biodiversity, open space, ecosystem services, or farmland, are always challenged to be effective and efficient with their limited funds. Their underlying goal is either to maximize the conservation assets they can protect or minimize loss of assets with a fixed budget (Kirkpatrick, 1983; Cocks and Baird, 1989; Pressey and Nicholls, 1989; Hyman and Leibowitz, 2000; Margules and Pressey, 2000; Haight et al., 2005; Machado et al., 2006; Messer, 2006; Wünscher et al., 2008). They need the assistance of researchers to develop performance measures to accomplish their goals. The challenge for researchers is to transform a multitude of scientific and technical data into useful and understandable information for decision makers to set conservation priorities. A calculated performance measure is inherently an estimate of the "true" conservation value of a site. Better estimates of conservation value should lead to more cost-effective decisions, but they come at a price of greater data collection and analytical capability to implement. Moreover, performance measures that are too difficult for practitioners to implement will seldom be used. On the other hand, measures that are overly simplistic may lead to inferior decisions. How much cost-effectiveness suffers in response to poorer estimates of the performance measure has not been adequately studied.

Newburn et al. (2005) described three components or types of information for calculating a performance measure for conservation planning: benefits, costs, and loss. In their terminology, "benefits" refers to the conservation assets currently occurring in a site. Loss is the reduction in the quantity or quality of benefits that would result from land use changes that are likely to occur if conservation action is not taken. Costs are the expenses to prevent the loss of benefits and may include acquisition, management, transaction, and opportunity costs. Newburn et al. (2005) proceeded to describe four conservation targeting strategies based on different combinations of these types of information. The Benefits-only targeting strategy obviously employs just the benefits information component. The focus is on identifying potential conservation areas with the greatest assets, regardless of their costs or vulnerability to loss. Conservation practice often uses a Benefits-only strategy, both by large governmental programs (Babcock et al., 1997; Ribaudo et al., 2001) and by local conservation groups (Tulloch et al., 2003). Recent papers in conservation planning have urged the explicit consideration of costs in addition to benefits for efficient protection (Babcock et al., 1997; Ando et al., 1998; Hyman and Leibowitz, 2000; Newburn et al., 2005; Messer, 2006; Naidoo et al., 2006; Davis et al., 2006; Murdoch et al., 2007; Perhans et al., 2008). This “Benefits-Cost” targeting strategy typically ranks sites by the ratio of benefits to costs. A small but growing number of researchers have also promoted the use of information about the net benefits of conservation per unit of cost (Hyman and Leibowitz, 2000; Newburn et al., 2005; Davis et al., 2006), which corresponds to the “Benefits-Loss-Cost” targeting strategy. Wünscher et al. (2008) use the term “benefits additionality” to indicate that the performance measure should only account for the contribution that conservation action makes, which is only the benefits that would be lost without action. This strategy aims to minimize loss of benefits for a given budget. To estimate potential loss requires a forecast or scenario of future land use. Newburn et al. (2005) demonstrated conceptually how each targeting strategy would select different types of areas, where the accuracy of the performance measure could in principle lead to selection of some parcels with little overall gain in public good.

In addition to the choice of which combination of benefits, loss, and cost factors to include, the degree of sophistication in modeling each factor affects the estimated performance measure. We refer here to the level of sophistication as the “quality of information.” Frequently the quality of information used corresponds to the number of types of information used. That is, planning based on the simplest data tends to use Benefits-only targeting, and the most complex data is usually compiled for Benefits-Loss-Cost strategies. Simple scoring indices have often been used as a measure of the conservation benefits (Pressey and Nicholls, 1989; Babcock et al., 1997; Guikema and Milke, 1999, Tulloch et al., 2003). They remain popular in practice, particularly with smaller conservation organizations, because the data requirements are relatively modest and the method is understandable by policy makers and the public (Hoobler et al., 2003; Sokolow and Zurbrugg, 2003, Tulloch et al., 2003). The Loss and Cost types of information by their nature tend to be more complex. At present the nature and magnitude of these tradeoffs are poorly understood. Are relatively complex spatial analyses to derive new data sets necessary or can readily available public data provide adequate performance estimates to set regional conservation priorities?

We address this problem here by comparing the overall cost-effectiveness of targeting strategies based on alternative performance measures in the context of preserving farmland from urban development. We initially developed a sophisticated performance measure that incorporated benefits, loss, and cost factors following the framework of Machado et al. (2006). Benefit criteria included all three major categories of public goods obtained by preserving farmland, namely agricultural productivity, rural amenities and ecosystem services, and support for urban growth management. In one analysis we systematically modify the performance measure of conservation value by sequentially removing Loss and Cost factors. In a second analysis we systematically lower the quality of information used to estimate conservation value. For both cases we then compare cumulative net benefits over a range of fixed conservation budgets to determine the effect of targeting with different combinations of information and how those effects vary with funding. In principal, all the cost-effectiveness of all performance measures will converge at the limit when all land is preserved. Our study explored whether that convergence occurs even at plausible budget levels.

Our specific research questions are:

1. How much does conservation cost-effectiveness decline when loss or cost information is ignored in estimating the conservation value used to prioritize farmland preservation investments? How does the size of the budget affect relative cost-effectiveness between these performance measures?

2. How much does conservation cost-effectiveness decline as a function of simplifying the estimates of conservation value and budget level?

3. How similar are the set of farm parcels selected by the different targeting strategies?

Although this study evaluates performance for farmland preservation, the methods could be applied to any other conservation goals such as biodiversity or public open space. Because farmland preservation is less familiar than biodiversity conservation, we provide a brief overview in section 2 about the public goods associated with farmland and alternative targeting strategies based on simple and complex performance measures.

2. Farmland Preservation Targeting Strategies

In parts of the United States, and to a lesser extent in Canada and a few other countries, citizens grew alarmed at the perceived rate of loss of farmland as cities and towns grew. Many communities formed either public or private organizations to target farmland to be preserved (Sokolow and Zurbrugg, 2003). The most common technique applies an agricultural conservation easement to the farm by purchasing the rights to development on the property while permitting agricultural activity to continue. This technique is akin to when conservation groups buy and hold timber concessions in tropical forests to prevent them from being logged. Initially these programs, which collectively became known as Purchase of Development Rights or PDRs, focused on preserving the most productive soils. Over time, the goals of farmland preservation have expanded to include ecosystem services and the capacity of farmland to support urban growth management policies (Machado et al. 2006). As these farmland PDR programs got larger, they began to need more formal performance measures to prioritize investments in a credible and transparent manner.

Many farmland PDR programs currently use a relatively simple Benefits-only approach to calculating their performance measure (e.g., Sokolow and Zurbrugg, 2003). Most of these approaches are derivatives of the Land Evaluation and Site Assessment (LESA) system (Ferguson et al., 1991; Pease et al., 1994). LESA consists of two parts. The land evaluation (LE) part rates the land for crop production, and the site assessment (SA) component accounts for other criteria such as farm size, zoning, and distance to existing conservation easements. Farms are assigned points based on their respective attributes for these criteria, which are then summed into an overall score to determine each farm's ranking. This LESA-based performance measure can be applied to criteria maps to rate all farms in a program area with relatively low demands for spatial data or technical expertise (Hoobler et al., 2003; Tulloch et al., 2003). Zurbrugg and Sokolow (2006) reviewed 46 major farmland preservation programs in the United States, and found that 34 use quantitative methods similar to those described above. Costs are usually not part of the score, and loss is never considered. Some of the remaining twelve programs use criteria to determine which farms are eligible (sometimes including a maximum price limit) and will acquire easements as landowners make their farms available. In other words these programs do not set priorities beyond classifying farms as eligible or ineligible.

At the other end of the spectrum, Machado et al. (2006) recently presented a benefits-loss-cost targeting framework for farmland preservation that paralleled the framework proposed by Davis et al. (2006) for biodiversity. This framework minimizes the loss of multiple farmland benefits in a planning period for a given budget. The conservation value CV_i of parcel i is calculated as a cost-effectiveness ratio, benefits-loss BL_i divided by cost C_i:

[1] $$CV_i = \frac{BL_i}{C_i}$$

Benefits-Loss is a weighted sum of the net benefits retained for all objectives for multifunctional agricultural land, expressed as:

[2] $$BL_i = \sum_{j=1}^{J} w_j W_{ij} = w_{ap} W_{i,ap} + w_{es} W_{i,es} + w_{gm} W_{i,gm}$$

where w_j is the weight assigned to objective j (agricultural production [ap], rural amenities and ecosystem services [es], and growth management [gm]). W_{ij} is the net benefits of preserving site i for objective j. Benefits in this framework are derived from measures of the resource quantity and quality of each criterion, such as soil productivity or provision of ecosystem service. Each of the objectives can also be decomposed into more specific criteria, such as the individual ecosystem services. Loss is based on a forecast of future land use change. Loss can be estimated either by the probability of urban conversion (Newburn et al., 2005) or deforestation (Wünscher et al., 2008) as a coefficient of loss (the exposure dimension of vulnerability according to Wilson et al., 2005) or by the potential loss or degradation of conservation benefits in the future or net benefits (the impact dimension of vulnerability in Wilson et al., 2005). The last piece of the framework is a benefit function (Arponen et al., 2005) that translates resource quantity and quality into a level of benefits W_{ij} for each objective. A benefit function acknowledges that the marginal benefit of protecting more of a resource depends dynamically on the level already protected. Because this Benefits-Loss-Cost framework provides the most comprehensive accounting of high quality information, we can presume that it provides a better estimate of conservation value than simple scoring methods of benefits in common practice by farmland PDR programs. However, the potential gain in cost-effectiveness comes at a cost in terms of greater demands on conservation practitioners for finding relevant data and applying more advanced spatial analysis operations.

3. Methods

3.1. Study area description

Our study was conducted in a 6,100 km^2 region in Sacramento and San Joaquin counties of California (Fig. 1). The region supports a large agricultural economy, with important farmland in the valley floor and scenic grazing land in the foothills. Due to growth pressure from the metropolitan areas of Sacramento, Stockton, and the nearby San Francisco Bay Area, agricultural land is rapidly being converted to urban uses, with 3600 hectares converted to urban use between 2000 and 2002 alone. There are complex economic and environmental trade-offs associated with new development, notably loss of prime farmland, increased development and associated risk in low-lying flood-prone areas, and loss of wildlife habitat. The Central Valley Farmland Trust (CVFT), a non-profit farmland preservation land trust, was recently formed to mediate the loss of farmland by acquiring fee title or agricultural conservation easements in these counties and two adjoining counties to the south. Like some other PDR programs, CVFT currently uses minimum screening criteria to determine which farms are eligible for preservation rather than using a formula to rank parcels. CVFT's guidelines direct them to preserve farms larger than 15 hectares (40 acres), outside of urban spheres of influence, and with important farmland. The CVFT can potentially invest considerable resources to this effort because they are the recipients of mitigation fees from new development on farmland. The establishment of CVFT provided an opportunity to compare the cost-effectiveness of their screening criteria against various targeting strategies and performance measures.

[Insert Fig. 1 about here]

3.2. Targeting strategies and information requirements

3.2.1. Strategies by type of information

The three most common strategies described by Newburn et al. (2005), namely Benefits-only, Benefits-Cost, and Benefits-Loss-Cost, were implemented and compared. The Benefits-Loss-Cost targeting strategy used all three types of information as proposed by Machado et al. (2006). See Table 1, right-hand column, for description of the criteria for calculating benefits. This strategy targeted farms that exceed a threshold value of the ratio benefit-loss over costs. The Benefits-Cost strategy ignored the Loss information and ranked parcels by a simple ratio of Benefits (rather than net benefits) over Cost, targeting farms above a threshold ratio (Newburn et al., 2005). The Benefits-only strategy used the same measure of the total Benefits as the other two strategies but ignored Loss and Cost information and targeted parcels with highest benefits. Thus each strategy used a different performance measure to target farms. We compared their overall performance in terms of net benefits preserved at given budget levels. It is also possible to target based on Cost-only, which selects the lowest cost sites first and tends to maximize area preserved (Babcock et al. 1997). Unless costs are inversely related to benefits, this strategy is generally not cost-effective and was not analyzed here.

Through a variety of geographic information system (GIS) operations, the Benefits, Loss, and Cost variables were calculated for all 31,032 agricultural parcels larger than 5 ha in the study area. Benefit measures were calculated for the three broad objectives of farmland preservation: farmland productivity, rural amenities/ecosystem services, and urban growth management. For each, we selected specific criteria that were relevant to the study area (Table 1). In this study, we have assumed that the objectives are equally-weighted for the basic analysis to reflect a balancing of competing interests. However, we tested the sensitivity of the results to the choice of weights as described in section 1.3. Loss was based on future development allowed in local plans. Data on the cost of development rights were not available for the study area, as they are not for most regions of the US. Instead, we developed a hedonic model using the land value of 740 recent real estate transactions of farms to predict market value of the remaining parcels as a function of explanatory characteristics such as distance to the nearest urban area and presence within the 100 year floodplain. The relationship between market value as reflected in the sales data and the value of development rights associated with conservation easements is uncertain because purchase of development rights has only recently been implemented in the study area. The CVFT believes that the fraction of market value represented by the development rights will be very high (B. Martin, personal communication). For this exercise, therefore, we assumed that the values of development rights are equal to market value. The implications of this and other assumptions are discussed in section 5.

3.2.2. Strategies by quality of information

The Benefits-Loss-Cost strategy described above also utilized the highest quality information available, where high quality means that the information is comprehensive and most effectively selects farms that retain the maximum possible benefits. It accounted for all types of benefits provided by farmland in the study area; it converted resources that were measured on various measurement scales into benefits through the use of benefit functions; it incorporated potential loss from the results of an urban growth model or from general plans; and it used a sophisticated statistical model to estimate costs. However, it requires more data and more analytical capacity than is typically employed in PDR programs. We refer to this as the Full Information Option. As less data is used, and used in less sophisticated ways, this reduction in the quality of information will similarly reduce the accuracy of estimate of conservation value and therefore level of benefits that are targeted. To test the magnitude of this effect, we systematically reduced the quality of information as shown in Tables 1 and 2 to three other levels.

The Basic Information Option represents the approach in common usage in PDR programs (Sokolow and Zurbrugg, 2003), based on the LESA methodology (Ferguson et al., 1991; Pease et al., 1994; Dung and Sugumaran, 2005). The goal can generally be stated as protecting the most productive farmland on large parcels zoned for agricultural use in local plans. Potential loss is not usually considered. In fact, agricultural zoning and large parcel size usually implies that the short-term threat of development is relatively low. Cost is often considered only as an eligibility criterion after the scoring and ranking has occurred in these programs. Therefore cost is not used as a criterion for the Basic Information option in this study. In summary, the Basic Information option only accounts for benefits, and these are only measured using a subset of basic criteria.

The Moderate Information Option is our attempt to create an intermediate hybrid option that includes the full set of objectives from the Full Information Option but uses a simpler scoring approach to calculate them. This option does not require as much GIS technical capacity as the Full Information Option to calculate criteria; for instance it does not require a scenario of future land use change. Ecosystem services and growth management criteria from the Full Information Option are included but estimated as simple scores of benefits. Similarly, the Moderate Information Option used an index of relative cost rather than the hedonic model of expected land values. Standard GIS layers, such as the general plans, parcel size, and distance from urban areas, were each categorized into High, Medium, and Low classes. Then the class maps were combined through a rule-based matrix into cost index classes that were assigned relative cost scores. This emulates a proposed method for using LESA to calculate a points-based cost model as an alternative to the expensive and time-consuming process of conducting formal land appraisals (Soil and Water Conservation Society, 2003). GIS tasks were limited to simple operations.

Some PDR programs only use quantitative methods to set minimum eligibility criteria, and then will accept any eligible parcel (Sokolow and Zurbrugg, 2003). We also wanted to compare the cost-effectiveness of the three levels of quality of information against this kind of screening strategy. First, we applied CVFT’s minimum criteria including: parcel size greater than 15 hectares, location beyond a city’s designated sphere of influence where new growth is encouraged, and high farmland quality. This screening strategy reduced the 31,032 agricultural parcels to 4,238 that would be considered eligible by CVFT’s current criteria. The prioritization process used none of the available information of the other levels, so all eligible parcels would be considered equal priority at this point. All eligible parcels were randomly ranked 1000 times to determine the mean of net benefits that could be preserved through this random approach, which we called the Minimal Information Option.

3.3. Analyses

Every parcel was scored and ranked in descending order for each of the targeting strategies and tiers of information. The top ranking farmland for each strategy was selected for preservation using a greedy heuristic (Church, 1974). That is, parcels were selected in descending rank order of the selection criteria and their cost added to the cumulative cost. Selection stopped when the cumulative cost of adding the next parcel exceeded the budget limit, using budget levels of $25 million, $50 million, $100 million, $250 million, $500 million, and $1 billion. This analysis was repeated for the quality of information options. For the Minimal Information Option, cost information was not used in the ranking and could not therefore be used in selecting parcels. Instead parcels were selected through a Monte Carlo sampling procedure with a uniform random variable that ranked the subset of eligible parcels 1000 times at each budget level. The loss averted for each criterion was recorded over 1000 trials to calculate a mean and standard deviation of accumulated benefits preserved at each budget level.

In comparing the cost-effectiveness of the three strategies and four levels of information quality, we calculated the total net social benefits preserved in each set of selected parcels. First, the potential averted loss of resources was summed for the selected parcels for each criterion j. Next the benefit function associated with criterion j was applied with the cumulative averted loss to calculate total net benefits retained by the strategy, W_j. Last, the net benefits for all criteria were weighted equally and summed to derive cumulative BL as per equation 2. Cumulative costs C were already determined by the fixed budget levels. Decreases in net benefits or Benefits-Loss, BL, from that of the Benefits-Loss-Cost strategy represent the trade-off in cost-effectiveness associated with the types and quality of information used to rank parcels.

In addition to the difference in cumulative net benefits, it would also be useful to know how many parcels were selected in common between targeting strategies at a fixed budget level. It is possible that a small set of especially valuable parcels could be identified with even minimal information. We compared sets of sites selected by various strategies using the Jaccard similarity index (Jaccard, 1901):

[3] $$J = a / (a + b + c),$$

where a is the number of parcels selected in common by a pair of targeting strategies, b is the number of parcels selected by the first strategy but not the second, and c is the number of parcels selected in the second strategy but not the first. The index can be interpreted as the proportion of parcels common to both lists (i.e., their intersection) of the combined set of all parcels selected by either strategy (i.e., their union). The index ranges from 0 if no parcels were shared to 1 if all parcels were shared. The index was only calculated for the set of parcels selected with a budget of $100 million, assuming that was large enough to select a meaningful number of parcels yet small enough that it might be reached in an aggressive preservation program.

Ranking parcels by cost-effectiveness could be strongly influenced by the choice of weights on the benefits criteria. The Full Information Option used equal weights. To test the sensitivity of results to weighting, we assigned new criteria weights, w_{ij}, to reflect the hypothetical preferences of three stakeholder groups—farmer interests, smart growth advocates, and environmentalists (Table 3). To represent farmer interests, the dominant weight was assigned to highly productive soils as most farmland preservation programs do. However, a small weight was also assigned to the growth management criteria in recognition that some programs value strategic targeting (Stoms et al., 2009). These programs typically do not strive to protect rural amenities and ecosystem services (except perhaps those that benefit farmers) so a weight of zero was assigned for this objective. Smart growth principles encompass a variety of goals besides controlling urban expansion. It also promotes access to rural amenities and locally-grown food. Therefore we assigned the highest weight to growth management criteria for this interest group but still assigned small weights to the other two objectives. We assumed that the Environmentalist group most supports the protection of habitat and ecosystem services, and therefore assigned a very high weight on the ecosystem services objective. A small weight was also assigned for growth management as a strategic tool for protecting environmental values. This group, however, does not generally care whether the farmland is productive, only that the environmental benefits are greater if the land is used for agriculture rather than urban development. Clearly membership in these three groups is not mutually exclusive, and many stakeholders might associate themselves with two or more of these groups. The weighted net benefits of parcels were recalculated and ranked for each group. Sensitivity was measured by the similarity of sets of parcels targeted relative to the equally-weighted version at the $100 million budget level. High similarity would indicate low sensitivity to weighting for this study area.

It is also possible that conservation cost and threat to resources are positively correlated. If so, the Benefit-Cost and Benefit-Loss-Cost targeting strategies should be nearly equally effective, and the simpler Benefits-Cost strategy would be a more practical option for practitioners. We calculated the Pearson's correlation coefficient between cost (predicted market value per hectare) and net benefits per hectare for all 25,380 parcels with positive net benefits and then just for the 344 parcels selected in the Benefit-Loss-Cost strategy with a $100 million budget.

4. Results

4.1. Strategies by type of information

The cost-effectiveness of parcels using the Benefits-Loss- Cost performance measure ranged from 0.0 to 0.92 (Fig. 2). The highest scoring parcels tend to be moderate to large size and relatively distant from the edge of urban development. However, there was no single area where cost-effective parcels were congregated. This absence of spatial coherence in ranking is caused by the complex interaction of the patterns of scores for the conservation objectives and the pattern of land market values.

[Insert Fig. 2 about here]

Total net benefits, BL, was used to quantify the effectiveness of the various targeting strategies for a fixed cost at different budget levels. Plotting the cumulative costs against net benefits is an effective method for comparing alternative targeting strategies (Gauvin et al., in press). The full Benefits-Loss-Cost strategy preserved the most additional benefits at every budget level evaluated (Fig. 3). The net benefits increased from 9.5 (in dimensionless units) at the $25 million budget level to 143.3 at the $1 billion level. The curve of net benefits vs. costs shows a steep rise in net benefits at lower budgets, with a gradual flattening of the slope as less cost-effective parcels are selected. Removing the Loss information still retained nearly all the net benefits of the full Benefits-Loss-Cost strategy, with a decrease in cost-effectiveness of only a few percent. In contrast, excluding both Cost and Loss information and ranking by Benefits-only caused a substantial decrease in the net benefits of selected parcels. This strategy was the least cost-effective of any tested, even compared to the Minimal Information Option in which eligible parcels were randomly selected. The Benefits-only strategy tended to select a few very large properties that were generally not threatened with development. The top ranked parcel in this strategy had a modeled land value of $35 million, which could not even be selected until the budget level was increased to $50 million. At the highest budget level, the Benefits-only strategy preserved less than 10% of the net benefits of the Benefits-Loss-Cost strategy.

[Insert Fig. 3 about here]

By targeting a small number of large farms, the Benefits-only strategy targeted just three parcels at the $100 million budget level. By virtue of their large size, these three parcels contained high benefits but were also expensive. None of these overlapped with any of the parcels targeted by the Benefits-Cost or Benefits-Loss-Cost strategies. As might be expected from their similar cost-effectiveness, the Benefits-Cost and Benefits-Loss-Cost strategies shared 77% of their parcels in common. This result further suggests that there is some flexibility in targeting parcels cost-effectively, perhaps using less information to target them.

4.2. Strategies by quality of information

The Full Information Option (same as the Benefits-Loss-Cost strategy) dramatically outperformed the other information options (Fig. 4). The net benefits of the Full Information Option grew rapidly at smaller budgets but with a slower rate of increase at higher budgets.

These diminishing returns reflect the objective of that strategy to preserve parcels with greatest cost-effectiveness first. At the smallest budget level evaluated ($25 million) the Full Information Option preserved ten times as much net benefits as the Moderate Information Option and nearly twenty times as much as the Basic Information Option. Because of the diminishing returns in the Full Information Option, its advantage decreased with increasing budget, but was still five to six times as effective as the other options. The results for the Basic and Moderate Information Options were both relatively low, with the Moderate Information Option preserving about 30% more net benefits than the Basic Information Option. These two options both generated linear cumulative net benefits accumulation curves. This result suggests that these strategies were not targeting the most cost-effective parcels first. Surprisingly, the Minimal Information Option that used random targeting performed more cost-effectively than the Basic and Moderate Information Options, especially at the lowest budget levels. If all farmland in the study area were preserved, at an estimated cost of $37 trillion, the curves would ultimately converge. Within the range of budgets we evaluated, however, the quality of information makes an enormous difference.

[Insert Fig. 4 about here]

Of the 40 parcels selected in the Basic and Moderate Information Options at the $100 million budget level, only one parcel was common to both. Neither shared any parcels in common with the 344 parcels selected in the Full Information Option. The sensitivity analysis of criteria weighting found that the results were robust to the choice of weights. The weighting schemes for farmer interests, smart growth advocates, and environmentalists all had greater than 90% overlap with the parcels selected in the equally-weighted Full Information Option (Table 3).

Although land market value is related to the same factors associated with threats, we found a weak negative correlation (-0.17, p<0.005) between predicted price per hectare and total net benefits per hectare for all 25,380 parcels with positive net benefits values. On the other hand, the 344 parcels selected in the Benefit-Loss-Cost strategy with a $100 million budget had a small positive correlation (+0.28, p<0.005). Thus in both cases the correlation was significant but relatively small.

5. Discussion and Conclusions

Prendergast et al. (1999) claimed that it was a matter of judgment whether it was more prudent to invest in more information or to invest in land conservation based on less information. Our study revealed enormous improvements in performance in net benefits when targeted by a combination of benefits, their potential loss if not preserved, and costs. Our findings showed an enormous increase in cost-effectiveness when supplementing Benefits information with Cost. In fact, the Benefits-only targeting strategy was only able to preserve three parcels with a $100 million budget. The high Benefits in those three parcels was the result of their large size, which also made them extremely expensive despite being at low risk of loss. To our surprise, including Loss information did not substantially increase cost-effectiveness in this study. The Benefits-Cost strategy was nearly as cost-effective as the Benefits-Loss-Cost strategy. Newburn et al. (2005) showed similar results in a hypothetical situation. Their Benefits-Cost strategy targeted some low cost-low risk hinterlands at the expense of some higher cost lands with high potential loss. Our results suggest that there are a relatively small number of parcels in the study area that are highly desirable for farmland preservation in terms of cost-effectiveness (relatively high benefits at risk for relatively low cost). Both the Benefits-Loss-Cost and Benefits-Cost strategies successfully targeted those parcels. However, the simpler Benefits-only strategy did not identify these parcels because its ranking method did not utilize the critical cost information. Other researchers have reported that cost information is especially important in setting priorities when the costs are more variable than the benefits (Messer, 2006; Naidoo et al., 2006; Perhans et al., 2008). In our study, Benefits-Loss data were slightly more heterogeneous than Cost data as measured by the coefficient of variation.

The quality of information had a dramatic impact on the cost-effectiveness of targeting. The Full Information Option was 5-20 times more cost-effective than the lower information quality options used in this case study, with the greatest proportional improvements at lower spending levels. Thus even farmland preservation programs with modest budgets would achieve better performance by employing this strategy. The next best level of information quality turned out to be the Minimal Information Option that used the rule-based eligibility guidelines of the CVFT. On average, this simple strategy slightly outperformed the Moderate Information Option, especially at smaller budget levels. Although the Minimal Information Option did not explicitly include any cost information, the rules about parcel size and urban spheres of influence indirectly promoted the selection of lower cost parcels.

Of course even the Full Information Option as calculated here is itself only an estimate of the "true" conservation value. For regional scale conservation targeting efforts, it is impossible to make direct observations of all factors. Most of the data are from indirect sources such as mapping from remotely sensed data (e.g., soil mapping) or modeling from sample data (e.g., our hedonic model of land values). Gauvin et al. (in press) concluded that the most heterogeneous factor would be the place to invest greater resources to map more accurately for the greatest gain in cost-effectiveness. We used the simplifying assumption that the cost of development rights was equal to market value of farmland, rather than the more complex analysis of subtracting agricultural rents (Plantinga and Miller, 2001). This assumption possibly biased the results by estimating larger than true costs for farms with lower development potential further from urban centers. Our implementation of the Machado et al. framework (2006) also did not include every possible bit of information that could be considered. For example, this study was basically static and ignored landscape dynamics. In practice, some land is protected each time period while some is lost to alternative land uses. Recent studies in biodiversity and open space conservation planning have explored the effects of these dynamics on the performance of targeting strategies (Meir et al., 2004; Haight et al., 2005; Grantham et al., 2008) and on land values (Armsworth et al., 2006). We would even expect that potential threat would shift dynamically as the demand for development would be transferred from parcels that were protected to other farmland. Because farmland preservation planning is less developed than similar methods for biodiversity, incorporating simulation modeling of dynamics remains a future research area. As another example, the criteria for biodiversity used in this study were relatively simple, in line with the modest interests of farmland preservation programs.

The Full Information Option was also relatively insensitive to the weighting of the criteria. Apparently for this study area, different stakeholder groups would find the same farms desirable for preservation. The CVFT could feel confident that various stakeholders might embrace the set of highest-ranked parcels, which all overlapped substantially with the equally-weighted version. In fact, sensitivity analysis of the weights could be used to help build consensus among stakeholders.

Of course, the technical and data requirements to develop a cost-effective strategy are quite demanding. Many land trusts, conservancies, and county agencies currently lack the capacity to implement the Full Information Option. In addition to building the database, organizations would be required to maintain it as farms are protected or developed or as other information changes (e.g., land values, general plans, or distance to nearest protected land). For CVFT to decide what level of effort to expend to rank parcels for preservation, the choices narrow down to two—a simple strategy with minimal requirements for data and spatial analysis or a complex Full Information Option with much greater information requirements but much greater payoff (by a factor of 5-20). Within the low information strategies, CVFT could do at least as well on average by preserving farms as they are offered that satisfy their minimum eligibility guidelines as they would using the Basic or Moderate Information options. The information processing would be limited to attributing parcels with data on their size and location with respect to prime farmland and urban spheres of influence and querying the database for parcels that satisfy all three conditions. It is possible that these results are just a circumstance of the particular patterns of farmland benefits, land market values, and development potential in Sacramento and San Joaquin counties. We expect, however, that results would be similar in most regions where large and well-funded farmland preservation programs are operating. Farmlands reflect relatively predictable gradients of land values with very high costs nearest urban centers. Similarly the patterns of potential farmland loss to urban development tend to be greatest on the leading edge of land speculation around urban centers where allowed by land use plans. Benefits are likely to be spatially heterogeneous in most regions. Taking a more complex approach, such as the Full Information Option, by incorporating potential loss and/or cost estimates would yield substantially greater social benefits. Wünscher et al. (2008) found that the added transaction costs of GIS support was minor relative compared to the improved additionality or net benefits in providing ecosystem services in Costa Rica. The spatial data needed to implement the framework for the CVFT are generally available in most parts of the United States. The main exception was the Cost information that required purchasing proprietary data on recent farmland sales. In other states, the tax assessor's data may be adequate. The primary cost to implement the Full Information Option of a Benefits-Loss-Cost targeting strategy therefore would be salary and overhead for a GIS analyst for up to one year to compile and process these data sets. This time and expense could be expedited if the framework were made operational in a spatial targeting toolbox that standardized much of the planning expertise of the approach.

Practitioners of farmland preservation will need help to overcome the technical obstacles they face to become more cost-effective in preserving the public good. As noted, the most cost-effective strategies used here require extensive spatial data and moderately sophisticated spatial analysis skills. Farmland programs need assistance to meet these requirements, or they will likely continue using less cost-effective targeting strategies. Most useful would be development of GIS planning and modeling tools to automate the complex data processing pathway while soliciting inputs from planners about social preferences, goals, and land use scenarios. Newburn et al. (2005) describe one such tool customized for Sonoma County, California. A GIS-based framework could also help build consensus by exploring alternative weighting schemes to satisfy various stakeholder objectives as we did in the sensitivity analysis. It could also allow rapid exploration of alternatives, such as testing different patterns of future urban growth. With an operational planning support tool in hand, organizations could concentrate on the social dimensions of their program, such as setting conservation goals and choosing criteria weights. We should point out that most PDR programs do not perform targeting strategies on the entire set of farms in their domain as we have done here. Rather they often operate more tactically on a smaller set of farms that are currently offered by willing sellers for preservation. Even then, the spatial database of benefits, loss, and cost information by parcel could be used to select the most cost-effective subset of farms that are currently available within an annual budget (Messer, 2006) or to query the cost-effectiveness of an individual farm that was being offered for a conservation easement. As the number of PDR programs expands, the usefulness of a planning tool grows in importance and helps to shorten the learning curve because new programs can take advantage of the experience already encapsulated in such a tool. Otherwise we expect farmland preservation programs will continue to employ suboptimal targeting strategies.

6. Acknowledgments

This project was supported by National Research Initiative Grant no. 2005-35401-15320 from the USDA Cooperative State Research, Education, and Extension Service Rural Development Program. Our project advisory group (Tim Duane, Julie Gustanski, Ralph Heimlich, Pete Roussopoulos, Rita Schenck, and Al Sokolow) provided many valuable suggestions that found their way into this study. We thank Matt Merrifield of The Nature Conservancy and Aubrey Dugger from the GreenInfo Network for sharing data. We deeply appreciate the encouragement and advice of Bill Martin, executive director of the Central Valley Farmland Trust.

7. References

Ando, A., Camm, J., Polasky, S., Solow, A., 1998. Species distributions, land values, and efficient conservation. Science, 279, 2126-2128.

Armsworth, P.R., Daily, G.C., Kareiva, P., Sanchirico, J.N., 2006. Land market feedbacks can undermine biodiversity conservation. P. Natl. Acad. Sci. USA, 103, 5403-5408.

Arponen, A., Heikkinen, R.K., Thomas, C.D., Moilanen, A., 2005. The value of biodiversity in reserve selection: Representation, species weighting, and benefit functions. Conserv. Biol., 19, 2009-2014.

Babcock, B.A., Lakshminarayan, P.G., Wu, J.J., Zilberman, D., 1997. Targeting tools for the purchase of environmental amenities. Land Econ., 73, 325-339.

Cocks, K.D., Baird, I.A., 1989. Using mathematical programming to address the multiple reserve selection problem: An example from the Eyre Peninsula, South Australia. Biol. Conserv., 49, 113-130.

Church, R.L., 1974. Synthesis of a Class of Public Facilities Location Models. Ph.D. thesis, The Johns Hopkins University, Baltimore.

Davis, F.W., Costello, C.J., Stoms, D.M., 2006. Efficient conservation in a utility-maximization framework. Ecol. Soc., 11, 33. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art33/.

Dung, E.J., Sugumaran, R., 2005. Development of an agricultural land evaluation and site assessment (LESA) decision support tool using remote sensing and geographic information system. J. Soil Water Conserv., 60, 228-234.

Ferguson, C.A., Bowen, R.L., Kahn, M.A., 1991. A Statewide LESA System for Hawaii. J. Soil Water Conserv., 46, 263-267.

Gauvin, C., E. Uchida, S. Rozelle, J. Xu and J. Zhan. In press. Cost-effectiveness of payments for ecosystem services with dual goals of environment and poverty alleviation. Environ. Manage., DOI: 10.1007/s00267-009-9321-9

Grantham, H.S., Moilanen, A., Wilson, K.A., Pressey, R.L., Rebelo, T.G., Possingham, H.P., 2008. Diminishing return on investment for biodiversity data in conservation planning. Conserv. Lett., 1, 190-198.

Guikema, S., Milke, M., 1999. Quantitative decision tools for conservation programme planning: Practice, theory and potential. Environ. Conserv., 26, 179-189.

Haight, R.G., Snyder, S.A., Revelle, C.S., 2005. Metropolitan open-space protection with uncertain site availability. Conserv. Biol., 19, 327-337.

Hoobler, B.M., Vance, G.F., Hamerlinck, J.D., Munn, L.C., Hayward, J.A., 2003. Applications of land evaluation and site assessment (LESA) and a geographic information system (GIS) in East Park County, Wyoming. J. Soil Water Conserv., 58, 105-112.

Hyman, J.B., Leibowitz, S.G., 2000. A general framework for prioritizing land units for ecological protection and restoration. Environ. Manage., 25, 23-35.

Jaccard P., 1901. Étude comparative de la distribution florale dans une portion des Alpes et des Jura. Bulletin del la Société Vaudoise des Sciences Naturelles 37, 547-579.

Kirkpatrick, J.B., 1983. An iterative method for establishing priorities for selection of nature reserves: an example from Tasmania. Biol. Conserv., 25, 127-134.

Machado, E.A., Stoms, D.M., Davis, F.W., Kreitler, J., 2006. Prioritizing farmland preservation cost-effectively for multiple objectives. J. Soil Water Conserv., 61, 250-258.

Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. J. Wiley & Sons, New York.

Margules, C.R., Pressey, R.L., 2000. Systematic conservation planning. Nature, 405, 243 - 253.

Meir, E., Andelman, S., Possingham, H.P., 2004. Does conservation planning matter in a dynamic and uncertain world? Ecol. Lett., 7, 615-622.

Messer, K.D., 2006. The conservation benefits of cost-effective land acquisition: A case study in Maryland. J. Environ. Manage., 79, 305-315.

Murdoch, W., Polasky, S., Wilson, K.A., Possingham, H.P., Kareiva, P., Shaw, R., 2007. Maximizing return on investment in conservation. Biol. Conserv., 139, 375-388.

Naidoo, R., Balmford, A., Ferraro, P.J., Polasky, S., Ricketts, T.H., Rouget, M., 2006. Integrating economic costs into conservation planning. Trends Ecol. Evol., 21, 681-687.

Newburn, D., Reed, S., Berck, P., Merenlender, A., 2005. Economics and land-use change in prioritizing private land conservation. Conserv. Biol., 19, 1411-1420.

Newburn, D.A., Berck, P., Merenlender, A.M., 2006. Habitat and open space at risk of land-use conversion: Targeting strategies for land conservation. Am. J. Agr. Econ., 88, 28-42.

Pease, J.R., Coughlin, R.E., Steiner, F.R., Sussman, A.P., Papazian, L., Pressley, J.A., Leach, J.C., 1994. State and local LESA systems: Status and evaluation, In: Steiner, F.R., Pease J.R. & Coughlin R.E. (eds.), A Decade with LESA: The Evolution of Land Evaluation and Site Assessment. Soil and Water Conservation Society, Ankeny, Iowa, pp. 57-75.

Perhans, K., Kindstrand, C., Boman, M., Djupstrom, L.B., Gustafsson, L., Mattsson, L., Schroeder, L.M., Weslien, J., Wikberg, S., 2008. Conservation goals and the relative importance of costs and benefits in reserve selection. Conserv. Biol., 22, 1331-1339.

Plantinga, A.J., Miller, D.J., 2001. Agricultural land values and the value of rights to future land development. Land Econ., 77, 56-67.

Prendergast, J.R., Quinn, R.M., Lawton, J.H., 1999. The gaps between theory and practice in selecting nature reserves. Conserv. Biol., 13, 484-492.

Pressey, R.L., Nicholls, A.O., 1989. Efficiency in conservation planning—scoring versus iterative approaches. Biol. Conserv., 50, 199-218.

Ribaudo, M.O., Hoag, D.L., Smith, M.E., Heimlich, R., 2001. Environmental indices and the politics of the Conservation Reserve Program. Ecol. Indic., 1, 11-20.

Soil and Water Conservation Society, 2003. Enhancing LESA: Ideas for improving the use and capabilities of the Land Evaluation and Site Assessment System. Soil and Water Conservation Society, Ankeny, Iowa.

Sokolow, A.D., Zurbrugg, A., 2003. A National View of Agricultural Easement Programs: Profiles and Maps -- Report 1. American Farmland Trust and Agricultural Issues Center, DeKalb, Illinois.

Stoms, D.M., Jantz, P.A., Davis, F.W., DeAngelo, G., 2009. Strategic targeting of agricultural conservation easements as a growth management tool. Land Use Policy, 26, 1149-1161.

Tulloch, D.L., Myers, J.R., Hasse, J.E., Parks, P.J., Lathrop, R.G., 2003. Integrating GIS into farmland preservation policy and decision making. Landscape Urban Plan., 63, 33-48.

Wilson, K., Pressey, R.L., Newton, A., Burgman, M., Possingham, H., Weston, C., 2005. Measuring and incorporating vulnerability into conservation planning. Environ. Manage., 35, 527-543.

Wünscher, T., Engel, S., Wunder, S., 2008. Spatial targeting of payments for environmental services: A tool for boosting conservation benefits. Ecol. Econ., 65, 822-833.

Zurbrugg, A., Sokolow, A.D., 2006. A National View of Agricultural Easement Programs: How Programs Select Farmland to Fund - Report 2. American Farmland Trust and Agricultural Issues Center, DeKalb, Illinois.

8. Figure Captions

1. Location map of the study region in Sacramento and San Joaquin Counties, California.

2. Map of the Benefit-Loss-Cost cost-effectiveness scores. White areas indicate parcels with scores of 0.0, which are mostly urban lands.

3. Graph of cumulative net benefits preserved as a function of budget level for strategies using different types of conservation information, from Benefits-only to Benefit-Cost to Benefit-Loss-Cost.

4. Graph of cumulative net benefits preserved as a function of budget level for strategies using different options for information quality and content, from minimal to full information. The Minimal Information Option was generated by randomly selecting parcels that met the minimum eligibility criteria of the Central Valley Farmland Trust. The shaded band shows the range of net benefits from 1000 runs at each budget level.

9. Tables

Table 1. Descriptions of the criteria for calculating farmland benefits by information options.

Objective	Criterion	Basic Information Option (LESA)	Moderate Information Option	Full Information Option (same as Benefits-Loss-Cost)
Maintain viable agricultural presence	Preserve the most important (productive) farmland	**(Land Evaluation)** Farmland Importance Classes (FMMP)	FMMP modified by urban edge effects	FMMP modified by urban edge effects
Maintain rural amenities and ecosystem services	Minimize liability of flood damage to property	NA	FEMA Q3 floodplains	FEMA Q3 floodplains
	Buffer small nature reserves to maintain habitat value	NA	Distance from nature reserves	Distance from nature reserves modified by ecological condition (roads, housing density, land use, parcel size)
	Protect priority habitat conservation	NA	Priority conservation areas	Priority conservation areas modified by ecological condition

Objective	Criterion	Basic Information Option (LESA)	Moderate Information Option	Full Information Option (same as Benefits-Loss-Cost)
	areas			(roads, housing density, land use, parcel size)
Encourage urban growth in desired areas	Protect agricultural land where compatible with general plans	**(Site Assessment)** General plan score + Parcel size score	General plan score * Parcel size score	General plan score * Parcel size score
	Reinforce sphere of influence boundaries	NA	Buffer around Spheres of Influence	Buffer around Spheres of Influence modified by distance from open space/easements

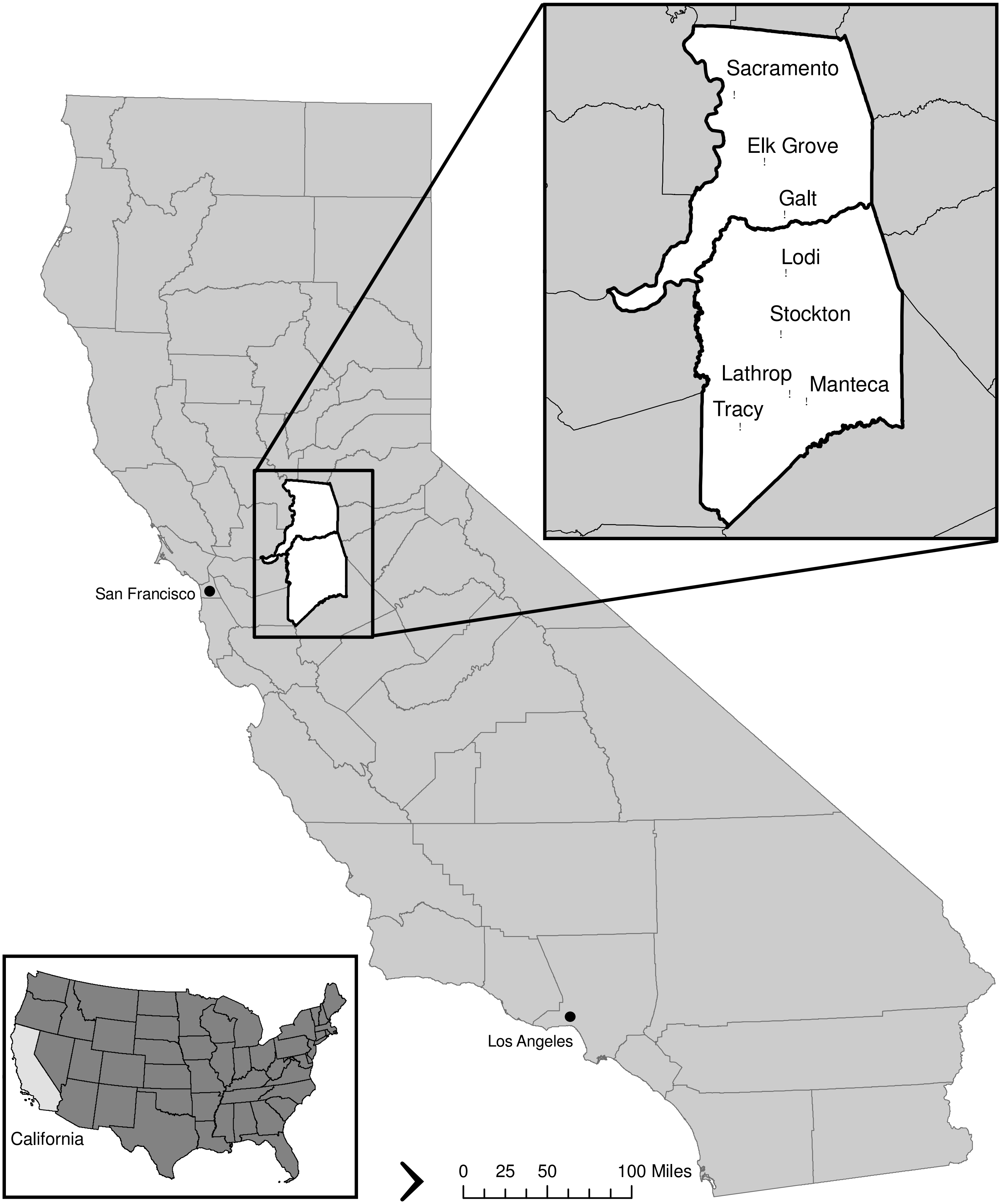
Table 2. Data and analytical requirements by information option to estimate conservation value

Type of Information	Minimal Information Option	Basic Information Option (LESA)	Moderate Information Option	Full Information Option (same as Benefits-Loss-Cost)
Benefits	Important farmland and minimum size as screening criteria	Resource quantity for only a few criteria (see Table 1)	Resource quantity and quality for all criteria (see Table 1)	Resource quantity and quality for all criteria (see Table 1)
Loss	Ignored loss	Ignored loss	Ignored loss	Potential development (urban growth model or general plans), benefit functions
Cost	Ignored cost	Ignored cost	Simple rule-based index of relative cost	Statistical model of market value of farmland
Data and analysis requirements	Standard data, simple GIS query for eligibility	Standard data, basic GIS overlay operations	Moderate data, moderate GIS operations, benefit weighting	Maximum data, complex GIS analysis, benefit weighting

Table 3. Weighing schemes for stakeholder groups for sensitivity analysis and Jaccard similarity of parcels targeted by them relative to those targeted with equal weighting in the Full Information Option (same as Benefits-Loss-Cost).

Stakeholder group	Agricultural production weight	Ecosystem services weight	Growth management weight	Jaccard similarity of Interest Group with equal weighting
Farmer interests	0.7	0.0	0.3	0.938
Smart growth advocates	0.1	0.3	0.6	0.966
Environmentalists	0.0	0.8	0.2	0.969
Equal weighting	0.33	0.33	0.33	--

Figure_1



Sacramento
Elk Grove
Galt
Lodi
Stockton
Lathrop
Manteca
Tracy
San Francisco
Los Angeles
California
0 25 50 100 Miles

Figure_2
Click here to download high resolution image

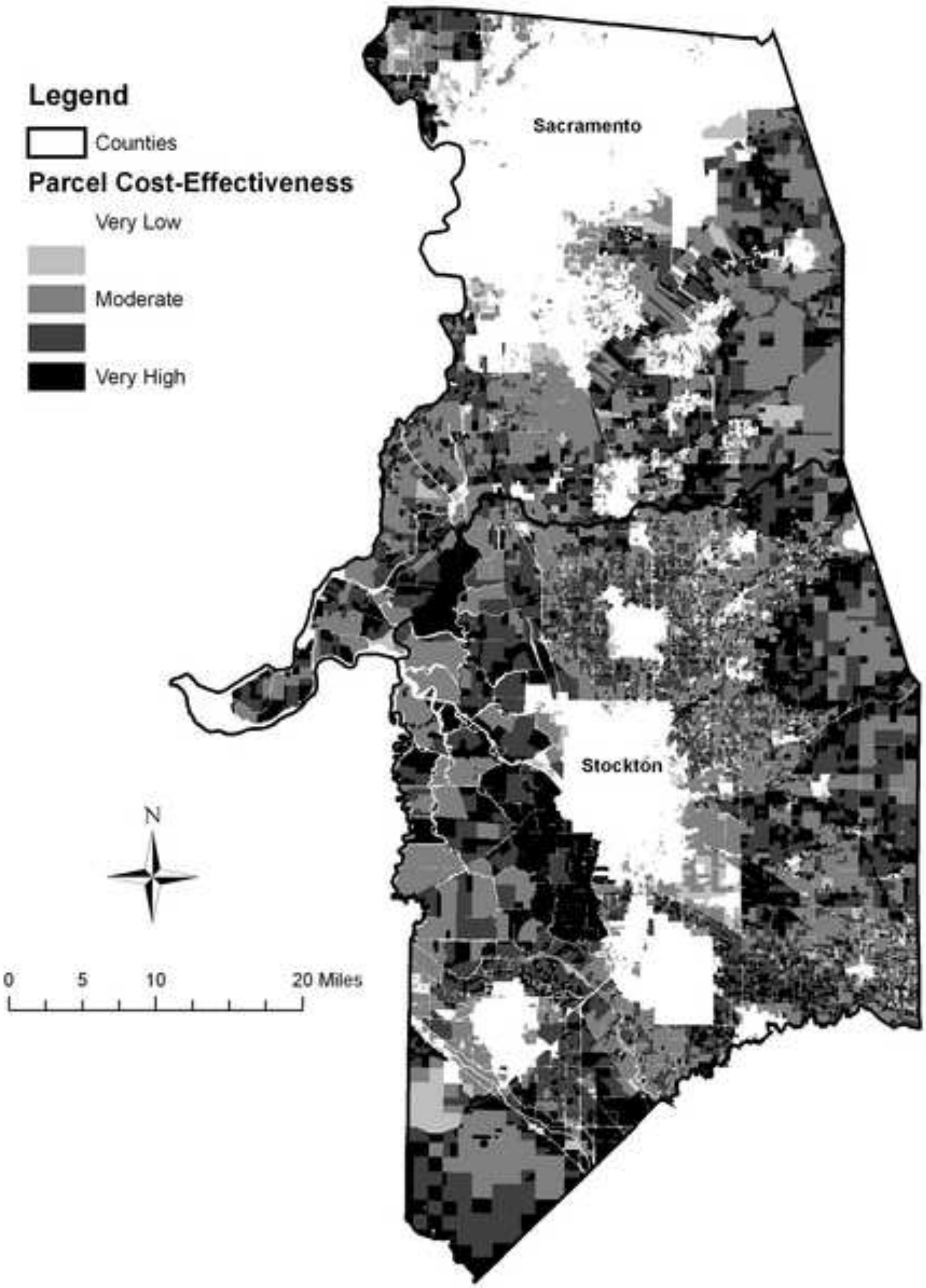
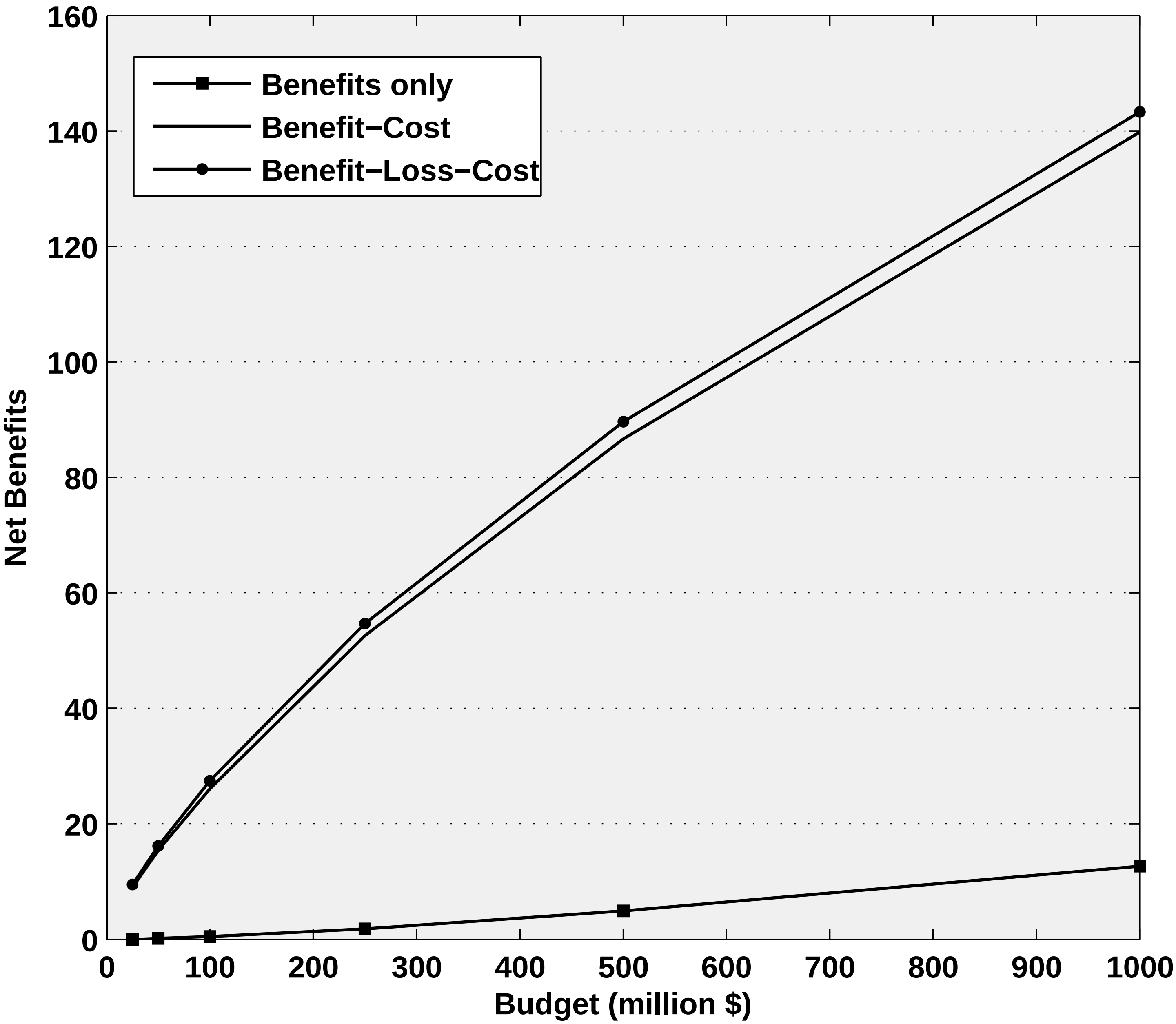
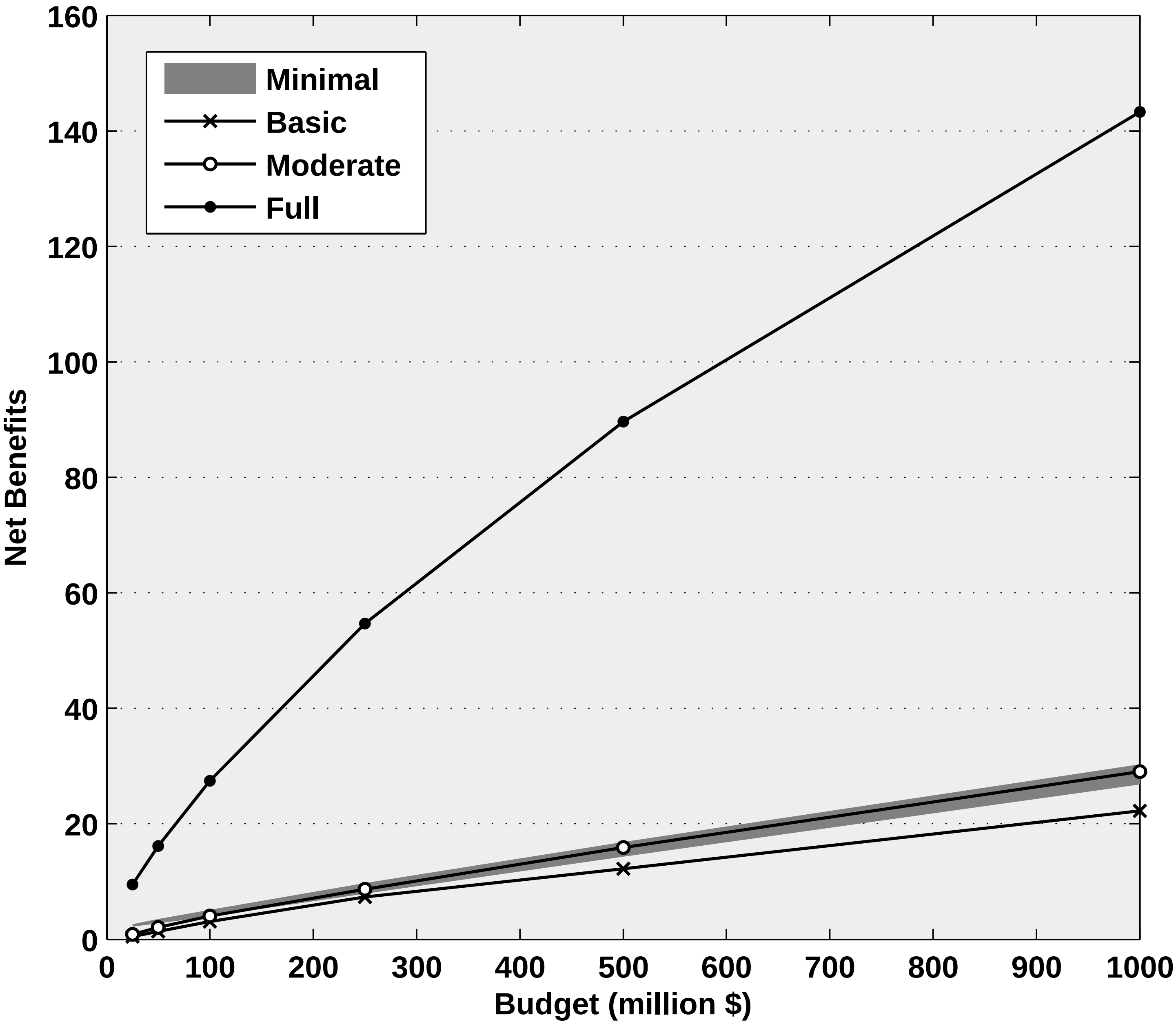


Figure_3



Benefits only
Benefit−Cost
Benefit−Loss−Cost
160
140
120
100
80
60
40
20
0
Net Benefits
0
100
200
300
400
500
600
700
800
900
1000
Budget (million $)

Figure_4



Minimal
Basic
Moderate
Full
160
140
120
100
80
60
40
20
0
Net Benefits
0
100
200
300
400
500
600
700
800
900
1000
Budget (million $)

***Suggested Reviewer List (include up to 5 names and their contact details)**

Suggested reviewers:

1. Kent Messer, messer@udel.edu, University of Delaware
2. Michael Strager, mstrager@wvu.edu, University of West Virginia
3. Stefan Hajkowicz, Stefan.Hajkowicz@csiro.au, CSIRO Sustainable Ecosystems, Australia
4. David Tulloch, dtulloch@crssa.rutgers.edu, Rutgers University, New Jersey
5. Jeffrey Hyman, jbhyman@indiana.edu, University of Indiana
6. Dan van der Horst, d.vanderhorst@bham.ac.uk, University of Birmingham