Prioritizing farmland preservation cost-effectively for multiple objectives

E.A. Machado, D.M. Stoms, F.W. Davis, and J. Kreitler

ABSTRACT: American society derives many benefits from farmland and is often willing to pay to preserve it from urbanization. We present an innovative framework to support farmland preservation programs in prioritizing conservation investments. The framework considers the full range of social benefits of farmland and improves the application of decision analysis methods to the process. Key factors for ranking farms are: 1) social objectives and priorities, 2) how much farmland value is expected to be lost to development if not preserved, 3) how much farmland value is already secured in the agricultural region, and 4) how much it will cost to secure the farm's benefits. The framework can be applied strategically over an entire region or to rank a set of applications from landowners. We demonstrate our framework using three criteria in the Bay Area/Delta bioregion of California.

Keywords: Amenities, conservation planning, decision analysis, ecosystem services, farmland preservation, GIS, public preferences, social value, urban growth management

Farmland supplies society with both essential market goods and non-market amenities such as open space, environmental protection, and urban growth management (Nelson, 1992; American Farmland Trust, 1997; Kline and Wichelns, 1998) that land markets fail to account for. Without market intervention, urban uses tend to outbid agriculture for land wherever urban suitability is high (Nelson, 1992). Besides an irreversible loss of existing farmland, the conversion process fragments the remaining farmland, often decreasing its production efficiency and thus its agricultural market value (Levia, 1998; Brabec and Smith, 2002), which reinforces the process.

Preserving farmland from urban encroachment has wide support both from farmers and the broader public as society begins to recognize the many social and environmental benefits that agriculture can provide (Kline and Wichelns, 1998; Duke and Aull-Hyde, 2002; Robertson et al., 2004). In the United States there are numerous programs for market intervention by federal, state, and local governments and private, non-profit land trusts and conservancies (Daniels, 1991; American Farmland Trust, 1997; Lynch and Musser, 2001). The purchase of development rights or conservation easements is among the most common types of incentive-based policies used in the United States (Alterman, 1997; American Farmland Trust, 1997).

When the number of voluntary applications to sell easements exceeds their budgets, most incentive-based farmland conservation programs prioritize conservation investments based on each site's conservation attributes. The challenge is to make the process transparent, objective, fair, easy to understand by all parties, and feasible to implement with available information. Most importantly, the process should facilitate the identification of the farmland of greatest importance to society.

Although many programs use qualitative judgment to make decisions, many others use quantitative prioritization methods, usually an additive point-scoring approach to assist with site evaluation and prioritization (e.g., Sokolow and Zurbrugg, 2003). Criteria are allocated a maximum number of points, with more points allowed for the most important criteria. Farms are assigned points based on their respective attributes. Points are then summed over all criteria to determine each farm's ranking.

Most current scoring approaches are derivatives of the Land Evaluation and Site Assessment (LESA) system (Ferguson et al., 1991; Pease et al., 1994). LESA was originally designed as a standard method for federal agencies to determine if their projects would negatively impact important farmland, as required by the National Environmental Policy Act. Later it was adapted for farmland preservation programs. LESA consists of two parts. The land evaluation (LE) part rates the land for crop production, and the site assessment (SA) component accounts for factors other than agricultural productivity. LESA-style scoring systems, generically called "index models," have been used in a reactive mode to evaluate the set of farms currently offered (Tulloch et al., 2003). Alternatively, in a proactive mode, a planner evaluates an entire region using comprehensive maps of the criteria, either to rank all farms simultaneously or to support strategic planning (Hoobler et al., 2003; Soil and Water Conservation Society, 2003; Tulloch et al., 2003).

This paper introduces a framework to support prioritization for farmland preservation that improves upon LESA-type index models in several essential ways. It emulates a similar framework for biodiversity conservation suggested by Davis et al. (2006). First, the framework considers the full range of socially-defined objectives. Second, objectives can be quantified by the decision maker and decomposed hierarchically into criteria that measure, to the extent practical, their actual contribution to the objectives. In contrast, the relationship between point-scoring methods and the underlying objectives is generally vague. Third, the framework accounts for the decision maker's preference for the amount of each resource type to be preserved, which may be a nonlinear relationship of social value (Guikema and Milke, 1999). Fourth, the criteria weights representing the decision maker's judgment of the relative importance of the objectives are made explicit and separate from the technical measure of the level of the criteria (Guikema and Milke, 1999). Fifth, the total conservation value of a

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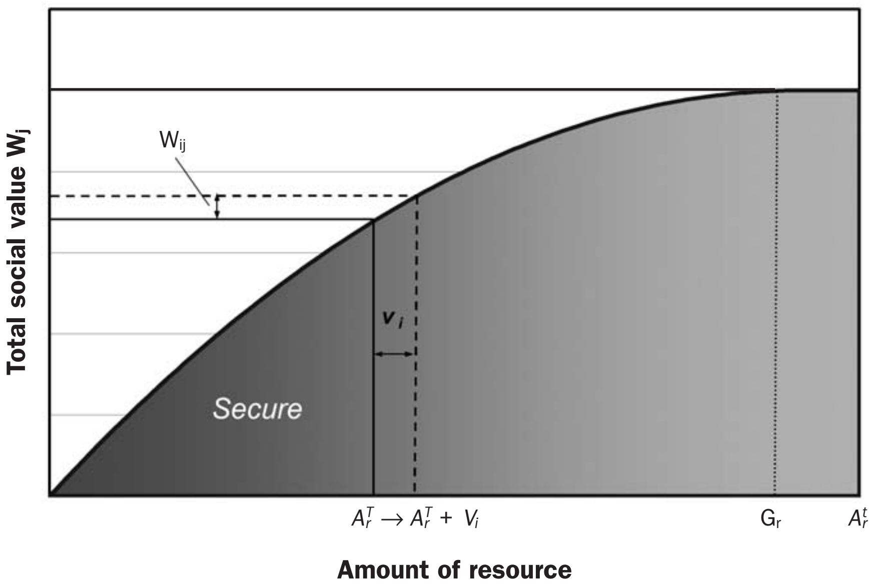
site is based on the net loss of benefits prevented per unit cost (the "bang for the buck"), which Newburn et al. (2005) termed benefit-loss-cost targeting. We demonstrate this framework for the Bay Area/Delta bioregion of California. Criteria values are derived from actual spatial data, but social preferences are based upon a hypothetical decision maker. The framework can be applied in either proactive or reactive mode, as described above.

Figure 1

Graph of total social value (W_j) as a function of resource amount (e.g., production capacity), shown here as a quadratic form corresponding to the preferences of a hypothetical decision maker.



Materials and Methods

Conceptual framework. Several spatial units of analysis are used in the framework. A planning region encompasses the entire area under consideration for conservation investments. Sites (i) are the candidate areas being prioritized for preservation (such as individual farms). A reference region (r) is the area over which a particular conservation objective is evaluated.

We state the planning goal as maximizing the expected social value provided by farmland that can be sustained in a planning region with a given level of funding. The task in a reactive mode is to determine the social value of each available site if it were the next one to be preserved. Determining social value requires a decision maker to state his/her preferences for varying levels of a given resource. Decision analysis provides methods for translating a decision maker's preferences into a mathematical function (Guikema and Milke, 1999). Figure 1 illustrates an example of such a function, where the amount of a resource, shown along the x-axis, is converted into a measure of social value for objective j (W_j) on the y-axis. In this example, the social value increases with increasing amounts of the resource secured, but the rate diminishes as the goal (G_r) is approached. Amounts above the goal accrue no additional social value. Note that the function is calculated with respect to the goal and not just the intrinsic attributes of a farm.

A key concept in the framework states that social value is measured as the net gain between taking action and no action, for example of preserving a site vs. not preserving it (v_i in Figure 1). Thus decision makers must have in mind some pattern of land use change that is likely to occur unless they intervene to preserve farmland. Of the current amount of the resource in the region (point Ar^t in Figure 1),it is likely that some fraction is secure (Figure 1) because it is located outside of the reach of threatening processes. Consequently, marginal gains in social value would be measured from the expected resource amount that would persist in the absence of any additional preservation action (point Ar^T in Figure 1). Preserving site i would shift the secured amount by v_i to the right, with a corresponding increase of W_{ij} in total social value. Changing the land use scenario would change the secured amount and thus the social value of preserving sites. Note that the secure region in Figure 1 includes farmland resources that were previously preserved and those that are not considered threatened but not formally preserved.

We approach farmland preservation as a multi-criteria decision problem. From a review of the literature (e.g., Kline and Wichelns, 1996; Duke and Aull-Hyde, 2002; Hellerstein et al., 2002), and existing farmland preservation programs, we identified three primary objectives: 1) maintain agricultural viability (the traditional emphasis), 2) preserve rural amenities/ecosystem services (Soil and Water Conservation Society, 2003), and 3) direct urban growth into desired areas (Daniels and Lapping, 2005). Each of these can be measured at every site by one or more criteria (Table 1). For instance, agricultural viability can be (partially) addressed by retaining farmlands with the greatest production capacity. Each criterion may have a unique social value function.

To identify the overall social value of each site, the social values of its individual objectives must be aggregated. We suggest a simple weighted summation decision rule. The decision maker chooses a set of weights that subjectively expresses the relative importance of each objective, thus making his/her preferences explicit. Consequently, stakeholders will endorse different sets of weights, leading to differences in ranking farmland. The aggregate social value (AW_i) of preserving a site is calculated as follows:

$$AW_i = \sum_{j=1}^{J} w_j W_{ij} \qquad (1)$$

where,

w_j = the weight assigned to objective j.
W_{ij} = the social value of preserving site i for objective j, that is a synthesis of an objective measure of resource amount and a subjective judgment of the gain in social value associated with an additional gain in resource amount preserved.

Then, the conservation value CV_i of site i is calculated as a cost-effectiveness ratio:

$$CV_i = \frac{AW_i}{Cost_i} \qquad (2)$$

Table 1. Hierarchy of farmland preservation goal, objectives, and criteria. Criteria highlighted in bold font are demonstrated in the paper. Note that economic markets already compensate for ecosystem production services.

Goal	**Maximize expected public benefits provided by farmland in the planning region with the financial resources available**		
Objectives	**Maintain agricultural viability**	**Preserve rural amenities / ecosystem services**	**Direct urban growth into desired areas**
Criteria	• **Preserve the most productive farmland**	• *Regulating services* - Climate regulation - Water regulation and flood control • *Cultural services* **- Scenic views** - Recreation and ecotourism - Sense of place - Rural heritage - Educational • *Production services* - Food and fiber - Locally-important agricultural products • *Biodiversity*	• ***Reinforce urban growth boundaries*** • Maintain community separators

where,

$Cost_i$ = cost of conservation action (e.g., purchasing an agricultural conservation easement to prevent the loss of farmland benefits or the transaction costs of accepting a donated easement) of site *i*.

Description of the California Bay Area/Delta bioregion. California is one of the premier agricultural areas of the world, generating over $30 billion income per year (California Agricultural Statistics Service, 2002). The Bay Area/Delta Region (Figure 2) contains some of the most valuable farmland in the state and is experiencing rapid urban growth. This bioregion encompasses the San Francisco Bay Area and the Sacramento-San Joaquin River Delta. According to projections, the greatest urban growth will occur in the eastern agricultural areas, whereas the coastal counties will experience less growth (California Department of Forestry and Fire Protection, 1997). The region is home to the world-famous Napa and Sonoma wine country and other scenic agricultural lands. Significant public and private funds are being invested to preserve agricultural land in this region. Next, we demonstrate how the framework could be implemented. We analyze actual spatial data from the study area to measure criteria values using one criterion each for agricultural, rural amenities, and urban growth objectives. Subjective values—goals, criteria weights, and social value functions—are used to interpret raw criteria values into a socially-defined conservation importance. In practice, these subjective values would be solicited from stakeholders or decision makers. However, because we are only demonstrating the framework, we assign plausible choices for a hypothetical decision maker for conservation goals, criteria weights, and social value functions. We assume a hypothetical decision maker who must allocate funds across a multi-county region.

Derivation of conservation value scores. The sites for which criteria were measured were 5 by 5 km (3 by 3 mi) quarter townships. Criteria were initially measured for 100 m (328 ft) grid cells, which were then aggregated over sites and reference regions as necessary. The process of ranking sites involved five primary steps:

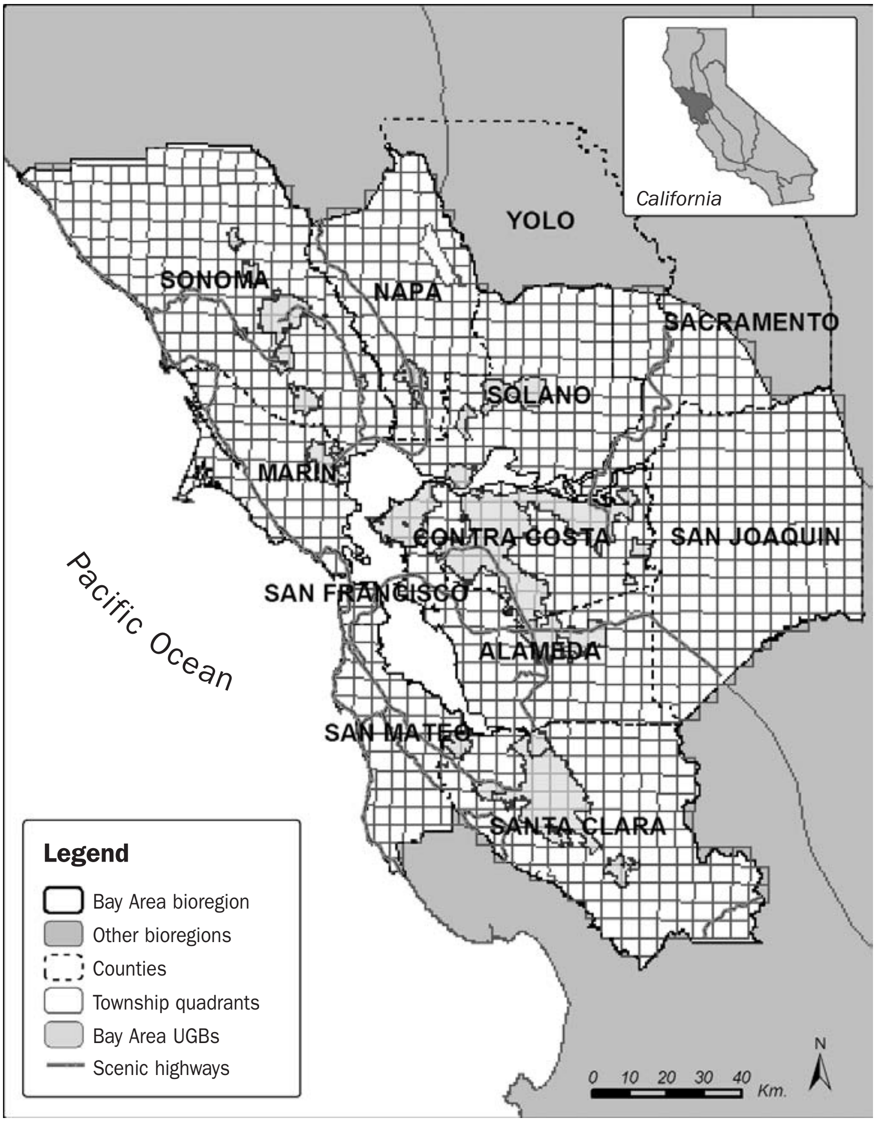
1. Define criteria to measure every conservation objective as directly as possible in terms of resource units.
2. Predict potential loss of the resources in the absence of market intervention (v_i) for each criterion.
3. Convert sites' criteria values to social value (W_{ij}) according to the preferences of the decision maker via its corresponding social value function with respect to the resource amount in a reference region.
4. Aggregate social value for each site over all objectives (AW_i) using weights that represent decision maker's preferences.
5. Compute conservation value (CV_i) as aggregate social value per unit cost of the conservation investment.

The methods for steps one through three are first described for the three objectives. More detail is provided for objective one, but the logic is similar for the other objectives. Then the aggregate social value is calculated by Equation 1. We arbitrarily use an equal weighting of the three objectives (i.e., w_j = 0.33) for the purposes of this demonstration. In practice, the weighting should be derived using one the various methods available from decision analysis such as preference ranking or pairwise comparison (Saaty, 1980). Even using formal methods, a decision maker is likely to be uncertain about quantifying their preferences. We recommend that in practice a sensitivity analysis be performed to assess the effects of this uncertainty on the ranking of sites.

Objective 1: Maintain agricultural viability. Many factors drive the viability of the agricultural economy, but the agricultural productivity of the soils is one of the most fundamental. We illustrate this objective by measuring the production capacity criterion, based on site capability and condition. The former is based on soil biophysical and chemical properties, climate, and water supply to grow sustainable yields, whereas the latter reflects the modification of that capability by the influence of adjoining land use. Most scoring systems assign points for production capacity based solely on site capability (Hoobler et al., 2003; Tulloch et al., 2003). We measured the production capacity as the product of the capability and condition status of the farmland area in site *i* in 2000, the beginning of the planning period. In particular,

Figure 2

Location map of the Bay Area/Delta bioregion, California.



$$a_i^{2000} = \sum_{o \in i} p_o\, c_o^{2000} \tag{3}$$

where,

a_i^{2000} = the production capacity for site *i* expressed as a product of agricultural capability (p_o) and condition (c_o) of each 100 m-grid cell *o*, summed over all cells in site *i*.

Production capability was derived from farmland importance classes as mapped by California's Farmland Mapping and Monitoring Program. We assigned numerical capability scores to each farmland importance category to represent p_o, with prime farmland receiving the highest value). Farmland capability may be constrained by social factors, primarily complaints from residential neighbors about farm practices in the "zone of conflict" (Bradshaw and Muller, 1998). A few farmers compensate for this increase in potential conflict by converting to high-value specialty crops or community-friendly marketing techniques (Heimlich and Anderson, 2001), but generally urban encroachment creates negative effects on traditional farming. We assessed site condition as one minus the proportion of urban cells (from the Farmland Mapping and Monitoring Program maps) within a 500 m (1640 ft) radius of each agricultural cell by geographic information system (GIS) operations. Thus the index c_o ranges from zero (surrounded by urban) to one (no urban edge in neighborhood).

Future urban growth impacts farmland production capacity in two ways. First, cells that become urbanized lose their production capability ($p_o = 0$). Second, the advancing urban frontier reduces the condition term for remaining farmland within the new zone of conflict. We used a projection of future urban growth generated by the California Urban and Biodiversity Analysis model (Landis et al., 1998) to recompute site agricultural capability, condition, and farmland production capacity for 2050 as above (Equation 3).

A site's expected resource loss v_i was calculated as the difference between production capacity now and a_i^{2000} in 2050 a_i^{2050} without conservation intervention as:

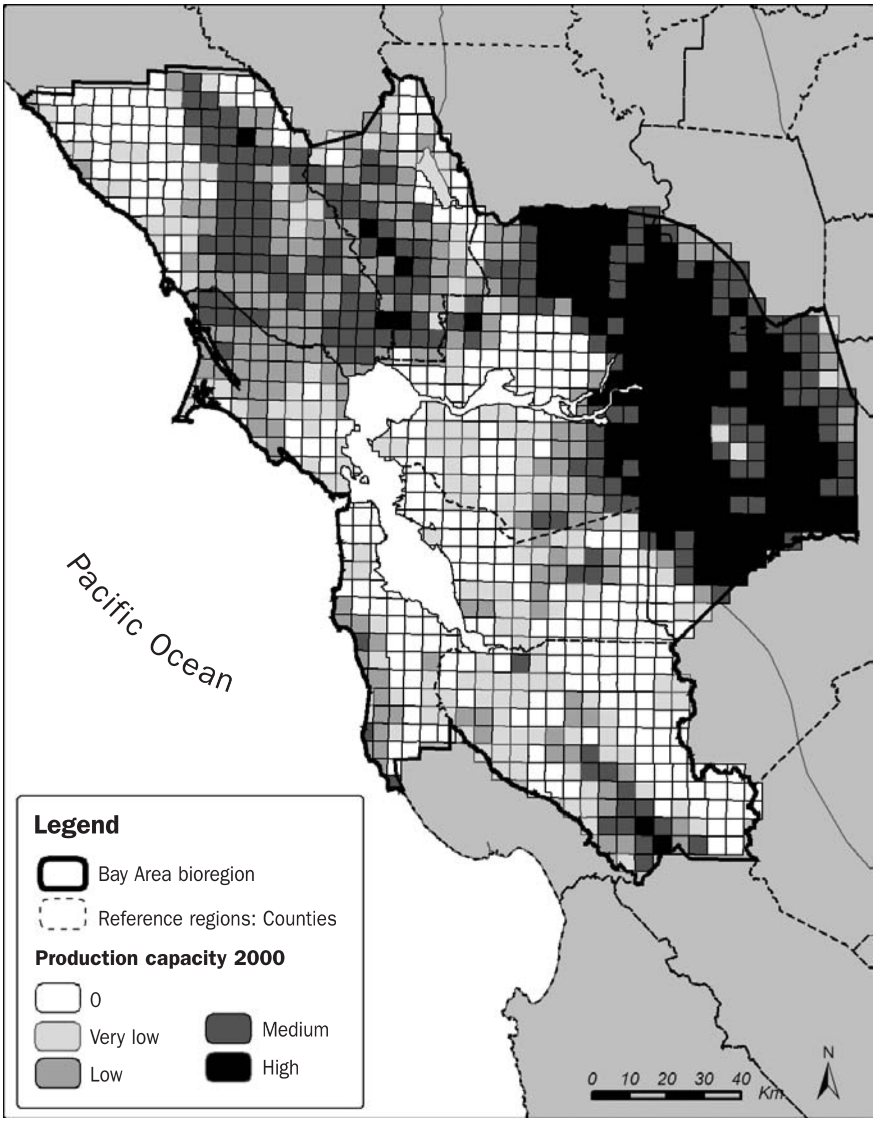
$$v_i = a_i^{2000} - a_i^{2050} \tag{4}$$

Total future production capacity A_r^{2050} was calculated for each reference region (r, here based on counties) as the sum of farmland production capacity over all the sites within each county in 2050. A_r^{2050} represents the baseline (i.e., secured production capacity without market intervention) for calculating the social value of additional conservation actions. Given a choice of two identical farms, our hypothetical decision maker would prefer to protect the one in a county with little secured farmland than the farm in a county with lots of secured farmland. A quadratic function fits these particular preferences (i.e., there are "diminishing returns" for preserving more and more) (Figure 1). In this case the preservation goal for each county was set at 100 percent of its current production capacity (e.g., $G_r = A_r^{2000}$). If a decision maker had a different set of preferences, for example to preserve just a "critical mass" of farmland to maintain agricultural infrastructure, the social value function would be less than A_r^t in Figure 1. If farmland in site *i* was preserved, v_i units of the resource would be gained towards the goal G_r, from the level already secured (point A_r^T in Figure 1), yielding an net gain in social value of W_{i1} (increase on the y axis in Figure 1).

Objective 2: Preserve rural amenities/ecosystem services. Rural amenities, which can also be categorized as ecosystem services (Table 1), include many non-market benefits of farmland that would diminish with urban development. The scenic resources of some agricultural lands in the Bay Area/Delta

Figure 3

Map of agricultural production capacity in 2000 (a_i^{2000}).



region, such as the Napa-Sonoma wine country, is are highly treasured. We demonstrate here one way that scenic value could be estimated in setting farmland priorities.

Farm and ranchlands visible from California Scenic Highways, or scenic views, served as a proxy for scenic areas, which have not been officially designated across the region. We assumed that urban development was the primary factor that degraded these pastoral landscapes. Therefore, the sites' view values (one if within a scenic view area, otherwise zero) were multiplied by the proportion of urban development within its corresponding scenic view (i.e., the reference region) as a measure of scenic condition. This analysis was performed in both the present day and using the California Urban and Biodiversity Analysis growth model to predict the net loss of scenic resources without conservation intervention by 2050. Our hypothetical decision-maker strongly prefers to preserve a unit of scenic resource in a threatened pastoral viewshed than a unit in a heavily developed viewshed. This preference is best represented by a concave quadratic social value function.

Objective 3. Direct urban growth into desired areas. Urban growth boundaries are a widely used policy option to counteract urban sprawl into agricultural areas (Daniels and Bowers, 1997). Preserving farmland adjacent to urban growth boundaries, regardless of soil productivity, reinforces that policy by permanently retiring the development rights. Some of the cities in the study area have adopted urban growth boundaries or urban limit lines, which were used to measure the relative conservation value of sites for the urban growth management objective. Our hypothetical decision maker wants a "greenbelt" 3000 m (9843 ft) wide around officially-designated urban growth boundaries and to anchor the greenbelt with existing protected areas (e.g., agricultural easements, nature reserves, and public open space). Thus the value of farmland cells within the greenbelt was based on their distance from the nearest protected area. We again used the Urban and Biodiversity Analysis growth model forecast to estimate the potential net loss of this criterion. Because any breach in the greenbelt by development could undermine the purpose of the urban growth boundary, the social value function used here is linear, for example marginal social value is constant, until the entire system of greenbelts is secured. That is, the single reference region for urban growth is the combined 3000 m (9843 ft) greenbelts of the entire planning region.

Aggregation of objectives and conservation value. The conservation value of farmland sites is calculated as the aggregate social value for all the objectives divided by the cost of implementing the conservation policy, as formulated in Equation 2. In reactive mode, landowners tell the decision maker their asking price for their development rights. Here we demonstrate the framework in proactive mode, so we must estimate this cost. We modeled easement costs from 31 recent farmland conservation easements in or near the Bay Area/Delta bioregion. Predictor variables suggested by Lynch and Lovell (2002) were derived by GIS processing and used to develop a statistical model that predicted the cost of easements for the farmland in each site (Machado et al., 2003).

Results and Discussion

The three objectives identify very distinctive areas of high priority farmland (Figures 5a-c) because of the differences in the farmland attributes emphasized in each one. Correlations between criteria social values were relatively low among units with cropland or grazing land (i.e., production capacity-scenic quality: 0.45; production capacity-urban growth: 0.02; scenic quality-urban growth: 0.25). The highest values of current production capacity criterion for sites are concentrated along the eastern portion of the bioregion in the Great Central Valley, which contains extensive areas of prime farmland (Figure 3). By 2050, some sites are predicted to have reduced capacity because of urban growth (Figure 4). A large area of important but threatened farmland is visible in the east (Figure 5a), but pockets also appear elsewhere.

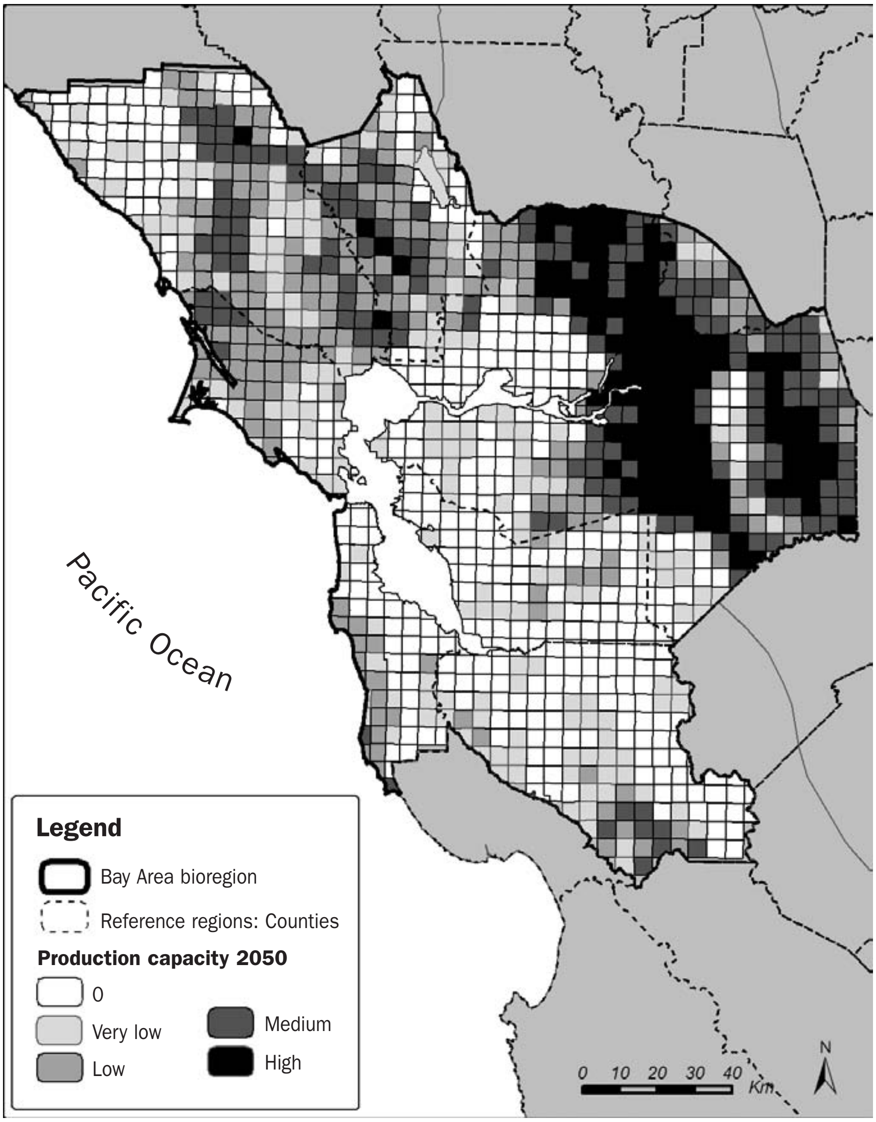
Scenic quality could be lost in a large block in southern San Joaquin County (Figure 5b). Additionally, growth in some of the scenic valleys is expected to infringe upon the viewsheds of grazing and farm lands. Elsewhere, such as along the coastline, agricultural land in scenic viewsheds is relatively secure.

The sites with the higher conservation value for growth control surround cities with adopted urban growth boundaries and existing easements or open space (Figure 5c). This includes grazing and farm land from the lower importance classes because productivity was not a factor in this criterion. Note that there are no priority areas in the eastern portions of the planning region because at the time of the analysis, cities in the Central Valley part of the region had not yet adopted urban growth boundaries. (Stockton adopted one in 2004).

To identify the most cost-effective sites for preserving farmland, the ratio of aggregate social value to predicted easement price was computed as per Equation 2. The conservation value (Figure 5d) shows a very different pattern than the social value values in Figures 5a-c. Most sites with high conservation value occur near the San Francisco Bay with a couple of blocks in Sacramento and San Joaquin Counties of the Central Valley. Note that our results are contingent upon the accuracy of the predicted easement prices, which have not been validated, and on the preferences of our hypothetical decision maker. Therefore Figure 5d should not be relied upon in making decisions for funding farmland preservation.

Figure 4

Map of agricultural production capacity in 2050 (a_i^{2050}).



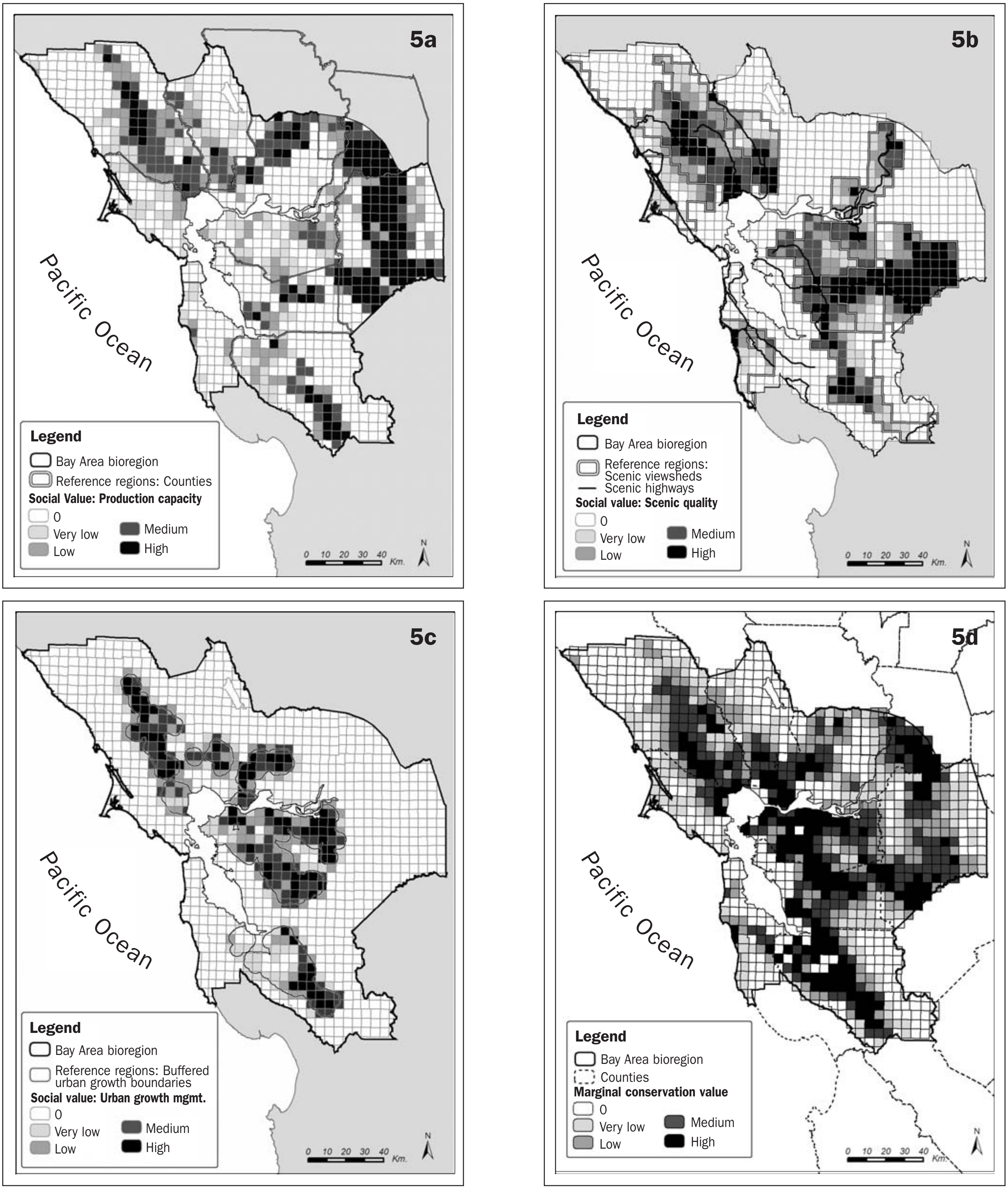
Summary and Conclusion

We have introduced several innovations for prioritizing farmland areas for preservation based on cost-effective achievement of multiple objectives. The framework evaluates a hierarchical set of objectives and associated criteria, implementing some of the recent recommendations for enhancing LESA (Soil and Water Conservation Society, 2003). Our framework generates scores for each site as do previous scoring methods derived from LESA, but the basis of the scoring is substantially different. Those systems base their scoring on the amount of a benefit a farm has or provides now. We extend that concept to relate those values to the conservation objectives; how much of the objective is already achieved within reference regions that may be unique for each criterion; how much would be lost without market intervention; and the cost-effectiveness of investing in each site. Thus we integrate threat and cost as interacting factors with the resource rather than treating them as an independent factor that can be simply assigned additional points. Comparing Figures 3 and 5d gives some sense of how much difference this change in perspective might produce in ranking farmland for preservation.

The framework is transparent, flexible, and feasible to implement. GIS is employed to measure resource amounts for the criteria when manual measurement may be tedious and inaccurate (Tulloch et al., 2003). It is particularly useful for collaborative planning processes in which stakeholder groups can explore and evaluate alternatives that reflect their social preferences and assumptions about future land use change. Just having a display of the spatial distribution of farmland attributes and relative conservation values can be very educational for planners and citizens

Figure 5

Map of the social value for three objectives and conservation value. a) Social value for retaining production capacity (W_{i1}), b) social value for scenic quality (W_{i2}), c) social value for urban growth management (W_{i3}), and d) conservation value (CV_i) or cost-effectiveness, which is the ratio of aggregate social value to estimated conservation cost.



alike. By design, the framework makes clear the appropriate roles of scientific judgment (e.g., estimating productivity of farmland) and of social values (e.g., the relative importance of maintaining productivity vs. amenity values) (Smith and Theberge, 1987; Guikema and Milke, 1999; Machado et al., 2003). This assigns the proper role to science, which cannot objectively determine which attributes of farmland are socially more important. The evaluation and prioritization process could be applied to a range of policy options for implementing farmland preservation (e.g., purchase or transfer of development rights, tax incentives, zoning, or growth management programs), assuming that costs of different conservation tactics can be estimated reliably. For instance, contiguous high-scoring areas could be designated as "agricultural protection zones," and farms within that zone could be eligible for conservation easements. Planners would rank farms by their score after owners reveal their easement bids. Many scoring systems are designed for ranking specific applications (i.e., reactive mode) and therefore can include information about farmers or their practices that is seldom mapped for comprehensive, proactive assessment (Tulloch et al., 2003). However, in principle it should be feasible to incorporate such farm-specific information, especially in reactive mode. Thus both the proactive mode and the reactive mode for ranking farmland could be conducted within the same conceptual framework. Planners could even allocate preservation funds optimally to maximize the improvement toward conservation objectives (Machado et al., 2003).

Despite the solid conceptual foundation of the framework, further research is required. First, we focused our valuation of farmland on one criterion from each of the three primary objectives because the data for measuring them were available. Many of the other criteria that stakeholders value (Table 1) have not been formulated effectively. We are continuing to develop methods for additional criteria but acknowledge that some of them may be challenging. The decision analysis methods underlying the framework can accommodate qualitative criteria with ordinal values (e.g., low, medium, high) as well as the quantitative ones used here. We have not yet addressed the issue of disamenities of farmland (e.g., odors, noise, nutrient runoff, and habitat fragmentation) in calculating "net benefits." Disamenities also vary across the agricultural landscape, but are largely based on farming practices that can be changed over time. Some scoring-based programs give extra points for farms using best management practices in order to minimize disamenities. We expect that the framework could be adapted to farmland restoration programs authorized in the USA Farm Bill that address the reduction of disamenities through scoring systems similar in concept to LESA. Further research is needed to assess the role of uncertainty in the choice of weights (Hoobler et al., 2003) social value functions, data accuracy, and future outcomes (e.g., threat of urban development). Finally, the framework needs to be tested in real world situations in different geographic regions, at different scales of analysis, and in different institutional settings (e.g., state and local governments, private land trusts) to determine its practicality. The methods for some programs are prescribed by their enabling legislation, so it is clearly impractical for them to adopt this framework at this time.

Planning is a social process that is as much art as science. A conceptual or theoretical foundation that is too complex to be understood by the participants will quickly be abandoned for more familiar, though less effective, decision methods. Because the familiar scoring methods do not adequately address the goal of maximizing benefits preserved per unit cost, we offer our framework as an alternative. The data requirements are similar to traditional methods, but the framework provides a sounder conceptual basis for transforming that data into useful information. As the number of farmland preservation programs grows, and as more people acknowledge the range of benefits that farmland provides, tools such as this framework can bolster planning decision making processes.

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