

A Framework for Setting Land Conservation Priorities in the Sierra Nevada¹

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In California, hundreds of different public and private organizations are involved in prioritizing and acquiring new conservation lands (California Environmental Dialogue 1999, California Continuing Resources Investment Strategy Project 2001). Although the State of California owns less than 3 percent of the land (Davis and Stoms 1998), it plays a significant role in the conservation of biodiversity, public open space, and commodity production. State government funding for land acquisitions and conservation easements comes from a variety of sources, including special funds, park-related bonds, and water-related bonds. Although bonds provide considerable public funds for conservation, they fall short of what most agencies and conservation groups believe is required to meet even short-term demands for farmland, open space, and habitat conservation (California Environmental Dialogue 1999). Thus, competition for these public funds is intense, and State funding agencies must make decisions in what are often acrimonious public forums.

In a 1996 analysis of State agency land conservation activities, the California Legislative Analyst's Office found that the State was unable to set clear conservation priorities because it lacked a comprehensive and cohesive statewide land conservation plan, suffered from poor coordination among departments, and had limited ability to formally evaluate conservation opportunities as they arose (California Legislative Analyst's Office 1996). In response, the California legislature mandated the creation of a new conservation planning program known as the California Legacy Project (CLP) (formerly named CCRISP, the "Continuing California Resource Investment Strategy Project") under the Resources Agency. The CLP's mission is "to enable the state and its partners in conservation to develop and implement a strategic and inclusive approach to conserving and restoring California's lands and natural resources" by addressing five fundamental questions:

What are California's significant lands and natural resources?

What are the key emergent threats and opportunities to improve our lands and natural resources?

What are the highest priorities for protection and restoration?

What is the most appropriate way to protect and restore these important, high-priority lands and resources?

How effectively are the State of California and its partners in conservation implementing this strategic approach to conservation?

In 2001, the Resources Agency contracted with the National Center for Ecological Analysis and Synthesis (www.nceas.ucsb.edu) to convene a working group to help bring systematic conservation planning theory and methods to bear on the design and implementation of CLP.

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The framework described below is one of the products from that working group. This paper provides a brief sketch of selected elements of this planning tool and illustrates its application to the Sierra Nevada bioregion. A detailed technical description of the framework can be downloaded from http://www.nceas.ucsb.edu/nceas-web/projects/4040/TerrBiod_framework-report.pdf.

Prioritizing Places for Conservation Investments

This framework is intended to serve the dual purposes of helping decision makers evaluate current opportunities (for example, current proposal applications for State conservation funds) as well as supporting development of longer-term conservation strategies. It is an analytical, data-driven planning process that has been applied and tested at planning scales ranging from single counties to multi-county bioregions.

The planning framework is organized into a hierarchy of conservation goals and objectives, each of which is further elaborated in terms of specific objectives, criteria, and sources of evidence. The highest level has three categories of conservation goals: resource production capacity, natural capital, and public open space (*table 1*). Although the high level of interrelatedness among these three concerns is recognized, individual conservation programs and stakeholder groups tend to emphasize one over the other two, and the logic of priority setting is somewhat different among these concerns. Conservation of cultivated lands, rangelands, and timberlands is included within the category of production capacity goals. Terrestrial and aquatic biodiversity are included under natural biodiversity goals.

Table 1— *Hierarchy of conservation goals.*

Conserve California’s lands and natural resources						
Maintain resource production capacity			Conserve natural capital		Provide adequate high- quality public open space	
Protect productive rangelands	Protect productive timberlands	Protect productive cultivated lands	Conserve aquatic and wetland biodiversity	Conserve terrestrial biodiversity	Preserve urban open space	Provide rural recreation

Spatial Units and Objectives for Conservation Planning

The framework involves four different kinds of spatial units.

The *planning region* encompasses the entire area under consideration for conservation investments. This could be a country, an ecological region, a state, or more local area. For the Sierra Nevada demonstration, the authors used the system of 10 bioregions for California that are defined by ecological and political boundaries and are already used by State resource agencies.

Sites are discrete spatial units that are the candidate areas being prioritized for conservation investments. The example below uses township quadrants from the Public Land Survey System. These roughly 3- by 3-mile areas conform closely to land ownership boundaries, and their relatively uniform size and shape facilitate the analysis of biodiversity patterns and spatial neighborhoods.

A *reference region* is the area considered when evaluating a site with respect to a particular conservation concern. For example, the Sierra Nevada bioregion could be the reference region for evaluating how well a species is represented in existing reserves. The entire State could be the reference region for examining how much a site contributes to protecting the known statewide distribution of a threatened or endangered species.

Observations are data pertaining to a particular resource concern that are available across the entire planning region at some minimum spatial resolution. This resolution could be the minimum mapping unit of a map of irregular polygons or the cell size of a regular grid, such as those produced by classification of remotely sensed imagery. For this demonstration in the Sierra Nevada, the observation unit for most of the data is a 100-meter grid cell. The demonstration also uses point observations of some threatened and endangered species as well as 5- by 5-kilometer grids of current and projected housing density.

This paper illustrates conservation planning for terrestrial biodiversity by using five general conservation objectives:

- Protect hotspots of rare, endemic, threatened, and endangered species (Dobson and others 1997, Noss 2000);

- Protect underrepresented species and community types (Cocks and Baird 1989, Pressey and others 1993, Scott and others 1993, Margules and others 1994);

- Protect wildlands for large carnivores and other “area-dependent species” (Soule 1991, Noss and others 1996, Noss 2000);

- Protect biophysical landscapes to maintain ecological and evolutionary processes (Belbin 1993, Forman and Collinge 1996); and

- Expand existing reserves (Cowling and others 2003).

These objectives are not completely independent; however, each represents a different policy for prioritizing conservation investments, and each invokes a distinctive set of biological and spatial criteria. In the authors’ experience in the Sierra Nevada, site conservation values for the different objectives may exhibit very low correlation with one another.

Simple functions were developed to estimate the conservation value of each planning unit with respect to each of these conservation objectives on the basis of the current conservation status of the reference region and goal-specific measures of resource value and threat (Davis and others 2003). These functions require information on both the extent and condition of terrestrial biodiversity resources.

A Simple Index of Ecological Condition

Because the focus is on setting conservation priorities for rural lands over large areas, the authors used relatively generic measures of ecological condition that could be obtained by operational remote sensing and did not require detailed site surveys. These include land conversion to urban or intensive agricultural use, residential housing density, road effects, and forest structure. Techniques have been developed for forecasting the future state of these variables, providing a means for formally estimating the threat to resource values over the planning period. These variables were assessed at a relatively fine scale (generally 1 hectare or finer) and integrated over the 3- by 3-mile planning units and multiple reference regions. The condition score increases if the area is not converted, has lower impact from residential development, is less affected by roads and, if forested, has mid- or late-seral forest structure (see Davis and others [2003] for details).

Maps of present and predicted future condition were derived from statewide GIS data on land use/land cover (California Department of Forestry and Fire Protection [CDFFP] FRAP),

roads (U.S. Census TIGER data), forest structure (CDFFP FRAP), and predicted housing densities for 2000 and 2040 (Spero 2001). Threat to biodiversity was measured as the difference between mapped condition in 2000 versus 2040 (*fig. 1*). This analysis considered only threat of development on private lands, focusing on new housing development and associated environmental degradation. Other scenarios of threat are certainly conceivable and could be substituted. For this demonstration, the authors also assumed that forest conditions remained constant and no new highways were constructed.

Modeled threat was highest on private lands in the western foothills of the Sierra Nevada, most notably in Butte, Nevada, El Dorado, Calaveras, and Madera counties (*fig. 1*). This threat was concentrated in valley oak, blue oak, and blue oak-foothill pine habitat types, as previously described by Duane (1996), Davis and Stoms (1996), and Spero (2001).

Marginal Conservation Value

The conservation value of protecting a site for a particular resource is calculated as a function of (1) the conservation goal for that resource (expressed as area, fraction of total resource in the region, number of occurrences of the resource, or some other quantity), (2) amount of the resource that is predicted to remain in the reference region at the end of the planning period in the absence of conservation action, and (3) the additional amount of the resource that would remain at the end of the planning period if new conservation actions were taken to protect the resource wherever it is currently threatened in the site.

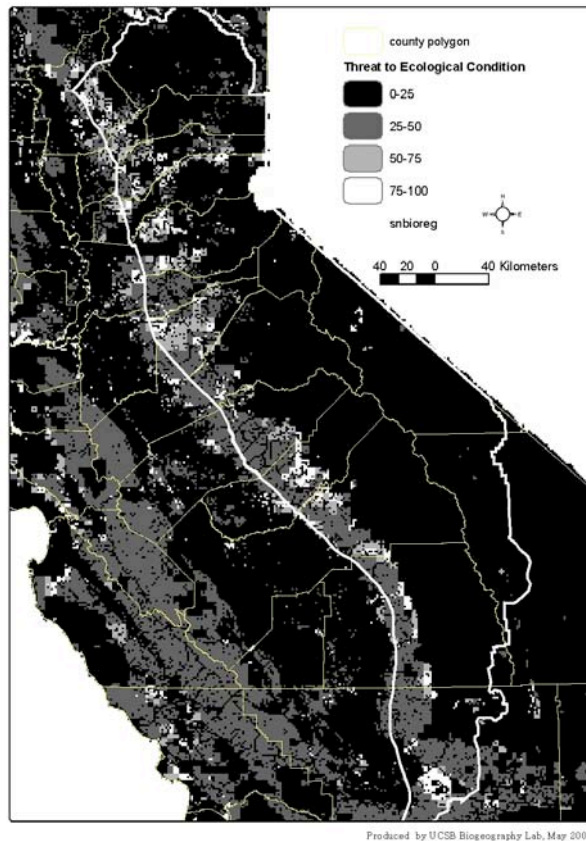


Figure 1— Calculated threat to current ecological condition from new housing development projected to occur between 2000 and 2040 A.D. The threat levels range from 0 to 100 and are calculated as the difference between modeled cell condition in 2040 and 2000.

This approach requires establishing a relationship between the level or amount of a resource (for example, acreage of a particular habitat type) and the “utility” associated with the resource. Utility is measured with respect to the amount or level of a resource in the reference region, rather than the level of protection of the resource. Total utility level of the resource is assumed to decrease as the resource is reduced in the region. (In principle, the utility level could also increase through rehabilitation and restoration activities.) An infinite variety of shapes are possible for this utility function, but the authors assume that utility is gained or lost most steeply at low levels of the resource and changes relatively little at very high levels of the resource (in other words, there are “diminishing returns” on increasing amounts of the resource in the region). One can also specify a goal beyond which increasing levels of the resource are seen as adding no utility. A utility curve and associated marginal benefit curve that capture these ideas are shown in *figures 2a* and *2b*. Utility is zero when the level of the resource is zero, increases at a constant rate to some specified level of the resource, and then increases in a quadratic form up to a target level beyond which no additional utility accrues. This produces a piecewise linear form for the marginal benefit curve. The marginal conservation value of any particular site is measured as the total utility that is retained by conserving that site (*fig. 2c*).

To measure a site’s value for conserving terrestrial biodiversity, its marginal conservation value is estimated for each of the five conservation objectives listed above. These are combined by weighting each objective and summing the weighted values for each site.

Allocating Conservation Funds

The final step in the framework is a budget allocation model. This approach to measuring conservation value is based on a cost-effectiveness framework similar to that of Hyman and Leibowitz (2000). Conservation investments, which are allocated at the site scale, may be the cost of outright acquisition of currently unprotected lands, purchase of development rights, stewardship incentives, or whatever action is deemed necessary to remove the threat. The authors attempt to identify the set of sites, which, if conserved, would minimize the loss of terrestrial biodiversity during the planning period. This requires consideration of each site’s resources, location, and spatial context; severity of threats; and conservation cost.

Identifying the “best” set of sites for conservation investments given a fixed budget can be an extremely difficult problem to solve because of the astronomically large number of feasible solutions. Several heuristic algorithms are available to ease implementation of the model for large problems. This demonstration uses a simple heuristic that involves a stepwise procedure in which the site that provides the greatest utility per conservation dollar (in other words, conservation “bang for buck”) is chosen first. Then, all resources and values are re-calculated on the basis of that conservation action, and the procedure is repeated until the budget has been spent. This is a version of the “greedy algorithm” in integer programming.

Example Results for the Sierra Nevada Bioregion

Marginal Conservation Values

Figures 3 and *4* illustrate patterns of marginal conservation value (or marginal utility) for two of the five metrics for terrestrial biodiversity: hotspots of rare, threatened, and endangered species (*fig. 3*) and areas supporting wildlife habitat types that are not well represented in existing public lands or private reserves (*fig. 4*). Results for the other metrics are described by Davis and others (2003).

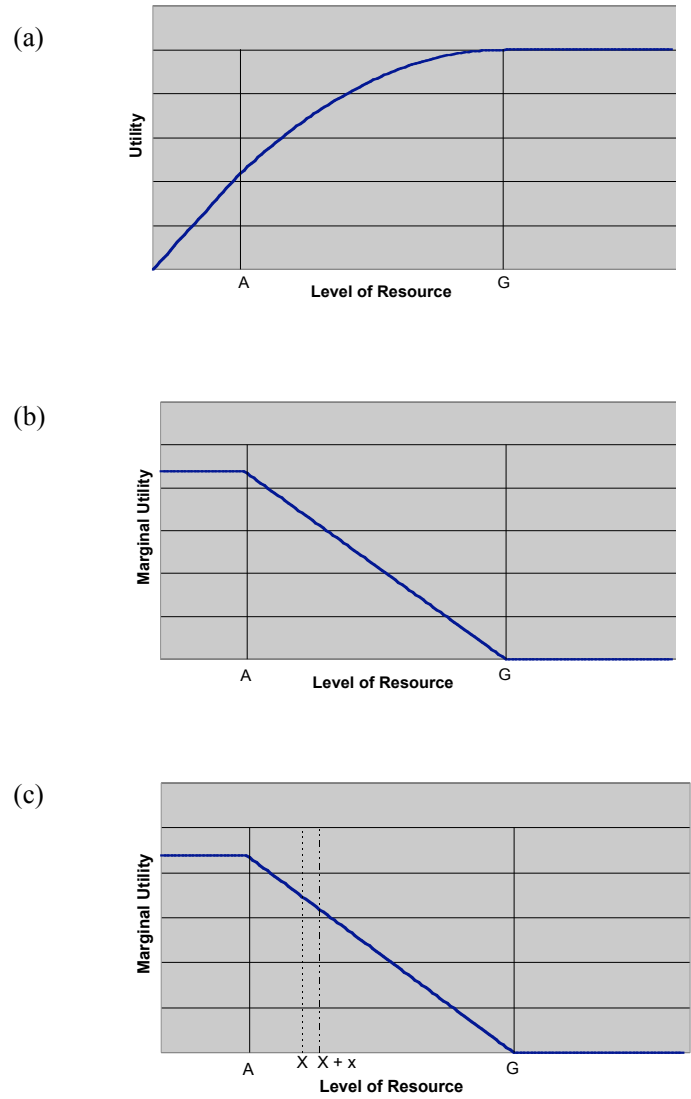


Figure 2— Utility functions and associated marginal utility functions for estimating site conservation value: (a) the utility function used here for evaluating terrestrial biodiversity in the Sierra Nevada bioregion; (b) the marginal utility function associated with (a); (c) change in marginal value associated with a conservation action today that increases the predicted future level of the resource from X to $X+x$. The total benefit of the conservation is calculated as the area under the marginal value curve.

The hotspot score (*fig. 3*) is based on the distribution of G1 and G2 plant and animal species according to the California Natural Diversity Database. A site has higher hotspot conservation value if it has more unprotected land that is in good condition and that land accounts for a large fraction of the known distribution for a relatively large number of rare, threatened, and endangered (RTE) species. Clusters of high-scoring sites are scattered across the private lands of the western foothills. Many of the high-scoring sites are areas with

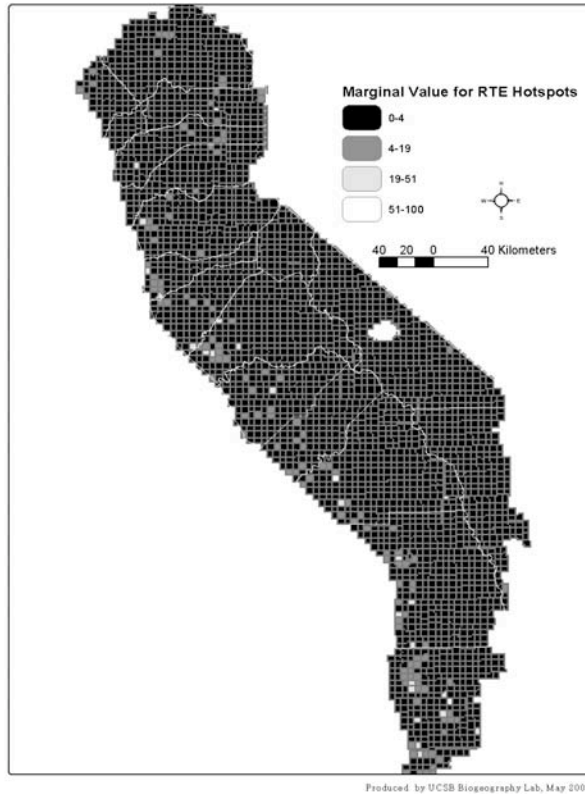


Figure 3— Hotspot value of township quadrants in the Sierra Nevada bioregion for rare, threatened, and endangered plant and animal species. Scores reflect documented distributions of all G1 and G2 species in the 2002 version of the California Natural Diversity database.

distinctive soils and associated concentrations of rare plant species. For example, the highest scoring cells in the foothills of Nevada, Placer, Amador, and El Dorado counties are locations of serpentine and gabbroic soils that support chaparral communities with rare endemic plant species such as *Calystegia stebbinsii* and *Fremontedendron californicum* ssp. *decumbens*. Similarly, several high-scoring sites at the southern end of the region in Kern County are areas of blue oak (*Quercus douglasii*) woodlands on adobe soils that support rare plant species, such as *Mimulus pictus* and *Fritillaria striata*. Because the majority of special-status species in the Sierra Nevada comprise narrowly distributed plant taxa, scores are largely dictated by plant species. A map of values based solely on animal species shows a quite different pattern (Davis and others 2003).

Site scores for protecting underrepresented habitat types (*fig. 4*) were derived for wildlife habitat types as defined in the California Wildlife Habitat Relationship (CWHR) System (Mayer and Laudenslayer 1988). A current map of CWHR types at 100 meters was obtained from CDFFP FRAP. The highest marginal values were associated with threatened CWHR types, including commercial conifer types, such as ponderosa pine forest and eastside pine forest, and oak woodland types, such as blue oak–foothill pine woodland and valley oak woodland. Township quadrants scoring the highest were those where habitat types with high marginal value and in relatively good condition occurred on threatened private lands (*fig. 4*). Thus, high-scoring sites are clustered at low- to mid-elevations on the western slope of the Sierra Nevada, where rural housing density has increased in recent decades and is projected to continue to increase (Duane 1996).

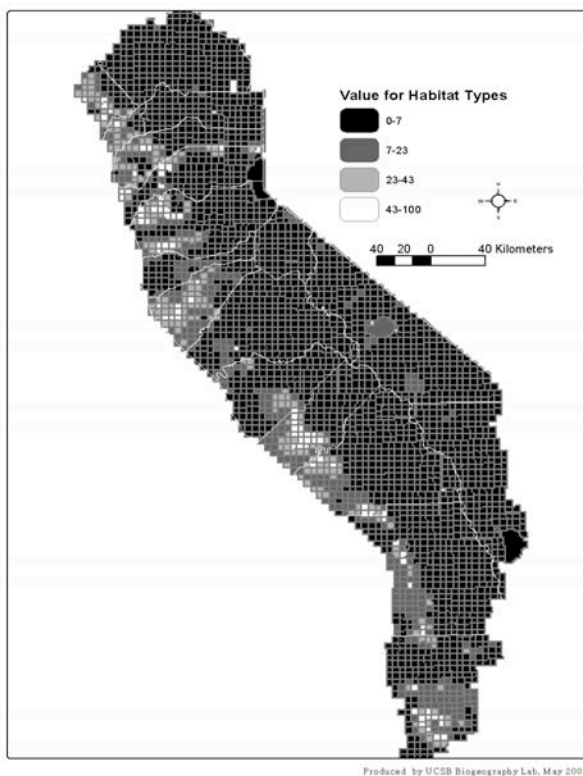


Figure 4— Marginal value of private lands by township quadrants in the Sierra Nevada bioregion for conserving wildlife habitat types.

The spatial patterns of conservation value vary considerably among the five objectives, with scores for RTE species showing the lowest correlation with other objectives. If the five objectives are weighted equally, many township quadrants in the Sierra Nevada bioregion show moderately high scores (*fig. 5*). Very few sites score highly in all objectives. Larger regions of high-scoring cells include central Placer County, southwestern and southeastern El Dorado County, central-western Calaveras County, central Madera County, south-central Tulare County, and south central Kern County.

Perhaps more to the point is that, based on relatively crude surrogates for biological composition, condition, and threat, many areas of the foothills and lower montane zone of the Sierra Nevada bioregion have high value for one or more objectives and at least moderate conservation value when all objectives are considered. A few areas of the eastern Sierra Nevada also appear consistently, although scores are generally lower because of lower projected threat of development and the high percent of public ownership. Thus, variations in costs and opportunities could play a significant part in determining priorities, as demonstrated below.

A Sample Investment Portfolio

For demonstration purposes, the authors considered conservation in the Sierra Nevada study area solely by outright acquisition. Land prices for undeveloped rural lands were estimated using 2002 data from the California Chapter of the American Society of Farm Managers and Rural Appraisers [available online at <http://www.calasfmra.com/landvalues/2002/index.html>]. County-level estimates for land value of rangeland were used for Butte, Placer,

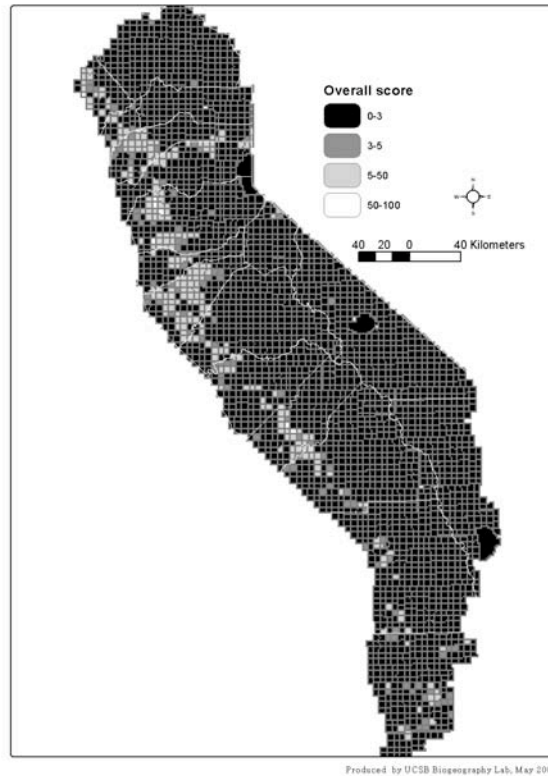


Figure 5— Composite conservation scores for terrestrial biodiversity private lands in township quadrants of the Sierra Nevada bioregion given equal weighting among the five conservation objectives.

Madera, Fresno (eastern half), Tulare, and Kern (eastern half) counties. Land values for the remaining counties were chosen to reflect the broad pattern of land use and development pressure relative to known county values. Counties in the eastern part of the Sierra Nevada bioregion were assigned the lowest land values; those in the central western foothills were assigned medium land values; and those lying just east of Sacramento were given relatively high values. For this demonstration, land values ranged from \$988 to \$2,470 per hectare (\$400 to \$1,000 per acre). The total conservation cost of a planning unit is the product of the per-hectare cost and the total area in hectares of land available for conservation in the planning unit (total land area minus public land and converted land).

A quick comparison of these land values with prices actually paid in recent years through California bond initiatives showed that the values used for this demonstration tended to correspond to the low end of the range for a county. Often, the high end of the range was several times the price used here, and where there were many acquisitions, the price range in a county was extremely variable. This suggests that county-level estimates grossly oversimplify the geography of the real estate market. However, the purpose here is to demonstrate the use of the model.

Using estimated land values and the measure of overall marginal value for terrestrial biodiversity conservation with equal weighting between conservation objectives, the greedy algorithm was run until an arbitrary 50 sites were selected at a predicted total acquisition cost of \$44 million for approximately 25,000 hectares, or about 10 percent of the remaining available land in the Sierra Nevada bioregion (*fig. 6*). This represents an average of \$1,760 per hectare, very close to the \$1,800 per hectare average estimated price in the bioregion. This scenario should be interpreted as one possible alternative, based on

an equal weighting of conservation objectives. The outcome is very sensitive to the very crude estimates of land values used here, choice of reference regions and goals, and the model of future urbanization.



Figure 6— A sample run of the greedy site selection algorithm. The algorithm was run until an arbitrary 50 sites were selected at a predicted total acquisition cost of \$44 million for approximately 25,000 hectares, or about 10 percent of the remaining available land in the bioregion.

In general, the mean marginal value for each objective in selected sites was much greater than the mean for all sites. Forty-two of the 50 selected sites had no marginal value for at least one of the five objectives. Interestingly, the spatial pattern of selected sites is quite scattered. Although spatial clustering is an important consideration in two of the metrics, with even weighting of all five objectives the selected sites are not clustered. Different weights would result in a different pattern.

A large fraction of the 50 sites occur in the eastern Sierra Nevada counties of Alpine, Mono, and Inyo, which were assigned the lowest estimates of land values. The composite marginal value for these eastside sites was four times less than those selected on the west slope of the Sierra Nevada, but the mean benefit-cost ratios were almost identical. Clearly, the estimates of land values used for this demonstration had a strong influence on the scenario, by allocating funds to more land of moderate conservation value than spending it all on relatively fewer hectares of land with the maximum marginal conservation value. This result underscores the point that making efficient and effective conservation investments requires more information than simply identifying sites with the highest biodiversity conservation value (Ando and others 1998).

Discussion

This framework developed for the California Legacy Project has not been fully vetted by the relevant State agencies or other stakeholder groups, so it remains to be seen whether the ideas and methods will prove useful in real planning efforts. Most of the calculations are relatively straightforward and easily implemented in ArcGIS and Access, so the framework should be widely accessible. The authors believe that the strengths of the framework are its generality, explicitness, applicability with readily available data, flexibility for exploring alternative goals and objectives, consideration of threats and costs as well as biodiversity values, and perhaps, most importantly, its ability to reveal short-term priorities and its usefulness in helping to choose among competing projects on the basis of a formal cost-effectiveness analysis.

The framework as currently implemented is somewhat cumbersome and needs a simple user interface and software to facilitate analysis and planning. The authors are currently developing such a planning support environment in collaboration with NatureServe (<http://www.natureserve.org/>). After developing such software, it will be much easier to conduct sensitivity analyses on models of development threat, different planning horizons, classification schemes, parameters, and marginal value functions, which are integral to estimating site conservation value.

The usefulness of this data-driven framework obviously depends on the quality of the data. The authors have deliberately limited the application to statewide data that are widely used, with accuracy and biases relatively well understood. In doing so, biological detail has been sacrificed for better consistency and accuracy. However, some Sierra Nevada counties (for example, Placer and Nevada) have recently developed more detailed geospatial databases that could be used in subregional analyses.

A major concern with the current framework is that it does not consider the effects of taking conservation actions on ensuing distribution of development threats. The authors are looking into ways of updating the threat surface as part of updating calculations of conservation value. This will be especially important for applications of the framework at finer spatial scales.

Acknowledgments

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