FRANK W. DAVIS
Institute for Computational Earth System Science
University of California
Santa Barbara, California

DAVID M. STOMS
Institute for Computational Earth System Science
University of California
Santa Barbara, California

RICHARD L. CHURCH
Department of Geography
University of California
Santa Barbara, California

WILLIAM J. OKIN
Department of Geography
University of California
Santa Barbara, California

K. NORMAN JOHNSON
College of Forestry
Oregon State University
Corvallis, Oregon

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Selecting Biodiversity Management Areas

ABSTRACT

Here we present and evaluate a conservation strategy whose objective is to represent all native plant communities in areas where the primary management goal is to sustain native biodiversity. We refer to these areas as Biodiversity Management Areas (BMAs), which we define as specially designated public or private lands with an active ecosystem management plan in operation whose purpose is to contribute to regional maintenance of native genetic, species and community levels of biodiversity, and the processes that maintain that biodiversity. Our purpose in this chapter is to explore opportunities for siting BMAs in the Sierra Nevada region. The strategic goal is to design a BMA system that represents all major Sierran plant community types, which we use as a coarse surrogate for ecosystems and their component species. We consider a community type to be represented if some pre-defined fraction of its mapped distribution occurs in one or more BMAs. We use a multi-objective computer model to allocate a minimum of new land to BMA status subject to the constraints that all community types must be represented, and that the new BMA areas should be located in areas of highest suitability for BMA status. Our purpose in this exercise is not to identify the optimal sites for a Sierran BMA system; instead it is to measure some of the likely dimensions of plausible, alternative BMA systems for the Sierra Nevada and to develop a rationale that would guide others in formulating such a system. Thus we examine a wide range of possible BMA systems based on different assumptions, constraints, target levels for representation, and priorities.

If one ignores current land ownership and management designations and sets out to represent plant communities in a BMA system based on Calwater planning watersheds (which average roughly 10,000 acres in size), an efficient BMA system requires land in direct proportion to the target level, at least over the range of target levels examined in this study. In other words, it takes roughly 10% of the region to meet a 10% goal, and 25% of the region to meet a 25% goal. The pattern of selected watersheds is very different from the current distribution of parks and wilderness areas, which are concentrated at middle and high elevations in the central and southern portion of the range.

Public lands alone are insufficient to create a BMA system that adequately represents all plant community types of the Sierra Nevada. Many of the foothill community types occur almost exclusively on private lands. Terrestrial vertebrates are reasonably well represented in a BMA system selected for plant communities. A BMA system selected for vertebrates alone, however, has little overlap with the one for plant communities.

Areas selected by the BMAS model show only a modest amount of overlap with areas selected by other SNEP working groups as focal areas for conserving aquatic biodiversity or late successional/old growth forests. However, the BMAS model can be formulated to favor these areas with little loss of efficiency, especially in the northern Sierra.

Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources, 1996.

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PROBLEM STATEMENT

The Sierra Nevada Ecosystem Project (SNEP) has highlighted some pervasive and resource-specific impacts of human activities on the region's aquatic and terrestrial biodiversity. We will not review these here, instead referring the reader to SNEP's key findings in Volume 1 of this report. Suffice it to say that virtually every ecosystem in the Sierra Nevada is impacted by one or more human activities such as impoundment and diversion of water, residential and agricultural development, logging, livestock grazing, suppression of wildfire, air pollution, introduction of non-native plant and animal species, mining, and recreation. To address these impacts, SNEP scientists have developed and evaluated a dozen or so alternative strategies for management and conservation of regional biodiversity.

Here we present one such strategy for conserving native biodiversity based on establishing a Sierra-wide system of Biodiversity Management Areas (BMAs), defined as specially designated public or private lands with an active ecosystem management plan in operation whose purpose is to contribute to regional maintenance of native genetic, species and community levels of biodiversity, and the processes that maintain that biodiversity. The BMA system is located to be representative of biodiversity but is not a comprehensive reserve strategy that in itself can guarantee the viability of the native biodiversity of the Sierra Nevada.

The assumption underlying the BMA strategy is that future land use activities as well as pressures on rural and wilderness areas will only increase the risk of losing native Sierran species and ecosystems. We also assume that the vulnerability of Sierran biodiversity to human activities can be reduced by increasing the amount of land devoted to conservation and management of the native biota. Finally, because managing an area as a BMA may conflict with other social or economic goals, we assume that BMA land should ideally be located as efficiently as possible both in terms of the amount and the suitability of the area that is allocated to this management objective.

The specific goal of the BMA strategy is to design a regional system of managed areas that represents all major Sierran plant community types, which we are using as a coarse surrogate for ecosystems and their component species. A community type is considered represented if some pre-defined fraction of its mapped distribution occurs in one or more BMAs. We use a computer model to produce BMA systems for the Sierra Nevada that represent all community types as efficiently as possible, that is, with minimal land allocation and located in areas with highest suitability for biodiversity conservation goals.

The purpose of this exercise is not to identify a specific set of sites that form the optimal design for Sierran BMA system. Instead, the purpose is to measure the likely dimensions of plausible, alternative BMA systems for the Sierra Nevada and to develop a rationale that would guide others in formulating such a system. Towards this end, we have examined a wide range of possible BMA systems based on different assumptions, constraints, target levels for representation, and priorities.

Specifically, we sought answers to the following questions:

1. What is the minimal area required to represent all Sierran plant community types in BMAs? How does an "optimal" BMA system compare to the existing set of parks, wilderness areas, and reserves in the region?
2. How does the location of BMAs relate to the distribution of areas of special interest that have been identified in other SNEP assessments and biodiversity strategies, in particular, Aquatic Diversity Management Areas, Significant Ecological Areas, and Areas of Late Successional Emphasis?
3. Can a representative BMA system be established on public lands only? If not, what area of private lands is required? How does the area requirement change if lands that are currently administratively withdrawn from grazing and timber harvest are classified as BMA lands?
4. How sensitive is the siting of BMAs to the way in which biodiversity is measured? Specifically, how do solutions to represent plant community types compare to solutions based on representing vertebrate species?
5. Do some general areas emerge from the analysis that appear especially well suited to serve as BMAs?

THE BIODIVERSITY MANAGEMENT AREA CONCEPT

Biological conservation strategies have traditionally centered on biological reserves, where a reserve is "an area with an active management plan in operation that is maintained in its natural state and within which natural disturbance events are either allowed to proceed without interference or are mimicked through management (e.g., most national parks, Nature Conservancy preserves, some USFWS National Wildlife Refuges, research natural areas)" (Scott et al. 1993, 34). Large (e.g., >10,000 ha) reserves are the most common strategy to maintain biotic communities over long time periods in areas undergoing large-scale conversion from wildlands to agricultural and urban systems (e.g., Shafer 1990). In areas of extensive habitat conversion, the design of reserve systems is typically based on a model of reserves as isolated islands of habitat for native species. The viability of a reserve system is gauged based on the size, shape, and connectedness of these remnant habitat areas.

A different situation prevails over much of the Sierra Nevada because a large portion of public and private lands is managed for renewable natural resources such as livestock forage, timber, and recreation. In contrast to largely agricultural or urban landscapes such as the Central Valley or Los Angeles Basin, the prevailing land cover types of the Sierra Nevada are managed forest, rangeland, and alpine ecosystems that sustain many if not most elements of native biodiversity while also supporting natural resource-based economies. In this setting, a BMA system could serve to provide "core habitat areas" of higher habitat quality for many species, sanctuaries for species and habitat types that are especially negatively impacted by human activities, and could possibly serve to buffer populations from unexpected environmental change or unintended consequences of extractive activities on remaining lands.

There is much debate among conservation biologists on the design of conservation land systems in regions such as the Sierra Nevada where the matrix lands (i.e., those outside of BMAs) contribute significantly to maintaining biodiversity. One view holds that nothing short of very large, well-connected wilderness areas can maintain native biodiversity over the long run, particularly if the biota includes wide ranging predators and migratory herds (e.g., Noss 1992). An opposing view is that smaller and more dispersed areas could suffice as long as the matrix lands are well managed for sustained yield of natural resources and the BMA lands are actively managed for native biodiversity (e.g., Alverson et al. 1994). In our opinion, there is not sufficient long term evidence to evaluate the relative merits of these opposing approaches to conserving Sierran biodiversity. The latter view forms the premise for the scenario presented here. That is, we will assume that Sierran biodiversity can be maintained by ecologically sound management of lands managed for renewable resource extraction, in combination with a rationally designed and located set of moderately sized areas managed specifically for native biodiversity. This assumption is most tenuous in areas such as the foothill zone of the western central Sierra Nevada where native habitats are being converted to urban, residential and agricultural purposes. The assumption also may not be sufficient to maintain some wide ranging predators such as the fisher that are especially sensitive to human activities.

Our concept of a BMA is similar to the Diversity Maintenance Areas concept proposed by Alverson and colleagues (1994). Diversity Maintenance Areas are envisioned as national forest lands that have biodiversity as the primary management priority. Alverson and colleagues (1994) propose that Diversity Maintenance Areas should be positioned to the degree possible to include existing forest reserve lands, should account for site history and biological legacy, and should be large and designed according to accepted principles of conservation biology. Economic activities including hunting, timber harvest and recreation are allowed on Diversity Maintenance Areas as long as they do not conflict with the primary management goal.

The BMA concept differs from that of Diversity Maintenance Areas in that it extends to both private and public lands and across both forest and non-forest habitats. Economic activities can go forward to the extent that they are compatible with the goal of maintaining native biodiversity. Most importantly, each BMA is managed as part of a system of BMAs that are themselves managed to limit the total risk to regional biodiversity through maintenance of a representative amount of all plant communities.

MODEL FORMULATION

The modeling approach is summarized here and presented in detail in appendix 58.1. First we divided the SNEP core area into six separate planning regions whose boundaries were defined by major river drainages (figure 58.1). This division was deemed necessary to capture latitudinal and longitudinal gradients in Sierran habitats, ecosystem processes, plant community composition, and population genetics that are not adequately reflected in current plant community classification systems (Davis and Stoms 1996; Shevock 1996; Millar et al. 1996). We have only analyzed the northern, central, and southern regions (figure 58.1).

In each region we defined a starting BMA system based on maps of land ownership and management. (For example, one alternative considers all parks, designated natures reserves, and ungrazed designated wilderness areas as BMA lands.) Next we established a target level for representing plant community types in BMAs. This level can be set for each individual element, but for simplicity we use the same target level, for example, 10% of the mapped distribution, for every plant community type. We then overlaid the map of existing BMAs on the map of plant community types to determine which types are not adequately represented and how much additional BMA land is needed for each type. This process of assessing vulnerability in relation to land management categories is the essence of gap analysis (Davis and Stoms 1996). We then used a multi-objective siting model to allocate a minimum of new land to BMA status subject to the constraints that all community types must be represented, and that the new BMA areas should be located in areas of highest suitability for BMA status.

We used Calwater planning watersheds as the land units for allocating new BMAs (figure 58.1). These watersheds were delineated by the California Department of Forestry and Fire Protection to support regional planning, and have a minimum size of 3,000 acres. There are 1,785 watersheds in the three regions averaging 3,024 ha (7,470 ac) in size. These watersheds make logical units for BMAs because they are readily located on the ground and are appropriate physiographic units within which to manage ecosystem and hydrologic processes. A single watershed might be sufficient to maintain viable populations of many plant and small animal species (e.g.,

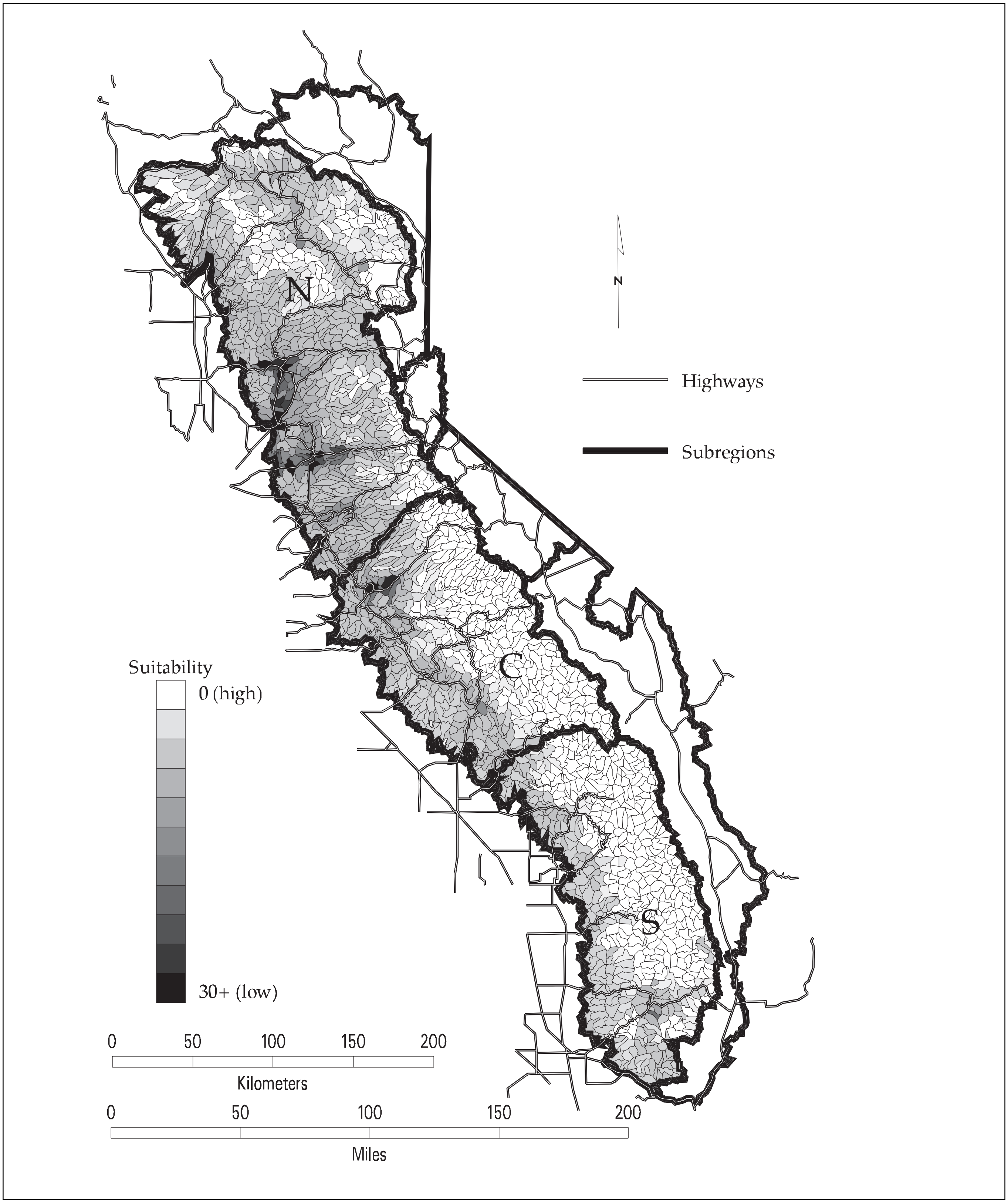


FIGURE 58.1

Outline of the SNEP core area showing the boundaries of the six hydrologic regions (bold lines) and Calwater planning watersheds for the northern, central, and southern hydrologic regions of the SNEP core area. The Watershed Suitability Index (WSI) is shown by a gray scale, where darker areas have a higher WSI (i.e., lower suitability).

Schonewald-Cox 1983), although our approach does not depend on this premise.

Only whole watersheds can be allocated to BMA status in the model. The area of different plant community types in each watershed are calculated by intersecting the watershed boundaries with a map of plant community types (Davis and Stoms 1996). The vegetation map was prepared at 1:100,000 scale for the gap analysis of the Sierra Nevada. In general, there are several vegetation units per watershed.

The suitability of each watershed for BMA management is estimated with a Watershed Suitability Index (WSI), which is the weighted sum of four factors: human population density, the fraction of the watershed affected by roads, the fraction of the watershed that is privately owned, and the degree to which public and private ownership are intermingled. These factors represent many of the known impacts on biodiversity, both in terms of habitat quality and management constraints. Certainly other factors also negatively affect biodiversity but spatial data covering the entire region were not readily available. The higher the value of this index, the less suitable a watershed is for BMA status (figure 58.1). This counter-intuitive scaling of WSI is needed to be consistent with the model's objective function, which seeks to minimize the area and WSI of the model solution. The development of the WSI is explained in greater detail in appendix 58.1.

Because we might consider hundreds of plant community types or species, and we can select from among hundreds of watersheds in a region, the number of potential BMA systems becomes quite large and the problem of selecting the optimal set of watersheds is relatively complex. We have formulated this decision problem as a robust heuristic model where the objectives are to minimize the total area and maximize the suitability of the regional BMA system, subject to the constraint that enough area is selected for all elements to be considered adequately represented (appendix 58.1). We call this model the Biodiversity Management Area Selection (BMAS) model. The output of BMAS is a map of a hypothetical BMA system.

Because the objective of the analysis is not to design a reserve system in the traditional sense, the current version of the BMAS model does not explicitly consider the spatial pattern of the selected watersheds. Based on general principles of conservation biology, one could argue that larger, better connected BMAs would tend to maintain biodiversity better than small, poorly connected systems (Reid and Murphy 1995). On the other hand, there is evidence that populations in several scattered sites are less vulnerable to large-scale environmental disturbances than populations in a single larger site (Harrison and Quinn 1989). Obviously, it would be useful to incorporate spatial considerations in the BMAS model in order to explore these issues more analytically. However, the BMAS model used here provides solutions that are the most efficient solutions only in terms of minimizing the area and WSI for a given set of parameters. Thus the solutions can be considered planning benchmarks in terms of the area requirements for representative BMA systems. Any additional constraints such as spatial design would necessarily increase the area of the solution.

Trade-off Analysis of the BMAS Model

The BMAS model solves a multi-objective decision problem that balances selecting the least area versus minimizing WSI. In general, one would expect a solution weighted towards watersheds with a low WSI to require more area than a solution for which suitability was given less weight. Conversely, one would expect the least area for a solution that ignored WSI. We conducted a sensitivity analysis in the northern hydrologic region to explore the range of feasible solutions generated by varying the weights for the two objectives.

We ran 12 variations of the model that varied in the weighting of area and suitability, in target level for representation, and in the starting BMA system. More specifically, we solved the BMAS model for area only, for WSI only, and for a balanced weighting of area and WSI. Each set of weights was applied to models with a target goal for representation of 10% or 25% for all plant community types, and for an initial BMA system consisting of Class 1 lands or for Classes 1 and 2 lands as defined for SNEP's gap analysis. (See Davis and Stoms 1996; discussions in the next section and in appendix 58.1.)

Solutions based on different weights can be plotted as trade-off curves of total area versus total WSI, which is obtained by summing the WSI values for all selected watersheds. These curves indicate the limits of feasible solutions for the specified target levels and initial conditions (figure 58.2). No solutions will be feasible closer to the origin of the graph. The curves also show that solving for both objectives simultaneously makes a substantial improvement in one objective with only a slight reduction (or trade-off) in the other. For instance, for the model with an initial BMA system of Class 1 and Class 2 lands (C1+C2) and a target level of 25%, the minimum area that can be selected while still meeting the 25% target for all elements is 341,153 ha (figure 58.2). However, the total WSI in that solution is 725. The minimum possible WSI (i.e., the cumulative index of the most suitable set) of selected planning units is 369, but this requires a total area of 444,550 ha to meet the 25% target. The multi-objective solution in the middle of the curve reduces WSI by 41% while only increasing total area by 15,000 ha (4%) relative to the "area only" alternative. Similarly, for a 20% reduction in area, the multi-objective alternative only increases total WSI by 16% relative to the "WSI only" alternative.

Exploring all possible combinations of weights for each set of definitions was beyond the scope of this analysis. It may be possible to improve the multi-objective solution through further moderate adjustments in the weights. However, the trade-off curves in figure 58.2 suggest that the opportunity for improvement is slight, and we expect that any improvement in the objective function will not significantly change the configuration of BMAs that were selected. Based on the

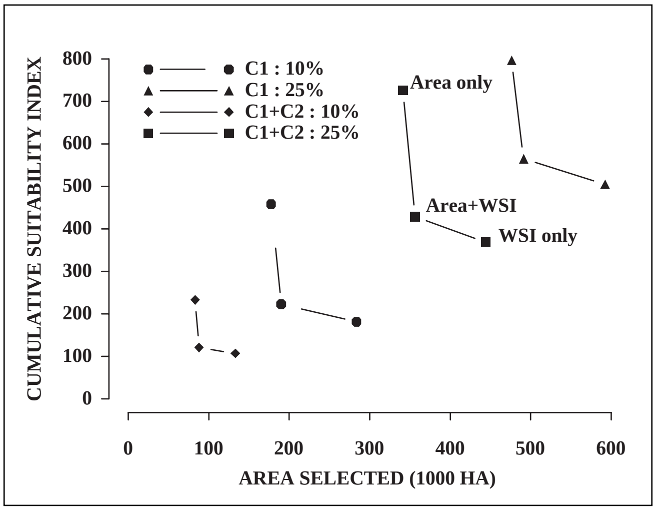


FIGURE 58.2

BMAS trade-off curves for the northern hydrologic region. Curves show the total area and summed Watershed Suitability Index (WSI) for selected watersheds for four different alternatives that vary in target levels (10% or 25%) and starting BMA system (Class 1 (C1) lands or Class 1 and Class 2 lands (C1+C2)). See text and appendix 58.1 for explanation of C1 and C2 lands. For each alternative, three sets of weights were applied: setting the area weight to 0 (WSI only), setting the suitability weight to 0 (Area only), and positive weighting of the two (Area + WSI, with weights scaled to their range of values). Thus the curves show the trade-off between solutions weighted towards area versus suitability for the four models.

sensitivity analysis for the northern region, we selected weights for multi-objective solutions for all of the planning regions. In the results section, all runs were based upon weights for area and WSI that roughly weighted them equally. These weights were determined by trial and error.

SUMMARY OF ALTERNATIVES AND FINDINGS

To answer the five questions listed above in the Problem Statement, we analyzed several dozen alternatives that varied in one or more model specifications. These alternatives can be grouped into six classes that vary in their starting BMA systems, inclusion of private lands, or measure of biodiversity. Within each classes of alternative, we ran the model with targets of 10% and/or 25% representation for two different levels of biodiversity emphasis. These alternatives and their solutions for each hydrologic region are summarized below. Our objective is not to provide a detailed analysis of the specific watersheds that are selected. Instead, we have focused on how much land is required for each alternative and how that land is distributed among different ownership and management categories. Also, we do not analyze specific plant community types in any detail. Appendix 58.2 provides a full listing of the plant community types and indicates which types required additional area under each model alternative.

Alternative 1

Represent all plant community types in BMAs, ignoring the current distribution of designated conservation lands. Minimize the area and WSI of the solution.

Solving this model alternative reveals the areal requirements of a representative BMA system whose extent and distribution is not tightly constrained by existing land allocations. Essentially, we are posing the question: "If there were no parks, reserves, or other areas in the Sierra Nevada managed primarily for biodiversity, how would one allocate land to a new set of areas in order to most efficiently represent the region's biodiversity?" Private lands were considered available for BMA allocation, although private ownership increases the WSI and thus reduces the likelihood of selection.

We solved this alternative for the central and southern regions based on a 25% target, which is roughly the fraction of those regions that is currently in designated parks, ungrazed wilderness areas, and other conservation areas. This land management category is labeled Class 1 lands by Davis and Stoms (1996) and in appendix 58.1. We do not show the solution for the northern region, where the amount of Class 1 land is only 2% of the region, because ignoring Class 1 lands has a negligible effect on the solution.

For the central region the solution required a total of 348,898 ha (861,778 ac) for the central region, or roughly 21% of the total area (table 58.1; figure 58.3). In the southern region the solution required 361,219 ha (892,212 ac) or 23% of the region (table 58.1; figure 58.3). The reason that the required area is less than 25% of the entire region is because we did not try to represent land use or cover types such as orchards and cropland, water, and barren lands.

In minimizing WSI, the solution favors public lands over private lands, and favors less roaded areas such as parks and wilderness areas over others. Nevertheless, only 22% of the selected area is drawn from existing Class 1 lands, an amount that is in proportion to the extent of Class 1 lands in each region. Although private lands comprise one-third of the two regions, they also contribute around 22% of the selected area. Lands administratively withdrawn from commercial timber harvest on the national forests (Class 2) contribute a relatively small area of the solution (4%), again in proportion to their extent in the two regions.

The selected watersheds are distinctly clustered, notably in east-west lines that span elevational gradients (figure 58.3). This clustering appears to be related to clustering in the watershed suitability index at the scale of larger drainage basins that encompass several to many planning watersheds.

In summary, the results for Alternative 1 suggest that an

TABLE 58.1

Comparison of biodiversity management alternatives.

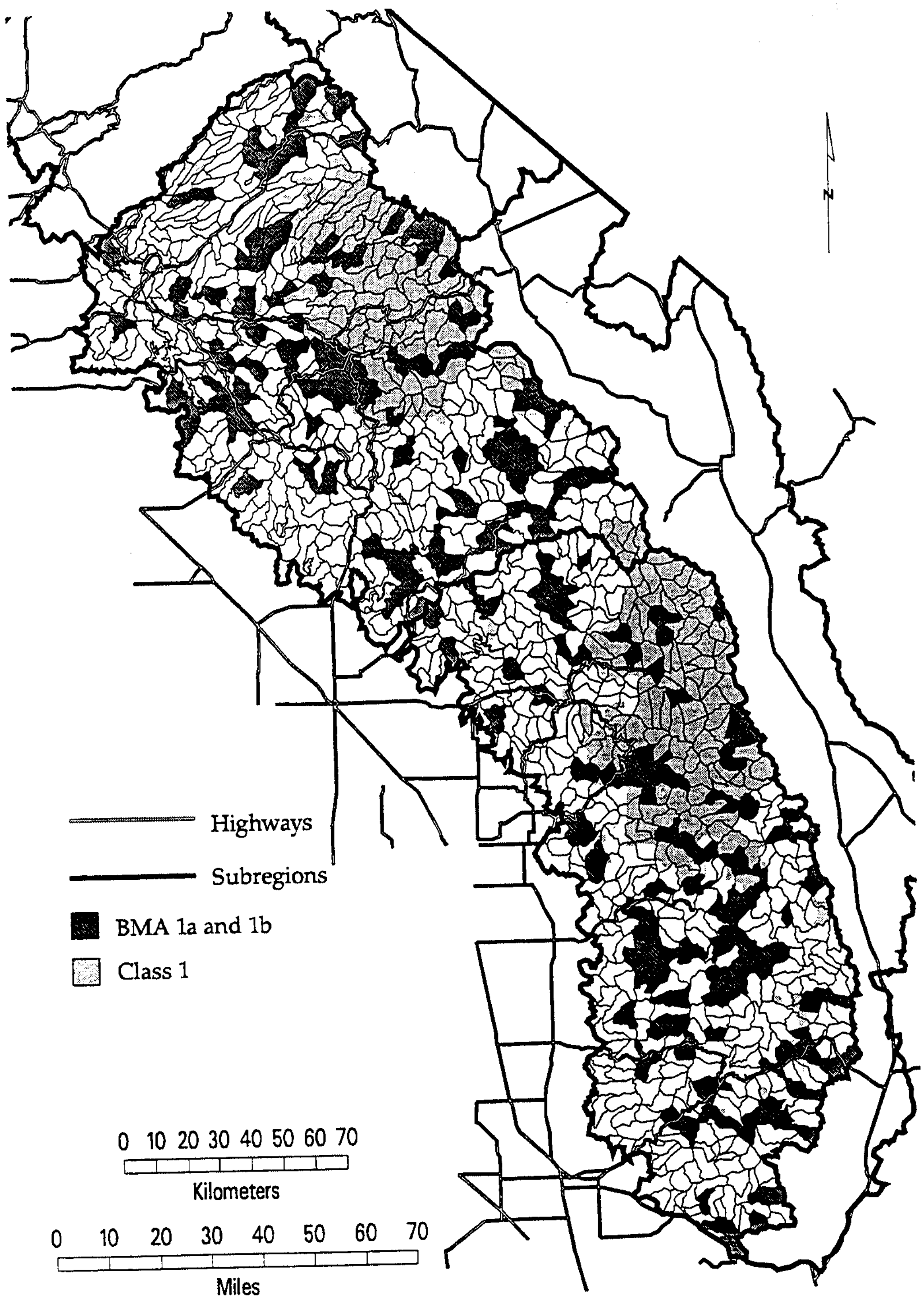
Alternative	Region	Initial BMA System	Target Level	Suitability Factors	Initial BMA Area (ha)	Vulner-able/ Total Community Types	# Selected Water-sheds/ Total	Additional Watershed Area Selected	Management Class Selected[a]					Class 5 as % of Selected Area	Class 5 as % of Region	Total BMA Area (ha)	BMA as % of Region
									Class 1 Area	Class 2 Area	Class 3 Area	Class 4 Area	Class 5 Area				
1a	Central	None	25%	WSI	0	55/55	100/482	348,898	79,968	15,132	107,848	66,767	79,183	22.7%	33.1%	348,898	21.0%
1b	South	None	25%	WSI	0	65/65	110/527	361,219	81,514	14,256	127,024	60,135	78,290	21.7%	30.5%	361,219	22.7%
2a	North	C1	10%	WSI	43,572	54/59	55/776	189,138	866	15,319	36,119	58,864	77,970	41.2%	47.9%	231,844	10.8%
2b	North	C1	10%	WSI+AD	43,572	54/59	53/776	202,456	349	17,540	33,458	53,116	97,993	48.4%	47.9%	246,028	11.4%
2c	North	C1	25%	WSI	43,572	56/59	123/776	489,326	1,190	38,532	82,363	142,088	225,153	46.0%	47.9%	531,708	24.7%
2d	Central	C1	10%	WSI	385,791	28/55	19/482	67,765	3,882	3,570	24,399	10,998	24,916	36.8%	33.1%	449,674	27.1%
2e	Central	C1	10%	WSI+AD	385,791	28/55	18/482	74,811	3,757	2,577	30,798	5,810	31,869	42.6%	33.1%	460,602	27.8%
2f	Central	C1	10%	WSI+SA	385,971	28/55	18/482	67,298	3,741	3,514	25,103	7,878	27,062	40.2%	33.1%	453,269	27.3%
2g	Central	C1	25%	WSI	385,791	35/55	42/482	179,428	3,367	9,585	49,791	37,457	79,228	44.2%	33.1%	561,852	33.9%
2h	South	C1	10%	WSI	403,500	30/65	23/527	71,785	98	2,963	32,175	10,295	26,254	36.6%	30.5%	475,187	29.9%
2i	South	C1	10%	WSI+AD	403,500	30/65	22/527	83,268	805	2,513	33,676	10,194	36,080	43.3%	30.5%	485,963	30.6%
2j	South	C1	10%	WSI+SA	403,500	30/65	20/527	79,154	805	2,366	34,162	9,698	32,123	40.6%	30.5%	481,849	30.3%
2k	South	C1	25%	WSI	403,500	47/65	56/527	195,886	852	5,284	82,730	24,446	82,574	42.2%	30.5%	598,534	37.7%
2l—Super-plan	North	C1	10%	WSI	43,572	54/59	29/251	240,328	837	17,692	46,578	69,319	104,955	43.7%	47.9%	282,116	13.1%
3a	North	C1+C2	10%	WSI	212,456	36/59	25/776	87,461	0	445	15,736	17,652	54,073	61.8%	47.9%	299,917	14.0%
3b	North	C1+C2	25%	WSI	212,456	50/59	86/776	350,999	107	3,659	64,281	87,786	198,932	56.7%	47.9%	563,455	26.2%
3c	Central	C1+C2	10%	WSI	441,484	21/55	15/482	50,818	2,614	1,629	21,000	6,182	23,636	46.5%	33.1%	492,302	29.7%
3d	Central	C1+C2	25%	WSI	441,484	32/55	38/482	154,009	2,740	3,737	42,359	25,601	76,962	50.0%	33.1%	586,406	35.3%
3e	South	C1+C2	10%	WSI	461,789	24/65	15/527	61,451	805	4	18,218	5,943	35,545	57.8%	30.5%	521,495	32.8%
3f	South	C1+C2	25%	WSI	461,789	41/65	47/527	163,167	1,392	670	60,727	16,478	83,750	51.3%	30.5%	622,744	39.2%
4	North	C1+AL	10%	WSI	335,036	36/59	25/776	84,768	0	4,569	10,650	14,135	55,414	65.4%	47.9%	419,804	19.5%
5—pub only	North	C1	10%	WSI	43,572	54/59	204/776	706,426	829	24,630	99,620	102,117	470,390	66.6%	47.9%	740,329	34.4%
6—verte-brates	North	C1	10%	WSI	43,572	300/375	50/776	175,100	94	8,019	28,470	65,432	73,085	41.7%	47.9%	218,672	10.2%

[a]The management classes are:
Class 1: Public or private land formally designated for conservation of native biodiversity.
Class 2: national forest land that is generally managed for its natural values but is not formally designated for conservation of native biodiversity.
Class 3: public land that is generally managed for its natural values, is treated in existing management plans as unsuitable for timber harvest, and may be grazed.
Class 4: Other public lands not included in Classes 1 through 3, mainly multiple-use federal lands.
Class 5: private lands other than those in Class 1.

Errata

December 19, 1996

Revised Figure 58.3, Volume II, Chapter 58, page 1510



Calwater planning watersheds to Calwater Superplanning watersheds (roughly a factor of three times larger).

Given a starting BMA system, this class of models begins with fewer underrepresented types and with smaller areal requirements than alternative 1. The model favors locating additional BMAs on public lands in watersheds with lower population density, road density, and fragmentation of public lands. The 10% and 25% target levels are arbitrary but in our view span the range from a relatively modest to a substantial allocation of lands to BMA status. Model variations 1) and 2) account for other SNEP biodiversity objectives and were run to evaluate the degree to which the objective of representing plant communities in BMAs can be met within areas identified by other SNEP scientists as of special biological significance. Model variation 3) tests the sensitivity of the result to the size of the planning unit, and provides a "large reserve" solution for comparison with the smaller watershed approach.

In the northern region, starting with Class 1 lands, 54 of 59 community types do not meet the 10% target for representation on BMA lands (figure 58.4; table 58.1, Alternative 2a). The 10% solution requires 55 watersheds and a total area that is roughly three-fourths the size of Yosemite National Park. This large areal requirement reflects the small amount of Class 1 lands in the northern region. Selected watersheds exhibit some clustering in the Plumas National Forest near Sierra Valley, in the Tahoe National Forest north of Highway 49, and on private lands in eastern Calaveras County. Despite weighting towards public lands, 41% of the selected BMA area falls on private lands, in order to capture foothill woodland, shrubland, grassland and meadow community types that are almost entirely in private ownership (Davis and Stoms 1996). Only 15,319 ha (18.6%) of the final BMA solution occurs on administratively withdrawn national forest lands.

Figure 58.5 indicates how the management profiles of individual plant community types in the northern region would change under Alternative 2a. Notice that 40% representation is exceeded for 4/59 types, and 25% representation is met or exceeded for 15/59 types. This "excess coverage" is an effect of selecting whole watersheds for BMAs, and applies especially to rare or widely scattered community types. For instance, the bar marked "KP" with nearly 50% representation indicates Knobcone Pine Forest, which occupies only 5 km^2 in the northern region. This is an indirect, and from a conservation perspective some might consider desirable, effect of the model: it tends to be most efficient for widespread types, and tends to provide excess coverage for rare or restricted types.

In assessing aquatic biodiversity in the Sierra Nevada, Moyle (1996a, 1996b; Moyle and Randall 1996; Moyle et al. 1996) identified forty-two watersheds that had unusually high value because they were rich in native aquatic vertebrate species and communities and/or contained particularly rare or unusual biotic elements. He referred to these watersheds as Aquatic Diversity Management Areas (ADMAs) and recommended that they be managed for their natural values. Solving the BMAS model with selection weighted towards ADMAs results in a large change in selected watersheds so that 36 of 53 occur in these larger basins that are of special interest in terms of aquatic biodiversity, notably the Cosumnes River Basin and the Middle Fork of the Feather River Basin. There is only a modest change in area (figure 58.4; table 58.1, Alternative 2b). This indicates that there is a good deal of flexibility in selecting BMAs to represent plant community types in this region, especially among publicly owned watersheds where WSI values do not vary greatly from one watershed to the next. Note however that, because ADMAs include private lands, a higher fraction of the solution occurs on private lands.

When the target representation level is raised from 10% to 25%, area requirements for the northern region increase by a factor of 2.56 to cover 56 community types (table 58.1, Alternative 2c). A slightly larger fraction of the solution must come from private lands (46% vs. 41%). The solution, which is comparable to solutions for the central and southern regions under Alternative 1, appears very efficient in the sense that it only requires 24.7% of the total region.

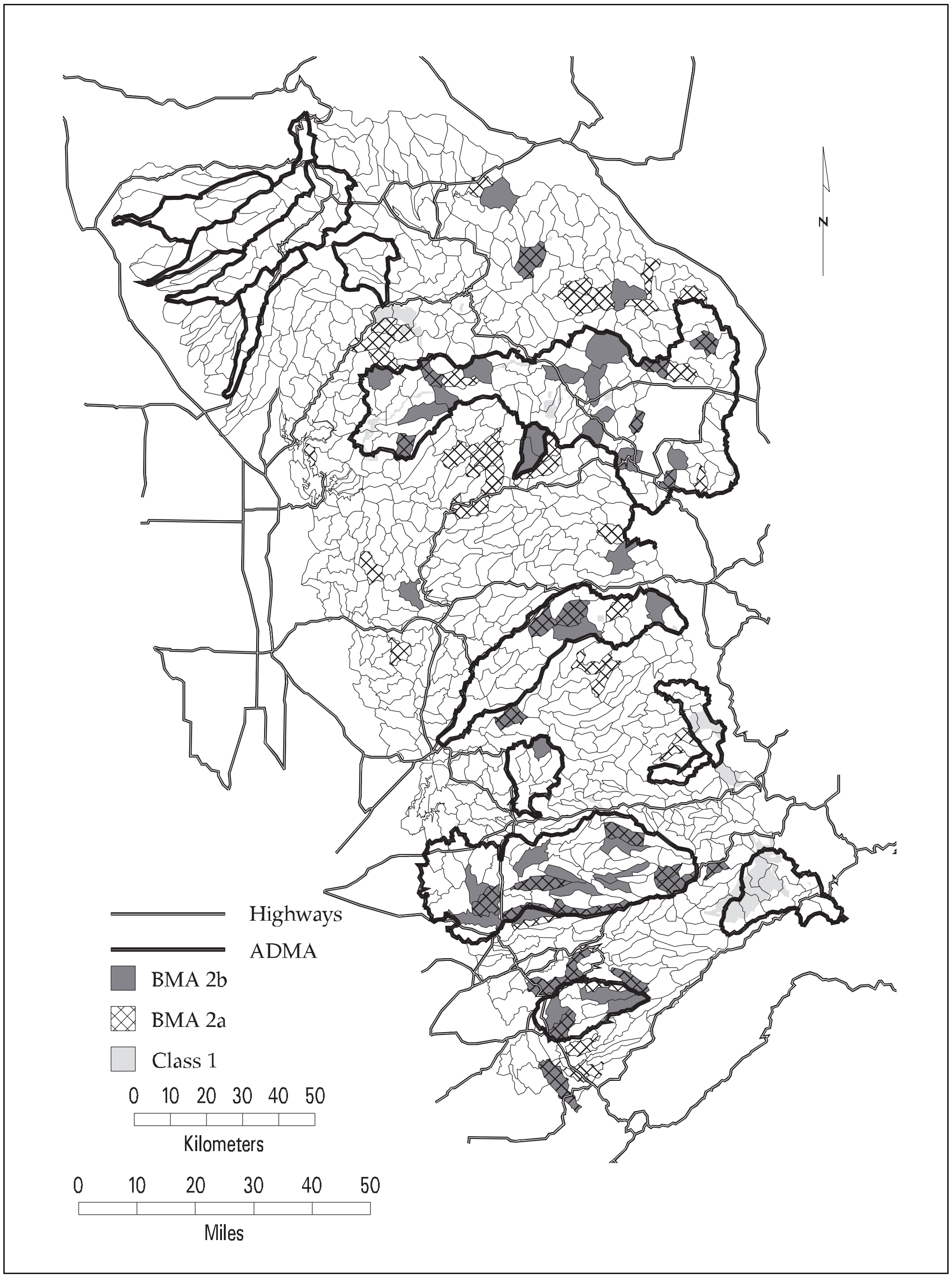
A very different set of solutions is obtained for the central and southern regions (Alternatives 2d through 2k). Because the national parks form a large starting BMA system, fewer plant community types are underrepresented. For example, with a 10% target only 28 of 55 communities are underrepresented in the central region (table 58.1, Alternative 2d), and 30 of 65 communities are underrepresented in the south (Alternative 2h). BMA systems to meet a 10% target require from 27% to 31% of the region. The large "excess" in BMA lands at this target level is due to the fact that a large portion of the distribution of many middle and higher elevation plant community types already falls on Class 1 lands (Davis and Stoms 1996).

The fraction of the solution coming from private lands is very consistent for the different variations on Alternative 2 in these regions (37-44%), and, unlike the northern region, is consistently higher than the private fraction of the total region (33.1% of the central region and 30.5% of the southern region). This reflects the fact that a disproportionate share of the types requiring additional acreage occur largely on private lands.

As in the northern region, the BMA solutions weighted towards ADMAs (Alternatives 2e and 2i) require slightly more land than those weighted only by WSI (table 58.1; figure 58.6). However, the BMA solution for plant communities is not as flexible as that for the northern region. In the central region, only 7/18 of the selected watersheds actually fall within ADMAs, notably within the lower Merced River Basin. Furthermore, 10/18 watersheds in Alternative 2a are selected in both the WSI-weighted and ADMA-weighted models. This is because the ADMAs for the central region are mainly middle and high elevation drainages that contain plant community types that are already well represented. The situation is even

FIGURE 58.4

Selected watersheds in the northern region for Alternatives 2a (hatched areas) and 2b (shaded areas). Both alternatives start with Class 1 lands, provide at least 10% representation, and account for both area and Watershed Suitability Index (WSI). Model 2b is weighted towards Aquatic Diversity Management Areas (ADMAs), which are outlined with heavy lines.



more extreme in the southern region, where only 6/23 selected watersheds fall within ADMAs (figure 58.6).

Millar et al. (1996) identified Significant Ecological Areas (SEAs) in the Sierra Nevada that were distinguished by containing unusually rare, diverse, or representative components of native biodiversity. Solving the BMAS model for the central and southern regions with selection weighted towards SEAs results in a somewhat different set of selected watersheds (figure 58.7, Alternatives 2f and 2j). The degree of colocation of BMAs and SEAs is limited, however, because SEAs were only mapped on public lands, whereas many of the underrepresented types occur mainly on private lands.

Meeting the 25% target requires 561,852 ha and 598,534 ha in the central and southern regions, respectively (table 58.1, Alternatives 2g and 2k). The additional area required increases by a factor of roughly 2.6 compared to the 10% solution, while the total area in BMA status only increases by a factor of 1.25. Unlike the northern region, the area requirement increases only by a factor of 1.25 because of the excess coverage at 10%.

We examined the effect of increasing the size of BMAs by

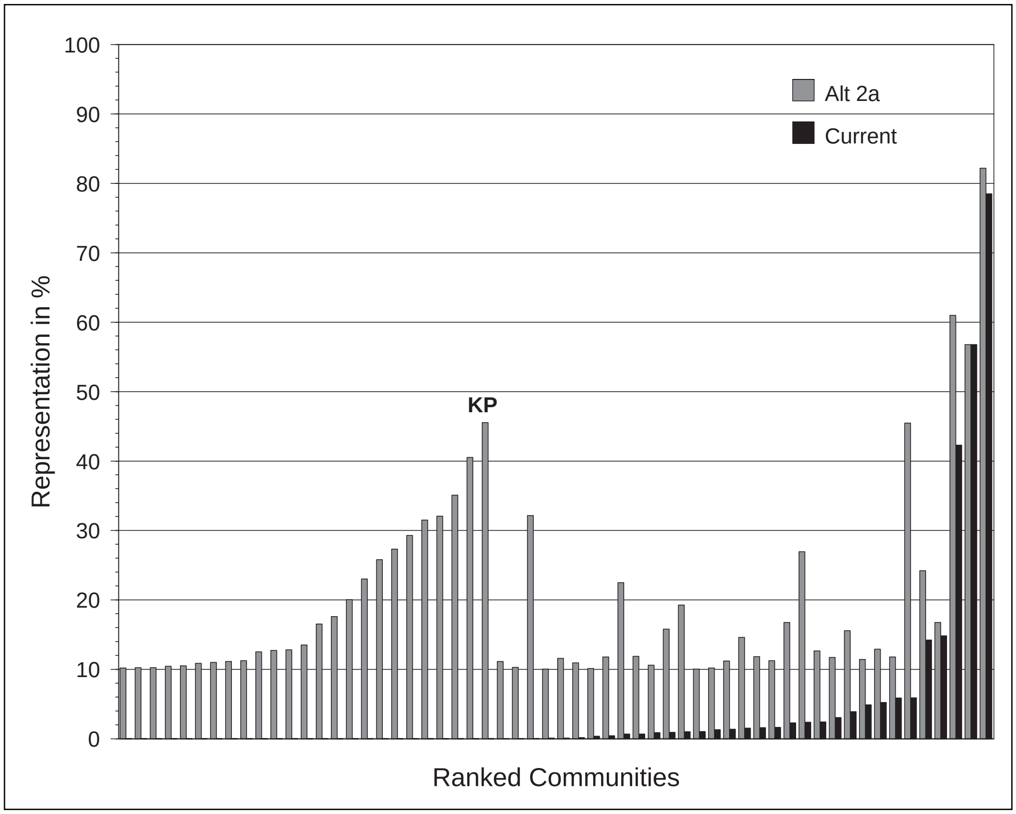


FIGURE 58.5

Representation of 59 plant community types in the northern region in existing BMAs (black bars) and in the BMAS solution to Alternative 2a (gray bars). Community types are ranked according to current representation on Class 1 lands. Ranks 1 through 25 have percentages close to zero, so only the BMAS solution is visible on the chart. "KP" indicates the Knobcone Pine Forest community, which occupies only 5 km^2 of the region.

using Calwater "superplanning watersheds" instead of planning watersheds as units of analysis. These superplanning watersheds are aggregates of the Calwater planning watersheds, which are the lowest level in the Calwater hierarchy. The average size of the superplanning watersheds is 8,565 ha (21,156 ac) or three times that of the average planning watershed.

The BMAS solution for the northern region changes considerably when superplanning watersheds are used as candidate BMA sites instead of the smaller planning watersheds. Twenty-nine of 251 watersheds were selected to meet the 10% target level (figure 58.8). Thus the number of new BMAs is reduced from 55 to 29 when the size of the sites is increased three-fold. While the spatial distribution of the two sets of sites is similar, only 19 of 55 planning watersheds selected in Alternative 2a are also selected in Alternative 2l. As expected, the area requirement increases as the size of the planning site increases. In this case, the total area increased by 51,190 ha (126,439 ac). The fraction of the solution from private lands increases slightly from 41.2% to 43.7%.

Alternative 3

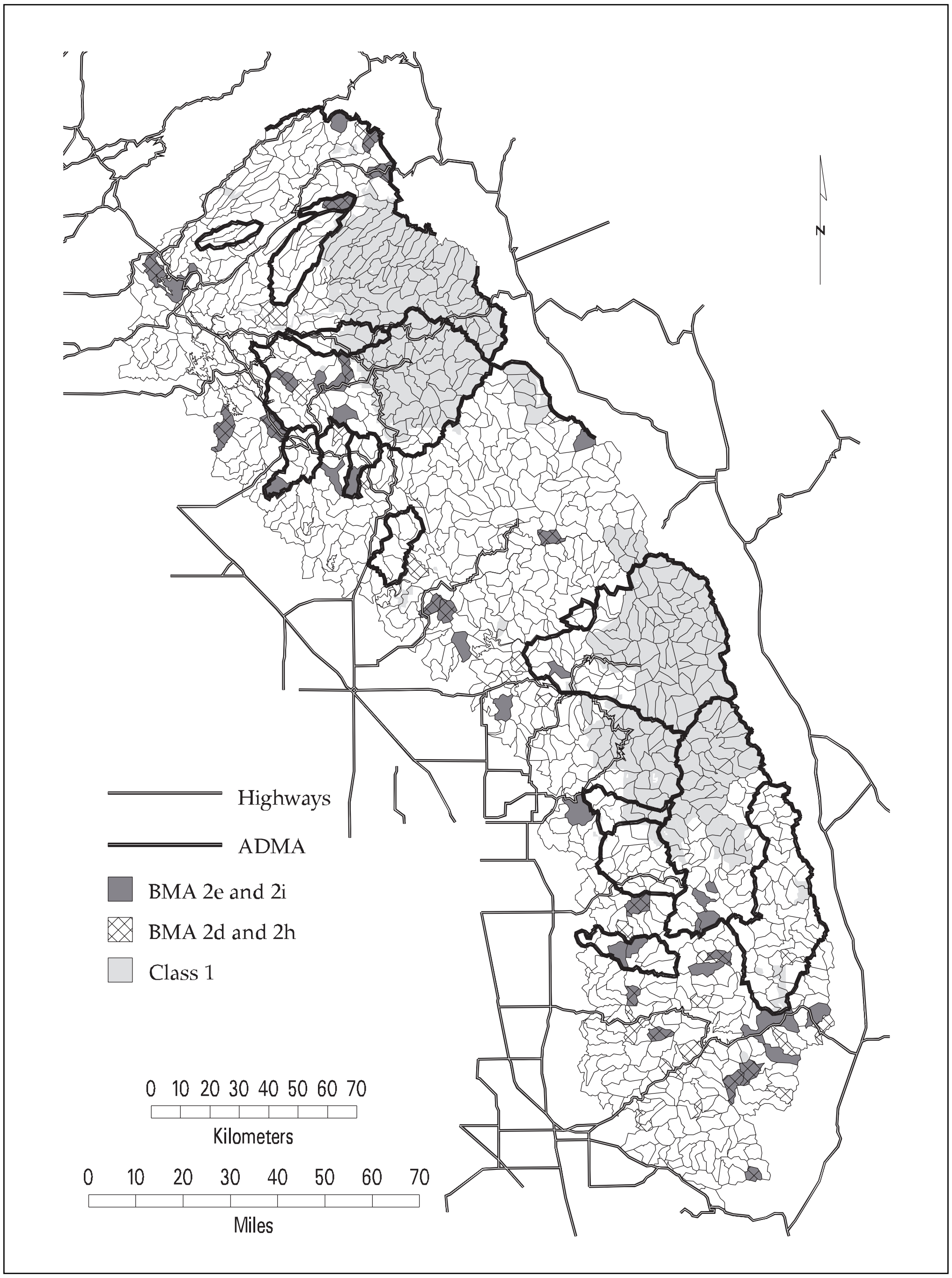
Represent all plant community types in BMAs, but treat GAP Class 1 and Class 2 lands (forest service lands that are administratively withdrawn from timber harvest and grazing based on current allotment boundaries and mapped land suitability classes) as the starting BMA system. Find additional area to meet target goals of 10% and 25%, balancing the objectives of minimal area and WSI.

The gap analysis of the Sierra Nevada (Davis and Stoms 1996) showed that lower to mid-elevation forest community types are not well represented in Class 1 lands, but that for a variety of reasons related to environmental and biological concerns, extensive tracts of these forest types are classified in current forest plans as unsuitable for intensive timber harvest and also fall outside of grazing allotments. These conservation lands are referred to as Class 2 lands by Davis and Stoms (1996) and in appendix 58.1. We considered one class of model alternatives in which these Class 2 lands were included with Class 1 lands as a starting BMA system for the region. This reduces considerably the number of underrepresented types and area requirements, and places greater emphasis in terms of area requirements on non-forest community types, especially on private lands at lowest elevations.

Starting with Class 1 and Class 2 lands in the northern region, 36/59 types do not meet the 10% target, compared to 54/59 when starting with only Class 1 lands (table 58.1, Alternative 3a). The solution requires 87,461 ha in 25/776 watersheds, which is less than half as much area as Alternative 2a. However, 62% of the area is on private lands, and the overall BMA system requires nearly 70,000 ha more than the solution that begins with Class 1 lands only. This indicates the fact that Class 2 lands in this region provide excess coverage

FIGURE 58.6

Selected watersheds in the central and southern regions for Alternatives 2d and 2h (hatched areas), and for Alternatives 2e and 2i (shaded areas). All of the alternatives start with Class 1 lands, provide at least 10% representation, and attempt to minimize both area and Watershed Suitability Index (WSI). Models 2e and 2i are weighted towards Aquatic Diversity Management Areas (ADMAs), which are outlined with heavy lines.



for a few community types, notably middle elevation forest types, but provide little or no representation for many other community types, especially hardwood forest, foothill woodland, and chaparral types. The solution becomes more efficient as the target level is raised (Alternative 3b). Thus the area required to meet a 25% target, while still predominantly falling on private lands, is only 1.5% more of the region than the model that starts with Class 1 lands only.

There is not much Class 2 land in the central and southern regions, so that the solutions for Alternative 3 are closer to those for Alternative 2 than in the northern region. In the central region (Alternative 3c), starting with Class 1 and Class 2 lands and a 10% target, the number of underrepresented types drops from 28/55 to 21/55, but the final area in BMA lands increases from 449,674 to 491,979, and an increasing fraction of new BMA land is located on private lands. The trend is similar for the 25% target (Alternative 3d). These findings reflect the fact that most Class 2 lands in the central region support plant community types that are already well represented in the national parks. Including Class 2 lands in the

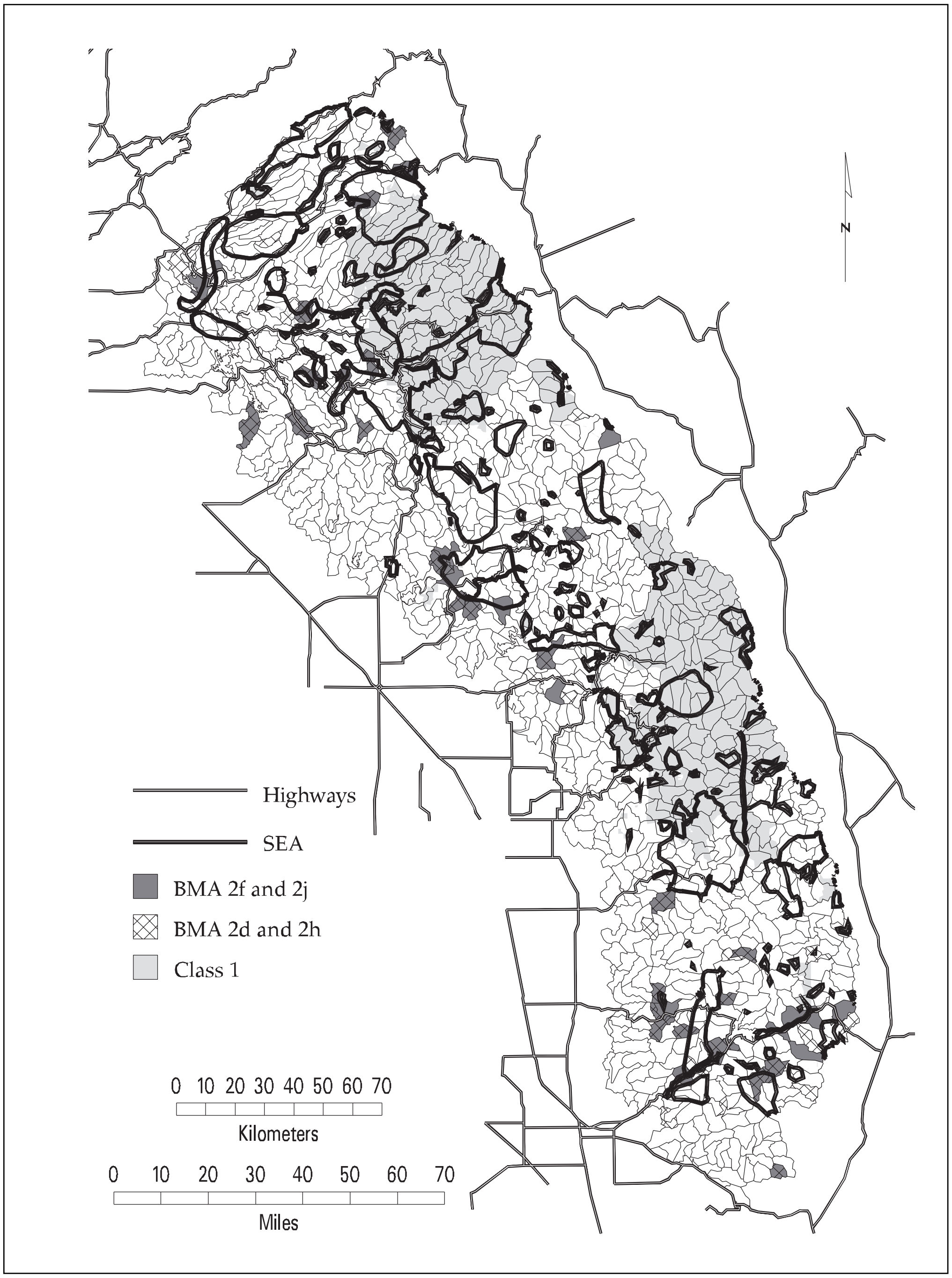


FIGURE 58.7

Selected watersheds in the central and southern region for Alternatives 2d and 2h (hatched areas), and for 2f and 2j (shaded areas). All of the alternatives start with Class 1 lands, provide at least 10% representation, and minimize area and Watershed Suitability Index (WSI). Models 2f and 2j are weighted towards Significant Ecological Areas (Millar et al. 1996).

starting BMA system for the southern region reduces area requirements slightly (Alternatives 3e and 3f). Once again, however, including Class 2 lands has little effect on the amount of private land in the final solutions. In fact the contribution from private lands actually increases in solutions to Alternative 3 for the central and southern regions.

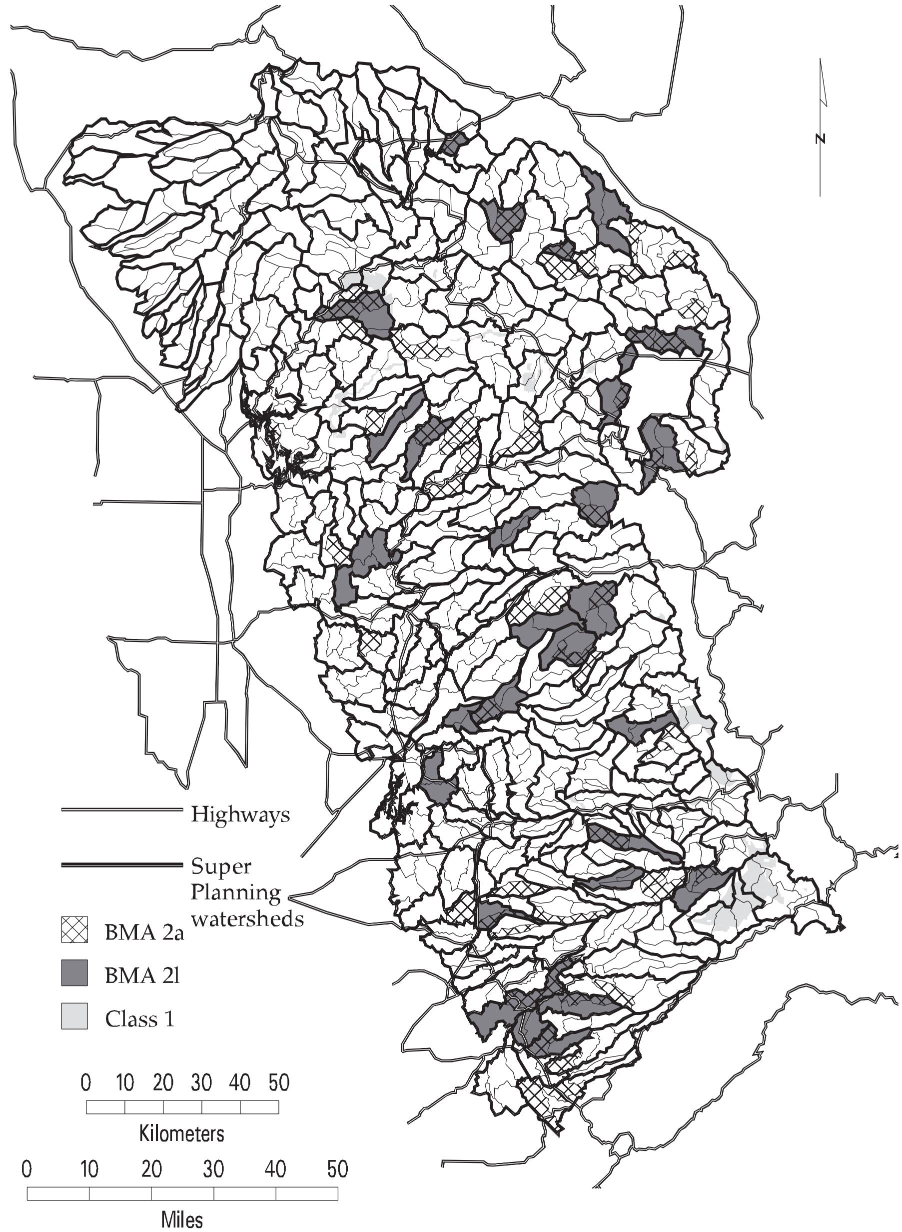
Alternative 4

Represent all plant community types in BMAs, but treat GAP Class 1 and ALSE lands as the starting BMA system. Find additional area to meet target goals of 10% and 25%, balancing the objectives of minimal area and WSI.

In their assessment of late seral/old growth forests of the Sierra Nevada, Franklin and Fites-Kaufmann (1996) delineated Areas of Late Successional Emphasis (ALSEs), which were large landscape units on the public lands that contained

FIGURE 58.8

Selected watersheds in the northern region for Alternatives 2a (hatched areas) and 2l (shaded areas). Both alternatives start with Class 1 lands, provide at least 10% representation, and account for both area and Watershed Suitability Index (WSI). The BMA sites for Model 2a are planning watersheds (thin lines), and for Model 2l are superplanning watersheds (heavy lines).



one or more extensive tracts of late seral/old growth forests. One strategy that they considered for conserving late seral/old growth forests in the Sierra Nevada was active management of designated ALSEs for late seral conditions.

This BMAS alternative tests the effect of adding ALSE lands to a starting BMA system that also includes Class 1 lands. (We should note that ALSE boundaries were slightly modified subsequent to our analysis, which was based on draft maps as of 1 Oct, 1995.) Defining ALSEs as BMAs presumes that they could also be managed to maintain non-forest plant communities occurring in those areas, as well as to maintain the compositional and structural components of forest types that would be the main focus of management practices.

Only the northern region was analyzed. The total area mapped as ALSEs in this region is 291,464 ha (13.5% of the study region) compared to 43,572 ha in Class 1 lands. Given a 10% target, the ALSEs provide excess representation for selected forest types, notably Sierran mixed conifer and Red fir community types. Because ALSEs were not aimed at woodland, shrubland and herbaceous types, the coverage of these

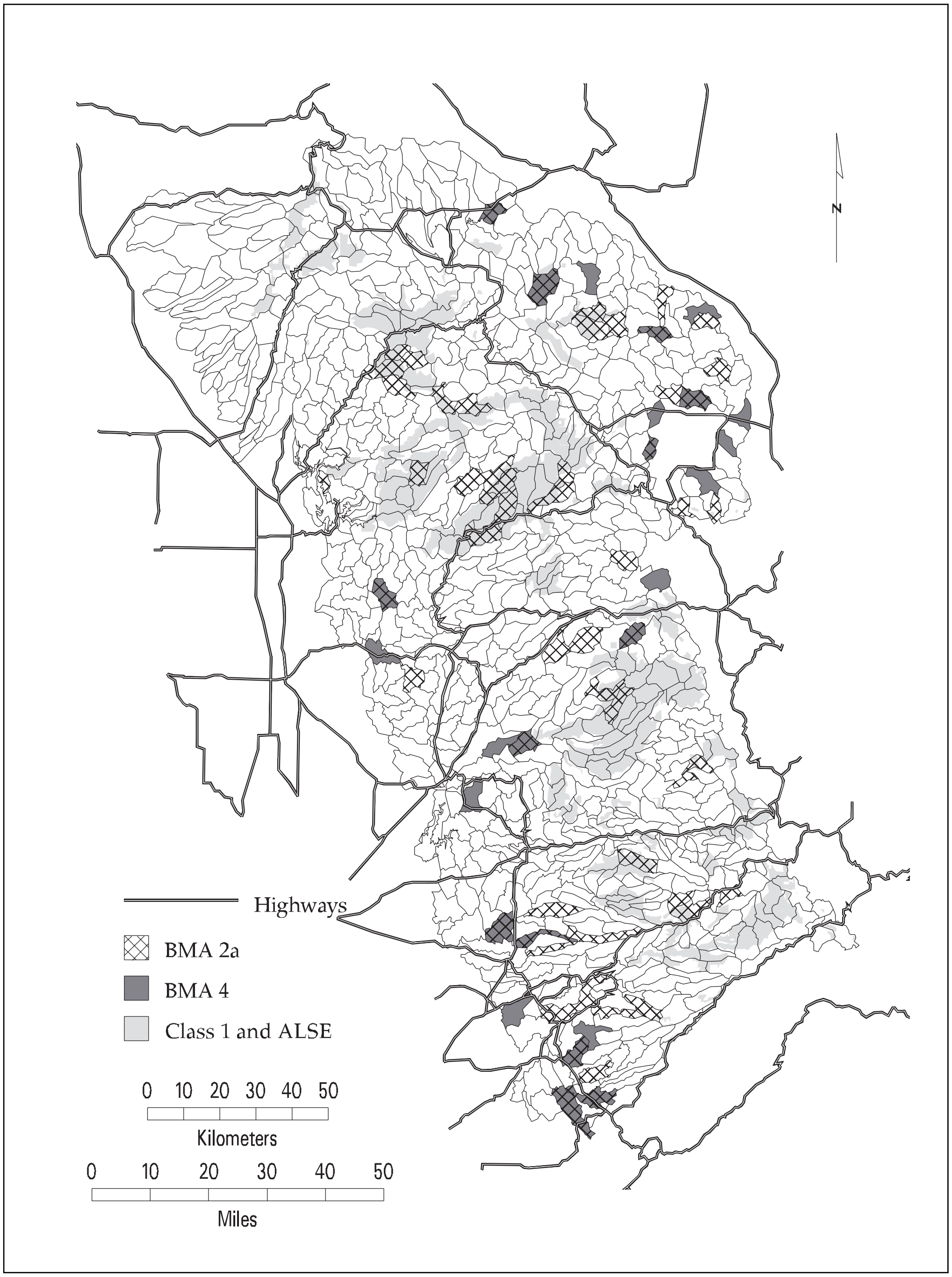


FIGURE 58.9

Selected watersheds (dark areas) in the northern region for Alternative 4. This alternative starts with Class 1 lands and ALSEs (light shaded areas), provides at least 10% representation, and accounts for both Watershed Suitability Index (WSI) and area. Selected watersheds for Alternative 2a (hatched areas) are shown for comparison.

types is largely unaffected by adding ALSEs to the starting BMA system. Thus the total area required for a 10% target is greater by a factor of 1.8 for this Alternative (figure 58.9; table 58.1, Alternative 4a) than the area of the solution that starts with only Class 1 lands (Alternative 2a). The selected watersheds fall almost entirely at lower elevation in the northeastern and southwestern portions of the region. Two-thirds of the additional area is selected from private lands.

Alternative 5

Represent all plant community types in BMAs, treating GAP Class 1 areas as the starting BMA system, but with the added constraint that the solution be comprised entirely of public lands. Find additional area to meet target goals of 10%, or as close to 10% as possible, for all plant community types, balancing the objectives of minimal area and WSI.

This alternative aims to build a representative BMA system from the public land base. We know from the gap analy-

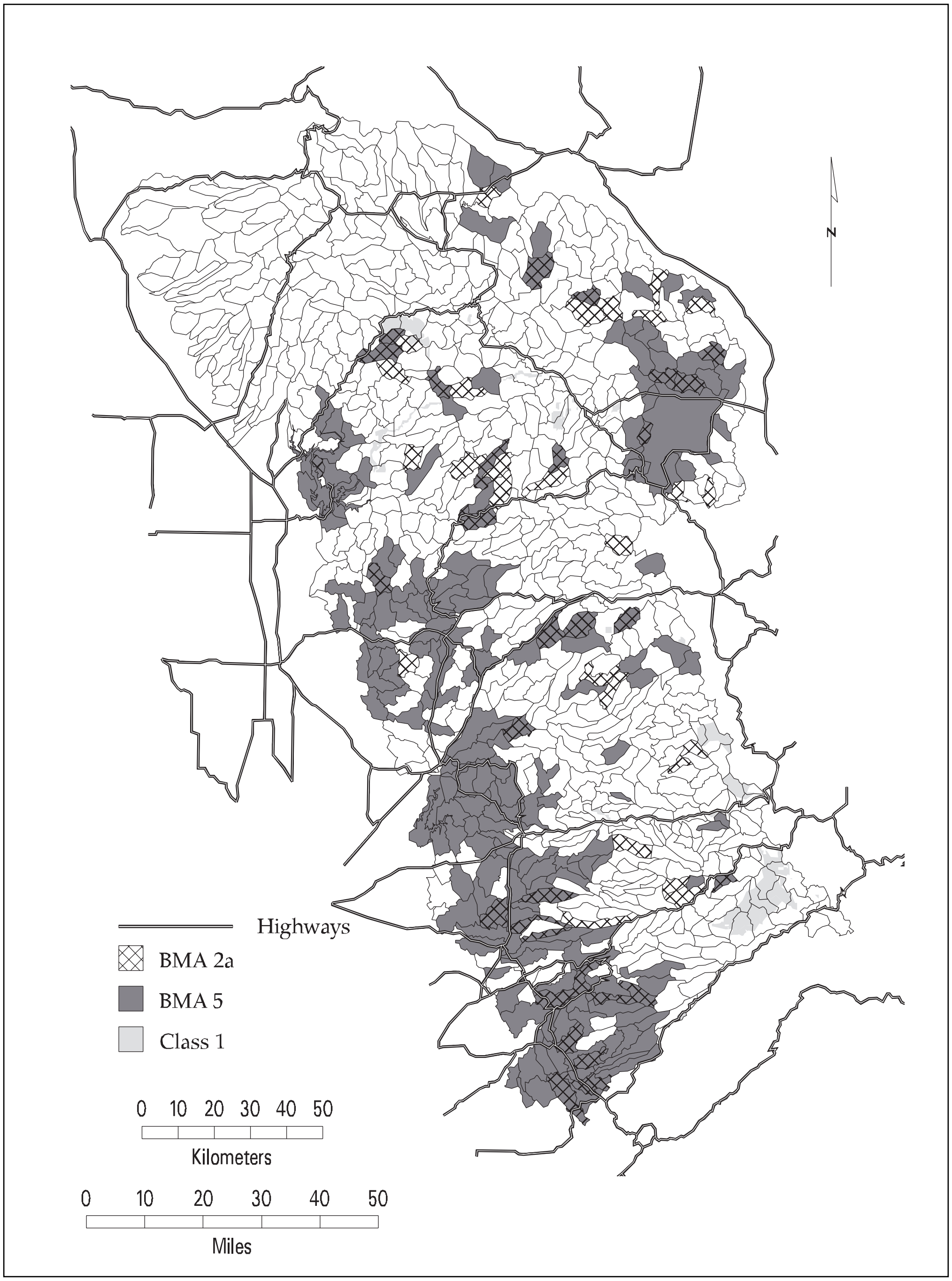


FIGURE 58.10

Selected watersheds (shaded areas) in the northern region for Alternative 5. This alternative starts with Class 1 lands, provides 10% representation or as close to that level as possible, accounts for both area and Watershed Suitability Index (WSI), but only public lands contribute toward representation targets. The solution when private lands are eligible (Alternative 2a) is shown as hatched areas.

sis data that several foothill types have less than 10% of their distribution on public lands. This model effectively allocates all of the public land in these types to BMAs, irrespective of the suitability of the watersheds, still minimizing area and WSI for the entire set of BMAs. Although private lands do not contribute towards representation of plant communities in this alternative, watersheds with private lands can still be selected if any public lands occurs within them.

This alternative results in selecting a very large number of watersheds at lower elevations on both western and north-eastern sides of the northern region in order to accumulate public lands with underrepresented types (figure 58.10). Over 1/3 of the land area in the region would have to be allocated to BMAs. This result certainly highlights the extremes that would be required in order to focus Sierran biodiversity management and conservation entirely on public lands if entire planning watersheds were the basic management units.

Alternative 6

Represent all vertebrates in BMAs, treating GAP Class 1 lands as the starting BMA system. Based on equation 3) in appendix 58.1, find additional acreage to meet a target goal of 10%.

This alternative was developed to test how much the BMA solution might change if a different measure of biodiversity were applied. We selected terrestrial vertebrates because their distributions are better known and more readily modeled than most other organisms. The distributions used in this analysis were produced using the gap analysis method as described by Hollander et al. (1994). The method entails intersecting coarse range maps (presence or absence in 7.5-minute USGS quadrangles) with maps of suitable habitats. Habitat maps were derived by re-classifying the vegetation data in the gap analysis database into the habitat types used in the Wildlife Habitat Relationships (WHR) system (Mayer and Laudenslayer 1988). WHR rates the suitability of general habitat types as well as structural classes within habitat types for breeding, feeding, and resting activities of all native vertebrates.

We applied a regionalized version of WHR that was modified from the original version by David Sterner and David Graber to apply more specifically to the Sierra Nevada Region. Our predicted vertebrate distributions were based on habitat type, except for forest types where we also subdivided the habitat into general size classes. Structural information was obtained from USFS timber strata maps, SNEP's Late seral/Old growth forest database, or in the absence of other information, by interpretation of recent air photos. (As it turned out, at the scale of the GAP vegetation map, there was very little difference between distributions predicted with or without forest structural information, so we will forego a more detailed discussion of this aspect of the modeling.) A species was predicted to be present if the mapped habitat was within the range of the species and of at least moderate suitability for breeding.

The main differences between using plant community types and vertebrate distributions predicted from habitat types derived from the vegetation map are 1) the use of vertebrate range limits (thus different species may occupy the same habitat type but in different parts of the Sierra), and, 2) the use of WHR habitat types, which are generally aggregates of the plant community types (especially the shrubland types).

Before reporting on the BMAS model results for vertebrates, it is also useful to examine how vertebrates are represented in the model results for plant community types, i.e. a "sweep analysis." To do this we overlaid the hypothetical BMAS system from Alternative 2a on the vertebrate distributions and tallied the percent of each species' distribution that fell within existing Class 1 or new BMAS areas. Of 375 native vertebrates predicted to occur in the northern region, 302 species were represented at the 10% target level or higher, and all species were represented over at least 7.5% of their mapped distribution. The number of species represented compared to the total in the group is 168/216 for birds, 85/97 for mammals, 19/26 for amphibians, and 30/36 for reptiles.

The BMAS solution to represent 300 vertebrates in the northern region that do not meet a target level of 10% requires 218,672 ha, almost exactly the same area as the solution for plant communities (Alternative 6 versus Alternative 2a). However, the spatial pattern of the vertebrate solution overlaps only slightly with the plant community solution (figure 58.11). Only 12 watersheds are common to both solutions, and there appears to be more grouping of the watersheds selected for vertebrates, for example up canyons and across elevational gradients. Although there are many more vertebrates than plant communities, the predicted distributions of most vertebrates are broader than the distributions of plant community types. Thus watershed selection for vertebrates is driven more strongly by WSI than it is for plant community types.

DISCUSSION

Weaknesses and Limitations of the Approach

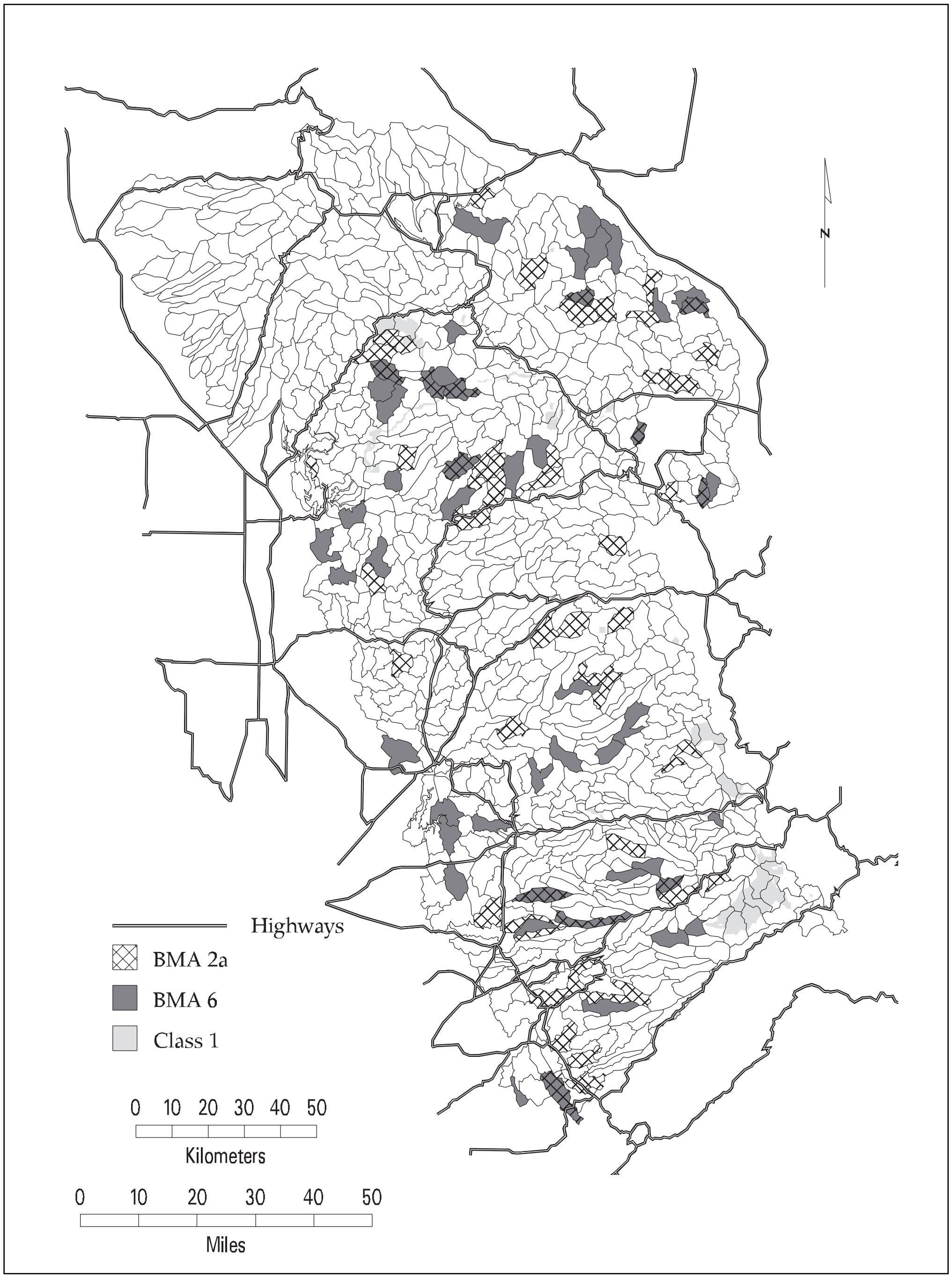
Our stated objectives for this scenario were to measure some likely dimensions of plausible BMA systems for the Sierra Nevada. To do this we formulated and applied an optimization model to produce BMA systems that represent all biodiversity elements in BMA sites using as little area as possible given the additional objective of selecting the most suitable sites. Following the logic of the gap analysis assessment, we have simply identified which types might be vulnerable given the geography of permitted land use in the region, rather than actual land use. We have not attempted to project possible future trends in regional biodiversity under existing or alternative land management systems.

Most previous applications of siting models to conservation planning have focused on designing a system to efficiently represent biodiversity and have not accounted for site suitability. Margules et al. (1991) argued that biological conservation should aim for sites of the highest biological importance, irrespective of other social or economic considerations. This argument may be compelling when the sites are very dissimilar from one another, for instance when the planning regions span biogeographic regions (e.g., national surveys) and when the planning sites are relatively large (e.g., hundreds of thousands of hectares). Our approach is tailored towards more regional or local scales where many sites may have very similar biota and differ mainly in their suitability for conservation management. The data that we used were tailored to a regional analysis and would not be appropriate for more detailed, local applications.

A BMAS solution that is optimal for minimizing area and WSI may not be optimal with respect to other design criteria, for example, political feasibility or economic cost. The model is useful for establishing minimal area requirements and in

FIGURE 58.11

Selected watersheds in the northern region for Alternatives 2a (hatched areas) and 6 (shaded areas). Both alternatives start with Class 1 lands, provide at least 10% representation, and account for both area and WSI. Alternative 2a represents plant community types, while Alternative 6 represents all terrestrial vertebrate species.



highlighting some areas that would appear to be good sites for a regional system. However, it does not consider many local political, economic, or biotic perspectives.

The BMAS model is relatively simple and straightforward, but it still requires that the user specify a weight for the area term and for each variable used to measure suitability, as well as a target level for each biodiversity element. Solutions could be very sensitive to weights applied to each term in the model, although there appears to be only modest sensitivity in this specific application. For example, the analysis of trade-offs between area and WSI indicates that area requirements might differ by only 20-30% between the model extremes where the weight for WSI is set to zero and those where the weight for area is set to zero.

Obviously, solutions will vary considerably depending on how one sets the target levels for each biodiversity element. Setting credible target levels is the most difficult aspect of the BMAS model. Given that the ultimate purpose of a BMA system is to contribute to maintaining regional biodiversity, one should probably relate a change in the level of an element's representation in a BMA system to a change in the likelihood of maintaining that element in the region over some specified time period. We have not attempted to do this kind of viability analysis for several reasons. First, the concept of viability is more readily applied to single elements such as a species or a specific component of an ecosystem (e.g., forest structure or chaparral fire return interval) than it is to a whole assemblage of species or ecosystem types. Secondly, the relative merits of one target level versus another could only be measured based on modeling ecological processes over both BMA and non-BMA lands. Such modeling could be extremely informative but was beyond the scope of our analysis. Thirdly, we felt that a viability analysis would focus too much attention on the specific sets of watersheds that comprised the model solutions.

We used plant community types and wildlife habitat types as our elements of biodiversity, but other mapped variables could also be applied, for example, an alternative vegetation classification system, physical environmental types, or species localities. Similarly, other criteria could be used to measure suitability. Based on results that we obtained using different biodiversity and suitability measures, site selection could be very sensitive to the choice of measures, however the total area selected and general distribution of the solution among biotic zones will remain fairly constant.

We did not explore how sensitive our results could be to errors in the mapping of plant community types or predicted vertebrate distributions. Davis and Stoms (1996) discuss some of the sources of error in the vegetation map, but to date no quantitative map accuracy analysis has been conducted. We expect that map errors affect the set of watersheds selected in the different model alternatives more than the total area or general spatial pattern of the model solutions. We also expect the errors to be most significant for very rare or localized vegetation types whose distribution was not as reliably mapped at the coarse resolution used for SNEP's gap analysis.

A more sophisticated siting model would also account for the neighboring watersheds in the site selection process. For example, it may be desirable to cluster BMAs into larger blocks. Also, one may want to adjust each watershed's suitability to incorporate the suitability of adjacent watersheds. The latter could be readily accomplished. The former objective of spatial clustering is a more difficult problem that we are currently pursuing.

Our analysis is limited by the fact that we have treated input biotic and cultural factors as static when in fact they can be very dynamic, even at the relatively coarse spatial scale of the Calwater planning watersheds. Any local change in plant community distributions or in watershed suitability could lead to a different optimal configuration of BMAs in the region. Although beyond the scope of our analysis, it is certainly possible and desirable to incorporate expected changes in biological distributions and human activities into the model. Even accounting for such dynamics, however, does not address the more complex problem that implementing a system of BMAs would necessarily be a staged, locally adaptive process. That staging could also affect how optimal any particular solution was. These concerns should serve to reemphasize that the main value of the model is as a tool for ongoing analysis and evaluation of conservation strategies at the regional level.

Answers to Key Questions

Question 1

What is the minimal area required to represent all Sierran plant community types in BMAs? How does an "optimal" BMA system compare to the existing set of parks, wilderness areas and reserves in the region?

If one ignores current land ownership and management designations and sets out to represent biodiversity in a BMA system based on Calwater planning watersheds, an efficient system requires land in direct proportion to the target level, at least over the range of target levels examined in this study. In other words, it takes roughly 10% of the region to meet a 10% goal, and 25% of the region to meet a 25% goal. The pattern of selected watersheds is very different from the current distribution of parks and wilderness areas, which are concentrated at middle and high elevations in the central and southern portion of the range. An efficient BMA system to meet a 25% target for all community types would require only slightly more land than existing parks and reserves, but this system would require much more even dispersal of BMAs from north to south and across elevations and land ownerships than occurs in the existing situation.

Although Class 1 lands occupy 15% of the combined north, central and southern regions, only 5/59 plant community types exceed a 10% target level in the northern region. Starting with Class 1 lands has little effect in the northern region, where efficient BMA systems still require roughly 200,000 ha to represent all plant community types.

Despite their large size, Yosemite and Sequoia-Kings Canyon National Parks do not encompass the full suite of plant community types that occur in the central and southern Sierra. Roughly half of the native plant community types in these regions do not meet or exceed a 10% target. Meeting that target would require a minimum of roughly 150,000 ha of additional BMA land, 30% of which is currently privately owned. A similar proportion would come from Class 3 lands (mainly national forest lands in grazing allotments and outside of areas suitable for timber harvest).

Increasing the size of the BMA sites by a factor of three from planning watersheds to superplanning watersheds has a surprisingly large effect on the distribution and areal efficiency of the solution, for example, increasing the area for a 10% target by 27%. This illustrates both the sensitivity of the model results to the choice of planning sites and also the tradeoff between increased BMA size and decreasing efficiency for representing regionally dispersed elements of biodiversity.

Question 2

How does the location of BMAs relate to the distribution of areas of special interest that have been identified in other SNEP assessments and biodiversity strategies, in particular, Aquatic Diversity Management Areas, Significant Ecological Areas, and Areas of Late Successional Emphasis?

Solutions to the BMAS model show only a modest amount of overlap with other SNEP biodiversity strategies unless the model weights are set to favor ADMAs, SEAs, and ALSEs. In the northern region, the pattern of biodiversity provides sufficient flexibility to find solutions of roughly similar area that also favor these areas. For example, 37% of the BMA area in alternative 2a occurs within ADMAs, but this doubles to 76% when the suitability index was weighted for ADMAs. In the central and south regions, many ADMAs are located at higher elevations and on public lands and thus do not supply a representative set of plant community occurrences to draw from in meeting BMAS objectives. Thus the proportions of overlap of BMAs and ADMAs in the central and southern regions are only 38% and 21%, respectively, for models weighted towards ADMAs. Similarly, even when the suitability index is weighted to favor SEAs, the overlap of BMAs with SEAs is only 27% in the central and 16% in the southern region.

ALSEs were developed on public lands to conserve late seral forest structure, especially in the mixed conifer and red fir types. ALSEs are oriented towards forested environments and do not cover many other types. Including ALSEs to the base level of currently protected areas provides a very high level of representation for forest types, but the total area required nearly doubles. It should be noted that there are several ALSE alternatives and that they are hypothetical. We used only one alternative configuration for BMAS modeling.

Question 3

Can a representative BMA system be established on public lands only? If not, what area of private lands is required? How does the area requirement change if lands that are currently administratively withdrawn from grazing and timber harvest are classified as BMA lands?

Many community types do not occur on public lands, or are present in insufficient extent to be adequately represented on public lands alone. To represent as much of these types that is on public lands requires over 1/3 of the land in the region. In our model, we allocated entire planning watersheds when selecting BMAs, even if the public land containing a type needing additional representation was only a small portion of it. Therefore, a large amount of private land was swept into this solution even though it did not count toward biodiversity representation. Of course, it would be possible to allocate individual parcels of public land for biodiversity management with much less total area required, but this would violate our premise that larger, ecologically-based units make superior BMAs.

Including Class 2 lands has a significant effect in the north but much less effect on solutions in the central and southern regions, because most plant communities that are widespread on Class 2 lands in those regions are also well represented in the national parks. Therefore the amount of private land required to satisfy the representation targets remains quite similar to that of Alternative 2.

Question 4

How sensitive is the siting of BMAs to the way in which biodiversity is measured? Specifically, how do solutions to represent plant community types compare to solutions based on representing vertebrate species?

The predicted distributions of most vertebrates are well represented by the solution for plant communities. Even the vertebrate species not fully represented in alternative 2a were nearly so. There was, however, considerable sensitivity in terms of the sites that were chosen in Alternative 2a compared to Alternative 6. Because vertebrates tend to be more widespread than plant communities, i.e., they occur in more planning units, the vertebrate alternative was more driven by suitability factors than was the corresponding plant community alternative 2a.

Question 5

Do some general areas emerge from the analysis that appear especially well suited to serve as BMAs?

As stated above, our purpose in this exercise was not to identify the optimal sites for a Sierran BMA system. Rather, we have attempted to scope out the dimensions of the decision space through evaluation of a set of plausible alternatives. Nevertheless, certain geographic areas were consistently identified in the alternatives based on the biological, efficiency, and suitability criteria and therefore were less sensitive to model assumptions and objectives. In the northern region, these general areas include the lower elevations in Calaveras County and portions of the Cosumnes River basin, mid-elevations of Sierra County north of Highway 49, and parts of Plumas County east of Highway 89 and south of Highway 70. Frequently selected watersheds in the central region are scattered along Highway 49, particularly in Mariposa County. Few watersheds are needed from higher elevation zones because Yosemite National Park provides coverage for most conifer and subalpine community types. Likewise in the southern region, higher elevation communities are generally well represented in the National Parks. The areas of BMAs from the alternatives tend to concentrate along the South Fork of the Kern River to Walker Pass and along the Greenhorn Mountains. These watersheds warrant more detailed study in any biodiversity management strategy for the Sierra Nevada region.

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APPENDIX 58.1

The Biodiversity Management Areas Selection (BMAS) Model

Definitions and Units of analysis

Biodiversity element: physical or biological feature of an area that serves as a metric of biodiversity. In the analysis reported here the elements are plant community types as defined by Holland (1986). In a companion report, we described the distribution, ownership and management status of these community types in the Sierra Nevada (Davis and Stoms 1996).

Landscape: map unit (polygons) used to represent the spatial distribution of biodiversity elements. For this analysis we use the Gap Analysis database and map of plant community types. Each map unit contains information on the occurrence and extent of up to three plant community types.

Biodiversity Management Area: an area with an active ecosystem management plan in operation whose purpose is to contribute to regional maintenance of native genetic, species and community levels of biodiversity and the processes that maintain that biodiversity. Generally a BMA will be comprised of several *landscapes*. In this analysis we considered four different starting points for a BMA system for the Sierra Nevada: 1) ignore current land allocation and assume no existing BMAs, 2) public or private lands that are formally designated for conservation of native biodiversity and within which economic activities such as development, grazing and timber harvest are precluded (Class 1 lands as defined in SNEP's gap analysis of the Sierra Nevada (Davis and Stoms 1996), Class 1 lands plus national forest lands that are administratively withdrawn from grazing and intensive timber harvest (Class 2 lands as defined in the SNEP gap analysis, and 4) Class 1 lands plus other lands identified by SNEP as Areas of Late Successional Emphasis (ALSEs).

Planning unit: spatial aggregate of landscapes used to map Biodiversity Management Areas. Because they provide comprehensive coverage and form rational units for ecosystem management, we use the CalWater Planning watersheds (~ 2400 at 3-10k acres each) as planning units. The Calwater system is hierarchical, with planning watersheds being aggregated into superplanning watersheds. In the northern region, the superplanning watersheds average about three times the size of planning watersheds. These were used in alternative 2l to test the sensitivity of the model to the size of planning units.

Planning region: the spatial domain of the analysis, in this case three of the six hydrologic regions of the SNEP core area (figure 1). We consider these regions as renewable resource zones that are relatively homogeneous in terms of their biotic composition.

Suitability Elements: mapped indicators of human activities that affect the suitability of an area for BMA designation. Our present model includes the following elements:

Human Population Density: 1990 Census data were obtained as an ARC vector coverage by block group from Professor John Radke at the University of California, Berkeley. The coverage had attributes for population and population density for each block group (population on the order of 1,000 persons per block group which is the first level of aggregation from census blocks). Data by block group were resampled to watersheds. The vector data were converted to an ARC GRID using the population density values over a 100 m grid. Next this grid was combined with a grid of watersheds and the population density per 1 ha was summed over all grid cells in the watershed. Then the total population per watershed was converted to density by dividing by the area of the watershed in hectares. Values range from 0 to 559.8 people per km^2 (mean of 7.4), with high values indicating urbanized watersheds that would generally be unsuitable for protection of most forms of native biodiversity.

Road Density: USGS 100,000 scale Digital Line Graph (DLG) datasets were obtained from USGS and converted to ARC coverages. The road arcs were buffered with a buffer width related to the class of road according to table 1. This buffer operation was used to estimate the area of land actually impacted by the presence of each road, where freeways were assumed to affect a greater spatial extent than dirt roads. This operation also accounted for the spatial distribution of roads which a simple measure of road density (i.e., km of road length per km^2 of area) does not. For instance, urban streets could total a long length but because they are so closely spaced, they do not affect as large an area of habitat as a similar length of road spread uniformly across a watershed. The road density index was calculated by summing the total area of buffered roads per watershed and converting the area to a percentage of watershed area.

There are a number of issues with the DLG data and with the index. The DLG files were largely compiled between 1975 and 1985 and therefore do not include more recent residential development in the foothills and logging activity in the mixed conifer belt. The index itself does not consider the kind of habitat the roads are in. Clearly a road in an urban area has less impact than a road in a natural land cover type. Values for the road density index range from 0 to 98 percent (mean of 15.7), with high values indicating watersheds heavily disturbed by a variety of human activities, making them less suitable for biodiversity management areas.

Percent of Land in Private Ownership: The cost of changing land management to better protect the long-term viability of native biodiversity is partly a function of current land ownership and management. Therefore we have included an index of the proportion of land in a watershed that is in private ownership (either individuals or corporations), derived from the land ownership/management coverage developed for Gap Analysis (Davis and Stoms 1996). Values range from 0 to 100 percent (mean of 31.9), with high values indicating watersheds with high probable costs for management of biodiversity.

Public-Private Interface: Intermingling of public and private lands, or fragmentation of ownership, can greatly complicate BMA management. To capture this feature of an area's land ownership we summed the length of boundary separating public from private lands. The total length was divided by watershed area to derive an index of length per unit area. Values range from 0 to 1.94 km / km^2 (mean of 0.33), with high values of the index indicating complex ownership patterns.

Watershed Suitability Index: There are many ways these four elements (road density, human population density, percentage of private ownership, and public-private interface) could be combined to create an overall index representing suitability for biodiversity management areas. Factors are scaled differently and should be normalized in some way before combining them. Because the factor indices are quite skewed in their distributions, we chose not to weight them by the reciprocal of their maximum value but by the reciprocal of their mean value. This has the effect of contributing very high factor values for watersheds when the values approach their maximum, such as urban areas for the population density factor. In such cases, the factor would receive a weighted score well above 1, whereas a low value would only be a small fraction of 1. Values of WSI range from 0 to 82.6 (mean of 4.0), with high values indicating watersheds that are either extremely high in one of the factors or are moderately high in several factors.

The BMAS Model

In order to formulate this model, we use the following notation:

j, J	index and set of planning units (e.g., small watersheds)
k, K	index and set of biodiversity elements considered vulnerable
a_j	the area of planning unit j
a_{jk}	area in planning unit *j* which contains element *k* and is potentially impacted by planned management activities in *j*
Min_k	minimum area containing element *k* that needs to be brought under biodiversity management in order to remove element *k* from the list of vulnerable elements
Hd_j	human density measurement for planning unit *j*
Rd_j	the percent of the area in planning unit *j* that is impacted by roads

Pla_j	the percent of the area of unit *j* that is held in private ownership
PPI_j	the density of public-private land interface
WSI_j	watershed suitability index for planning unit *j* (index approaches 0 if most suitable)
w_l	weight attached to term *l* in the objective function
X_j	$\begin{cases} 1 \text{ if site } j \text{ is selected for a Biodiversity Management Area} \\ 0 \text{ if not} \end{cases}$
l	index of weights for terms in the objective function

We can formulate the general Biodiversity Management Area Selection (BMAS) Model in the following manner:

$$\text{Minimize } Z = \sum_j \left(w_1 a_j + w_2 WSI_j \right) X_j \quad (1)$$

Subject to the following conditions:

1) Element k is sufficiently represented in BMAs to be considered not vulnerable, that is,

$$\sum_j a_{jk} X_j \geq Min_k \text{ for each } k \: \varepsilon \: K \quad (2)$$

2) Integer requirements: X_j = 0 or 1 for each $j \: \varepsilon \: J$

This model, which we have termed the biodiversity management area selection (BMAS) model, involves selecting the most suitable planning units that contain underrepresented biodiversity elements. An element is considered vulnerable until a specified fraction of its mapped distribution occurs in areas designated as BMAs. This is established by condition 1). Either a planning unit is selected as a BMA or it is isn't. This is enforced by condition 2).

The objective function (Equation (1)) contains two terms. The first term is strictly an area term, and has the effect of minimizing the total area selected for biodiversity management options. The second term is a suitability term. As we define it , the less suitable an area is, the higher this term becomes. Thus this term operates to minimize the total "unsuitability" of the selected areas. The target levels for representation of plant communities can be set for each type individually. This formulation provides some flexibility in the way that rare or endemic elements are treated relative to more widespread types.

The Suitability index can be expanded to include a number of cultural or biological variables. For example, in Equation 3 the term has been expanded to four terms that contribute weighted values for the suitability elements in the *j*th watershed planning unit.

$$\text{Minimize } Z = \sum_j \left(w_1 a_j + w_2 Hd_j + w_3 Rd_j + w_4 Pla_j + w_5 PPl_j \right) X_j \quad (3)$$

Unless we state otherwise, we have used this last equation as the model formulation for the results described in the text. We use the term *Watershed Suitability Index* (WSI) to describe the sum of the four suitability elements in Equation 3. That is,

$$WSI_j = \sum \left(w_2 Hd_j + w_3 Rd_j + w_4 Pla_j + w_5 PPl_j \right)$$

where the weights w_l equal 1 / mean of the factor score.

APPENDIX 58.2

Vulnerable Plant Community Types by Alternative

Holland Code	Holland Name	Alternative																					
		1a	1b	2a	2b	2c	2d	2e	2f	2g	2h	2i	2j	2k	2l	3a	3b	3c	3d	3e	3f	4	5
34200	Mojave mixed scrub and steppe		X								X	X	X	X						X	X		
34210	Mojave mixed woody scrub		X								X	X	X	X						X	X		
34300	Blackbush scrub		X								X	X	X	X						X	X		
35100	Great Basin mixed scrub	X	X	X	X	X	X	X	X	X					X	X	X	X	X			X	X
35210	Big sagebrush scrub	X	X	X	X	X					X	X	X	X	X	X	X			X	X	X	X
35211	Low sagebrush scrub[a]	X		X	X	X	X	X	X	X					X	X	X	X	X			X	X
35212	Silver sagebrush scrub[a]		X	X	X	X					X	X	X	X	X	X	X			X	X	X	X
35220	Subalpine sagebrush scrub					X																	
35300	Sagebrush steppe	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
35400	Rabbitbrush scrub			X	X	X									X	X	X					X	X
35500	*Cercocarpus ledifolius* woodland[a]		X	X	X	X					X	X	X	X	X	X	X			X	X	X	X
35600	*Wyethia mollis*[a]	X		X	X	X				X					X		X		X			X	X
37100	Upper Sonoran mixed chaparral			X	X	X									X								X
37110	Northern mixed chaparral	X	X	X	X	X	X	X	X	X					X	X	X	X	X			X	X
37200	Chamise chaparral	X	X	X	X	X	X	X	X	X					X	X	X	X	X			X	X
37400	Semidesert chaparral		X																				
37510	Mixed montane chaparral	X	X	X	X	X				X				X	X		X				X		X
37520	Montane manzanita chaparral	X	X	X	X	X	X	X	X	X				X	X		X		X				X
37530	Montane ceanothus chaparral	X		X	X	X	X	X	X	X					X	X	X		X				X
37531	Deer brush chaparral			X	X	X									X	X	X						X
37541	Shin oak brush		X											X									
37542	Huckleberry oak chaparral	X	X	X	X	X				X				X	X		X		X			X	X
37550	Bush chinquapin chaparral	X		X	X	X									X	X	X						X
37810	Buck brush chaparral	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
37900	Scrub oak chaparral		X	X	X	X					X	X	X	X	X					X	X		X
37A00	Interior live oak chaparral	X	X	X	X	X	X	X	X	X				X	X	X	X				X	X	X
37B00	Upper Sonoran manzanita chaparral	X	X	X	X	X	X	X	X	X				X	X	X	X	X	X		X	X	X
37E00	Mesic north slope chaparral	X	X	X	X	X	X	X	X	X				X	X		X		X		X	X	X
39000	Upper Sonoran subshrub scrub		X								X	X	X	X							X		
42110	Valley needlegrass grassland	X		X	X	X									X	X	X					X	X
42200	Non-native grassland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
45100	Montane meadow	X	X	X	X	X									X	X	X					X	X
45210	Wet subalpine or alpine meadow	X	X	X	X	X									X	X	X					X	X
45310	Alkali meadow		X								X	X	X	X						X	X		
52320	Transmontane alkali marsh		X								X	X	X	X						X	X		
61410	Great Valley cottonwood riparian forest		X	X	X	X								X	X	X	X				X	X	X
61420	Great Valley mixed riparian forest		X								X	X	X	X						X	X		
61430	Great Valley valley oak riparian forest	X	X				X	X	X	X	X	X	X	X				X	X	X	X		
61510	White alder riparian forest	X					X	X	X	X								X	X				
61530	Montane black cottonwood riparian forest		X								X	X	X	X						X	X		
63500	Montane riparian scrub	X	X	X	X	X									X	X	X					X	X
71110	Oregon oak woodland		X	X	X	X					X	X	X	X	X	X	X			X	X	X	X
71120	Black oak woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X	X
71130	Valley oak woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
71140	Blue oak woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

continued

[a]Addition to the standard Holland classification.
X indicates that the alternative was required to select additional area for that community type. Communities are not necessarily vulnerable in every region in which they occur.

		Alternative																					
Holland Code	**Holland Name**	**1a**	**1b**	**2a**	**2b**	**2c**	**2d**	**2e**	**2f**	**2g**	**2h**	**2i**	**2j**	**2k**	**2l**	**3a**	**3b**	**3c**	**3d**	**3e**	**3f**	**4**	**5**
71150	Interior live oak woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
71310	Open foothill pine woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
71322	Nonserpentine foothill pine woodland	X	X	X	X	X				X	X	X	X	X	X	X	X		X	X	X	X	X
71410	Foothill pine–oak woodland	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
71500	Cismontane juniper woodland[a]	X	X	X	X	X									X	X	X					X	X
71600	Oak–piñon woodland[a]		X											X							X		
72110	Northern juniper woodland	X		X	X	X									X	X	X					X	X
72121	Great Basin piñon–juniper woodland		X											X							X		
72122	Great Basin piñon woodland	X	X				X	X	X	X	X	X	X	X				X	X	X	X		
72123	Great Basin juniper woodland and scrub	X					X	X	X	X								X	X				
72220	Mojavean juniper woodland and scrub		X								X	X	X	X						X	X		
73000	Joshua tree woodland		X								X	X	X	X						X	X		
81320	Canyon live oak forest	X	X	X	X	X								X	X								X
81330	Interior live oak forest	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X
81340	Black oak forest	X	X	X	X	X	X	X	X	X				X	X		X		X				X
81400	Tan oak forest			X	X	X									X		X						X
81B00	Aspen forest	X		X	X	X									X		X					X	X
83210	Knobcone pine forest	X		X	X	X	X	X	X	X					X			X	X			X	X
83330	Southern interior cypress forest		X								X	X	X	X						X	X		
84210	West-side ponderosa pine forest	X	X	X	X	X				X					X	X	X		X				X
84220	East-side ponderosa pine forest			X	X	X									X	X	X					X	X
84230	Sierran mixed conifer forest	X	X	X	X	X				X					X		X						X
84240	Sierran white fir forest	X	X	X	X	X				X					X		X		X				X
84250	Big tree forest		X																				
85100	Jeffrey pine forest	X	X	X	X	X								X	X		X				X	X	X
85120	Red fir–western white pine forest[a]	X	X			X																	
85210	Jeffrey pine–fir forest	X	X	X	X	X								X	X		X				X		X
85310	Red fir forest	X	X	X	X	X									X		X						X
86100	Lodgepole pine forest	X	X	X	X	X									X		X						X
86210	Whitebark pine–mountain hemlock forest	X																					
86220	Whitebark pine–lodgepole pine forest	X		X	X	X									X	X	X						X
86300	Foxtail pine forest		X																				
86600	Whitebark pine forest	X	X																				
86700	Limber pine forest	X	X				X	X	X	X								X	X				
87100	Lower cismontane mixed conifer–oak forest[a]	X	X	X	X	X	X	X	X	X				X	X	X	X		X		X		X
87200	Upper cismontane mixed conifer–oak forest[a]	X	X								X	X	X	X							X		
91120	Sierra Nevada fell field	X	X				X	X	X	X				X				X	X		X		
94000	Alpine dwarf scrub	X	X											X							X		

[a]Addition to the standard Holland classification.
X indicates that the alternative was required to select additional area for that community type. Communities are not necessarily vulnerable in every region in which they occur.

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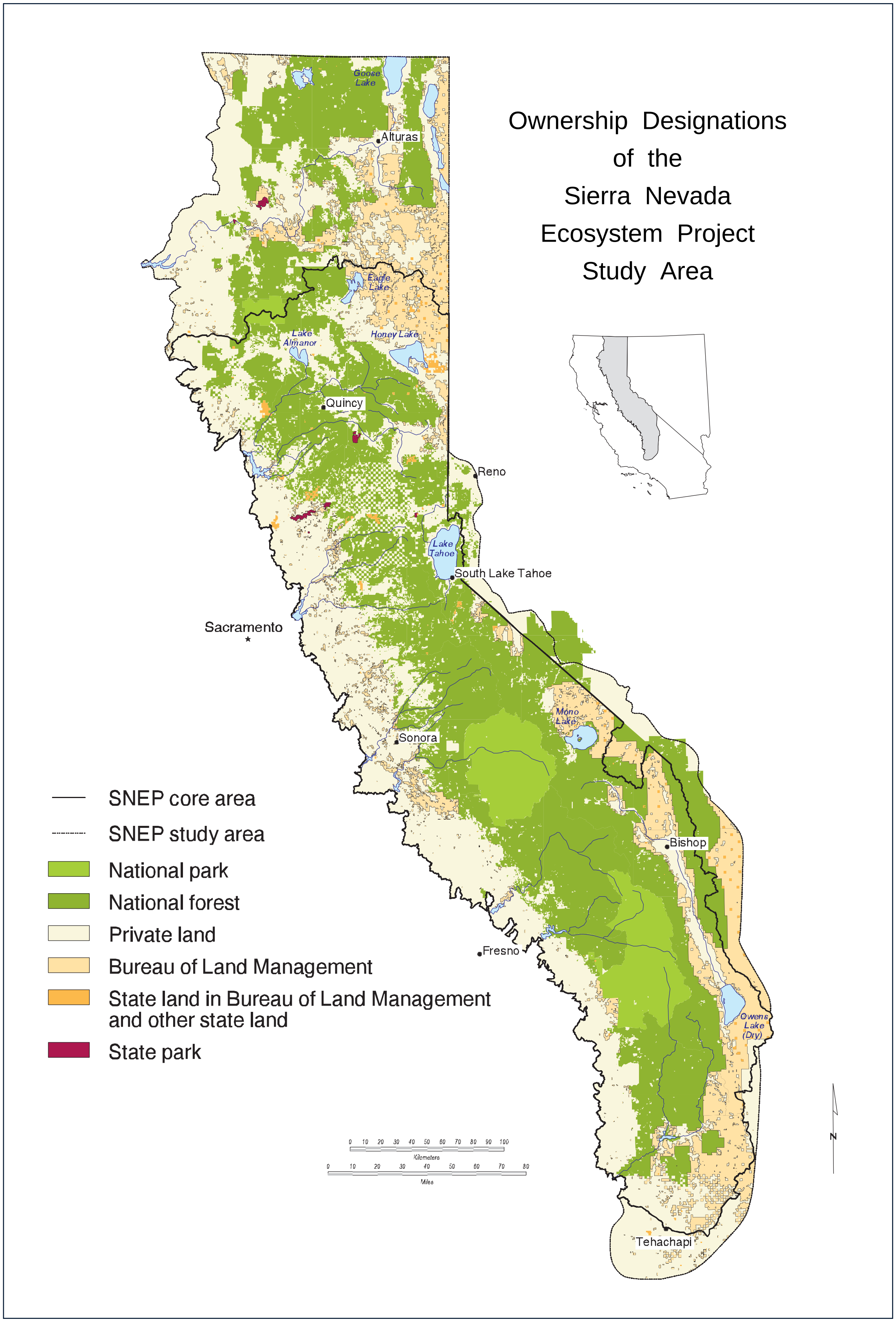

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