Forest Conservation Planning

Michael D. White and James R. Strittholt

Abstract This chapter reviews the application of Ecosystem Management Decision Support (EMDS) to conservation planning in a large forest landscape. A significant challenge faced by conservation planners is explicitly defining and mapping values of interest. EMDS is a powerful decision support application development tool that can be used to facilitate explicit and consistent definition of subjective conservation values, which can then be used in a variety of spatial assessments. We describe a case study for the Sierra Checkerboard Initiative where we used EMDS to assess and map three conservation values across a largely forested 4,856 km^2 landscape in the northern Sierra Nevada of California: biodiversity, mature forest connectivity, and passive recreation.

Keywords Forest conservation · Conservation planning · Biodiversity · Forest connectivity · Recreation · Spatial decision support · EMDS

Abbreviations

GIS	Geographic Information Systems
EMDS	Ecosystem Management Decision Support System
HCVF	High Conservation Value Forests
FSC	Forest Stewardship Council
USFS	U.S. Forest Service

M. D. White (✉)
Tejon Ranch Conservancy, PO Box 216, Frazier Park, CA 93225, USA
e-mail: mwhite@tejonconservancy.org

J. R. Strittholt
Conservation Biology Institute, 136 SW Washington Avenue, Suite 202, Corvallis, OR 97333, USA
e-mail: stritt@consbio.org

K. M. Reynolds et al. (eds.), *Making Transparent Environmental Management Decisions*, Environmental Science and Engineering,
DOI: 10.1007/978-3-642-32000-2_9, © Springer-Verlag Berlin Heidelberg 2014

1 Introduction

Conservationists are concerned with the protection of natural resources in the face of human-induced changes. Natural resources targeted for protection are varied and often closely tied to subjective value systems. For example, a focus of the early conservation movement in the United States was preserving clean water, productive soils, and sustainable yields of fish, wildlife, and forest products for human uses (Pinchot 1947). However, at the same time, early preservationists were making non-utilitarian arguments for protection of wild nature for wilderness and spiritual values (Callicott 1990). In recent decades, the targets of conservation have largely shifted to the preservation of biodiversity, ecosystem services, and associated aesthetic values (Chan et al. 2006; Daily et al. 1997; Groves 2003; Margules and Pressey 2000; Swart et al. 2001). Thus, conservationists may be concerned with protection of specific values such as rare species or habitats, or more subjective values such as wilderness experiences or ecological health. Not only are many of these values ill-defined, often no data exist to directly describe them in a spatially-explicit fashion, which is essential for effective conservation planning. In spite of these limitations, conservation planners must integrate available data, often imperfect for the intended application, to describe the distribution of and relationships between conservation targets and values of interest. Furthermore, conservation planning results have to be conveyed in a transparent and understandable fashion to on-the-ground conservation practitioners, funders, and public policy decision-makers, who frequently have little or no technical background. This chapter discusses our experience in applying EMDS as a conservation planning tool. In particular, we discuss its utility in explicitly defining and mapping subjective conservation values for a large, mostly forested region in the northern Sierra Nevada, California.

2 Background

Systematic conservation planning has been practiced since the 1970s (Groves 2003), and has become more sophisticated with the development of new theoretical models for conservation reserve planning, the evolution of geographic information systems (GIS), better spatially-explicit data describing natural resources, and increasingly powerful computing systems. To be effective, conservation planning requires clear definition of targeted conservation values and the metrics used to describe them (Margules and Pressey 2000). However, given the complexity and variability of ecosystems and the subjective human perception of value, it is often difficult to develop broadly-applicable quantitative models to describe many conservation values. Knowledge-based reasoning is well suited for conservation planning because it allows representation of the conceptual factors that contribute to conservation values and the logical relationships between them

(Reynolds 2001, 2003). In knowledge-based models, data used to evaluate the conceptual factors can be specified, and the manner in which available data are used to arrive at a conclusion defined. Incorporating fuzzy logic into knowledge-based models allows imprecise information typical of natural resources science to be used in modeling (Reynolds et al. 2000). Knowledge-based reasoning can be a powerful approach for (1) describing conservation values, in terms of landscape characteristics or conditions (e.g., acres of forest, numbers of special status species, levels of habitat fragmentation), (2) defining the specific data that will be used to evaluate these conditions, and (3) documenting the logical relations between the factors used to describe conservation values and the data used to evaluate them.

EMDS is a knowledge-based decision support application development tool that uses spatial data and maps, and applies hierarchically organized fuzzy logic networks to these data, in a GIS environment. Gordon et al. (2004) found it to be one of the most versatile and comprehensive of over 30 software packages tested for forest assessment and planning. Although EMDS provides a potentially useful tool for conservationists, it has been used relatively infrequently in conservation planning. White et al. (2005a) used EMDS to quantify the distribution of conservation values in the northern Sierra Nevada, California (described in a case study in this chapter). However, we are aware of relatively few conservation planning applications of EMDS (Strittholt et al. 2006, 2007; Staus et al. 2010; Manzuli 2005; Stoms et al. 2000, 2002, Chap. 8, this volume; Humphries et al. 2008).

EMDS has been successfully used to map High Conservation Value Forests (HCVF, Strittholt et al. 2007; Staus et al. 2010). The HCVF concept, which is sometimes referred to as Principal 9 of the Forest Stewardship Council (FSC) forest stewardship guidelines, refers to forests that contain one or more high conservation values (Jennings et al. 2003). High conservation value is defined by criteria indicative of forests with significant biological, environmental, and social values (for examples, see Strittholt et al. 2007; Staus et al. 2010). HVCF is an important concept gaining global acceptance within forest ecosystems not only within the FSC context, but also outside of this specific certification system.

Strittholt et al. (2007) used EMDS to map endangered forests in the Alberta Foothills Ecoregion of Canada, a subset of HCVF that some forest conservation groups consider inappropriate for industrial timber harvest. Areas of high conservation value in the Alberta Foothills were identified as those with a combination of high landscape values and high biodiversity values. High landscape values were defined using degree of landscape integrity and amount of historical impacts from oil and gas development and logging. High biodiversity values were defined using distinct bird, fish, caribou, grizzly bear, forest, and natural heritage conservation values, i.e., concentrations of rare plants and animals. The analysis identified portions of the Alberta Foothills that merited greater protection than received, and allowed an explicit evaluation of how special land management provisions may affect high conservation value forests.

Staus et al. (2010) used EMDS to identify HCVF in western Oregon as part of evaluating proposed changes to the Bureau of Land Management (BLM) portions

of the Northwest Forest Plan. Using EMDS, model outputs highlighted areas in western Oregon, including significant BLM lands that were important to protect to maintain stated forest conservation values.

Manzuli (2005) used EMDS within a monitoring and evaluation program for a gas pipeline project to assess the conservation status of the Chiquitano Dry Forest in Bolivia. Manzuli defined conservation opportunities within the study area as a function of four conditions (amount of forest clearings, fuel-wood collection pressure, browsing cattle pressure, and logging pressure), and used various landcover, demographic, and social data sets to evaluate contributions of each condition within a fuzzy logic network. This analysis allowed evaluation of the contributions of both direct and indirect factors on the conservation status of the Chiquitano Dry Forest. It also established a baseline description of conservation status against which future assessments could be compared.

Stoms et al. (2002, Chap. 8) evaluated the suitability of sites for a scientific research reserve using EMDS. Research site suitability is a function of how well a candidate site meets particular scientific, academic, and administrative criteria. However, these criteria can be imprecise (e.g., site is "close" to campus) and the manner in which criteria should be combined and weighted is undefined. The fuzzy knowledge-based approach of EMDS is well-suited to such a problem, and allowed the investigators to explicitly define and evaluate a knowledge-based system that incorporated standard, but imprecise site suitability criteria.

The role of socioeconomic suitability factors when targeting land for conservation purposes was considered by Humphries et al. (2008) using EMDS. In this analysis, EMDS was used to develop suitability rating scenarios for analysis units based on ownership (public vs. private), number of land cover types, and area. These suitability ratings were then converted into "cost" scenarios, and then incorporated into a conservation reserve-selection algorithm.

Strittholt et al. (2006) employed EMDS to carry out a global conservation assessment that emphasized biological (e.g., high wildness and biodiversity values), socioeconomic (e.g., high levels of aboriginal involvement and a low cost to value ratio), and political (e.g., stable government) considerations. The outcome of this EMDS model helped direct conservation philanthropy in several locations in the world that best met the specific desired conditions set forth by the anonymous foundation that commissioned the study.

3 Case Study: Sierra Checkerboard Initiative

We often conduct conservation planning work with partners across large landscapes, much of it in North American forests. These forests provide numerous important ecosystem services that are increasingly threatened by the synergistic effects of timber harvest, mining, rural residential development, road building, altered fire regimes, forest diseases, alien species invasions, pollution, and global

climate change (Sierra Nevada Ecosystem Project SNEP 1996; Lindenmayer and Franklin 2002; The Millennium Assessment 2005).

The California Sierra Nevada supports a diverse array of complex and interrelated conservation values. It lies within one of the world's biodiversity hotspots (Mittermeier et al. 1999; Conservation International 2005) and is one of the most floristically diverse regions in North America (Shevock 1996). Nearly 30 % of California's total runoff originates in Sierran mountains (Kattelmann 1996). Its mountain forests are an important source of wood products and store hundreds of millions of metric tons of carbon (Zhu and Reed 2012). Valuable rangelands are located in nearby foothills and intermountain valleys. In addition, the Sierra Nevada provides highly sought-after recreational and scenic resources for millions of people.

Land in the northern Sierra Nevada is characterized by a checkerboard ownership pattern, a legacy of the United States government's granting of alternate square miles to the Central Pacific Railroad during construction of the transcontinental railroad in the 1860s (Duane 1999). Many individuals and private corporations now hold these land grants, which are interspersed with public lands administered by the U.S. Forest Service. This checkerboard ownership pattern, where private industrial timberland is interspersed with public lands important for biodiversity protection and recreational uses, creates great challenges for regional conservation and land management.

Recognizing the threats to conservation values posed by this ownership pattern, the Trust for Public Land (TPL) initiated the Sierra Checkerboard Initiative (White et al. 2005a) to work towards a more sustainable land management and ownership landscape in the region. To prioritize their conservation work in the region, TPL commissioned the Conservation Biology Institute to better quantify and understand the distribution of conservation values across a 4,856 km^2 northern Sierran landscape (Fig. 1).

Working with TPL and other conservation partners in the region, we identified three primary conservation values as the focus of our work–biodiversity, mature forest connectivity, and passive recreation. Our challenge was twofold: to quantify these values in a spatially-explicit fashion using available data, and to spatially integrate the data across the landscape in a way that could be clearly articulated to conservation partners and the general public. We found EMDS ideally suited for this analysis. EMDS allowed us to clearly model the magnitude and distribution of these three conservation values in the Sierra Checkerboard Initiative area. The EMDS logic networks also allowed us to integrate numerous disparate data sets and to easily update the analysis as data sets were refined. Our assumptions and approach were transparent, and the logic networks could be easily modified to evaluate the influence of individual model components.

In our model, an evaluation unit (the most basic landscape unit) supported high conservation values if it supported high biodiversity value, high mature forest connectivity value, *or* high passive recreation value (Fig. 2, Table 1). In NetWeaver, we constructed a hierarchical fuzzy logic network that defined these relations. The three component logic networks under the premise of high

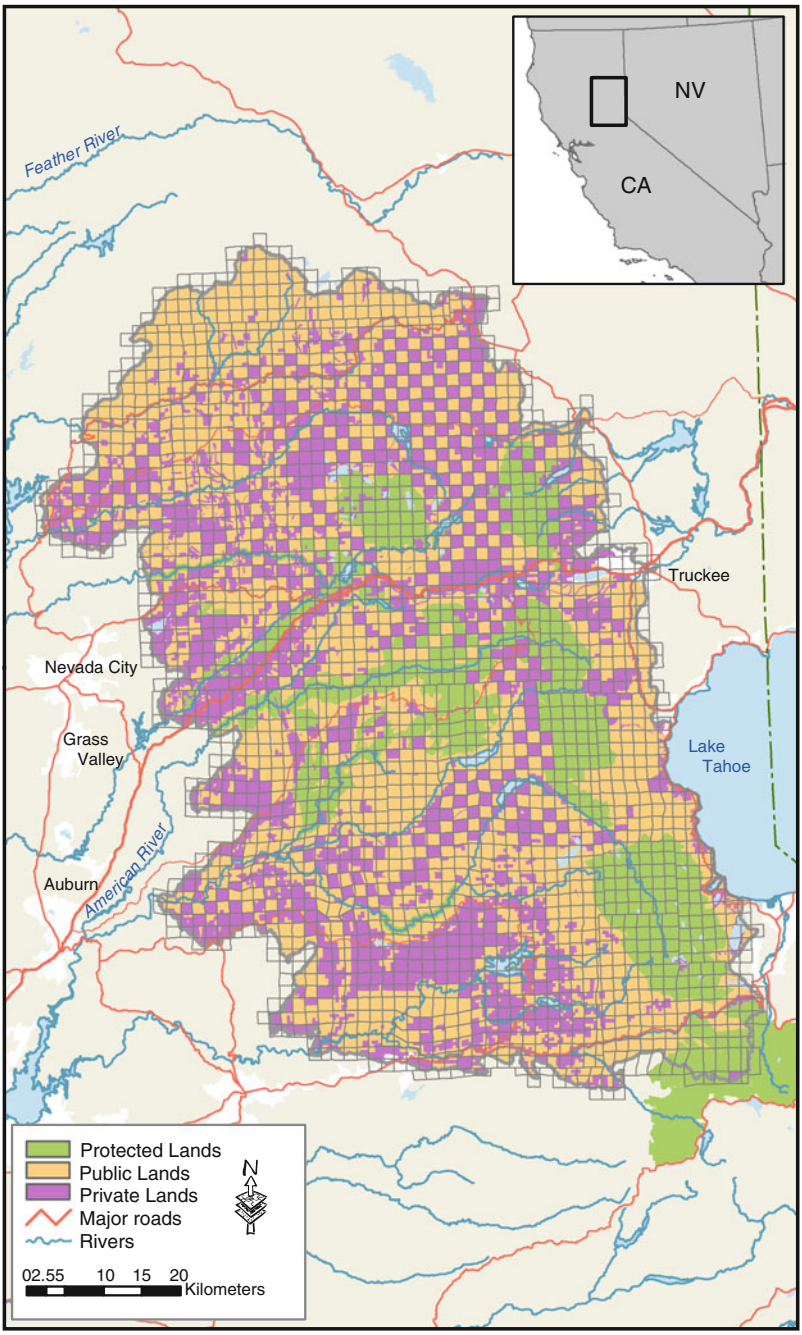


Fig. 1 Location of the Sierra Checkerboard Initiative study area showing the grid of EMDS evaluation units. Protected areas were defined as Wilderness, Wild and Scenic Rivers, and Inventoried Roadless Areas

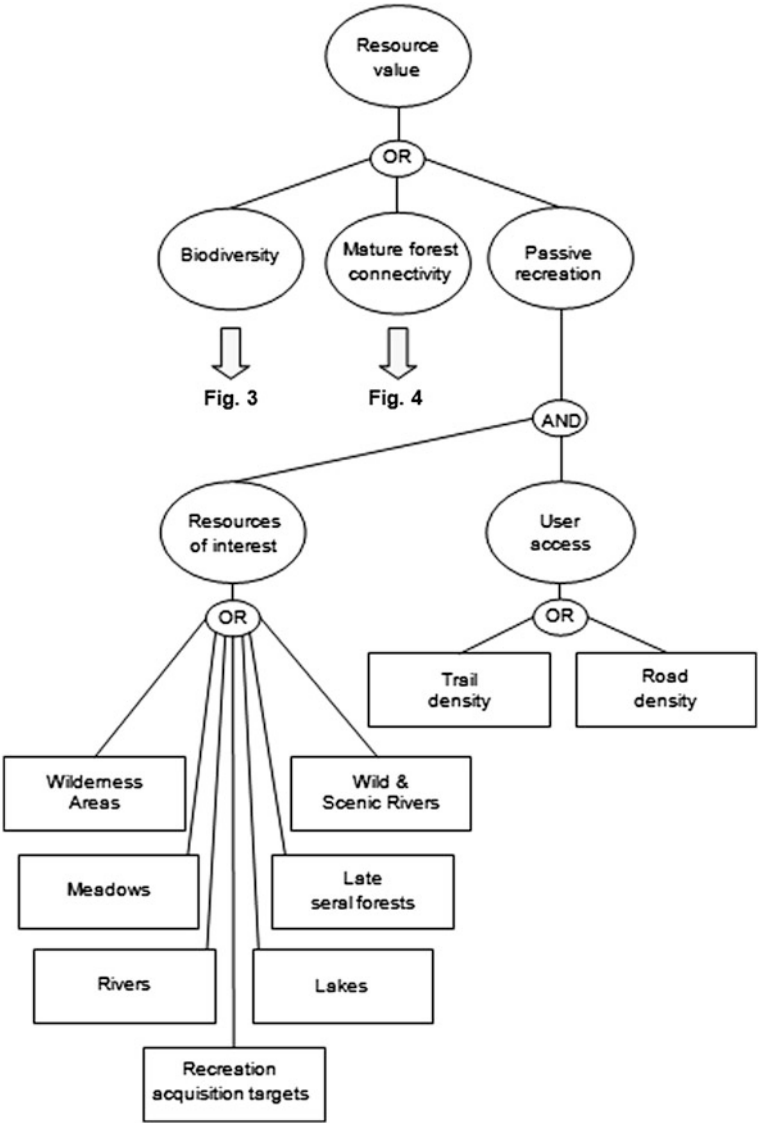


Fig. 2 The resource value network showing the logic for evaluating the passive recreation conservation value of an evaluation unit

conservation value are discussed in the following sections. In all logic networks, circles represent presumed conditions or states, small ovals are logic operators, and boxes represent input data. Evaluation units were Sections of land within the U.S. Public Land Surveying System, generally 2.59 km^2 (or $\sim$1 mi^2).

Table 1 Outline of propositions and subpropositions used in the Sierra Checkerboard Initiative model to map resource values in the study area, and the elementary topics used to assess the evidence in support of them

Propositions and subpropositions	Elementary topics
1. The site supports high **biodiversity**	–
A. The site supports high **existing biodiversity**	–
i. The site supports high **terrestrial biodiversity**	–
a. The site has good **landscape condition**	Road density, Roadless Area, Human impact
b. The site supports **under-represented habitats**	Priority vegetation types
c. The site supports **terrestrial special elements**	Sensitive terrestrial species, Late seral forests, Rare edaphic features
ii. The site supports high **aquatic biodiversity**	–
a. The site has high **watershed condition**	Reservoir volume, Roads near streams, Roadless area of watershed, Roads on steep slopes
b. The site supports **aquatic special elements**	Sensitive aquatic habitats, Sensitive aquatic species
B. The site supports high **future biodiversity**	Biodiversity in neighborhood
i. The site supports **potential biodiversity**	Rare edaphic features
a. The site has low **development density**	Relative development
b. The site has high **site productivity**	Site class
2. The site supports high **mature forest connectivity**	–
A. The site supports high existing mature forest connectivity	–
i. The site has low **mature forest fragmentation**	Mean patch size, Number of patches, Mean distance to nearest neighbor, Proportion mature forest, Total core area index
ii. The site has low **mature forest fragmentation in the neighborhood**	Mean patch size in neighborhood, Number of patches in neighborhood, Mean distance to nearest neighbor in neighborhood, Proportion mature forest in neighborhood, Total core area index in neighborhood
B. The site supports high **future mature forest connectivity**	–
i. The site has high **mature forest recovery potential**	–
a. The site has low **development density**	Relative development
b. The site has high **site productivity**	Forest site class
3. The site supports passive recreation	–
A. The site supports recreational **resources of interest**	Wilderness areas, Meadows, Rivers, Lakes, Wild & Scenic Rivers, Late seral forest, Recreation acquisition targets
B. The site has good **user access**	Trail density, Road density

Bolded words correspond to the labels in the logic network figures

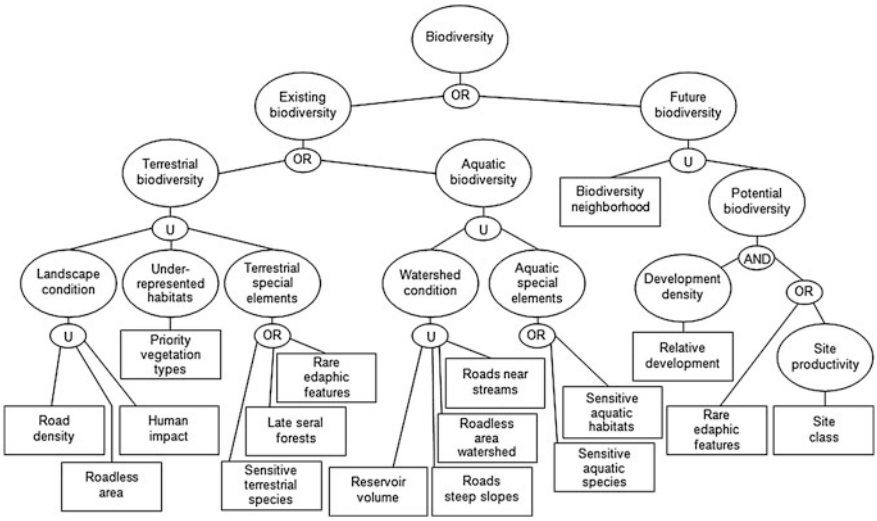


Fig. 3 Biodiversity conservation value network

3.1 Biodiversity Value

The objective of the biodiversity value assessment was to identify areas supporting the rich diversity of flora and fauna in the northern Sierra Nevada. Since comprehensive, fine-scaled data describing biodiversity patterns did not exist for the study area, we used a number of indirect measures that we assumed could serve as surrogates for biodiversity. The interplay of the diverse geology and terrain, range of elevations, climate variation, and variety of aquatic habitats is largely responsible for the characteristic biodiversity of the Sierra Nevada region. Our conceptual model (Fig. 3) recognized that terrestrial and aquatic systems make important biodiversity contributions, and that areas with low existing biodiversity values can recover to support high biodiversity values in the future.

Terrestrial biodiversity value was assessed via three factors: landscape condition, presence of under-represented habitats, and presence of special elements. Areas of high landscape condition (i.e., areas that are relatively unaltered by human modifications such as road building and residential development) often support intact ecosystem processes, allow for species movements through the landscape, and support species that are sensitive to human modifications of the landscape, such as mammalian carnivores (Saunders et al. 1991; Trombulak and Frissell 2000; Brooks et al. 2002; Crooks 2002), and were thus considered to be good predictors of biodiversity. Landscape condition was evaluated using a UNION operator, which averaged the truth values of the data inputs of percent roadless area, road density, and area of human footprint. Under-represented habitats were those not well represented in protected areas in the region (Scott et al. 2001), and were a

priority for protection in the northern Sierra. A representation analysis of vegetation communities within protected areas in the region was used to identify under-represented habitats, with high-priority habitats (i.e., those with less than 20 % of their extent in protected areas) or medium-priority habitats (i.e., those with 20–35 % of their extent in protected areas) selected as important contributors to biodiversity value. Special elements were defined as rare species or habitats (e.g., mature forests) or rare edaphic features (e.g., serpentine geology) that contribute to regional biodiversity. The logic network for terrestrial biodiversity also used a UNION operator to evaluate the collective contributions of the three terrestrial biodiversity factors.

Aquatic biodiversity was treated similarly in our logic network but used only two factors, watershed condition and presence of special aquatic elements (aquatic habitat types were not mapped at an adequate resolution to perform a representation analysis). As with terrestrial landscapes, fragmentation and human modifications, such as dams and diversions, can alter aquatic ecosystem processes, degrade habitat quality, and facilitate invasions of non-native species (Poff et al. 1997; Kattelmann 1996). We used data describing road density on steep slopes, road density near streams, percent of watersheds that were roadless, and size (volume) of reservoirs to assess good watershed condition via a UNION operator. Aquatic special elements were defined as species and habitats with regionally restricted distributions that contributed to the unique biodiversity of the region, such as wetlands, fens, and springs. Watershed condition and presence of special aquatic elements were evaluated via a UNION operator.

Although much of the northern Sierra Nevada ecosystem has been historically managed for targets other than biodiversity (U.S. Forest Service 2001), the ecosystem is dynamic, and with appropriate management actions, is capable of recovering conditions that support specific biodiversity values. We wanted to ensure that areas currently supporting low biodiversity values, but that have a high potential for recovery, were not disregarded. Our biodiversity logic network (Fig. 3) therefore included an element for high future biodiversity values, assessed as the UNION of high potential biodiversity values (i.e., biodiversity values resulting from ecosystem recovery) and existing biodiversity values in the surrounding neighborhood (defined as a 5 km^2 area in this analysis). Thus, to support high future biodiversity values, an area must be capable of recovery and have high existing biodiversity values in its immediate vicinity that can serve as a recovery source. Existing biodiversity values were assessed via the logic network described above, and averaged within a 5 km^2 neighborhood around each evaluation unit. The logic network for potential biodiversity assumed that the evaluation unit must have both low development density, and either support rare edaphic features or have high site productivity, as measured by site class. We assumed vegetation growth and recovery rates following disturbance would be positively related to site productivity, and thus site class would be indicative of potential biodiversity.

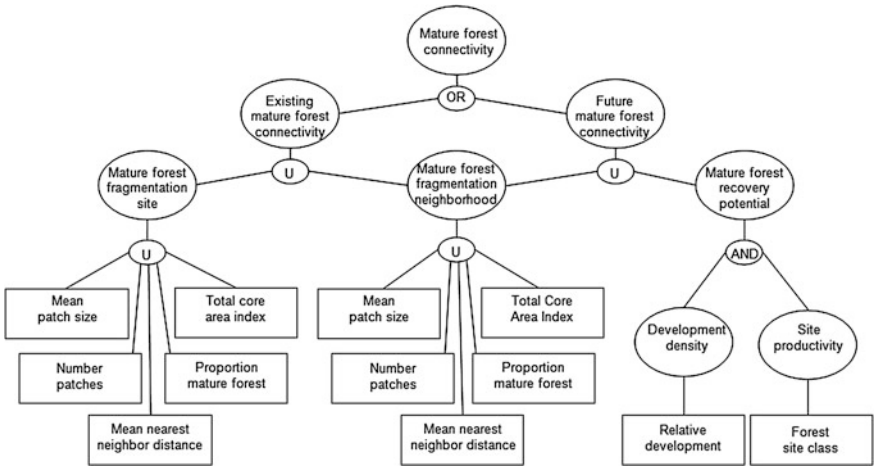


Fig. 4 The mature forest connectivity network showing the logic for evaluating the mature forest connectivity value of an evaluation unit

3.2 Mature Forest Connectivity Value

Mature forests (most trees in a forest plot >28 cm diameter at breast height) and especially the late-successional component (forests with many of its trees >50 cm diameter) provide many important ecosystem functions, wildlife habitat, and benefits to human society (Franklin and Fites-Kaufmann 1996; Graber 1996; Marcot 1997). However, commercially important forest types in the Sierra Nevada, such as west-side mixed-conifer forests, are deficient in mature forest characteristics relative to their pre-settlement conditions (Franklin and Fites-Kaufmann 1996). The loss of mature forests in the northern Sierra Nevada has eliminated habitat and decreased habitat connectivity for associated wildlife species throughout the Sierra Checkerboard Initiative study area. Thus, mature forest connectivity was identified as a conservation value in our assessment. For the purposes of our assessment, we defined mature forests as forest stands with >40 % canopy cover and 28 cm diameter or larger trees.

As with biodiversity value, our NetWeaver model for mature forest connectivity recognized that conservation value can be associated with existing or future mature forest connectivity (Fig. 4). The supposition of high existing mature forest connectivity was assessed as the UNION of the degree of fragmentation of mature forests in the evaluation unit and fragmentation within a 5 km^2 neighborhood around the unit, i.e., the collective contribution of mature forest fragmentation at local and neighborhood scales. At both scales, fragmentation was assessed as the UNION of five fragmentation metrics (proportion of mature forest, mean nearest neighbor distance, total core area index, mean patch size, and number of patches). These fragmentation metrics were calculated by running FRAGSTATS

(McGarigal et al. 2002) on the mature forest data layer. Our model for future mature forest connectivity assumed that an evaluation unit must have both high potential to recover and have mature forests with high connectivity in the immediate vicinity. Thus, future mature forest connectivity was assessed by evaluating the UNION of existing mature forest fragmentation within the 5 km^2 neighborhood and the potential for mature forest recovery within an evaluation unit. Mature forest recovery potential was high where development density (number of dwelling units per unit area) was low and productivity (site class) was high.

3.3 Passive Recreation Value

The northern Sierra Nevada provides a wide variety of recreational opportunities, and demand for these resources is high and increasing (Duane 1996). The U.S. Forest Service (USFS) collects recreation visitor information in eight categories: developed recreation, motorized and mechanized travel, dispersed recreation, winter sports, resorts and cabins, hunting, fishing, and nature study (U.S. Forest Service 2001). The Sierra Checkerboard Initiative focused on passive recreation values, which would exclude motorized and mechanized travel, some winter sports (e.g., downhill skiing), and resorts and cabins.

In our model, for a site to support high passive recreation values it must display both good user access AND support resources of recreation interest (Fig. 2). User access was considered good if there was either good trail OR road access, as measured by trail or road density. We defined resources of high recreation interest as rivers, lakes, Wild and Scenic Rivers, late seral forests, meadows, Wilderness Areas, and areas identified by public land managers in the region as land acquisition targets. The proposition that a site supported resources of high recreation interest was evaluated by considering the presence of any of the seven resources types via an OR operator.

3.4 Membership Functions and Data

Logic networks terminate in links to elementary topics where data are evaluated. We used fuzzy membership functions to assess *degrees of truth* or evidence (Reynolds 2003) in support of each proposition and subproposition (Table 1). For the majority of variables in our logic networks, we established linear relationships between the maximum and minimum values in the given data set and the full support (+1) and no support (−1) truth values (Fig. 5). For example, the presence of a Wilderness Area designation fully supported the proposition–*supports resources of recreational interest*–in the passive recreation value network (Fig. 2). The corresponding no support value in the membership function was set at the minimum value (no percent Wilderness Area) and the full support value was set to

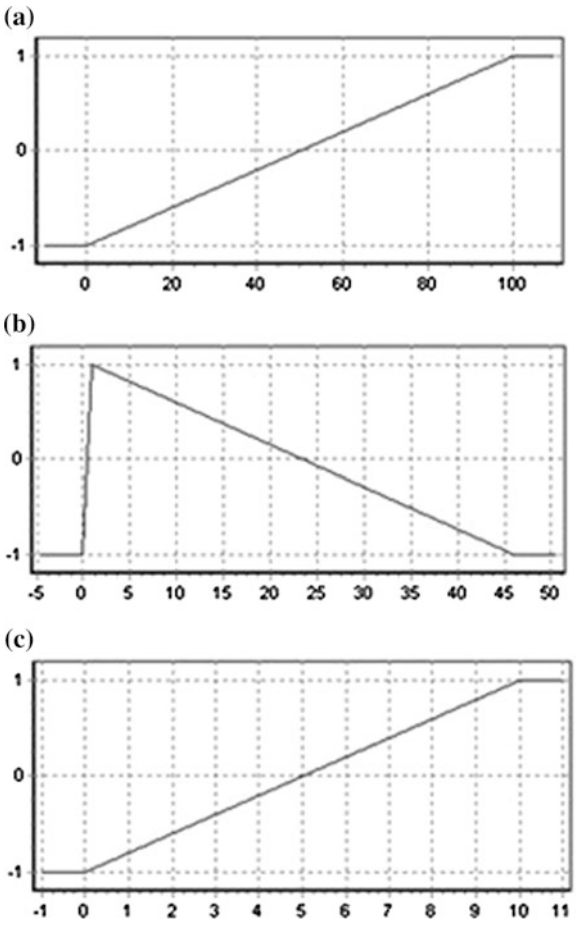


Fig. 5 Examples of membership functions used in the Sierra Checkerboard Initiative: **a** percentage of evaluation unit in a Wilderness Area, **b** number of mature forest patches in an evaluation unit, and **c** percentage of evaluation unit area with lakes. The ordinate in all figures is the level of support for the proposition under evaluation

the maximum value (100 % Wilderness Area, Fig. 5a). Conversely, the number of patches of mature forest was inversely related to the proposition–*low mature forest fragmentation of site*–in the mature forest connectivity value network (Fig. 4). Corresponding end members of the membership function were no support, at the minimum value of 0–no patches of mature forest–and full support at a value of 1 (one patch of mature forest), and again no support at the maximum value in the number of mature forest patches (mature forest is highly fragmented, Fig. 5b).

Where appropriate we also modified the relationship between the range of values in the datasets and their degree of support for each proposition. For example, the presence of lakes supported the proposition–*supports resources of recreational interest*–in the passive recreation value network (Fig. 2). Because lakes are such an attractive recreational resource, we assumed that relatively low lake area in an

evaluation unit would provide as much recreational interest as high lake area. Thus, we arbitrarily set the value connoting full support for the proposition at an arbitrary threshold of ≥10 % lake area within the evaluation unit (Fig. 5c), and the value for no support at the minimum value of 0 [no percentage area of lake(s)].

Metadata for data used in the analysis were described in White et al. (2005b). All data sets were summarized for each evaluation unit in the study area prior to running EMDS.

3.5 Sierra Checkerboard Initiative Results

While the main focus of this chapter was to describe how we used EMDS to construct models of conservation values for a forest conservation planning application, it is illustrative to review the output maps for the respective conservation values in light of the formulation of their models.

Figure 6 shows the results of the Biodiversity Value component of our model (i.e., the results of the logic network in Fig. 3). The Biodiversity Value logic network was driven by landscape condition (such as presence of roadless areas), known occurrences of special habitats and species for both terrestrial and aquatic environments, presence of under-represented terrestrial habitats (such as mixed conifer forests), and high forest productivity and recovery potential. These features occurred within mid-montane forests on the west slope of the Sierra Nevada along the western half of the study area (Fig. 6). The eastern half of the study area, largely supporting upper montane and alpine habitats, had fewer of these features, and thus lower biodiversity value, as defined in our model.

The Mature Forest Connectivity Value component of our model (i.e., logic network in Fig. 4) displayed a pattern of higher values in the western half of the study area and lower values in the eastern half (Fig. 7). The western half of the study area supports a greater proportion of mature forest, configured in large patches, and with greater core area, than does the eastern half of the study area, and these forests exhibit relatively high productivity and recovery potential. The upper montane forests in the eastern half of the study area tended to be more fragmented than in the western half as a result of a naturally fragmented condition along the crest of the Sierra Nevada, where significant amounts of exposed granite occur, and where urban and rural development near Truckee and the Tahoe basin were evident.

Passive Recreation Value (i.e., the logic network in Fig. 2) exhibited a different pattern than either Biodiversity or Mature Forest Connectivity Values. Higher Passive Recreation Values occurred in the eastern half of the study area (Fig. 8). This result was largely driven by the greater availability of recreation resources (e.g., rivers, lakes, meadows, Wilderness Areas) along the crest of the Sierra Nevada.

The result for Resource Value, which combined Biodiversity Value, Mature Forest Connectivity Value, and Passive Recreation Value (Fig. 2), showed high

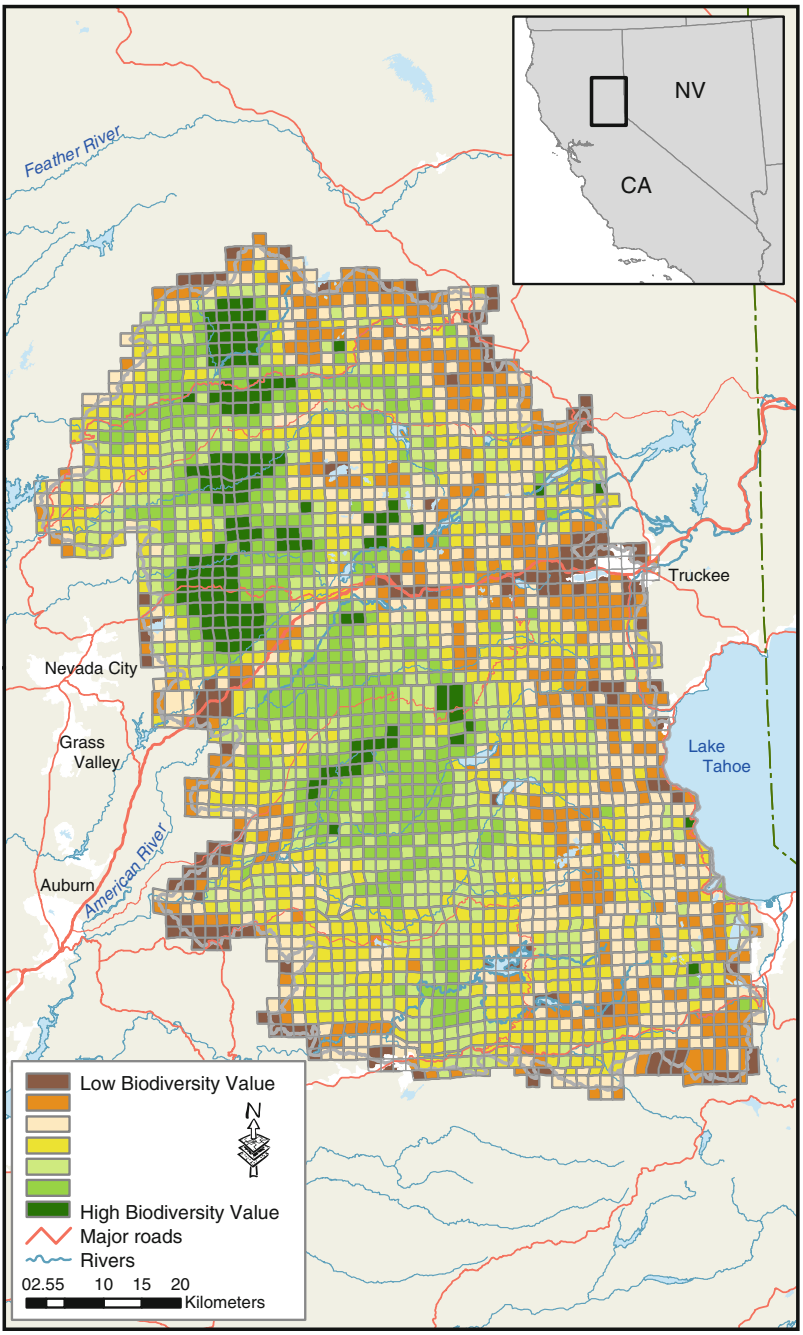


Fig. 6 EMDS results for the biodiversity value

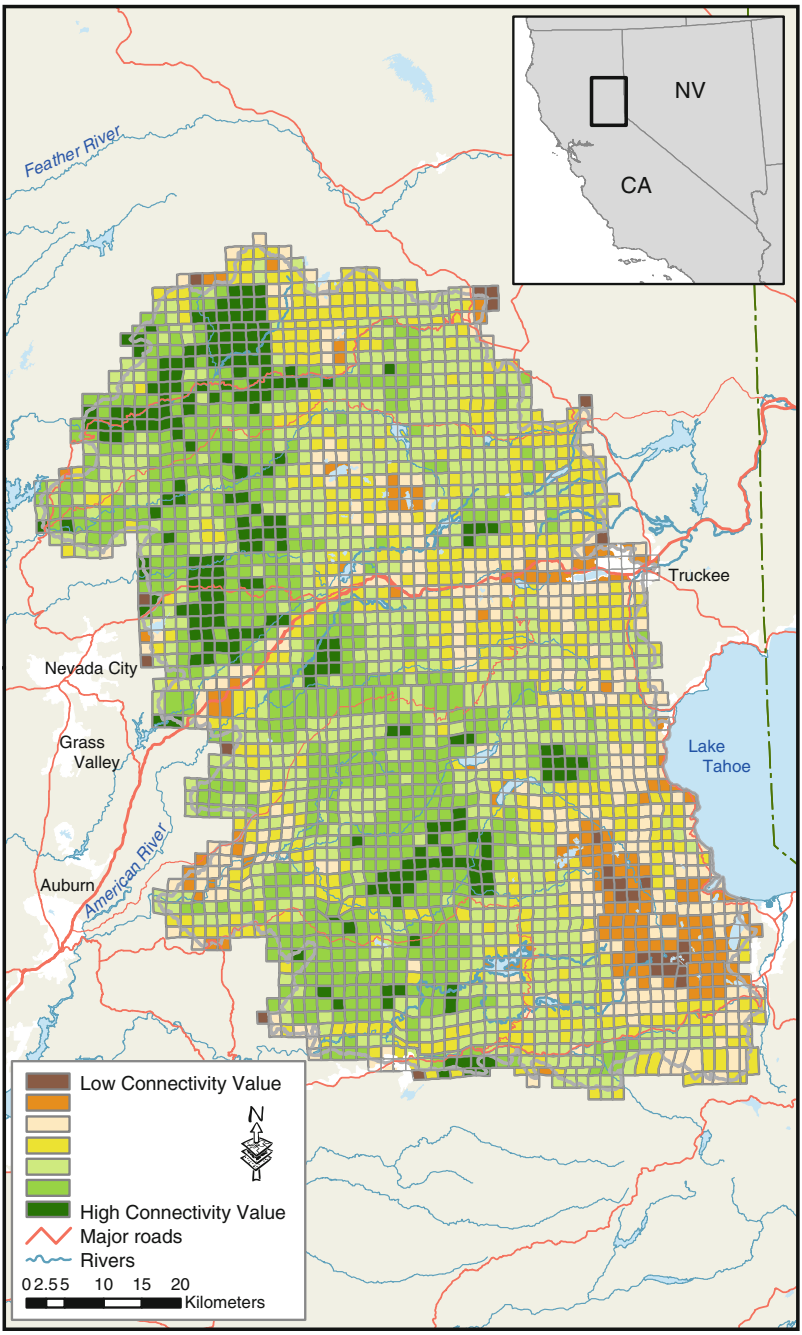


Fig. 7 EMDS results for mature forest connectivity value

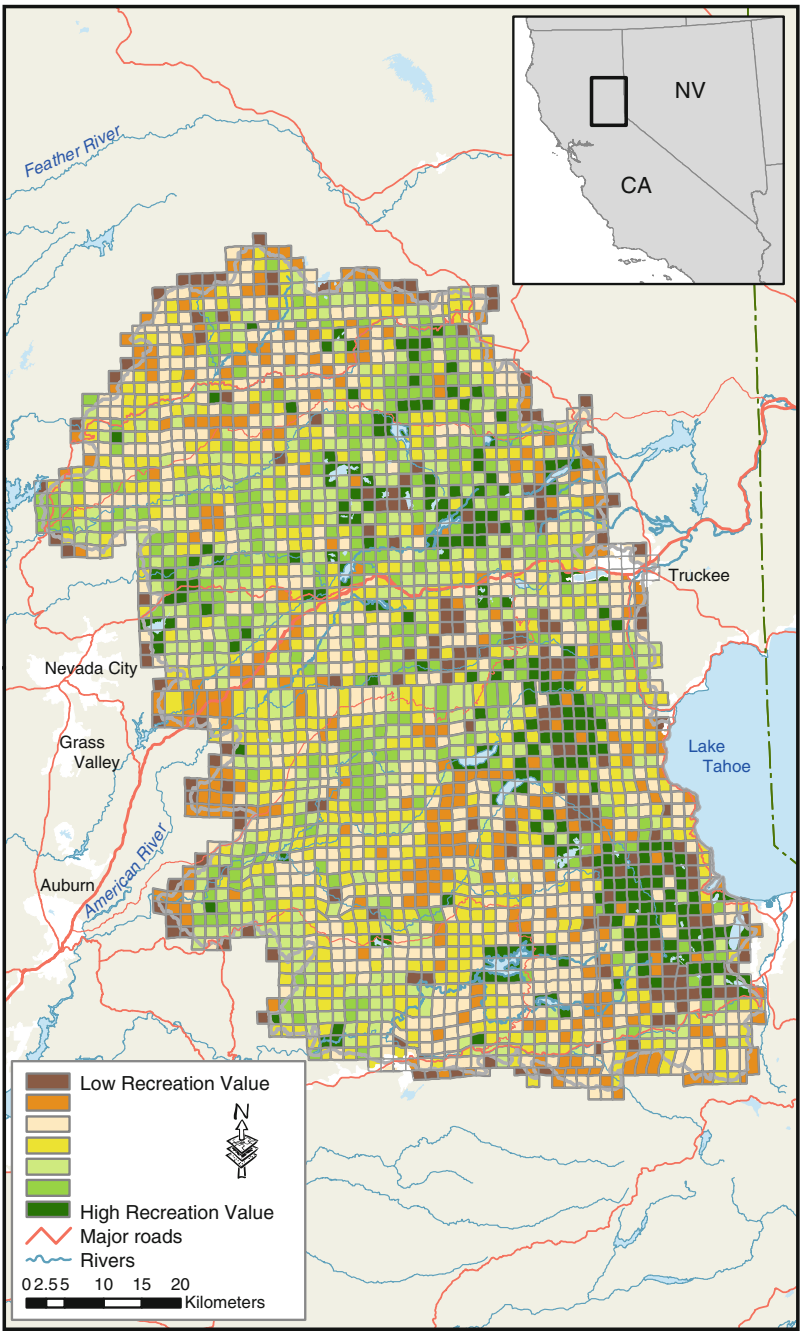


Fig. 8 EMDS results for passive recreation value

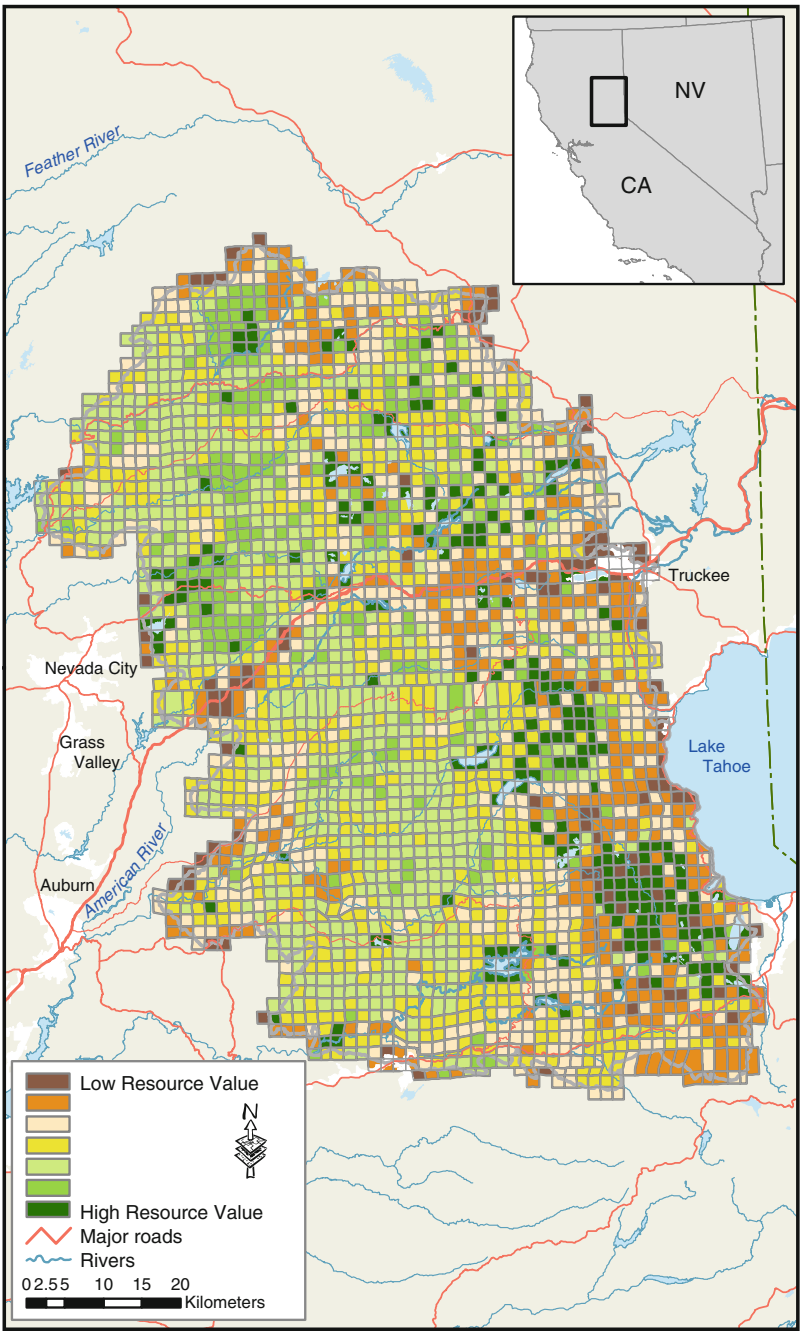


Fig. 9 EMDS results for resource value

values in the eastern (driven by Passive Recreation Value) and western halves (driven by Biodiversity and Mature Forest Connectivity Values) of the study area (Fig. 9). These results were used by TPL to identify and prioritize geographic areas supporting individual conservation values, or their specific elements. Conservation strategies were developed for the Sierra Checkerboard Initiative (White et al. 2008) to address specific values in priority areas. For example, privately-owned landscape areas or watersheds that were currently in good condition could be prioritized for fee simple purchase or could be considered for conservation easements. In other areas, for example, on actively managed forest lands, management agreements could be negotiated with owners who possess lands that currently display a low to moderate conservation value, but with good chance of recovery.

In developing conservation strategies, we used the results of our EMDS models to identify portions of the study area that supported specific conservation values, or key elements of conservation values (e.g., high integrity watershed basins). For these lands, we developed desired future conditions to maintain or enhance these values, identified potential conservation implementation strategies, and potential funding mechanisms to achieve these outcomes. The results of the EMDS analysis were used by TPL and their partners to clearly explain the rationale for their decisions and to garner support for the Sierra Checkerboard Initiative.

4 Conclusions

EMDS is a useful tool for conservation planners, allowing them to explicitly design logic models to define conservation values, the interrelations between factors contributing to conservation value, and the influence of specific data sets in determining the results. We have successfully applied EMDS in several conservation planning applications that demonstrate its utility. In the Sierra Checkerboard Initiative, we used EMDS to define and integrate three distinct conservation values: biodiversity, mature forest connectivity, and passive recreation. This approach had a number of important advantages: (1) we were able to apply our conceptual model regarding conservation values to a knowledgebase; (2) the knowledgebase linked our concept with spatial data representing conservation values in a transparent manner; (3) we produced spatially explicit maps of the results with intuitive results; (4) our logic models were defined such that our conservation partners and end-users could understand our assumptions, model structure, and results; (5) the influence and interrelationships of specific variables within the knowledgebase could be understood by all observers; and (6) the use of EMDS allowed us to easily integrate disparate data sets across a large and complex landscape.

Acknowledgments Funding for the Sierra Checkerboard Initiative was provided by grants from the Richard and Rhoda Goldman Fund, the Bella Vista Foundation, and The Sierra Fund to the Trust for Public Land. Keith Reynolds provided valuable guidance with EMDS and NetWeaver

software. Members of the Sierra Checkerboard Initiative Science Advisory Panel—Michael Barbour, Frank Davis, Don Erman, David Graber, Bob Heald, and Bill Zielinski provided valuable input and advice. We thank Sue Britting for her contributions to the project. Wayne Spencer provided useful comments on this manuscript. We thank the Trust for Public Land's Sierra Checkerboard Initiative team—Dave Sutton, Elise Holland, Robin Park, Carl Somers, Trish Strickland, and Dan Martin for their support.

References

Brooks TM, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Rylands AB, Konstant WR, Flick P, Pilgrim J, Oldfield S, Magain G, Hilton-Taylor C (2002) Habitat loss and extinction in the hotspots of biodiversity. Conserv Biol 6:91–100

Callicott JB (1990) Whither conservation ethics? Conserv Biol 4:15–20

Chan KMA, Shaw MR, Cameron DR, Underwood EC, Daily GC (2006) Conservation planning for ecosystem services. PLoS Biol 4(11):e379. doi:10.1371/journal.pbio.0040379

Conservation International (2005) Biodiversity hotspots revisited. Center for Applied Biodiversity Science at Conservation International. http://www.biodiversityhotspots.org/xp/hotspots

Crooks KR (2002) Relative sensitivities of mammalian carnivores to habitat fragmentation. Conserv Biol 16:488–502

Daily GC, Alexander S, Ehrlich PR, Goulder L, Lubchenco J, Matson PA, Mooney HA, Postel S, Schneider SH, Tilman D, Woodwell GM (1997) Ecosystem services: benefits supplied to human societies by natural ecosystems. Issues Ecol 2:1–18

Duane T (1996) Recreation in the Sierra. In: Sierra Nevada ecosystem project, final report to Congress, vol II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources. http://ceres.ca.gov/snep/pubs/

Duane T (1999) Shaping the Sierra: nature, culture, and conflict in the changing West. University of California Press, Berkeley

Franklin JF, Fites-Kaufmann JA (1996) Assessment of late successional forests in the Sierra Nevada. In: Sierra Nevada ecosystem project, final report to Congress, vol II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources. http://ceres.ca.gov/snep/pubs/

Gordon SN, Johnson KN, Reynolds KM, Crist P, Brown N (2004) Decision support systems for forest biodiversity: evaluation of current systems and future needs. Final Report—Project A10 National Commission on Science and Sustainable Forestry. www.ncssf.org

Graber DM (1996) Status of terrestrial invertebrates. In: Sierra Nevada ecosystem project, final report to Congress, vol II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources. http://ceres.ca.gov/snep/pubs/

Groves CR (2003) Drafting a Conservation Blueprint: A Practitioner's Guide to Planning for Biodiversity. Island Press, Washington, DC

Humphries HC, Bourgeron PS, Reynolds KM (2008) Suitability for conservation as a criterion in regional conservation network selection. Biodivers Conserv 17:467–492

Jennings S, Nussbaum R, Judd N, Evans T (2003) The high conservation value forest toolkit, 1st edn. Proforest. http://hcvnetwork.org/

Kattelmann R (1996) Hydrology and water resources. In: Sierra Nevada ecosystem project, final report to Congress, vol II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources. http://ceres.ca.gov/snep/pubs/

Lindenmayer DB, Franklin JF (2002) Conserving forest biodiversity: a comprehensive multiscaled approach. Island Press, Washington, DC

Manzuli AG (2005) Knowledge-based monitoring and evaluation system of land use: assessing the ecosystem conservation status in the influence area of a gas pipeline in Bolivia. Doctoral dissertation Mathematisch-Naturwissenschaftlichen Fakultäten der Georg-August-Universität Göttingen, Germany

Marcot BG (1997) Biodiversity of old forests of the West: a lesson from our elders. In: Kohm KA, Franklin JF (eds) Creating a forestry for the 21st century: the science of ecosystem management. Island Press, Washington, DC

Margules CR, Pressey RL (2000) Systematic conservation planning. Nature 405:243–253

McGarigal K, Cushman SA, Neel MC, Ene E (2002) FRAGSTATS: spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available at www.umass.edu/landeco/research/fragstats/fragstats.html

Millennium Assessment (The) (2005) Millennium ecosystem assessment synthesis report. www.millenniumassessment.org/en/index.aspx

Mittermeier RA, Meyers N, Mittermeier CG (1999) Hotspots: earth's biologically richest and most endangered terrestrial ecoregions. CEMEX, Mexico City

Pinchot G (1947) Breaking new ground. Brace and Company, Harcourt, New York

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC (1997) The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47:769–784

Reynolds KM (2001) Fuzzy logic knowledge bases in integrated landscape assessment: examples and possibilities. General technical report PNW-GTR-521. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR

Reynolds K (2003) Ecosystem management decision support extension. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR

Reynolds KM, Jensen M, Andreasen J, Goodman I (2000) Knowledge-based assessment of watershed condition. Comput Electron Agric 27:315–333

Saunders DN, Hobbs RJ, Margules CR (1991) Biological consequences of ecosystem fragmentation: a review. Conserv Biol 5:18–32

Scott JMFW, Davis RG, McGhie RG, Wright RG, Groves C, Estes J (2001) Nature reserves: do they capture the full range of America's biological diversity? Ecol Appl 11:999–1007

Shevock JR (1996) Status of rare and endemic plants. In: Sierra Nevada ecosystem project, final report to Congress, vol II, Assessments and scientific basis for management options. University of California at Davis, Centers for Water and Wildland Resources. http://ceres.ca.gov/snep/pubs/

Sierra Nevada Ecosystem Project (SNEP) (1996) Sierra Nevada ecosystem project, final report to Congress, vol I, Assessment summaries and management strategies. University of California at Davis, Centers for Water and Wildland Resources

Staus N, Strittholt JR, DellaSala DA (2010) Evaluating high conservation value in western Oregon, USA, with a decision support model. Conserv Biol 24:711–720

Stoms DM, McDonald JM, Davis FW (2000) Knowledge-based site suitability assessment for new NRS reserves for the proposed UC Merced campus. University of California, Santa Barbara. http://www.biogeog.ucsb.edu/projects/snner/nrs_report.pdf

Stoms DM, McDonald JM, Davis FW (2002) Fuzzy assessment of land suitability for scientific research reserves. Environ Manage 29:545–558

Strittholt JR, Frost PA, Staus N, Rustigian H, Heilman G Jr (2006) A global conservation prioritization assessment using EMDS. A special report for the Full Circle Foundation, Hong Kong

Strittholt JR, Staus N, Heilman G Jr, Bergquist J (2007) Mapping high conservation value and endangered forests in the Alberta Foothills using spatially explicit decision support tools. Special report for Limited Brands. http://consbio.org/what-we-do/mapping-high-conservation-value-and-endangered-forests-in-the-alberta-foothills-using-spatially-explicit-decision-support-tools?searchterm=alber

Swart JAA, van der Windt HJ, Keulartz J (2001) Valuation of nature in conservation and restoration. Restor Ecol 9(2):230–238

Trombulak SC, Frissell CA (2000) Review of the ecological effects of roads and terrestrial and aquatic communities. Conserv Biol 14:18–30

U.S. Forest Service (USFS) (2001) Sierra Nevada forest plan amendment, final environmental impact statement. United States Department of Agriculture, Forest Service, Pacific Southwest Region, Jan

White MD, Heilman GE, Stallcup JA (2005a) Science assessment for the Sierra checkerboard initiative. Prepared for the trust for public land, July. http://consbio.org/files/sierra-assessment-p1-report.pdf

White MD, Heilman GE, Stallcup JA (2005b) Online technical appendix to the science assessment for the Sierra checkerboard initiative. Prepared for the trust for public land, July. http://consbio.org/what-we-do/science-assessment-for-the-sierra-checkerboard-2/full-metadata-index/science-assessment-for-the-sierra-checkerboard

White MD, Heilman GE, Budge NA (2008) Conservation stratgey for implementing the Sierra checkerboard initiative. Prepared for the trust for public land, Jan. http://consbio.org/files/Final%20Sierra%20Checkerboard%20Conservation%20Strategy.pdf

Zhu Z, Reed BC (eds) (2012) Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the Western United States. U.S. Geological Survey Professional Paper 1797, p 192. http://pubs.usgs.gov/pp/1797/