Sensitivity of Forest Vegetation Simulations to Scale of the Input Data and Impact to Estimates of Key Habitat Indictors, Tree Size, and Density

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Abstract—We demonstrate that the results of landscape-level vegetation projections using FVS differ depending on the strategy used to aggregate the input data. To illustrate the point, we picked landscape-level variables that are important to addressing habitat components for old forest-dependent species, a contemporary forest management issue for the Sierra Nevada Bioregion, California. The approach was to compare FVS results using: (1) Traditional strata maps developed by USDA Forest Service Region 5 for regional planning where the "average" condition of all the relevant FIA plots is aggregated into a series of timber strata representative of large landscapes. (2) Modified strata maps developed by calculating the "mode" of the relevant FIA plots but also aggregated into timber strata. (3) Projections of the individual FIA plots without aggregation. Interpretation of two continuously valued variables we studied did not vary significantly between aggregation methods, but the interpretation of the discretely classed variables greatly differed. Our inspection of the results suggested that the unaggregated data gave more realistic projections of size and density distribution that seemed to best represent fundamental ecological processes. Nonetheless, we argue that using aggregated data is necessary when the spatial integrity of the analysis needs to be maintained. The implications of our observations on landscape analysis are discussed.

The paradigm for management of the California National Forest lands has shifted away from management for resource production such as timber and mining and into management strategies for preserving and enhancing habitat characteristics (Committee of Scientists 1999). The change is driven by the conflicts among the legal requirements for species preservation, reflecting a shift in societal perspectives, a burgeoning population (approaching 35 million within the State alone), the popularity of the diverse recreational activities offered by National Forest lands, and the continued need of the forests to provide water and other historic resources in support of local communities.

In an effort to reconcile the complicated interactions and conflicts among the many stakeholders, the Sierra Nevada Framework Project was established. The framework's original charge was to combine the best of the scientific knowledge within the Forest Service's Pacific Southwest Research Station and the best of the management experience within the interdisciplinary teams from Region 5 to prepare an Environmental Impact Statement for modifying the forest plans of the 10 National Forests and the Lake Tahoe Management Unit that occupy the Sierra Nevada Bioregion (Final Environmental Impact Statement 2000).

The work was intended as an outgrowth of the Sierra Nevada Ecological Project (Sierra Nevada Ecosystem Project 1996) submitted as a Congressional report. Out of that project, five key topics emerged as the most serious threat to the health and sustainability of Sierran ecosystems (Record of Decision 2001):

- Protect, increase, and perpetuate old forest ecosystems and provide for the viability of native plant and animal species associated with old forest ecosystems.
- Protect and restore aquatic, riparian, and meadow ecosystems and provide for the viability of native plant and animal species associated with these ecosystems.
- Manage fire and fuels in a consistent manner across the National Forests, coordinate management strategies with other ownerships, integrate fire and fuels management objectives with other natural resource management objectives, address the role of wildland fire, and set priorities for fire and fuels management actions.
- Reduce and, where possible, reverse the spread of noxious weeds.
- Maintain and enhance hardwood forest ecosystems in the lower westside of the Sierra Nevada.

The charge of the Framework was to use all available tools to define, analyze, evaluate, and present probable consequences of eight independent management alternatives developed to address the five key topics. To do so, the Forest Vegetation Simulator (FVS) was used in combination with several other models to produce a set of scenarios where the needs of forest, woodland and riparian habitats were balanced with needs of fire protection, while attempting to return Sierran ecosystems to a more natural fire regime and ecological balance.

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The Sierra Nevada Bioregion occupies roughly 15 million acres, of which the Forest Service manages 11.5 million acres. The remaining lands are a polyglot of private, State, National Parks, and other Federal agency ownership. The primary range extends for about 800 miles, roughly north-south and about 120 miles in the east-west direction. The elevations start at near sea level on the western edge and climb to the highest peak in the continental United States at Mount Whitney at over 14,000 feet. Because of the huge diversity in geological formations leading to widely varying landscapes, California contains the highest number of individual ecosystems of any U.S. State. Half of that natural diversity in California resides in the Sierra Nevada Bioregion (Sawyer and Keeler-Wolf 1995). Human population forecasts indicate between 1.8 and 2.0 million people will occupy the region in 2040, mostly at elevations below 7,000 feet (Duane 1996). The population densities are heaviest in the central and southern part of the bioregion. In addition to permanent residents, the Sierra Nevada draws millions of visitors every year. Like the permanent settlements, visitor days tend to be heaviest in the central part of the region. The management emphasis on several of the individual National Forests has slowly shifted from resource extraction to recreation, both of which can have significant impacts on habitat quality (Final Environmental Impact Statement 2000).

Sierran ecosystems are highly heterogeneous with patches of dense, young trees immediately adjacent to open stands of very old trees, large trees emerging from shrub patches, and an interdigitation of ecosystems that makes accurate mapping and identification difficult at a scale appropriate for the characterization of habitat for many animals. Understanding and projecting vegetation characteristics that are key to habitat values is a relatively new science. By far the most challenging aspect of habitat projections is simply identifying key vegetation characteristics required by specific species in a quantitative manner. And, obviously, key characteristics are species-dependent, thus highly variable in scale. What might be an important requirement for foraging habitat for the Sierran fisher would be of little quantitative use in understanding habitat for yellow-legged frogs.

Many of the metrics used in standard FVS modeling such as tree size and density were useful for vegetation modeling for habitat characteristics. Other metrics need to be modified or developed such as distribution patterns of trees and growth projections for nontree species. This being said, however, the FVS offers the best and most comprehensive model for landscape-scale evaluation of forest responses to management alternatives.

Two primary sources of input data are available for Sierrawide modeling — the Forest Inventory Assessment (plot-based) data, and the Region 5 strata maps, developed from satellite imagery. The two data systems have been coordinated so that strata map information corresponds to plot information and vise-a-versa. The strata maps use broad forest-type categories and for the most part, underrepresent nontimber types. For example, the presence of as little as 10 percent conifers in a stand of oaks is enough to have the stand classified as a conifer-type. However, the maps are important visual tools for decisionmaking and for presentation to stakeholders and the public at large. The FIA plot data, on the other hand, includes species composition, vegetation distribution patterns, and historical information but can only represent a small sampling of particular places. It is impossible to derive map products from the FIA data alone. In the Sierra Nevada, because of the scale and heterogeneous nature of the forests, the statistical variation within a cluster plot may exceed the variation across plots.

An effort was made to combine the two data sets in a way that allowed for reclassification of the forest strata data based on the FIA distribution information and then use FVS projection of this new hybrid data to estimate changes over time. An interesting problem occurred during this hybridization process: the results of vegetation projections for the eight proposed alternatives differed substantially depending on whether the strata average, strata mode, or pure FIA plot data were used for the input data source.

What follows is a summary of the approach for combining map-based information with the FIA data, the results of the different data reduction schemes and a brief discussion of the use of the FVS in evaluation of key habitat indicators. This paper explores the sensitivity of a number a continuous variables such as the number of large trees, and class habitat data such as serial stage, under various level of data aggregation from the plots, to the stand, the stratum, and the landscape. The implications for using these data at different scales are discussed.

Methods and Materials

Vegetative Mapping and Stratification

The forests within Sierra Nevada Bioregion were mapped from Thematic Mapper satellite imagery. Map polygons representing forest species type, tree size classes, and crown cover density were defined by processing the satellite imagery data by a combination of supervised and unsupervised classification systems. Vegetation maps were produced first using spectral analysis of data combined with ecological modeling. Polygons representing stands of trees defined by major forest type, tree size, and canopy closure density class were the primary sampling units for assignment of the ground plot data used to describe these strata. These vegetation-type polygons are the basic unit for which management decisions are made and are the unit areas for which wildlife habitat type is typically assigned within Region 5.

Linking Ground Plot Data to Map Polygons

Approximately 2,900 Forest Inventory and Analysis (FIA) plots were distributed across the 10 National Forests in Region 5. The individual sample plots are aggregated into vegetation classifications according to a vegetation map defined above. This map is the primary bookkeeping tool for tracking vegetation on the forests, based on summaries of the plots sampled within each strata.

Forest inventory ground data were linked to forest type or polygon maps through the strata label attribute. That is, the unique vegetation labels from the FIA data were aggregated into similar classes and then ground plots were allocated to vegetation polygons. Traditionally, these strata were defined for the purpose of sampling timber volume. Each vegetation polygon was then assigned to a stratum which

had an associated set of FIA plot data. The total number of acres on a particular national forest associated with a given stratum label was estimated by summing among map polygons with identical stratum labels. For example, the total number of large trees (those greater than 30 inches d.b.h.) associated with map areas within a given stratum label were estimated by calculating the per acre average from the inventory data and multiplying by total number of acres as determined from the vegetation type map.

The Region 5 method of using vegetation-type maps to stratify and assign ground plots was designed to describe general conditions, relative to timber, especially stocking measured by cubic volume. There was no intent to provide detail description of vegetation condition in any specific place, much less all places. As a consequence, data from 2,978 plots used in this analysis cannot be used to describe any other polygon than the one sampled.

CWHR System

The California Wildlife Habitat Relationships System (CWHR) is a generalized model of habitat relationships for 643 resident or regularly migrant terrestrial vertebrate species in California (CWHR 1988). The University of California at Berkeley and the California Department of Fish and Game developed it, cooperatively. The CWHR models were originally designed to closely approximate the timber strata presented in FIA system. The system allows a user to predict the occurrence and habitat quality for any of these species based upon the presence of specific habitat types or habitat elements. It includes species notes for each species including life history, range maps, legal status, habitat requirements, and so forth. The CWHR habitat system, like many other vegetation classification systems, uses the combination of plant species, size, and density to classify habitats. The CWHR system then uses this habitat classification to identify habitat relationships between the vegetation and the wildlife specie likely to be found in that area.

The CWHR models are designed to evaluate wildlife response to habitat change over relatively large spatial and temporal scales. CWHR was considered an appropriate approach to a quantitative analysis at the bioregional scale for a large array of species that occur in the Sierra Nevada. The accuracy of this model for many species is often enhanced with information on special habitat elements such as snags or dead and down material. CWHR was conceived to operate using existing timber type maps. Thus for the most part, the definition related to size and canopy closure was similar to those used for FIA.

Differing Needs, Conflicting Strategies — One Forest

One objective when developing a vegetation classification system is to create enough classes so that management activities can be modeled, while at the same time restraining the number of classes so that the modeling does not become excessively complex. The Region 5 planning efforts found that creating 16 to 50 vegetation classes or forest strata within an individual National Forest planning unit is the most appropriate for modeling activities over time at that scale. Without a stratification scheme, each of the Sierran Forests would contain between 350 and 800 individual vegetation types. Other than making the modeling effort cumbersome, collecting plot-level data for 350 to 800 independent vegetation types is unrealistic under the current FIA protocols and enormously expensive for the individual Forests to undertake on their own. Lumping vegetation types, however, reduces the depth of information available to conduct ecosystem assessments for key species or critical habitats. Many of the ecosystems (or habitat types) of greatest concern occupy small land areas, thus perhaps lost in the large classification schemes. Therefore, the variation among plots within strata is equally important as the average trend of the strata. We tracked this variation by classifying each plot in a consistent manner and then tabulating the number of plots of each class found within each stratum. Plots, which are stand-level characterizations, were classified first into forest types according to a standardized rule set developed by Region 5, and then into size and canopy closure classes based on the CWHR typing scheme (table 1).

Table 1—Definition of California Wildlife Habitat Relations tree classifications.

CWHR HABITAT STAGES			YOUNG				MATURE		
			size class 0	size class 1	size class 2	size class 3	size class 4	size class 5	size class 6
			non-stocked	seedling	sapling	poles	small tree	large tree	multi-canopy
				<1-in DBH	1-5.9"-DBH	6-10.9"-DBH	11"-23.9"-DBH	>23.9"-DBH	size 5 over 4 or 3
OPEN	no cover	<10% canopy cover	non-stocked	stocked					
OPEN	sparse cover (S)	10-24% canopy cover		1x	2S	3S	4S	5S	
OPEN	open cover (P)	25-39% canopy cover		1x	2P	3P	4P	5P	
CLOSED	moderate cover (M)	40-59% canopy cover		1x	2M	3P	4M	5M	
CLOSED	dense cover (D)	60-100% canopy cover		1x	2D	3D	4D	5D	6

Application of the Forest Vegetative Simulator to Habitat Assessment

The FVS is the basic tool for simulating forest dynamics at the plot or stand level. Projections of management activities on changes in tree size class and density are a critical part of the National Forest analytical process for habitat assessment. Inspection of initial projections using ecological principles indicated a bias in the results and suggested that the bias might be due to the original starting condition data set. To test this hypothesis, the starting condition was adjusted to reflect three statistical approaches:

Stratum Average Condition: This is the traditional way of modeling forest dynamics by aggregating like FIA plot data from the same vegetation zone into a single stratum. Projections were then made using data that were aggregated by strata label as the initial condition.

Stratum Modal Condition: This method applies the most frequently encountered value (the mode) of all plots, rather than the arithmetic average. This value is then applied to the stratum. It most closely reflects timber type maps from which the CWHR stand classifications were based. Projections in FVS were based on the aggregated strata as the initial condition.

Plot Average Condition: Each vegetation-type plot was treated separately. Proportionate weight of the plots relative to the landscape is based on the total area represented by the plot within the stratum. For example, if there were six plots used to describe a stratum of 12,000 acres, each plot would carry a weight of 1/6 of 12,000 or 2,000 acres. Each of these 2,000 acre "plots" were then projected individually, rather than beginning with an aggregated strata. Following each period of projections, the total number of acres was reapportioned based on the percent of land occupied by that plot within the stratum, and then a new round of modeling would begin.

Results

Three examples of outcomes from FVS modeling of Sierran forests based on differing input data are shown in figure 1. Each panel represents a tree size and stand density that was identified as suitable habitat for old forest dependent species. The size classes for the trees are species dependent. In general, size class 4 would be saw timber less than 24 inches dbh, class 5 would be trees greater than 24 inches dbh. The "D" in the delineation indicates a dense stand. Size class 6 is unique in that it takes into account understory structure as it contributes to a multilayered stand of tall, large trees with smaller trees and large shrubs in the understory. The measure used in the analysis was acres occupied by each size class and density class, regardless of the species composition.

These data demonstrate three patterns in modeling results. The size class 4D begins with a relatively similar number of acres across the different input data; the plot-based data are slightly lower than the strata and mode data (which are nearly identical) (fig. 1A). Over the 150-year projection, the number of acres consistently decline, but the rates of decline differ so that projections 150 years out using the plot data indicate more acres than either the strata mean or mode data. The example shown for the 5D class begins with different starting acres (fig. 1B). Neither the strata mean nor the mode data include any initial acres in this class, while the dataset that maintains the richness of the individual plots indicates roughly 16,500 acres. The projections for future acres also differ substantially. The projections using the modal data indicate no change in acreage until the eighth decade, an increase to about 10,000 acres, and a subsequent decline back to near zero by the end of the period. The strata mean-based data starts with a 25,000 increase in the first two periods and then a drop back to nearly the starting point. This type of outcome seems most prevalent in class-based data; the fewer the classes and the bigger the categories, then the more likely stands are prone

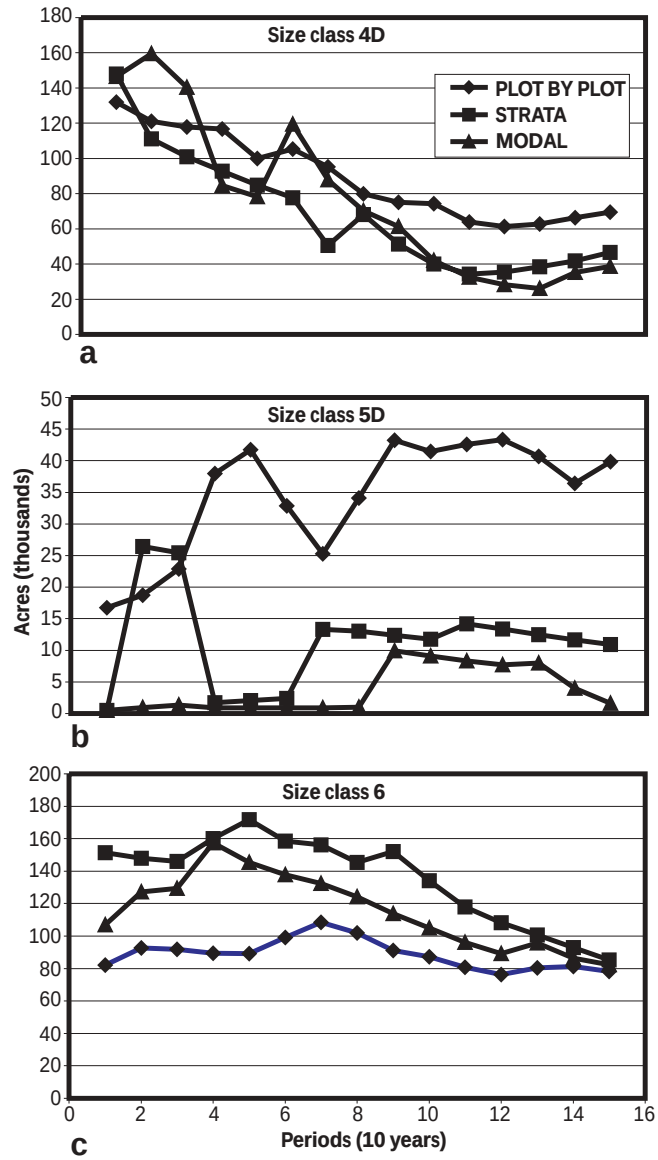

Figure 1—Projected changes in acres of tree size classes and tree densities assumed to be important to old forest dependent species.

to sudden jumps from one class to another. A second jump occurs in the seventh period, and the number of acres remains fairly stable, or perhaps decreases slightly. The more detailed plot data illustrates an entirely different result. Not only is the starting point much greater, acres increased over the modeled period. A loss of more than 10,000 acres is shown in year 70, but the loss seems to be recovered 20 years later. Using acres classed as 6, the starting data differs by about 2.5 fold, but all three datasets converge at 55,000 acres after 150 years (fig. 1C). All results indicate a decline in acres. The plot-based dataset starts at about 57,000 showing the smallest decline, while the averaged strata data decline to less that half of its starting acres.

In contrast, the continuous variables (number of trees greater than 30 inches and number of snags) show little dataset-based differences (fig. 2). A slight increase in the number of large trees is observed for the plot data. The mean and mode data indicates a slight increase in the first seven decades and subsequent decline back to the starting point by year 150. Snags (an admittedly difficult parameter to model, for lack of empirical data) increase by about 13 percent in all cases.

If it is assumed that the total acres in forested lands do not change over time, by plotting all size classes and densities together in a single figure one can ascertain (within the model) how stands change over time (fig. 3). In comparing the projections by input dataset, changes based on plot data are smoother than either of the other datasets. Both the strata mean and strata mode start with larger inventories of 4M (smaller saw timber in moderately dense stands), smaller inventories of seedlings, and sparse and light stands, and particularly in the strata mean approach size classes 5D and 6. Most of the difference between the methods occurs in the first half of the modeling period.

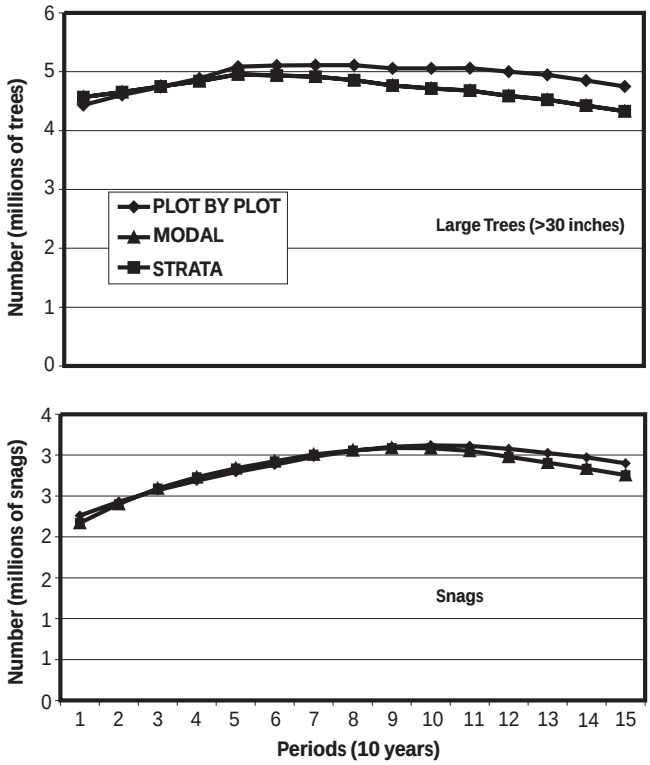

Figure 2—Projected changes in the number of large trees and snags, continuous variables, over a 150-year modeled period.

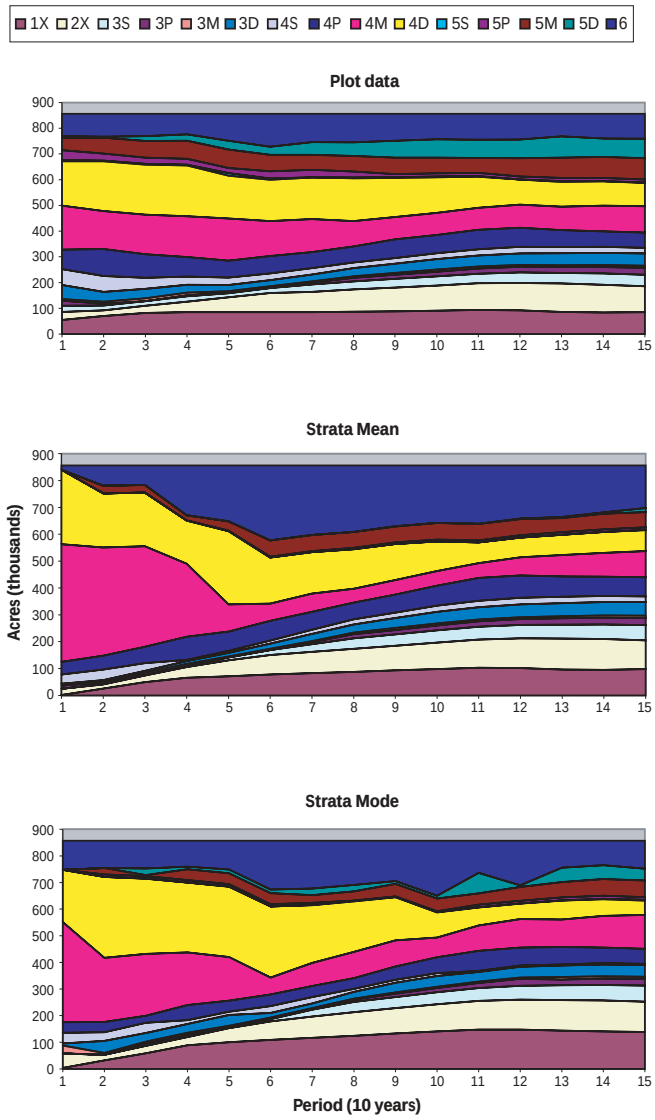

Figure 3—Combined changes in all size classes and tree densities over a 150-year modeled period.

Discussion

Each input source had its own strengths and weaknesses depending on the objective of the projections and the needs of the analysis. Using nonaggregated plot data allows us to maintain the data richness of the plots, but we lost spatial integrity. When aggregations based on the mean and modes were used, we lost track of very small or very large size classes and densities but maintained the spatial integrity of large geographic images.

The problem with assessing habitat condition using the individual FIA plots as the input data source is that there are more polygons within the stratum than there are FIA plots to represent the polygons. This means that the majority of polygons are not sampled on the ground and therefore, no direct linkage between the mapped data and the plot data can be maintained. Because the plot data cannot be mapped as a continuum, one loses the geographic integrity of a map.

Averaging plots, on the other hand, may create a model "vegetation stratum" that does not actually occur, especially if the distribution of plot stand conditions is not a normal distribution. However, the geographic coverage is maintained and a map product can be produced. An alternative to averaging plot data is to use the statistical mode of the plot data. Under this scheme, polygons are classified based on the most frequent or modal condition found within or between stands within the same stratum. This method most closely imitates the traditional interpretation of aerial photos used to develop timber types maps that were most of the source material when CWHR system was developed.

Forest Vegetation Simulator projection of continuous variables such as the number of large trees or the number of snags indicated close correspondence among the three data input variants. In contrast we found large differences among the three approaches when discrete data sets, such as size and density classes, were projected. Stratum averages or modes tend to promote large numbers of acres into the next class, resulting in gains or losses of particular classes in timeframes that seem unrealistic from an ecological perspective.

Scale is a key concept in habitat analysis. However, managers, biologists, and other specialists often fail to adequately consider the impacts of scale especially when developing desired future condition or rules to limited or restrict activities. Improvements and ease in digital processing vegetative mapping and plot data have made conducting analyses at appropriate scales and resolution both more important and at the same time more difficult. Increasingly, forest managers are expected to assess the implications of management activities beyond the site being treated and to broader landscape impacts. This necessitates sampling and using remote means to provide maps and descriptions of various habitats. This can be problematic when variables such as species, size, density, and spatial arrangement of the vegetation are considered important. Maps and related data tables can be valuable tools for understanding; however, they may mislead investigators. Analysts share the responsibility to ensure that habitat information used in decisionmaking are instructive generalizations and not misrepresentations.

In conclusion, forest management objectives shift in response to population pressure and changes in the public desires from their lands. In California forests, and other regions adjacent to large urban centers, human activities and expectations of the National Forest System are often conflicting. The ability to understand and project the outcomes of management activities and decisions is crucial to planning. Not only are habitat and ecosystem assessments used within the forest management teams but also for interactions with the public. The Forest Vegetation Simulator is a powerful information tool but care must be taken in understanding the scale at which the primary data are used and interpreted.

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