Use of GIS in Optimizing Timber Thinning Strategies in the Eastern Sierra Nevada

By: Paul A. Knapp, Judith M. Lancaster, Kathleen A. Bishop, and Richard L. Taylor

1993 Knapp, P.A.; Lancaster, J.; Bishop, K.; and Taylor, R.L. Use of GIS in optimizing timber-thinning strategies in the eastern Sierra Nevada. The Professional Geographer 45:323-331.

Abstract:
This paper demonstrated the use of Geographic Information System (GIS) to develop timber thinning strategies on the Kyburz Planning Area of the Tahoe National Forest in northeastern California. The primary criteria used in an assessment of selective thinning potential were forest health and fire hazard ratings. By eliminating environmentally sensitive, economically unfeasible, or low fire hazard areas from consideration, the use of GIS reduced the area that was considered appropriate for thinning by approximately 58%. GIS offers considerable potential for improving resource management strategies.
Key words: timber thinning, fire hazards, GIS, Tahoe National Forest

Article:
The Kyburz Planning Area (KPA) of the Tahoe National Forest, Sierraville Ranger District (SRD), is on the east slope of the Sierra Nevada Mountains and is a region that has a legacy of human impacts on the environment (Fig. 1). The first major anthropogenic impact was in the 1860s when a stage road was built through the area and a hotel/restaurant was constructed on the edge of the Kyburz Flat meadow. From the late 1800s through the early 1900s, the area was not under any form of management and sheep grazing was widespread. Particularly sensitive areas (i.e., meadows, fens, riparian areas) were excessively grazed. In addition, "cut and leave" logging practices, driven by the demand for lumber for the gold and silver mines in Nevada, were dominant from the late 1890s until the early 1930s. This type of logging practice harvested all the merchantable trees which were almost exclusively *Pinus ponderosa* (ponderosa pine), *P. jeffreyi* (Jeffreyi pine), and *P. lambertiana* (sugar pine). Tress left uncut were those that were either too small and poor quality timber such as *Abies concolor* (white fur) and *A. magnifica* (red fir), or were infested with the parasite mistletoe, *Arceuthobium spp*. The net result of these "cut and leave" activities was a forest of substantially different species dominance and a forest that had a high percentage of trees infested with mistletoe (R. M. Condon, Sale Administrator, Sierraville Ranger District, Tahoe National Forest, telephone call, 2 June 1992; Horvath et al, 1980; Gunderson, 1990).

The KPA came under the jurisdiction of the Tahoe National Forest in the early 1930s following the cessation of intense logging activities. Several management policies were implemented including a reduction in allowable grazing activities, stream restoration, construction of check dams, and discing and seeding of areas damaged by overgrazing. Timber activities were primarily confined to small, scattered sales designed to log dead, dying, and diseased trees. Fire suppression activities such as fire prevention without fuel treatment and aggressive suppression also began during the 1930s, although by 1961 the efficacy of this policy was challenged by the Donner Lake burn. This burn, which occurred from the Donner Lake area to the south border of the KPA, illustrated the potential for severe crown fires caused by the dense stands of unthinned trees (Condon 1992; Horvath et al. 1980).

In the early 1970s, fire suppression activities on the KPA were changed. New management practices included putting in fire breaks, thinning trees around human occupied areas, fuel treatment, and using prescribed/controlled burns during the spring months to reduce the chances of potentially more severe fires.

Wildfires, regardless of human or natural origin, are still extinguished as quickly as possible by the Forest Service (S. F. Bishop, District Ranger, Sierraville Ranger District, Tahoe National Forest, telephone call, 1 June 1992).

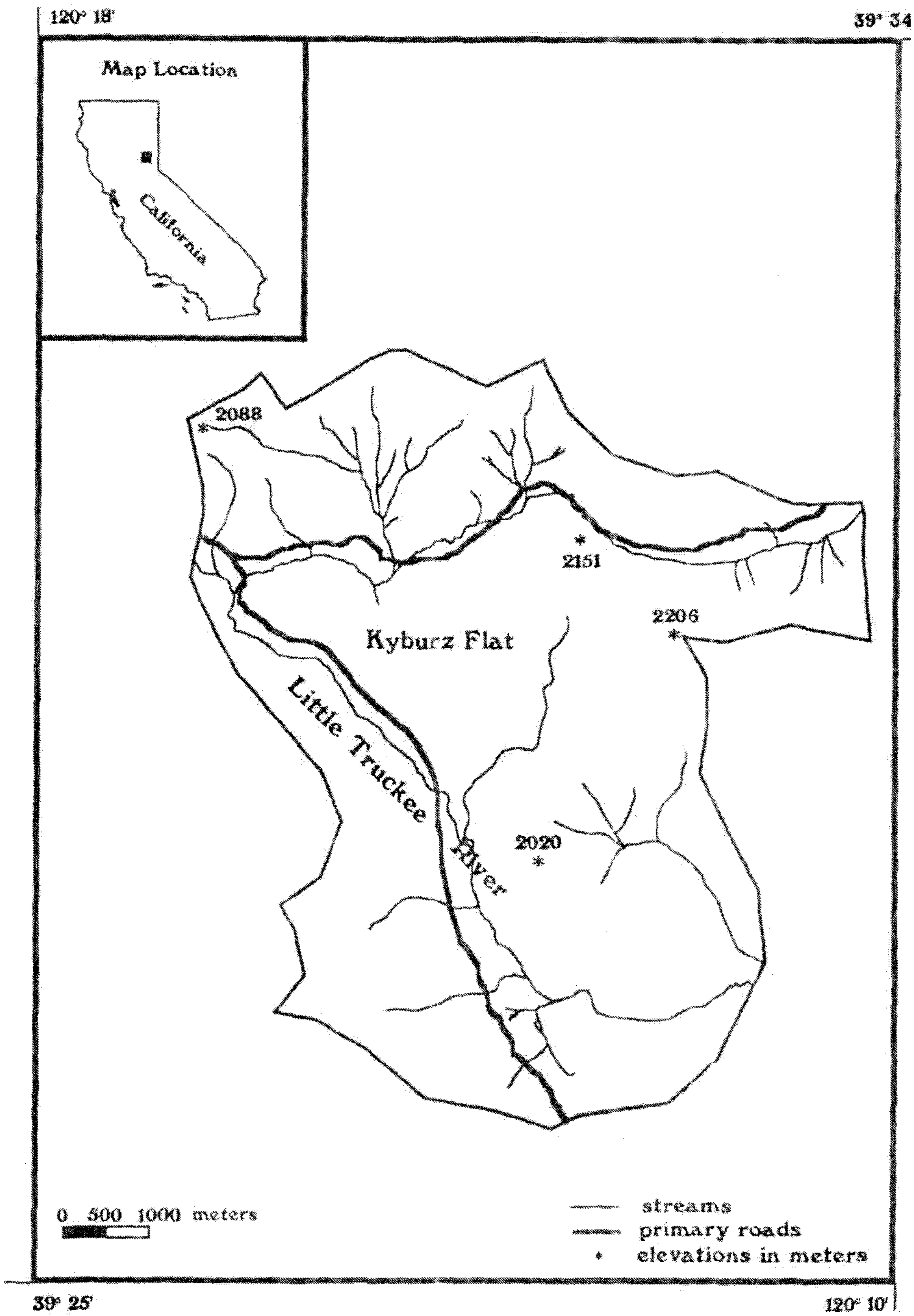

Figure 1: *The Kyburz Planning Area, California*

By the 1980s, the health of the KPA forests had become a major concern to SRD managers (R. M. Condon, telephone call, 2 June 1992). Decades of fire suppression had led to an overstocked (high tree density) condition that, in turn, had increased stress on the trees through a chain reaction of events. Conifers stressed by overstocked conditions become deficient in water, light, and nutrient supplies which made the species susceptible to bug infestations such as the fir engraver beetle. *Scolytus ventralis*, and the western pine beetle, *Dendroctonas brevicomis*. Similarly, stressed trees were also vulnerable to *Arceuthobium spp*. infections. These infections often reduce growth, deform trees, increase tree mortality and lead to an increased fire hazard (Geils and Mathiasen 1990; Hawksworth and Giels 1990; Mathiasen et al. 1990; Parmeter and Scharpf 1982). Coupled with the overstocked situation was the influence of a six-year drought that began during the wet season (winter) of 1985-1986. By the end of 1991, up to 10% of the trees (firs were especially affected) on the KPA were dead (S. F. Bishop, telephone call, 1 June 1992).

Given the history of the KPA, the SRD sought ways to best manage this forest resource. Traditional methods of determining potential thinning areas involved simple map interpretations; however, this technique did not allow the SRD personnel to view more than a couple of maps at a time or to mix and match maps to meet all of their criteria. In addition, the analysis of potential thinning areas was slow and tedious.

A Geographic Information System (GIS) was identified as a tool that could facilitate resource analysis. Specifically, the SRD was interested in using GIS as a rapid way to integrate resource information (both qualitatively and quantitatively) for assessing land cover characteristics on the KPA, and to present the assessment as a visible display for public consumption. The purpose of this paper is to demonstrated how GIS was used in determining areas most appropriate for selective tree thinning in the KPA. The methods and results of this study are then assessed to determine their applicability to other east-slope planning areas in the Sierra Nevada.

Study Area

The KPA covers an area of 45.17 km^2 and lies from 39° 26' 47" to 39° 31' 32" N and from 120° 10' 15" to 120° 15' 54" W. The topography varies from nearly flat meadows to steep slopes, and elevations range from approximately 1,830 to 2,206 m (Fig. 1). The KPA lies on the east slope of the Sierra Nevada and is in a weakly expressed rainshadow of the Sierra crest. Annual precipitation at Sierraville (elevation 1,509 m), which is approximately eight km north of the KPA, is 65 cm (NOAA 1991). Estimated annual precipitation at the KPA is from 65 to 90 cm depending on aspect and elevation (James 1964). Precipitation is winter-dominated with nearly 75% of the yearly total falling from November through April. Most precipitation falls as snow. Temperatures exhibit both large diurnal and seasonal contrasts with diurnal fluctuations often exceeding 22° C. The mean January and mean July temperatures for Sierraville are -2.8°C and 18.3°C, respectively. Slightly cooler (1-2° C) temperatures are found in the KPA.

The dominant trees of the KPA are pines (*Pinus jeffreyi, P. ponderosa*), firs (*Abies concolor, A. magnifica*), and juniper (*Juniperus occidentalis* [western]). Secondary trees are *Pinus lambertiana* (sugar pine), *P. monticola* (western white pine), and *P. murrayana* (lodgepole pine). The dominant shrubs are *Artemisia tridentate* (big sagebrush), *Purshia tridentate* (antelope bitterbrush), *Arctostaphylos patula* (Manzanita). *Symphoricarpos vacciniodes* (snowberry), *Cercocarpus ledifolius* (mountain mahogany), *Ceanothus velutinus* (tobacco brush), and *Prunas emarginata* (bitter cherry). The common herbs are *Lupinus breweri* (Brewer's lupine), *Wyethia mollis* (mountain mule-ears), *Monardella odoratissima* (mountain monardella), and *Paconia brownie* (wild peony). Meadows are dominated by *Agropyron spp*. (wheatgrass), *Carex spp*. (sedges), and *Brodiaea spp*. (brodiaea). Additional grasses that are scattered throughout the KPA are *Poa spp*. (bluegrass), *Agropyron spp.*, Bromus tectorum (*cheatgrass*), and *Fescue idahoensis* (Idaho fescue).

The soil types of the KPA are varied, and consist primarily of sandy, gravelly, or cobbley loams. Parent materials are either weathered andesite, fractured andesite, or andesitic tuff, although weathered rhyolite occurs in isolated areas. Rock outcrops are common within the KPA (Condon 1992).

Methods

Fifteen copies of 1:24,000 scale mylar composite topographic map were provided by the SRD to develop the KPA database. The base map was composed of parts of six 7.5-minute California quadrangles (Dog Valley, Sardine Peak, Sierraville, Boca, Hobart Mills, and Independence Lake) matched together so as to include the entire KPA. Each map included the boundary of the KPA and one of the following characteristics; percentage slope, management area sensitivity, soil erosion rating, soil compaction limitations, percentage soil cover, deer habitat zones, sensitive plant species, survey sections, streams, vegetation habitat types (based on species composition and dominance), roads, timber stands (based on size, health, density, and species composition), watershed boundaries, goshawk habitat, and fire hazard rating (based on standing fuel and forest litter in tons/acre). Information for all the maps was compiled by the SRD through 1:32,000 color IR aerial photography interpretation and field checks. Using PC ARC/INFO 3.4D, produced by ESRI, each map was digitized in vector format, and inaccurate in digitization were corrected using the "clean," "build," and "editfeature" commands. Attribute data for each variable class on the map were entered into tables, which could be cross-referenced with the map using the "join" command. A series of checks was made at each stage of entry to ensure the accuracy of map replication and attribute descriptions (Campbell and Mortensen 198).

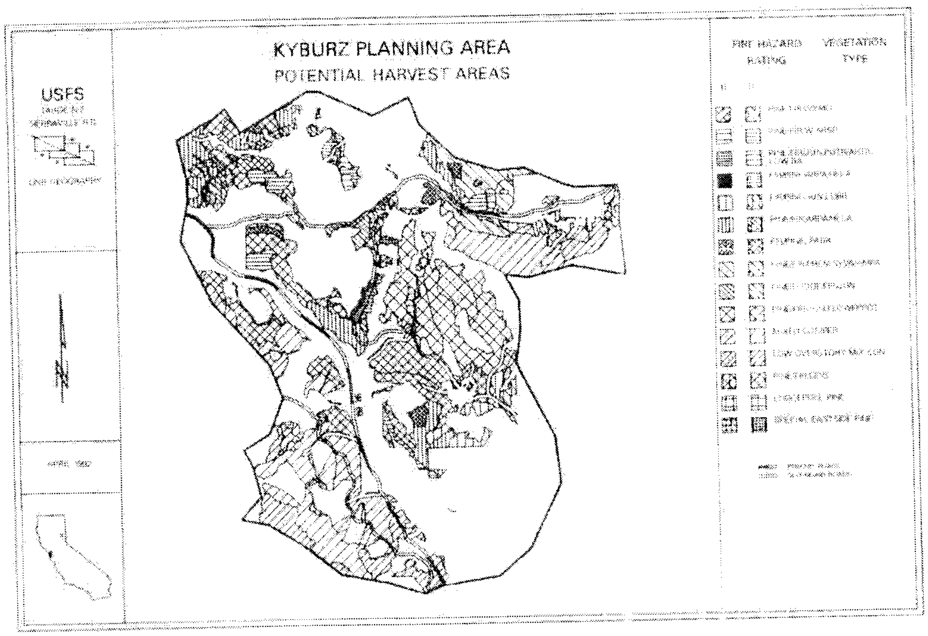

Figure 2: *Potential harvest areas of the Kyburz Planning Area.*

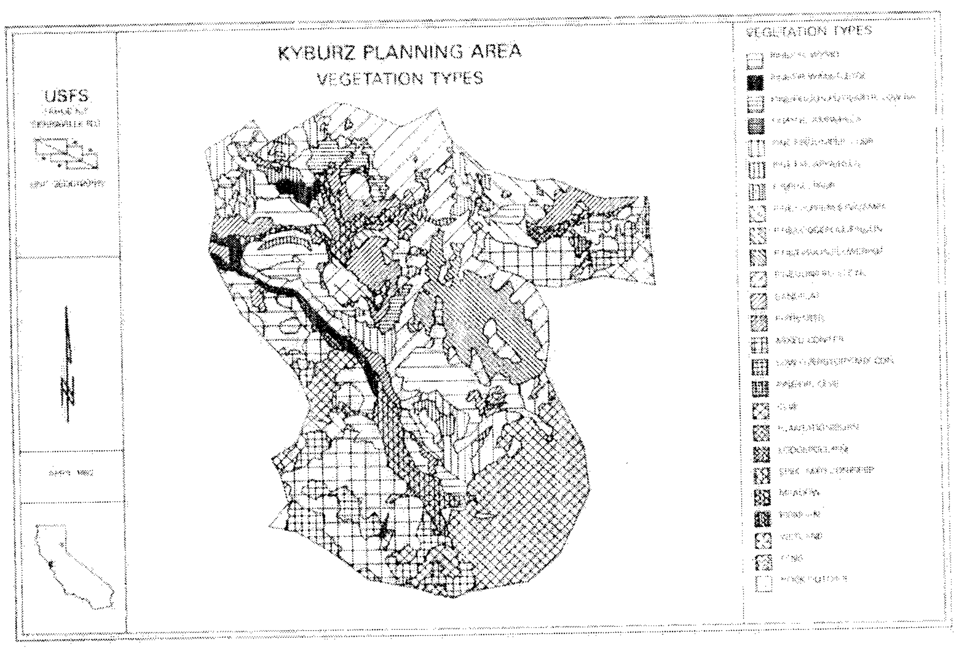

Figure 3: *Vegetation types of the Kyburz Planning Area*

Data from six coverages (percentage slope, streams, vegetation habitat types, roads, timber stands, and fire hazard ratings) were overlayed to generate two composite maps with statistical information generated from the attribute tables. The first map was entitled "Potential Harvest Areas" and included percentage slope, streams, vegetation habitat types, roads, timber stands and fire hazard ratings (Fig. 2). Categories for some of the coverages were eliminated because they represented areas either unsuitable or inappropriate for timber thinning. Eliminated categories included slopes greater than 50%, privately owned timber stands, areas of low fire hazard rating, and all non-forested or non-commercial vegetation habitat types. In addition, buffer zones of 50, 100, and 150 feet were placed around ephemeral, intermittent, or perennial streams, respectively. A 300 feet buffer zone was applied to the only river in the KPA, the Little Truckee. Riparian areas and fens had 100 and 200 feet buffer zones, respectively. All vegetation types falling within the buffer zones were eliminated from the final map since these were areas of too great an environmental sensitivity for logging, leaving 15 vegetation habitat types for analysis from the original 24 types.

The six data layers used in the Potential Harvest Area map were given priority by the SRD because district staff felt that this combination of coverages provided a satisfactory reduction of potential harvest areas without unnecessarily complicating the interpretative ability of the map. No weighing of the data layers occurred. Other coverages, such as deer habitat zones or sensitive plant species, could have been included to further reduce the available harvest areas. Inclusion of additional layers in the analysis, however, would have caused the project to exceed completion deadlines and costs, and these layers were not considered important enough by the SRD to warrant additional costs.

The second map, entitled "Vegetation Types," consisted of vegetation habitat types (Fig. 3). This second map was used to provide baseline information about the forests in the KPA prior to thinning (such as the total amount of area in a vegetation habitat type and for visual consumption). After both maps were completed, statistical information (areas in km^2) was generated and then converted into percentages for input into the planning process.

Table 1 *Kyburz Vegetation Habitat Types and Amount of Area*

Vegetation Habitat Type[a]	Amount of Area (km^2)
PIPO/PIJE/ABCO, WYMO	5.813
PIPO/PIJE/ABCO with ARSP	0.230
PIPO/PIJE/ABCO/JUOC, PUTR/ARTR, low cover area	1.110
ABCO/PIPO/PIJE, ARPA/HELA	0.804
ABCO/PIPO/PIJE/JUOC, LUBR	0.883
PIPO/PIJE/ABCO, ARPA/HELA	2.206
PIPO/PIJE/ABCO, PABR	0.918
PIPO/PIJE/ABCO, PREM/SYVA/AMPA	1.320
PIPO/PIJE/PIMU/ABCO/JUOC	0.341
PIPO/PIJE/ABCO/JUOC, flowering	2.877
PIPO/PIJE/JUOC/ABCO, CELE, noncommercial	5.996
Sandflat	0.123
PUTR/ARTR	3.362
ABCO/ABMA/PILA/PIPO/PIJE	5.520
ABCO/ABMA/PILA/PIPO/PIJE, with low overstory	2.483
PIPO/PIJE/ABCO, CEVE	0.173
CEVE	1.030
Plantation and burned areas	6.474
PIMU/PIPO/PIJE	0.175
ABCO/ABMA/PILA/PIPO/PIJE, open	0.039
Meadow	2.120
Riparian	0.712
Wetlands	0.426
Fen	0.045
Total Area	45.1[illegible]

[a]Abbreviations for species are:
PIPO - *Pinus ponderosa*
PIJE - *Pinus jeffreyi*
ABCO - *Abies concolor*
WYMO - *Wyethia mollis*
ARSP - *Arceuthobium spp.*
JUOC - *Juniperus occidentalis*
PUTR - *Purshia tridentata*
ARTR - *Artemisia tridentata*
ARPA - *Arctostaphylos patula*
HELA - *Helianthella californica*
AMPA - *Amelanchier pallida*
PIMU - *Pinus murrayana*
CELE - *Cercocarpus ledifolius*
ABMA - *Abies magnifica*
PILA - *Pinus lambertiana*
CEVE - *Ceanothus velutinus*
LUBR - *Lupinus breweri*
PABR - *Paeonia brownii*
PREM - *Prunus emarginata*
SYVA - *Symphoricarpos vaccinioides*

Results

Vegetation Habitat Types

Twenty-four different vegetation habitat types are identified on the KPA and range in area from over six to less than one km^2 (Table 1). The two most dominant vegetation habitat types are plantation and naturally burned areas and PIPO/PIJE/JUOC/ABCO, CELE, noncommercial (noncommercial ponderosa and jeffrey pine, western juniper, white fir, and mountain mahogany), both of which were not considered in the development of tree thinning strategies because of either private ownership or low fuel totals. The dominant remaining groups that were part of the planning strategy were PIPO/PIJE/ABCO, WYMO (ponderosa pine, jeffrey pine, white fir, and mountain mule ears) and ABCO/ABMA/PILA/PIPO/PIJE (white fir, red fir, sugar pine, ponderosa pine, and jeffrey pine), with each habitat type covering slightly more than 5 km^2. The least abundant groups were the thinned vegetation habitat types and PIMU/PIPO/PIJE (lodgepole, ponderosa and jeffrey pine) and PIPO/PIJE/ABCO with ARSP (ponderosa pine, jeffrey pine, white fir, all with mistletoe).

Potential Harvest Areas – High Fire Hazard

Fire hazards are determined by the potential rate of fire spread which is controlled by vegetation type, fuel loads, and tree density. Approximately 60% of the potential harvest areas of the KPA are classified as having a high fire hazard (Table 2). Areas likely to burn are typically found on south, southwest, and west-facing slopes where drier conditions and slope aspect are conducive for fires. On extremely steep slopes (> 50%), however, it becomes economically unfeasible and environmentally imprudent to thin. Thinning trees on the extreme slopes would require either helicopter lifting (high cost) or setting choker and dragging (high resource impact) for removal.

Of the 15 vegetation habitats analyzed for thinning, PIPO/PIJE/ABCO, CEVE (ponderosa pine, jeffrey pine, white fir, and tobacco brush) had the highest percentage of area falling in the high fire hazard category (96.13), while PIPO/PIJE/ABCO with ARSP had the lowest (0.21). Spatially, ABCO/ABMA/PILA/PIPO/PIJE (mixed conifer) represented 3.96 km^2 of the KPA, while ABCO/ABMA/PILA/PIPO/PIJE (special mixed conifer) and PIPO/PIJE/ABCO with ARSP represented less than 0.01 km^2 each. When all 15 high fire hazard vegetation habitats are combined, they represent 31.6% or 14.30 km^2 of the entire KPA. When vegetation habitat types are grouped according to the most likely harvest strategy, 7.54 and 6.75 km2 are designed for standard and light thinning, respectively (Table 3). A negligible area is appropriate for clear-cutting.

Table 2 ***Percentage of Vegetation Habitat Types in Potential Harvest Areas with High and Medium Fire Hazard***

Vegetation Habitat Type[a]	Thinning Classification[b]	High-Fire Hazard	Medium-Fire Hazard	Total of High and Medium Fire Hazard
PIPO/PIJE/ABCO WYMO	ST	50.82 (2.65)	22.18 (1.15)	73.01 (3.81)
PIPO/PIJE/ABCO with ARSP	CC	0.21 (0.0)	95.96 (0.22)	96.17 (0.22)
PIPO/PIJE/ABCO/JUOC PUTR/ARTR low basal area	ST	42.68 (0.47)	23.46 (0.26)	66.14 (0.73)
ABCO/PIPO/PIJE ARPA/HELA	LT	28.17 (0.13)	49.94 (0.23)	78.11 (0.37)
ABCO/PIPO/PIJE/JEOC LUBR	LT	44.32 (0.39)	18.88 (0.16)	63.20 (0.56)
PIPO/PIJE/ABCO ARPA/HELA	ST	77.81 (1.62)	12.17 (0.25)	89.99 (1.87)
ABCO/PIPO/PIJE PABR	LT	58.56 (0.47)	31.62 (0.25)	90.08 (0.74)
PIPO/PIJE/ABCO PREM/SYVA/AMPA	ST	68.28 (0.90)	13.37 (0.23)	86.41 (1.14)
PIPO/PIJE/PIMU/ABCO/JUOC	ST	68.57 (0.23)	13.37 (0.05)	81.84 (0.28)
PIPO/PIJE/ABCO/JUOC flowerpot	ST	50.75 (1.46)	48.61 (1.34)	97.30 (2.80)
ABCO/ABMA/PILA/PIPO/PIJE	LT	71.76 (3.96)	7.60 (0.42)	79.36 (4.38)
ABCO/ABMA/PILA/PIPO/PIJE with low overstory	LT	73.27 (1.81)	4.92 (0.12)	78.18 (1.93)
PIPO/PIJE/ABCO CEVE	ST	96.13 (0.17)	0.61 (0.00)	96.74 (0.17)
PIMU/PIPO/PIJE	ST	13.56 (0.02)	33.34 (0.06)	48.91 (0.08)
ABCO/ABMA/PILA/PIPO/PIJE special	LT	2.16 (0.0)	97.87 (0.04)	100.00 (0.04)
Totals		60.28 (14.30)	20.30 (4.82)	89.19 (19.11)

[a] Abbreviations same as for Table 1
[b] This is the most likely thinning classification, but may not be the only one applicable to the vegetation habitat type. CC = Clearcut; LT = Light Thin; St = Standard Thin
[c] Area (km^2) is shown in parenthesis

Potential Harvest Areas – Medium Fire Hazard

Approximately 20% of the potential harvest areas are classified as being medium fire hazard (Table 2). The percentages for habitat types range from 0.61% for PIPO/PIJE/ABCO, CEVE to 95.96% for PIPO/PIJE/ABCO with ARSP. In regard to area, PIPO/PIJE/ABCO/JUOC, flowerpot (ponderosa pine, jeffrey pine, white fir, western juniper all in flowerpot type soil) and PIPO/PIJE/ABCO, WYMO were the most extensive with 1.34 and 1.15 km2, respectively. All the other vegetation habitat types with the exception of ABCO/ABMA/PILA/PIPO/PIJE were represented by less than 0.3 km^2. The 15 medium fire hazard vegetation habitats represent 10.6% or 4.82 km^2 of the entire KPA. When vegetation habitat types are grouped according to the most likely harvest strategy, 3.36, 1.24, and 0.22 km^2 are designed for standard thinning, light thinning, and clear-cutting, respectively (Table 3).

Table 3 ***Area (km2) and Percentage of the KPA Suitable for Thinning***

Fire Hazard	Thinning Strategy: Heavy[b]	Standard	Light	Clear-cut	Total
High	-----	7.54 (16.69)	6.75 (14.95)	0.00 (<0.01)	14.30 (31.66)
Medium	-----	3.36 (7.43)	1.24 (2.74)	0.22 (0.48)	4.81 (10.66)
Total	-----	10.90 (24.13)	7.99 (17.69)	0.22 (0.49)	19.11 (42.32)

[a] Area in km2 is shown in top and percentage is shown in parenthesis
[b] Heavy thinning is not normally applied to any particular vegetation habitat type, but rather to specific problem areas within a stand

Discussion

The SRD has two major criteria for thinning trees on the KPA: forest health and fire hazards. Both of these criteria are complicated by economic considerations. Questions asked before thinning strategies can be implemented concern whether it is economically feasible to thin an area, the type of vegetation under consideration, and the best sites for thinning. Prior to the GIS analysis, these questions were difficult to answer because Forest Service personnel were limited in their ability to consider all the factors necessary to make sound decisions. For example, some environmental sensitivity factors concern what areas should be left untouched either because trees are too close to streams, or they are on slopes that are too steep. Similarly, economic factors to be considered include which trees are too distant from present roads, or have no commercial value.

Three types of thinning are considered on the KPA (heavy, medium, and light). These thinning techniques are designed to create a diversity of tree sizes even though there is no diversity of tree ages. Also, while thinning practices are done according to vegetation habitat type, often sufficient variation exists within a vegetation habitat type to make more than one thinning practice appropriate. For reasons of showing general patterns and management implications, this paper assigned only the most common thinning strategy to each vegetation type.

A heavy thin occurs when 70-90 ft^2 ba/acre of trees remain after thinning. This type thinning process is done in areas of the KPA where there are many damaged trees and heavy pine domination. The reason for this criterion is that damaged trees are both commercially nonproductive and present a major fire hazard. In addition, a heavy thin is best suited to areas dominated by pines because pines are not likely to be shocked by a large increase in sunlight. The other benefits of this thinning strategy are that is opens and may improve forage areas for the resident mule deer populations, and the remaining trees grow larger faster and thus become a potentially better economic crop (Fiddler Et al. 1989).

A second thinning strategy is a medium or “standard” thin. Trees on the KPA are selectively cut until there is an average of 100 to 110 ft^2 ba/acre of trees remaining. A standard thin is the most common thinning strategy used and would be applicable to the pine-dominated vegetation habitat types on the KPA where there is not a high incidence of damaged trees.

Light thins are a third type of management strategy where 130 to 180 ft^2 ba/acre of trees are left after cutting.

This type of thinning is done primarily on mixed conifer and fir-dominated stands because heavier thins would allow too much sunlight exposure on the firs and would produce a “shocking” effect on the trees, thereby reducing their growth rates and increasing the likelihood of mortality. In addition, because firs do well growing closer together than pines, it would not be economically prudent to cut more heavily. A final benefit of this strategy is that it provides shelter for a variety of animals within the KPA including deer and goshawk.

Thinning priority in the KPA is allocated to the zones classified as being high fire hazard. These are areas that are viewed as being most likely to burn in the next several years. Prior to fire suppression activities, surface fires were frequent but of low intensity with less than 5% tree mortality per fire. Fire recurrence intervals averaged 12 years. Fire suppression, however, has led to fewer fires and fuel loading. Subsequently, present day surface fires often lead to crown fires that may kill 80 to 90% of the affected trees (Condon 1992).

GIS analysis of appropriate thinning areas shows that approximately one-third of the entire KPA is suitable for some form of prioritized thinning. Since fire suppression mutes the ecological benefits of fire, such as the cleanup of heavily diseased and dead stands of trees and the prevention of overstocking (Condon 1992), it is imperative that the SRD engage in an assessment of what areas have the highest priority. Until the implementation of a GIS, these assessments were inly crude, qualitative estimates. With the GIS-based maps, the SRD now knows what areas are the best candidates for cutting. Considerations such as stream equality, slope stability, and vegetation are available in both map and statistical form. In addition, the proximity of roads to the potential harvest areas is known, allowing decisions to be made on what areas are most accessible and most economically feasible.

Conclusions

North American forestry is in a period of fundamental change concerning silvicultural practices (Long and Roberts 1992). Pubic land stewards have come under increasing pressure to implement strategies that balance the opposing viewpoints between landscape-conserving protection and landscape-converting use (Vale 1989). An impetus exists today to develop techniques and methods that help address this management conflict. In the KPA, for example, the SRD was interested in finding a better way to determine potential thinning areas to reduce fire hazards. This concern was heightened because decades of fire suppression (causing fuel loading) and a current six-year drought have made the KPA extremely fire prone.

The major benefit of using a GIS to develop timber thinning strategies is that it allows the SRD to view a variety of different scenarios before implementing a management program. In addition, new management perspectives may be created because of the insights provided by the data layering ability of a GIS. Insights provided by GIS analysis of the KPA may well be applicable to other Sierra Nevada eastside planning areas that are facing similar management decisions.

This project was a contracted pilot study on the feasibility of using a GIS to develop new resource management strategies in the Tahoe National Forest. Feedback from SRD personnel about the results have been favorable (S. E. Bishop, telephone call, 1 June 1992). GIS analysis has allowed the SRD to reduce by two-thirds the area of the KPA that needs priority management attention. In addition, an extensive database of 15 coverages of KPA resources exists that can be used either to update changes on the KPA or for further analysis of potential thinning areas.

Literature Cited

Campbell, W. G. and D. C. Mortenson. 1989. Ensuring the quality of geographic system data: A practical application of quality control. *Photogrammetric Engineering and Remote Sensing* 55: 1613-18.

Condon, R. M. 1992. Summary of vegetation history in eastside types. Sierraville Ranger District, California. Unpublished report, Sierravielle Ranger District, Tahoe National Forest, California.

Fiddler, G. O., D. R. hart, T. A. Fiddler, and P. M. McDonald. 1989. *Thinning Decreases Mortality and Increases Growth of Ponderosa Pine in Northeastern California.* USDA Research Paper PSW-194. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station.

Geils, B. W. and R. L. Mathiasen. 1990. Intensification of dwarf mistletoe on Southwestern Douglas-fir. *Forest Science*, 36: 955-69.
Gunderson, B. 2990. Kyburz timber sale. Unpublished Cultural Resource Inventory Report 05-17-74. Sierraville, CA: Tahoe National Forest.
Hawksworth, F. G. and B. W. Geils. 1990. How long do mistletoe-infected ponderosa pines live? *Western Journal of Applied Forestry* 5:47-48.
Hovarth, L., S. Baker, and L. H. Shoup. 1980. Archeological reconnaissance of the Kyburz Timber Stand Improvement Area. Unpublished Archeological Reconnaissance Report 05-17-404. Sierraville, CA: Tahoe National Forest.
James, J. W. 1964. The effect of wind on precipitation catch on a small hill. *Journal of Geophysical Research* 69: 2521-24.
Long, J. N. and S. D. Roberts 1992. Growth and yield implications of a “new forestry” silvicultural system. *Western Journal of Forestry* 7: 6-9.
Mathiasen, R. L., F. G. Hawksworth, and C. B. Edminster 1990. Effects of dwarf mistletoe on growth and mortality of Douglas-fir in the Southwest. *Great Basin Naturalist* 50: 173-79.
N.O.A.A. 1991. *Climatological Data – Annual Summary: California 1991.* Asheville, NC: National Oceanic and Atmospheric Administration, National Climatic Data Center.
Parmeter, J. R. and R. E. Scharpf. 1982. *Stem Infection by Dwarf Mistletoe in California Firs.* USDA Research Paper PSW-165. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station.
Vale, T. R. 1989. Vegetation management and nature protection. In *Natural Areas Facing Climate Change,* ed. G. P. Malanson, 75-86. The Hague: SPB Academic Publishing.