LAND UNIT MAPPING WITH THE WILDLAND RESOURCE INFORMATION SYSTEM

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INTRODUCTION

A wildland manager, like his urban counterpart, must combine land, labor, and capital to produce socially desirable goods and services. In forest administration, land is a particularly vital factor in resource planning. That wildland managers must keep track of their land is indisputable. The only question is: To what degree should they do so?

My particular concern is forest inventory in general, with emphasis on National Forest timber lands. What species of timber are there and how fast do they grow? Answers to these and other questions are of major economic importance. National Forests have a timber cutting goal or allowable cut which directly affects employment and income in rural communities. The level of the cut is largely based on analysis of inventory data.

Inventory data should be provided with a precision appropriate to the resource values at stake. Historically, information needed for extensive forestry was met by ocular estimates. In the last few decades, numerous sampling designs have been developed to improve these estimates. Initially the statistical designs were simple, but implementation required extensive field work and manual data collection. The dramatic decline in computation costs experienced in that last 15 years has radically changed inventory design. Expensive sample-plot work is minimized by using complex statistical designs made practical by computer technology.

The U.S. Forest Service's Wildland Resource Information System (WRIS) continues the trend of substituting computer-oriented inventory system designs for manual data collection in the forest (Russell and others 1975a). WRIS was developed at the Pacific Southwest Forest and Range Experiment Station. It can compile and display geographically distributed resource information. It provides location data affecting management decisions. Although initially developed for timber inventory specialists, it has general resource application. Its key element is the polygon of known area and classification. Collectively these land units form a map. Computer programs provide the means to edit, process, store, retrieve, update, and display land units.

WRIS has been used to compile geographic information for the Stanislaus and Eldorado National Forests in California, and data from three other National Forests are now being processed. In every case two main phases must be completed. In phase one, opportunities for silvicultural treatment are mapped. Normally three map overlaps or layers for the same area are required. In phase two, the classes defined and identified in the first phase are sampled. Forest inventory data customarily collected include timber volume, growth, and structure measurements. Together these two phases provide the quantitative timber information essential to the computation of the National Forest's allowable cut.

THE SPATIAL DATA BASE

A National Forest timber inventory begins with aerial photography. Both the photographs and the maps compiled from them are at several scales. The resource photography is interpreted according to regional standards, and the delineations are rectified onto planimetric maps. The map format may be systematic like the familiar U.S. Geological Survey 7-1/2-minute quadrangle. But foresters are also accustomed to the General Land Survey township which can be highly irregular. A standardized format aids our method of map digitizing but is not essential.

The land units, or polygons, exhaust the mapped area. All polygons, including any blank or null area, are identified. Every polygon has a unique numerical identity in addition to its classification or descriptive label. Our data processing method imposes two requirements on polygon boundaries. Boundary lines must be wide and dense enough to be detected by an optical scanner. Lines must join other lines including the map border. In practice, this means that polygons cannot occur within one another, such as an island in a lake. Additional lines are drawn to join the island to the shore, and the polygons created are assigned labels.

Map layers or overlays are filled with polygons having mutually exclusive labels. In our inventory work in California, we have found three layers adequate. One map shows delineated silvicultural conditions or opportunities termed treatment classes. Another map contains naturally or administratively determined conditions termed management components. The components are actually constraints that limit the number of treatment alternatives. The third layer shows political and administrative boundaries.

WRIS programs enable the land manager to retrieve and display overlaid map information for any combination of maps as well as to tabulate acreages. This capability allows the manager to evaluate the interactions between biological conditions shown on the treatment class map and the edaphic, geologic topographic, aesthetic, and other constraints embedded in the other two maps. Then the manager can determine realistic management opportunities tied to specific land areas. After land treatments are performed, any changes reflected on maps can be inserted into WRIS without resorting to a new mapping project.

SILVICULTURAL TREATMENTS

Silvicultural treatment classes serve dual purposes. First, their names reflect biological conditions within the land unit that has a potential for treatment. Second, the treatment classes function as volume strata for sampling. The map scale is 4 inches per mile (1:15,840).

Treatment classes mainly describe wild stands which will be converted into managed even-aged stands over many decades. The hundreds of categories occurring on the maps are maintained for display, but aggregated for statistical sampling. The six broad categories are:

- Highly decadent, overmature stands.
- Poorly stocked stands of all classes.
- Mature stands.
- Two storied stands having a mature or overmature overstory and a younger understory.
- Young sawtimber stand.
- Pole and sapling stands.

MANAGEMENT COMPONENTS

Management components reflect natural or administrative factors affecting timber management alternatives on a given National Forest area. Boundary placement depends strongly on the classifier's personal knowledge because many key variables are not mapped, such as "tractor loggable," "cable loggable," and "landscape sensitive." Clearly a practical knowledge of logging engineering is required to delineate these categories. Categories vary slightly between forests, but seldom exceed 20. Since the number of components is less than the number of polygons on the silvicultural treatment maps, scale can be reduced to 2 inches per mile (1:31,680) and computation cost reduced moderately.

ADMINISTRATIVE BOUNDARIES

Only National Forest, ranger district, and county boundaries are delineated. It would be expensive to digitize each township separately because each has only a few lines. Instead a map at the scale of 1/2 inch per mile is drawn with all administrative boundaries on one sheet. This procedure helps achieve a substantial saving in processing expense.

LAND UNIT SAMPLING

A multistage sampling design is particularly applicable for inventorying insects, range vegetation, and trees (Hazard and Stewart 1974). In two-stage sampling, samples are drawn from the primary sampling units. In an early application of multistage sampling, the four stages were Apollo 9 satellite photographs, aerial photography at representative fractions of 1:12,000 and 1:2,000, and ground plots. Only 10 field plots were needed to estimate the gross cubic feet of timber on 6 million acres in Louisiana, Mississippi, and Arkansas with a sampling error of 13% (Langley 1969).

The multistage sampling scheme used for two California National Forests starts with conventional aerial photography rather than satellite imagery. It is designed to minimize the cost of field work while providing a timber volume estimate with a 10% standard error. The design takes advantage of increasingly precise volume estimates at each stage.

Sampling begins with delineation of treatment-class strata on aerial photographs. Intermediate stages are successively larger-scale photographs, with successively decreasing ground areas. The last stage consists of ground plots. Volume estimates at each stage are used to draw a sample at the next lower stage with probability proportional to estimated volume. Calculations follow the reverse path. Ground sampling estimates are expanded according to the probabilities previously estimated for each higher stage until volume for the entire forest is estimated. This method yields unbiased estimates with the sampling error determined by the precision of the predictions at each stage.

Multistage sampling is an efficient design, but has the disadvantage of being operationally complex. A major difficulty is the need to measure elevations accurately at low flying heights over mountainous terrain in order to calculate photo scales. By products of space development, such as laser altimeters, and on-board computers, will solve the elevation data problem. These tools and multispectral cameras favor the application of a multistage sampling design.

FACTORS AFFECTING SYSTEM DESIGN

MAPPING SYSTEM TECHNOLOGY

The past decade has seen a three-stage transition in methods from completely manual map data collection to hand-guided machine operation to automatic scanning. In keeping with the technology of the times, the first data-collection format was an arbitrary grid (Amidon 1964). With the grid cell approach, setup cost is negligible, but the direct cost of handcoding is high. Cell contents are described by a variety of codes, such as shades of grey caused by overprinting as in the SYMAP system (Harvard University 1973). More detail is available with codes of two characters per cell, yielding 2,304 to 4,096 distinct possibilities with a 48- to 64- character print chain (Amidon 1966). Fixed grid systems remain because the ubiquitous line printer is an inexpensive graphic output device. A recent urban system development called GRIDS can process massive amounts of census data (U.S. Bureau of the Census 1972).

Several systems are expressly designed for natural resource management applications. Enough cost and productivity data are available to judge each system as an investment alternative (Amidon 1974). Systems with hand-operated digitizing methods fall in the moderate initial investment cost category, or the range of $15,000 to $30,000. An example is the Map/Model system of the University of Oregon, used for regional as well as forest problems (Arms 1970). Another example is NRIS, or Natural Resource Information System, developed for the U.S. Department of Interior. It uses a manual digitizer with a plotter attached for on-line editing (Raytheon Co., Autometric Operations 1973). WRIS is at the low end of the high initial cost category with $65,000 investment enough for an automatic scanner and a manual digitizer. Really large investments generally are associated with military or space agencies. One experimental scanning system both digitizes and plots on film. Only the film is kept for long-term storage (Diello 1970). In a large investment class by itself is CGIS, or the Canadian Geographic Information System. A drum scanner was built solely to digitize full-sized, scribed map sheets for an expected input of 20,000 especially prepared maps. Forestry information is just one of many layers of data. Agricultural spatial information and socio-economic file data comprise the bulk of the data (Tomlinson 1967).

SOURCE MAP CHARACTERISTICS

WRIS has broad capabilities for handling land unit data. Although the system was designed to meet the needs of timber management planning, it is unaware whether polygon labels represent timber, range, or even urban data. Control over map production was a distinct advantage because timber type maps could be compiled so as to facilitate subsequent processing. We know from past experience that the maps would normally contain irregular lines and less than 500 polygons, and that the smallest land unit would be 5 acres. Such characteristics assume importance when data storage strategies are being considered, if it is known that 10,000 polygons can occur in just the timber type layer on one forest. Data-compression algorithms which exploit the occurrence of straight lines are of little value to us. Usually only administrative boundaries are straight and comprise only a small part of the total boundary data stored. Knowledge of the approximate number of polygons expected to occur affects trade offs between line and label storage in the computer memory. The expectation that land units should exceed 5 acres is of value to search and error-detection programs because smaller areas can trigger an inspection.

Land unit labels--polygon attributes--are simple for management component and administrative maps. Forest-type symbols on silvicultural treatment maps are complex for two reasons. First, some symbols do not exist in the computer's character set and the equivalent must be established. Second, the sequence and position (numerator/denominator) of the map symbol is an implicit code. Symbol transcription rules must be defined and memorized by label encoders. Every polygon label by X, Y location is keypunched and examined by editing programs. Out of thousands of possibilities, about 1200 different forest type labels of 36 characters or less are found in a forest type map. Essentially, the original map detail is preserved on magnetic tape for flexibility. The individual land units can be aggregated into any sampling strata required for a given statistical design.

COMPUTATIONAL FACTORS

The generally decentralized nature of the Forest Service's organization favors direct computer communication from regional headquarters to the individual National Forest. Map and associated resource file data are initially compiled and stored in the forest supervisor's office. And most of the questions for the information system originate there also. With continued progress in miniaturization, computer mapping may one day be feasible at the forest level.

At present WRIS is operational at the regional level with high-speed access to a medium-sized computer in batch mode. Three people process 300 to 500 maps a year at a regional office. Centralized processing has several advantages. Although the computer is a shared, general-purpose device, the peripheral equipment is not. Digital plotters have numerous alternative uses, but scanning microdensitometers are mainly used for scanning aerial photographs and maps. One scanner can serve the entire U.S. Forest Service's California Region.

THE IMAGE DIGITIZING SYSTEM

Nearly all computer mapping systems rely on manual methods to digitize land units directly from a map. The intent is to avoid either copying the original map or preparing a source map especially for digitizing. An important exception is the Canadian Geographic Information System. Full-sized scribed map sheets are rotated on a drum, where a stationary sensor detects densities or "grey" levels. But the hardware, which costs several hundred thousand dollars, has no alternative use. WRIS requires a reduced map image in order to use commercially available, multipurpose scanning digitizers. Most maps are not copies but drawn for scanning as well as general field use.

BASIC CAPABILITIES

WRIS is an operational production tool for storing the boundaries and calculating the acreages of all mapped polygons for a National Forest. At least three people are required for continual processing, one of whom can perform system maintenance. Proliferation of options is avoided since the system already exceeds 20,000 FORTRAN statements. Even the hand digitizing alternative is considered a mixed blessing. It does enable simple maps to be processed at less cost than scanning, but at the price of more maintenance. Since WRIS is designed for production the following list of capabilities may seem austere:

1) Maps are prepared for input to the system. Aside from a few basic drawing rules, the maps can be any format or scale that can be photographically reduced. We have had maps 3 feet by 5 feet reduced eleven times commercially onto a 4- by 6-inch "105" high-constrast copy negative.

2) The arbitrary coordinates established at scanning time can be transformed into general coordinates. The options are geographic (latitude/longitude), State Plane (Lambert Conformal), Transverse Mercator and Universal Transverse Mercator.

3) Map editing is performed by using local coordinates identified as rows and columns on line printer output. Most errors are detected by programs which selectively display just enough graphic data to correct the problem.

4) Software was developed in standard FORTRAN compiled by UNIVAC's EXEC 2 executive system.* Current implementation is by the EXEC 8 version for two remote UNIVAC 1108's, one 30 and the other 1,200 miles away. A senior programmer should be available to install the system and provide some assembly language programs for efficiency. Documentation in the form of printed material and program comment cards is available.

MAP DATA PREPARATION

The rules for map preparation are simple. Strict adherence to the rules is, however, extremely important. Processing cost depends on map quality because editing is the major expense.

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*Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

Polygon boundaries to be digitized by scanner are drawn in ink on stable plastic. All lines join others including the map border. Polygons cannot overlap one another, and the entire mapped area is labelled; empty polygons are not allowed. All non-boundary information, such as labels and coordinates, are written with a non-photo blue pencil.

Selection of the appropriate line width will depend on each user's circumstance. Optical scanners, particularly high-speed models, offer a limited number of apertures and spacings. To compensate, map reduction can be varied to accommodate the available scanner settings. Alternatively, for a fixed reduction, line width can be varied. Instructions for achieving an optimum balance between aperture and spacing alternatives are available in a user's guide (Russell and others 1975b). For our largest maps, 2 feet on a side, and a negative reduced tenfold (10X), we normally scan a thousand lines and readings (rows and columns). More intricate maps can be resolved by taking more density readings but this increases computer processing cost.

MANIPULATIVE OPERATIONS

Once the polygon data are correct a few manipulations are performed. Multi-stage timber volume inventory requires map "windowing". A rectangle subset of the timber type layer is randomly selected. Within the frame acreages are calculated automatically. A display accompanies photographs to the field for ground plot delineation.

Forestwide acreages are also accumulated by using logical operations. For each township the forest type layer is overlaid on the management component map. The intermediate, output map consists of polygons formed by the intersections of polygons in the two input maps. The polygon labels on the output tape are a composite of the input labels. The output tape becomes input for overlaying the third layer, administrative boundaries. Conceptually this pairwise process can continue indefinitely. In practice the output polygons fragment with each successive layer. Since polygons of insignificant size are automatically assigned a null label, output becomes less useable with successive layers. System computational restrictions usually take hold before the proportion of "slivers" can become excessive. Two limitations inhibit fragmentation. First, the polygon count for the two input files and the output file cannot exceed 2,000. Second, a pair of polygons cannot cross each other more than 800 times. As a general rule, to stay within these constraints the number of polygons in each input file should not exceed 500.

Composite maps can be plotted, but normally just an acreage table is needed. The simplest form is a list of every polygon with its area and perimeter. In the next level of aggregation, every polygon is assigned to a class. The acreages in an overlay are shown by categories in a two-way table. Finally, acreages can be accumulated over any group of townships by merely arranging the township-acreage decks in the desired sequence.

SUPPORT PROGRAMS

Digital map data are written on magnetic tape, staged to Fastrand drums for processing, and written onto tape again for permanent storage. The tape usually includes a file, or collection of records, for each township layer. Backup tapes contain duplicate files for each of the 200 to 300 maps per forest. A forest's timber type file may have as many as 1,000 distinct labels.

As the regional data base grows, support programs assume greater importance. Computer programs provide the basic functions of file searching, packing, and copying. Other routines give map data summaries in varying degrees of detail and facilitate sorting, checking, adding or deleting labels. Detecting incorrect labels requires maintenance of a master label file. This drum file is a list of all permissible labels on a forest for each type of map. The number of labels depends mainly on the complexity of the forest type layer, but fluctuates between 1,000 and 2,000 labels per forest.

Maps are drawn automatically by a digital plotter. We rely mainly on the Calcomp 1136 incremental drum 3-color plotter, but have an EAI 430 flatbed plotter in reserve. A very complex Calcomp plot requires 45 minutes of work. One color is used to plot control points, x and y scales in map coordinates, a title, and polygon boundaries. A constrasting color is used for polygon labels to make visual editing easier. The few plot options are available for resolving the occasional, highly complex map editing problem. A plot can be a variable rectangular frame, and the scale within it varied by supplying a blow-up factor. Polygons can be identified by label or automatically assigned a sequence number. Since printout is less expensive for editing, almost all maps are plotted only in final form.

COST

In 1973, the direct cost to process a typical township (36 square miles) was about $200. Now that five National Forests in California are in process, the work flow is well established and editing methods have improved. Current cost for a highly complex, million-point scan is $170. Because less than a fourth of the cost is for labor, system expense is closely tied to the general cost of computing. The assumption that equipment can be rented is well justified, except possibly for the input scanner. The number of maps to be digitized will determine whether an investment of at least $40,000 in a scanning microdensitometer can be amortized.

RESEARCH AND DEVELOPMENT

The stimulus for additional development now comes more from operational problems externally generated than from internal innovations. A key problem is tape reading or writing, particularly on peripheral digitizers and plotters but also at the computer center. Careful maintenance helps minimize the error rate, but cannot eliminate the problem. We plan to store our processed data in demountable disk packs instead of on tape. This change will nearly solve the reliability problem for the permanent data base, but not for the peripheral devices.

Another problem over which we have more control but still cannot eliminate is map defects. Although it is well known that input quality is of paramount importance, ink problems persist -- particularly in line width and density. One solution is a change from ink to scribing, but the additional cost of map drawing may exceed the present loss caused by editing. Despite quality control problems with ink, tracing followed by scanning is less expensive than manual digitizing of the original copy, except on simple maps.

The bottleneck in a system will vary with the level of output. Our PDS 1010 scanning microdensitometer is accurate but slow -- 10 hours are required for a typical million-point scan. Its replacement is expected to accomplish this task in less than 10 minutes. This speed will permit repeated scans to find the best "slice" separating lines from background. The final selection can be made by a built-in minicomputer, resulting in savings in both computer time and manual-editing labor.

To date, we have relied on printout and occasional line plots for editing map data. A paper-saving alternative is the cathode ray tube (CRT). Of the many types, the storage-tube type of CRT appears most economical because it needs refreshing only at hourly intervals by a computer. Resolution is adequate for forest maps, and editing with a light pen should be quite rapid. The CRT editing approach has been used on a production basis for automated hydrographic charting (Graphic System Design and Applications Group 1972).

FUTURE PLANS

SPATIAL ANALYSIS

Until now the production orientation of WRIS has prevented the inclusion of capabilities that would provide new spatial information. Current measurement and analysis techniques simply consist of area calculations and map overlays. These dominant functions are expected to be enhanced by adding manipulative techniques ranging from simple tabulations to complex spatial analyses. For example, the occurrence of points in polygons has sampling applications. Calculations of distances between nodes in a network is basic information for a transportation analysis.

Logical operations, such as overlaying maps or sieving data, can be extended. Currently data for each township or quadrangle is processed independently of data for its neighbor. Overlaying and sieving operations across map borders is a logical next step.

The ability of a system to generate certain artifical shapes has found urban application (Tomlinson 1972). Bands or corridors at varying distances from roads aid logging and forest transportation analyses. Similarly, one can generate a circle about a point, such as a pulp mill site, and calculate the timberland area within it. Ground sampling within the circle will estimate the volume of wood in the "timbershed."

More advanced techniques of spatial analysis are seldom operational--presumably because of high computation cost. An exception is terrain data analysis in which elevations are used to compute slopes, aspects, and visibility between points (Sharpnack and Akin 1969), (Amidon and Elsner 1968), (Travis, Elsner, Iverson and Johnson 1975).

MINIATURIZATION

WRIS is characterized by bulky source maps, intermediate printouts, and final plots. The original map and a few copies for field annotation must be full-sized. All subsequent products are subject to miniaturization. Paper printout from the editing process may be eliminated by a CRT. Usually one final plot per map is enough. Map, table, and text copying for distribution accounts for nearly all the material subject to reduction.

Storage and handling cost of materials for distribution can be greatly minimized by microforms. Different forms include roll microfilm and microfiche (National Microfilm Assoc. 1973). Each form has a range of reductions. The most widely used are 20:1 (20X), 24X, 42X, and 48X. The best reduction factor for our needs is 24X and 48X, and microfiche appears to be the most desirable form.

Source maps or plots on plastic or paper will be photographically reduced. Text and tables can also be handled the same way, or the material written directly on film under computer control. This process, whereby paper is eliminated, is called computer-output-microfilm or COM (National Microfilm Assoc. 1974). Polygon acreages and administrative summaries will be reduced 24X or 48X onto 4- by 6-inch COM microfiche for distribution. Although the forms are generally regarded as office material, portable viewers are available for field use.

MAINTENANCE

Software is currently maintained for National Forest use on UNIVAC 1100 series computers. Conversion to the IBM 360 computer system is being carried out because it is widely available.

Two of our National Forest data bases need updating already. Currently our updating process is based on replacing information on a township basis. We can update by using logical operations and the usual editing techniques. But just replacing an entire map sheet is simpler.

More National Forests are communicating with central computers over data terminals. Acquisition of large, reliable data bases will soon lead to requests for interactive, conversational connections between the field and the regional data bank. The centralized batch-processing mode of data reduction will remain unaffected. The processed data will be deposited in a storage and retrieval system for access by all National Forests and maintained indefinitely.

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