Remote Sensing: The Unheralded Component of Geographic Information Systems*

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ABSTRACT: From the mid-1940s when the management of the nation's natural resources began to be taken seriously, three major types of data were considered essential as a fundamental source of information: imagery, maps, and descriptive attribute and statistical data. The integration of these latter descriptive and statistical data into computer based management information systems (MIS), and the subsequent planning model development utilizing operations research techniques, set the stage and provided the rationale for the establishment and maintenance of natural resource information systems as an integral part of the management function. The introduction of digital imagery from satellites into this community was greeted with initial enthusiasm, but was quickly replaced by benign indifference by all but a few. Generally considered a product before its time, digital image processing languished as an operational tool while the supporting technologies of digital mapping and database management combined with MISs already in place to form the basis of computer-aided geographic information systems (GIS). The introduction of SPOT satellite data in the mid-80s with resolutions and capabilities more compatible with on-going GISs, and the explosive development of microcomputer technology, has provided a unique opportunity to reintroduce digital imagery, not as "remote sensing," but as a spatially oriented digital database and an important part of any operational resource-based GIS.

IN DISCUSSING REMOTE SENSING and its special relationship to geographic information systems (GIS), it is important to review its development and the sequence of events that has created exciting opportunities. The Forest Products Industry will be used as the basis for this review. While not exactly typical of the satellite data user community, it is representative of a very large industrial complex with massive land holdings throughout the United States. Interesting parallels and important correlations applicable to the commercial market place can be inferred from this as a model. From the beginning of modern resource management, significant allocations of both operating and capital resources have been expended toward gathering information on inventories, harvest, and growth rates in order to maximize production and minimize the price of the delivered raw materials; the highest single cost in the production process. Three major data sources have traditionally represented the core of such information systems, or schemes: imagery, descriptive statistics and attributes, and line maps of various descriptions.

IMAGERY

On lands with little or no information, either descriptive or graphic, the aerial photograph traditionally represented the most efficient ground reference data source available. In such situations, these photos served as a rough mapping tool, a means for qualitative assessments of ground conditions, and in some cases as the basis for quantitative estimates of timber volumes and stocking levels. It was a situation where some information was better than none. It might be said with emphasis that such conditions still exist in this country, are the rule rather than the exception world wide, and are not restricted to forestry applications. As lands come under some level of geographic control and as a qualitative and quantitative database is accumulated, the needs for imagery shift to that of inventory design and updating support. In this capacity, the aerial photograph becomes a source of prior knowledge essential in establishing spatial relationships and levels of vegetative variation. In this context, the photograph is indispensable in scene stratification for optimization of sample design and in monitoring change.

DESCRIPTIVE STATISTICS

Extensive data are collected at the smallest unit of management, variously called stands, compartments, units, or fields. Stands will be used for the remainder of this paper to refer to such entities which exhibit general homogeneity with regards to vegetative characteristics and the specific stand conditions of cover type, productivity, age, topographic position, and vegetative densities. These are the variables which contribute most to growth and yield prediction. A stand exhibiting homogeneity with regard to these variables becomes a predictable entity that can be moved through time. Unfortunately, theoretical homogeneity seldom coincides with actual conditions. As in field crop definition, soil type maps, and geological field maps, practical considerations transcend biologic or geologic boundaries such that there is often as much variation within class type as between them, a truly perplexing situation for remote sensing depending on "ground truth" for support. It also represents a basis for assumptions which were brave if not dangerous, albeit inescapable in the past.

Because of the individual conditions and growth characteristics of each stand, certain economic assignments can be made with respect to harvesting conditions, difficulty of site preparation and planting, costs of other cultural activity, and the current and future value of crop being grown (timber in this case). Thus, data describing the stand in economic terms were added to attribute database, putting entirely new emphasis on the integrity of the field data, especially with respect to area allocations.

MAPS

Spatial definition from the imagery, and descriptive attributes provided from the field statistics and economic assignments, provide the basis for working documents, or maps. Figure 1 illustrates a forest type map, which places all data within the context of a coordinate system. The basic data in terms of imagery, descriptive attributes, and cartographic control were in place, but not integrated into one coherent system.

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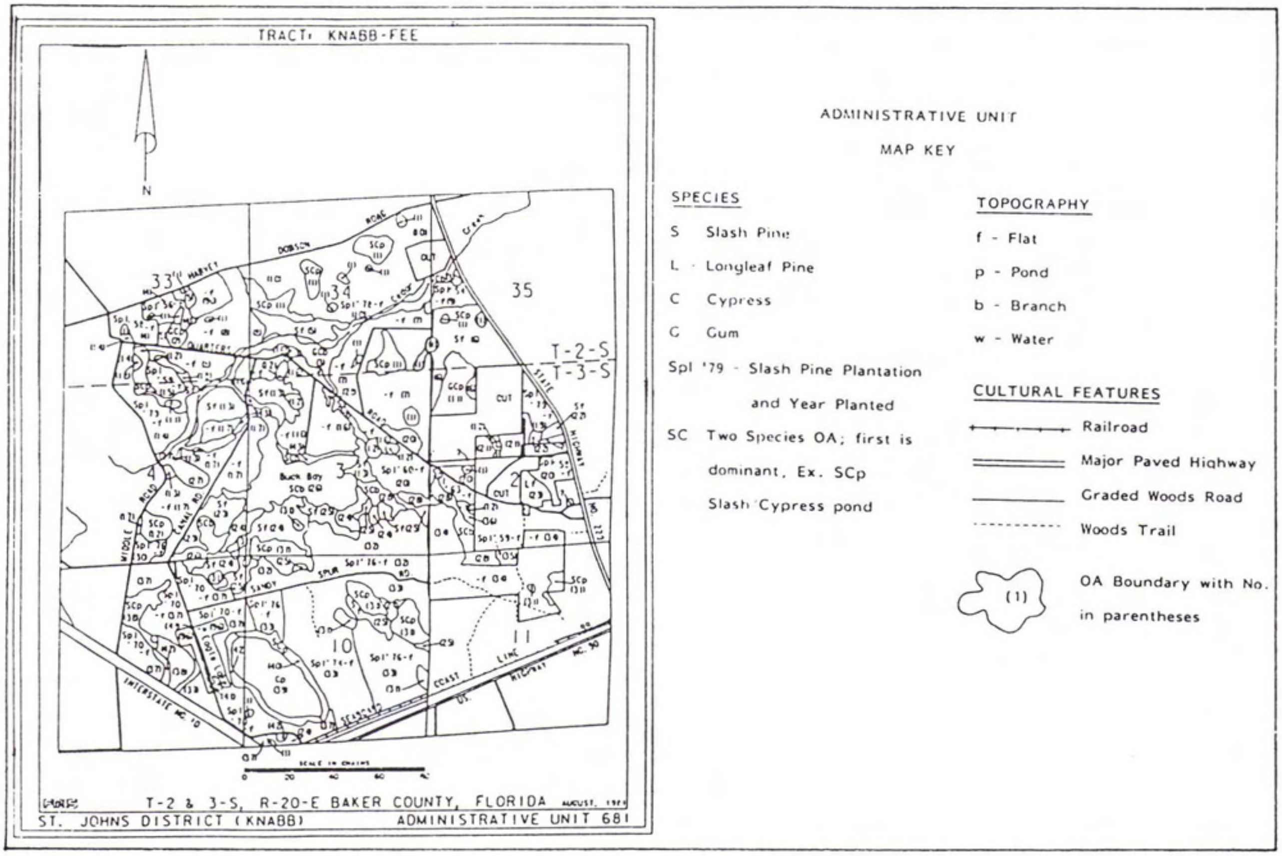

FIG. 1. Typical forest cover type map.

In early studies only the statistical and attribute information could be easily updated. These data were formatted for computer-aided processing and analysis, and were used in the operations research procedures that rapidly emerged in the 1960s and 1970s. In order to take full advantage of linear programming and simulation methodology, it became apparent that data and information must be maintained in a current condition. This involved updating the database. Because it was neither physically or economically feasible to update the imagery and, therefore, the maps, serious errors of assumption accumulated rapidly with respect to the areal extent and spatial relationship of the forest stands. This of course impacted the totals as expanded from per unit values.

Nevertheless, the database was updated as precisely as possible, and this provided input into the planning model scheme. Briefly, this involved an optimum harvest scheduling of all the stands within the area of interest based upon the present value of current and future stands, and the restriction of the optimum solution to meet practical operational considerations. With a harvesting schedule for the planning horizon, and with the ability to predict growth and yield, a forest simulation model was then entered which essentially moved each stand through time for the period of the plan. Finally, the third in the trio of models, the financial model, was entered with an operational plan derived from the first two. This model calculated the return on investment for the operational plan selected. A schematic of the operation of these models is presented in Figure 2. Although rough to begin with, these models improved with experience, and senior managements took them quite seriously as the basis of strategic planning, and of the yearly operational plan.

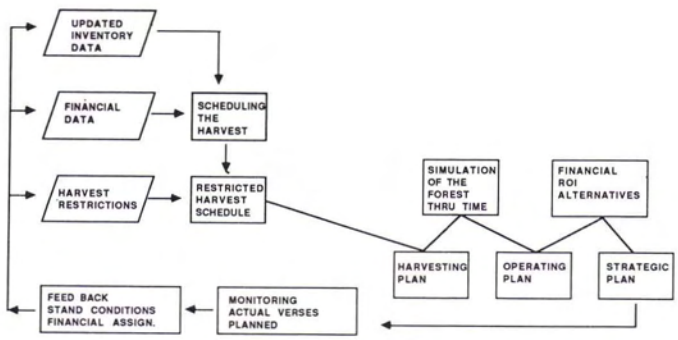

FIG. 2. Flow of a typical planning model in forest resource management.

Much of this activity happened before the advent of satellite-based imagery or digital cartography and, while the above case is from a specific application, there are several parallels to be drawn within the commercial land-based management community. It is important to understand where the development of management information systems (MIS) fell in the sequence of events. It became the basis for strategic planning and as such had direct impact on profit center performance (the bottom line). The MIS provided the frame work and rationale for the yet to be developed geographic information systems (GIS).

On 21 July 1972, the first Earth Resources Technology Satellite (ERTS-1) was launched into near-polar orbit from Cape Canaveral, Florida, and civil remote sensing from satellite platforms was born in the United States. Configured with two prototype sensors, the Return Beam Vidicon (RBV) and the Multispectral Scanner (MSS), the ERTS system was launched as an experiment both in

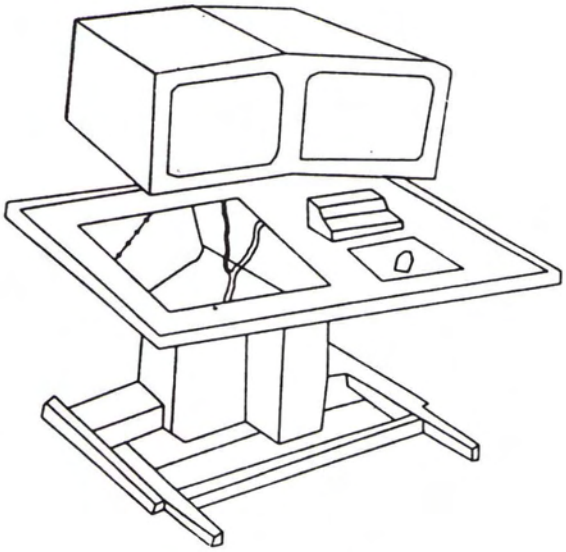

FIG. 3. Typical digitizing facility.

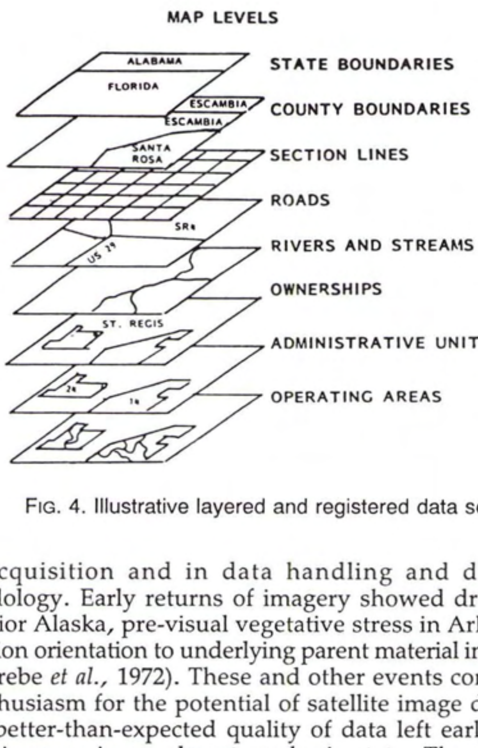

FIG. 4. Illustrative layered and registered data set.

data acquisition and in data handling and distribution methodology. Early returns of imagery showed dramatic fires in interior Alaska, pre-visual vegetative stress in Arkansas, and vegetation orientation to underlying parent material in the Ozarks (Landgrebe *et al.*, 1972). These and other events contributed to the enthusiasm for the potential of satellite image data.

The better-than-expected quality of data left early scientific/academic users in an almost euphoric state. The system was given an additional and unexpected, albeit premature, boost by a ready-made commercial market in exploration geology. This was brought about by the rapid rise of the Organization of Petroleum Exporting Countries (OPEC), and the worldwide oil shortage precipitated by that body in 1973, scarcely one year after the launch of ERTS-1. By early 1974 and into 1975, the byword was applications and the notion of an experimental system for scientific research had all but vanished. It was in this environment that the ERTS program was renamed Landsat and a second satellite (Landsat-2) was launched with expectations that applications in agriculture, forestry, land-use planning, geology, and myriads of associated resource management activities would parallel the spectacular successes of the communications satellite business.

A plethora of applications investigations, variously called Applications Systems Verification and Test (ASVT) and Applications Pilot Test (APT) and funded at least in part by NASA, followed the launch of Landsat-2. The new world of "high tech" remote sensing had indeed reached a pinnacle from which it has been falling ever since. Some of the fall can be attributed to natural euphoric cooling typical of new technology, and still more to Government indecision/inaction, which has seriously impinged on the systems credibility. Much of the dulling of the bloom, however, was caused by the nature of the technology itself and its relationship to the general user community. Such an overwhelming inundation of data, sophisticated machinery and processing techniques, access options, and capabilities presented a mind boggling problem of assimilation. The users initial feeling of seeing something "nice but not available" was unhappily borne out by reality. Data production, also designed as an experimental system, was sporadic, unreliable, and slow if at all, and processing and georeferencing was costly and not locally available. Interactive access at a stand-alone user facility was essentially not even addressed, and the availability of low cost output product generation capability did not and for the most part does not now exist. In short, space remote sensing arrived on the resource management scene out of sequence. The supporting technology was simply not in place. Under these conditions, image data were more a part of the problem than they were the solution, and as such were viewed as more a phenomenon than a practical working tool.

In a parallel and far less dramatic way, computer mapping and database management methodology were being developed in several non-compatible formats and applications. These developments were done separately from remote sensing, for the most part, as managers sought means to put their plans into some sort of spatial context. The concept of the Forest Resource Information System, as developed by the St. Regis Corporation (Barker, 1983), was to integrate imagery, maps, and tabular attribute files into one integrated information system. Initially, however, it was the imagery around which the system was being designed. Early on in the program, it was recognized that imagery as a stand-alone data source did not comprise a coherent information system. With resolutions of 80 m as provided by the Landsat MSS, and a scene size of over 13 thousand square miles, a controlled geographic referencing system and not the image itself had to be considered as the framework for all the related databases, including imagery. While seemingly obvious, this revelation was not a trivial one, considering the raster format of the imagery and the vector format of the maps. The problems associated with gridded data (imagery) and vector data (map) continues to be an impeding factor in integrating image data into a GIS.

Another restricting factor was the shear quantity of digitizing required to reduce the maps to digital format and the high front-end cost of the equipment required to establish and maintain a digital information system. Digitizing tables and monitors similar to those shown in Figure 3 are used to capture the data. The digitizing table itself is a Cartesian surface (grid) with energized intersections typically resolving to 0.001 inch. Thus, any X, Y location within the domain of the map can be directly related to the map coordinate system. For GIS applications data are captured in layers to permit updating and highly specific spatial analysis (Figure 4).

Point, line, and area (polygon) coordinates, along with corresponding attribute data are captured and stored (Figure 5). By attaching the descriptive attributes to the geographically controlled map base, the attributes take on spatial relevance (Figure 6). Clearly, if imagery can be registered and attached to the same geographic framework, the map becomes the vehicle for descriptive attributes to be attached to the image data. The significance of this is substantial when considering the quantitative data contained in those attribute files.

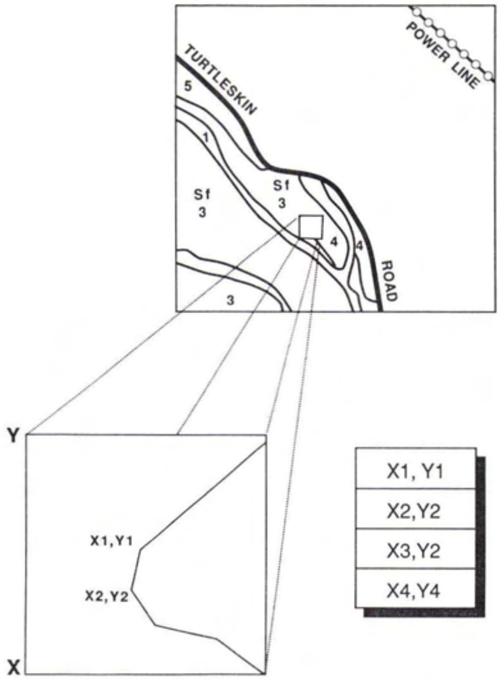

FIG. 5. Digital map storage.

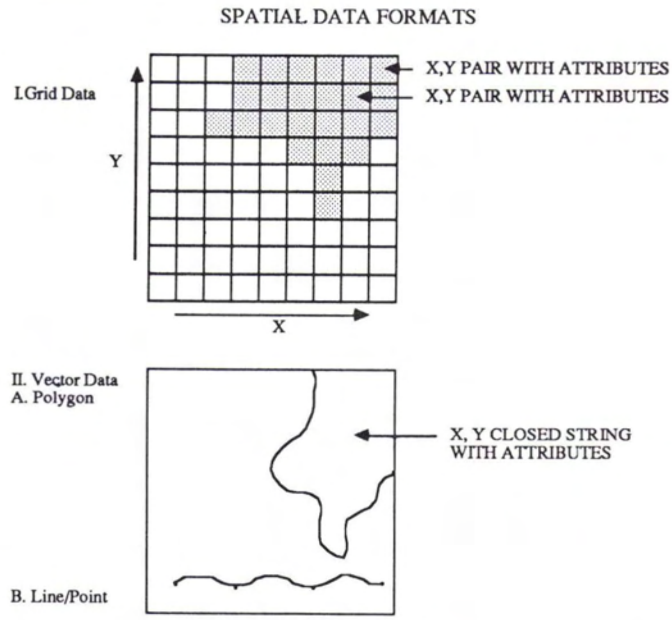

FIG. 7. Spatial data types: Gridded, vector, line, and point.

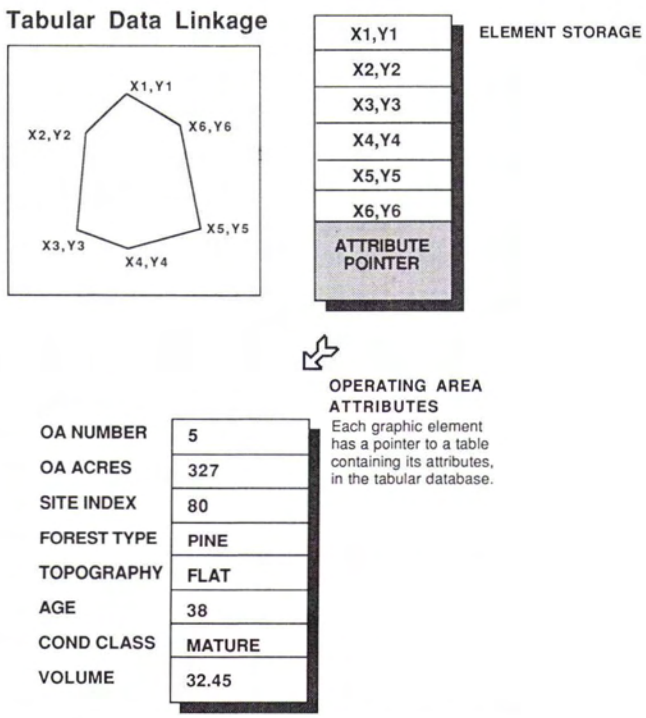

FIG. 6. Complexing and attribute attachment.

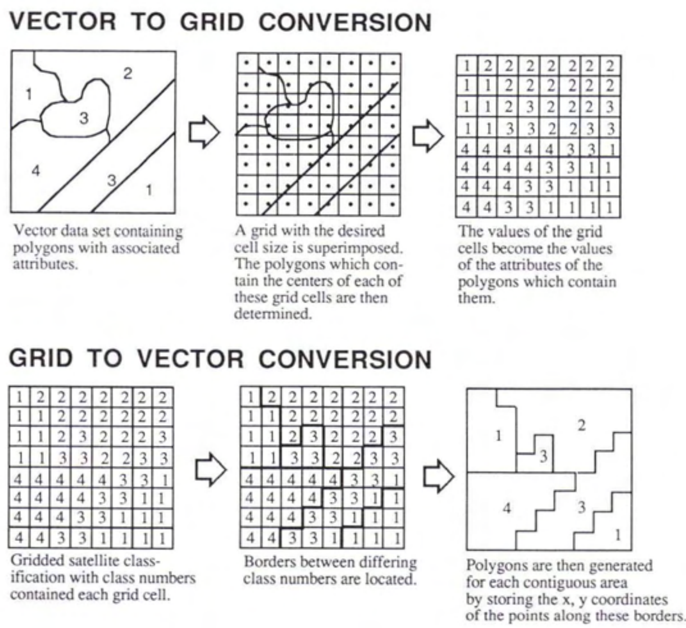

FIG. 8. Summary of the vector to grid - grid to vector transformation philosophy.

Unfortunately, and predictably, the merging of image data into a geographically based information system is not straight forward. This is due to a multiplicity of data types as illustrated in Figure 7. Transformation procedures have been developed and are generally available. One simplistic approach is illustrated in Figure 8.

In converting vectors to gridded or raster data, a decision algorithm must be implemeted to decide what to do when a vector line splits a grid cell, with different values assigned to each side of the line. That is, to what side of the line shall the grid cell and its information content be assigned? In the most simple case, an absence or presence decision could be made; a purely binary yes or no. That is satisfactory for a simple boundary overlay, and where attributes have not yet been assigned. For more complex boundary and cover type assignments with attached attributes (type names), greater resolution is required. This can be done with the placement of a center dot in the grid cell. The cell is labeled for the polygon in which the center dot falls. For even more precision, the cell can be flooded with a multitude of dots, and a predominant point assessment made. This would be a majority rules type decision, and is especially applicable to complex and irregular shaped entities. Figure 8 employs the center dot concept for illustrative purposes. The reverse of the process, vectorizing gridded data, involves generating smooth lines that represent boundaries or discrete features. While this appears to be simple, to transform a classified image into a vector data set is a task of tedious proportions. Yet, with low resolution data, vector format is necessary to avoid the large blocky appearance of the final product. In fact, with 80-m and, to a lesser extent, 30-m data, even the vector data have stair-step edges at all but the smallest of scales.

The ability to merge vector and gridded data sets opens up a whole new area of analysis potential utilizing imagery as an important polygonal component. The classified image data enter the information system as closed polygons with associated attribute files. Polygon processing and spatial analysis utilizing these data are now a rough but useful reality. With the launch of the French satellite SPOT in February 1986, added offerings of image data provided a varied choice for the user community. In no area has this become more apparent than in the mapping and cartographic disciplines. Resolutions of 20 m in the multispectral and 10 m in the panchromatic allow clear identification of cultural and physical features at the level for which many GISs are designed. In addition, movable mirrors allow stereo coverage of an area, adding the topographic dimension to the data mix available.

Without question, many issues still remain to be resolved with respect to the means and methodology of efficient data integration. Nonetheless, all the data required to build an efficient information system for resource management and the integrating technology to accomplish it are in place. It is time that remote sensing be recognized as providing imagery that can be employed as contributory databases, a tool long over due in the building and maintenance of geographic information systems.

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