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FORESTLAND TYPE IDENTIFICATION AND ANALYSIS IN WESTERN MASSACHUSETTS: A LINKAGE OF A LANDSAT FOREST INVENTORY TO AN OPTIMIZATION STUDY

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ABSTRACT

Digital land cover files derived from computer processing of LANDSAT and soil productivity data are linked and used by linear programming model to determine production of forested areas under different management strategies. Results of model include maps and data graphics for four-county region in western Massachusetts.

1. INTRODUCTION

A number of natural resource planning programs involving Federal, state, and local governments are in operation. One of these is the Cooperative River Basin Studies (CRBS) which is responding to Section 6 of Public Law 83-566 established in 1954. This program is to identify and delineate the severity and extent of natural resource problems in river basins, and to identify those problems amenable to solution by government and private programs. The analysis required by the CRBS program and similar studies in forested areas requires a detailed examination of alternative land use strategies and the impact of these strategies on environmental and economic issues. A system which supports this analysis and its link to LANDSAT and other data sources is demonstrated in the following pages. The system provides outputs responsive to the needs of planners and decision makers in both the private and public sectors.

2. METHODOLOGY

2.1 ANALYTICAL SYSTEM

The Resource Analysis Procedure (RAP) (Ref 1) is a computer software package consisting of three internally linked components: a data base, a computer composite mapping system, and two mathematical programming algorithms. RAP was developed by the Bureau of Economic and Business Research at the University of Utah for Northeastern Area — State and Private Forestry, USDA Forest Service. The procedure is an outgrowth of various existing systems including the Composite Mapping System (CMS) and the Functional Mathematical Programming System (FMPS) (Ref 2). The CMS was developed by Consolidated Analysis Centers Inc. (CACI) for the Economic Development Administration (EDA) of the Department of Commerce. The CMS system grew out of a basic technique used by Dr. George Nez.

RAP enables resource planners to perform optimization or simulation analyses and to produce maps and data graphics of the solutions in various alphanumeric formats. It also produces histograms of distributions and maps of time-dependent and/or geographically dependent data. Finally, maps are produced that express relationships among geographic areas based on single or multiple topic characteristic terms aggregated to meet user specifications.

A mathematical programming model is used for spatial optimization analysis in which quantities and locations (right hand side constraints) of usable resources are automatically generated using the data base and composite mapping routine. The model's final basis solution is mapped to show the location of both limiting resources used and products produced.

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2.2 DATA GENERATION

Digitized maps and external files are used in developing spatially dimensioned data, which are processed by the RAP system. Major land cover and land use files are produced by the Bendix Aerospace Systems Division from LANDSAT CCTs, and by the US Geologic Survey from aerial photography for its LUDA (Ref 3) program. The US Bureau of Census DIMECO and URBAN ATLAS files and the USDA Forest Service COMLUP files are also potential inputs.

The major RAP inputs for this investigation were digital land cover and soil productivity files for the counties of Berkshire, Franklin, Hampden, and Hampshire in western Massachusetts (Figure 1), an area of about 2,500 square miles.

The digital land cover inventory was produced on the Bendix Multispectral Data Analysis System (MDAS) (Ref 4) from LANDSAT computer compatible tapes (CCTs) collected over the test site on 31 August 1976 (Scenes 5500-14151 and 5500-14153). These processing techniques (Ref 5, 6) have been under continuous development at Bendix for the past 9 to 11 years, primarily using aircraft multispectral scanner (MSS) data and more recently using satellite MSS data.

For this inventory, the LANDSAT CCTs were transformed into interpreted land cover files for the sixty-three (7.5-minute quad) maps covering the study area. A data sample within each file had a north-south grid orientation covering an area of 31.6 by 57.9 meters and was coded to identify land cover within that sample. Of interest to this study were codes identifying the two forest types — hardwoods/mixedwood and softwood. The mixedwood could not be reliably separated from the hardwoods due to the severe channel banding (noise) in the LANDSAT scenes and the uneven solar illumination of the western Massachusetts hills at 9:30 a.m. Other scenes should permit this separation. Supporting information used to process LANDSAT tapes included detailed land cover maps produced by Massachusetts Map Down (Ref 7).

Maps provided by the Soil Conservation Services were interpreted and digitized into two soil productivity groups representing medium (50-85 Cu Ft/Ac) and low (0-49 Cu Ft/Ac) forest capabilities. The two forest types were aggregated into a forestland category and composited on the two soil groups. This composite generates spatially dimensioned input data used to constrain the optimization model.

3. MODEL STRUCTURE

The optimization model is a linear programming formulation representing production capabilities of counties in the study area. The model performs three functions: (1) identifies production levels possible under alternative management strategies, (2) allocates resources available in each county among strategies, and (3) geographically locates and simulates the impact of strategies on the resource base.

Three management strategies were used: (1) present condition, (2) maximum multiple use, and (3) maximum fiber. The present condition strategy represents management as presently practiced. This strategy is extensive, using no capital investment to increased production. The maximum multiple use strategy uses all activities that economically maximize product outputs. The maximum fiber strategy emphasizes harvest and utilization of wood fiber by reducing other product output as needed to meet a goal. These latter two strategies involve long-term capital investment to improve production potential. All three strategies could be used in Berkshire and Franklin Counties. Only the present condition and maximum fiber strategies could apply in Hampden and Hampshire Counties.

All three management strategies generate multiple outputs, which include sawtimber, pulpwood, wildlife, general recreation, special recreation, sediment, and stream flow. Market prices are attached to wood products, while prices for other outputs are based on previous research.

The strategies were applied to the forest/soil composites using the optimization model. It was reasoned that investment would occur on higher productivity sites that would yield the most return per dollar invested. Consequently, the maximum multiple use and maximum fiber strategies, which involve long-term investments, were applied only to forestland on medium productivity soil. The present condition strategy applied only to forestland on low productivity soil.

4.0 ANALYTICAL RESULTS

4.1 RESOURCE AVAILABILITY

The 2,500 square mile, four-county study area and its relationship to the rest of Massachusetts is shown in Figure 1. The study area represents approximately 30% of Massachusetts, with heavy forests, substantial agricultural, and recreational resources. The Connecticut River Valley is within its boundaries.

Table 1 shows the medium and low soil productivity group acreages in each of the four counties in the study area. Figure 2 shows the geographic distribution of these two productivity groups in each county.

Table 2 and Figure 3 show the acreage and spatial distribution, respectively, of hardwood/mixed and softwood forest types in the study area. This information was derived directly from the digital land cover files produced from the computer processing of LANDSAT CCTs. As can be seen, there are very few stands of pure softwood in the area studied.

The synthesis of forest cover and soil productivity groups are shown as acreage in Table 3 and geographic distribution in Figure 4. Direct interpretation of the composited map data provided both the tabular output in Table 3 and the resource data that were read directly into the right hand side constraint column of the linear programming model. Table 4 and Figure 5 represent refinements in the tabulation and geographic distributions of resource data input to the linear programming model. The acreage amounts and geographic locations of hardwoods/mixed and softwood types on medium and low soil productivity groups are determined.

4.2 OUTPUTS PRODUCED

Each management strategy produced seven products. As shown in Table 5, only the present condition and maximum fiber strategies were used in this production process. The present condition strategy applied only to the lower productivity group, while the maximum fiber strategy applied to the medium quality productivity group. This situation held in each of the four counties in the study area.

The objective function value for this model was $19,797,272, representing net value after removal of operating and investment costs. The marginal value products shown in Table 6 represent the amounts by which the objective function would increase if one more unit of the resource were available for use. Two additional facts regarding a maximum multiple use strategy emerged in Berkshire and Franklin Counties. For every unit of limiting resource forced into use by this strategy in Berkshire County, the objective function would be reduced by $0.86. A similar action would cause a reduction of $0.14 per unit in Franklin County.

4.3 MANAGEMENT STRATEGIES EMPLOYED

These strategies reflect present management alternatives in Massachusetts. They are not positions on the production surface representing maxima. The strategies are suboptima biologically, but may represent constrained optima recognizing local cultural conditions and general management objectives. They represent aggregates of all forest types in the individual counties. The output levels per acre are weighted averages over the soil productivity group and forest types.

Table 7 reflects the solution to the optimization model. It contains the acreage distributions for management strategies on forestland by soil productivity group in each of the four counties. Figure 6 shows the geographic distribution of these management strategies. This map shows where productive activities occur but does not show the amount of production per acre because the management strategies employed yield joint-products. If each strategy produced only one product instead of the present seven, it would be possible to directly interpret production levels from the maps. Figure 6 is the mapped linear programming solution which adds the desired spatial dimension to the optimization analysis.

5. SUMMARY

This work demonstrated the use of LANDSAT digital land cover files as a directly readable RAP data source for analysis involving linked use of mathematical programming and computer composite mapping of a forested study area in western Massachusetts. Production constrained to forested areas on two soil productivity groupings was determined through linear programming. A spatial dimension was added using computer composite mapping. This spatial aspect is emphasized; without it, the results of planning efforts have limited impact on the public for whom they are intended.

Two major caveats regarding interpretation of the results are warranted. First, the management strategies are based on informed judgment of field personnel and probably do not represent production frontiers. (Since this is a linear model, constant returns to size and scale are assumed.) Second, the model used is a simple one that was derived from a larger more complex model of the full state's forest economy. Due to time constraints and expositional simplicity, this generality was necessary.

6. REFERENCES

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TABLE 1. MEDIUM AND LOW SOIL PRODUCTIVITY GROUPS' ACREAGES IN STUDY AREA COUNTIES

Counties	Soil Productivity Groups	
	Medium (Acres)	Low (Acres)
Berkshire	473,615.77	136,701.02
Franklin	169,095.17	283,018.03
Hampden	307,749.67	87,773.90
Hampshire	218,647.99	170,845.99

TABLE 2. FOREST TYPE ACREAGES IN STUDY AREA COUNTIES

Counties	Forest Types	
	Hardwoods/Mixed (Acres)	Softwoods (Acres)
Berkshire	448,552.46	944.09
Franklin	371,973.47	468.78
Hampden	250,605.66	471.99
Hampshire	274,647.61	941.64

TABLE 3. FORESTED ACREAGE ON SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties	Soil Productivity Groups	
	Medium (Acres)	Low (Acres)
Berkshire	327,847.41	116,471.48
Franklin	138,634.28	233,341.05
Hampden	216,143.70	28,315.80
Hampshire	173,965.75	101,623.60

TABLE 4. FOREST TYPE ACREAGES ON SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties and Soil Productivity Groups	Forest Types	
	Hardwoods/Mixed (Acres)	Softwoods (Acres)
Berkshire		
Medium	327,375.18	472.23
Low	116,471.48	0
Franklin		
Medium	138,634.28	0
Low	232,872.27	468.78
Hampden		
Medium	216,143.70	0
Low	27,843.81	471.99
Hampshire		
Medium	173,965.75	0
Low	100,681.97	941.64

TABLE 5. PRODUCT OUTPUTS FROM FORESTED LANDS IN STUDY AREA COUNTIES

Counties and Management Strategies	Products						
	Sawtimber (MCF)	Pulpwood (MCF)	Wildlife (AUM)	General Recreation (VD)	Special Recreation (VD)	Sediment (Tons)	Streamflow (Acre-Ft)
Berkshire							
Present Condition	571	12	338	243,424	54,741	3,844	125,789
Maximum Fiber	3,246	1,508	951	698,314	154,088	11,475	750,770
Franklin							
Present Condition	1,493	70	583	256,675	252,008	51,335	235,674
Maximum Fiber	1,150	180	347	156,656	159,429	33,272	288,359
Hampden							
Present Condition	119	6	71	37,376	30,580	623	56,913
Maximum Fiber	2,075	2,161	778	285,309	265,856	4,842	481,999
Hampshire							
Present Condition	742	41	701	238,814	110,769	2,236	202,230
Maximum Fiber	2,157	887	1,200	450,569	436,652	4,175	356,628
Total	11,553	4,865	4,969	2,358,137	1,464,123	111,802	2,498,362

TABLE 6. MARGINAL VALUE PRODUCTS FOR SOIL RESOURCE IN STUDY AREA COUNTIES

Counties and Soil Productivity Groups	Marginal Value Products (Dollars)
Berkshire	
Medium	14.24
Low	12.51
Franklin	
Medium	12.32
Low	12.74
Hampden	
Medium	16.48
Low	14.83
Hampshire	
Medium	19.75
Low	15.48

TABLE 7. MANAGEMENT STRATEGY ACREAGES ON FORESTED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

Counties and Forested Soil Productivity Groups	Management Strategies	
	Present Condition (Acres)	Maximum Fiber (Acres)
Berkshire		
Medium	----	327,847
Low	116,471	----
Franklin		
Medium	----	138,634
Low	233,341	----
Hampden		
Medium	----	216,143
Low	28,315	----
Hampshire		
Medium	----	173,965
Low	101,623	----

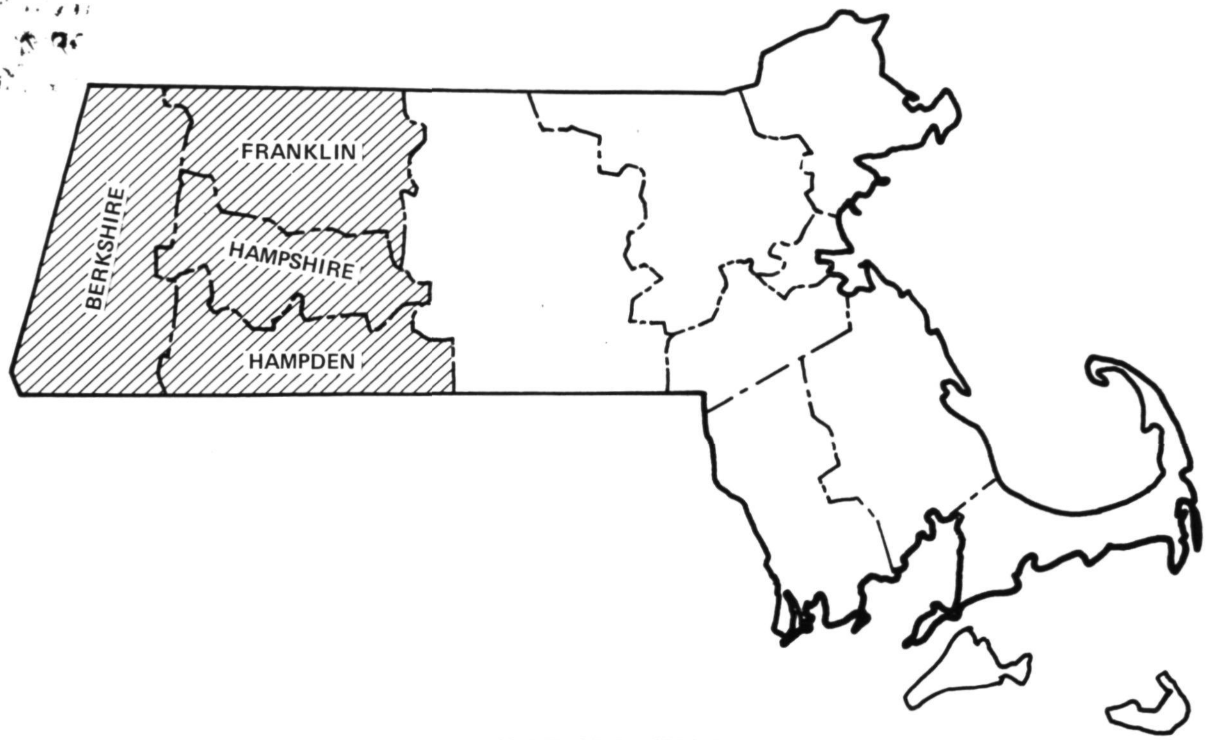

FIGURE 1. FOUR-COUNTY STUDY AREA IN MASSACHUSETTS

FIGURE 2. MEDIUM AND LOW SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

FIGURE 3. FOREST TYPES IN STUDY AREA COUNTIES

FIGURE 4. FORESTED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

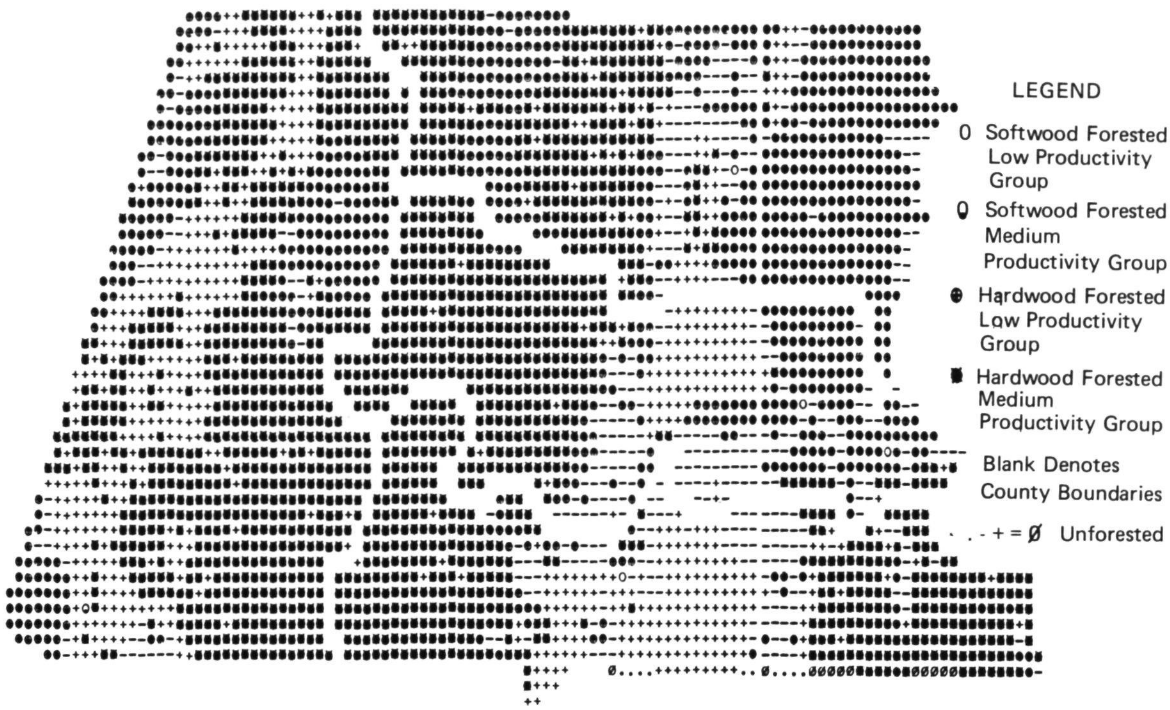

FIGURE 5. FOREST TYPED SOIL PRODUCTIVITY GROUPS IN STUDY AREA COUNTIES

FIGURE 6. MANAGEMENT STRATEGY DISTRIBUTIONS IN THE STUDY AREA