A PROPOSED PERIODIC NATIONAL INVENTORY OF LAND USE LAND COVER CHANGE

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BIOGRAPHICAL SKETCH

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ABSTRACT

Three alternatives using digital thematic mapper (TM), analog TM, and a combination of either digital or analog TM data with low altitude photography are discussed for level I and level II land use/land cover classes for a proposed national inventory. Digital TM data should prove satisfactory for estimating acreage in level I classes, although estimates of precision may be unreliable. Either the digital or the analog TM combined with low-altitude photography (LAP) are expected to yield satisfactory estimates for most level I and level II classes. Reliable estimates of precision can be obtained for those classes where LAP is "truth".

INTRODUCTION

The economic models used for the mandated task of estimating present and future supplies, demands, and prices of renewable resources involve several variables, including land use/land cover. Therefore, it is necessary to have a regular systematic inventory of these variables or changes in them. Ideally an annual inventory would be most helpful, but its attainment is not feasible with standard forest surveys that address a multitude of variables, many of which must be sampled on the ground. A new sampling scheme that gives accurate land use/land cover estimates and reduces the amount of ground sampling is needed. Remotely sensed data can provide some of the information needed more quickly and economically than ground sampling, but with some loss of information and accuracy. The possible use of remotely sensed data is discussed for a natural resource inventory focusing on the Southern United States, where more frequent periodic estimates are most needed. Such an inventory procedure should be tested there before it is applied in other parts of the country.

This paper presents 3 possible sampling designs for estimating land use/land cover acreage and change in these acreages over time utilizing TM imagery. The sampling designs and the classification scheme (Table 1) are designed to be used in the Southern United States, where a short survey cycle is deemed necessary. The sampling designs are evaluated on the basis of cost, ease of use, and potential reliability of the data. Since land use patterns change rapidly at times, particularly in the South, the adaptability of the designs to a short survey cycle is very important.

REVIEW OF LITERATURE

Many factors are involved in choosing the proper remote sensing system for any sampling design. It is impossible to select the one system that will meet all conditions with optimum efficiency. Therefore, it is important to define the critical conditions that must be met. For the purposes of this proposed survey, the major concerns are acquisition of the land use/land cover data and economic data, along with accuracy of the interpretation. The data must be collected within the repeat cycle of the survey and ideally, provide as close to a snapshot view of current resources as possible. In addition, the proposed survey will cover large areas; therefore, acquisition cost of the data must be kept as low as possible. It was decided that imagery routinely being obtained would prove to be more economical than data contracted specifically for this purpose. We have therefore limited the proposed survey to using existing remote sensing programs, such as the National High Altitude Photography program (NHAP) and satellite imagery.

Photography

NHAP is a government-sponsored program designed to acquire small-scale (1:58,000) color infrared (CIR) photographs of the continental U.S. within a 5-6 year cycle. While the NHAP program provides extensive coverage at an adequate scale, it was determined that NHAP would be inappropriate for the survey we have envisioned. The main concern was with the time required for repeated cycles. The 5-6 year NHAP cycle exceeds the proposed survey cycle of 1-2 years. Also, due to flight planning and problems with cloud cover, acquiring total photographic coverage within a given state may take up to 4 or 5 years. This would not allow for a snapshot view of a state or region.

Satellite imagery has the potential to provide the information desired with the repeated coverage necessary to provide the snap shot view of existing land cover. Two sources of satellite data that have proven successful in obtaining land cover information are Landsat and National Oceanic and Atmospheric Agency (NOAA) weather satellites.

Satellite imagery options

Landsat MSS. The multispectral scanner (MSS) is a line scanning electro-optical imaging radiometer. The MSS is characterized by 79 m resolution in four spectral regions: green, red, and two near-infrared reflectance bands. The satellite is in a sun-synchronous orbit with an 18-day repeat cycle. Since the launch of the first satellite in 1972, MSS data have been applied to the inventory and monitoring of forest resources. However, the spatial, spectral, and radiometric characteristics of MSS data have limited such applications (Irons 1982).

Using MSS data, Aldrich (1979) reported that at the regional level of ECOCLASS, forest and grasslands were separable 92-99% of the time. The lower levels in the classification hierarchy were not separable at an acceptable level of accuracy.

Hoffer et al. (1978) compared Landsat MSS and USDA Forest Service Forest Inventory and Analysis Survey (FIA) forest acreage estimates for 158 counties in four states, involving all or parts of 16 FIA Survey Units. The results indicated that gross forest acreage estimates were comparable provided that appropriate techniques were utilized in developing the training statistics for the computer processing of the MSS data.

The Large Area Crop Inventory Experiment (LACIE) demonstrated that the Landsat MSS can help provide timely and reasonably accurate estimates of foreign wheat production. However, the U.S. spring wheat estimates were not as accurate as those for the U.S.S.R. and Canada. This is largely due to the inability of the MSS to resolve the U.S.'s narrow strip-fallow wheat fields. Also, the four MSS spectral bands were inadequate for use in distinguishing spring wheat from some of the other small grains (MacDonald and Hall 1980).

The MSS provides valuable information with regard to land use/land cover classifications. The literature indicates that MSS-derived land use/land cover estimates are useful when based on broad categories, such as urban, fields, grassland, forest, and water. However, the quality of estimates for lower levels in the classification hierarchy (e.g., conifer, hardwood, and mixed forests) is limited by the spatial, spectral, and radiometric characteristics of MSS data. In fact, these estimates are usually too inaccurate to be of use.

Landsat Thematic Mapper (TM). The TM is a nadir-pointing, electro-optical scanning radiometer. In terms of basic design, there are at least two fundamental differences between the MSS and TM. First, the TM scans and obtains data in two directions. The bidirectional approach was employed to reduce the scan rate and provide the dwell time needed to produce improved radiometric accuracy. Second, the TM detector arrays are located within the primary focal plane of the instrument, allowing incoming light to be reflected directly onto the detectors without transmission through fiber optics, as with the MSS.

The TM operates in seven spectral bands. These bands were chosen primarily for vegetation monitoring except for band 7, which was added primarily for geological applications. An important design goal was the achievement of better radiometric sensitivity bands. The radiometric sensitivity of the TM is much improved over that of the MSS, even though the TM spectral bandwidths are narrower and the ground sample size (pixel size) is smaller. In addition to greater radiometric sensitivity, the TM provides improved spatial resolution over that of the MSS. A pixel size of 30 m (ground resolution) in all but band 6 will allow classification of areas as small as 2.5 to 4 ha (6 to 10 acres). Band 6, a thermal band, will achieve a pixel size of 120 m on the ground. The improvement of spatial resolution will result in an increase of pixels that do not overlap field boundaries and hence represents a single cover type (called pure pixels). A mixed pixel overlaps at least one boundary and thus integrates energy reflected from more than one cover type. As the proportion of pure pixels increases, so does the accuracy of data classification and area mensuration.

Hill (1984) used TM to classify the forested areas of Baldwin County, Alabama. Forty-three spectral classes were combined to form six forest categories: medium-aged slash pine, medium-aged loblolly pine, young pine, natural pine, hardwood, and non-forest. The stand-types were differentiated by their spectral and spatial characteristics. Only data from bands 4 and 5 were analyzed because preliminary work suggested that these bands yielded the greatest spectral separation. An overall accuracy of 88.4% correct for slash pine, young pine, loblolly pine, natural pine and mixed hardwood-pine was achieved. The individual classification accuracies ranged from 76.6% correct for hardwood-pine to 98.5% correct for slash pine.

Quattrochi et al. (1982) studied forest wetland species in the Tennessee Reelfoot Lake area. They used bands 2, 3, 4, 5 and 7 from a 1982 TM scene to delineate five species; cypress, mixed hardwood, willow cypress, floating aquatics and brush, and grass emergents. The classification accuracies ranged from 91.92 percent correct for willow cypress to 98.75 percent correct for cypress, with an overall accuracy of 95.36 percent correct.

The improved spatial resolution of the TM may enhance the ability to perform manual interpretation from TM color composite images. Early results indicate that interpretation of TM images could provide important land cover information. DeGloria (1984) cites the ability to detect agricultural and forest boundaries, roads and streams, and small clearings resulting from forest management. If image interpretation proves accurate with TM, imagery from the French satellite SPOT (System Probatoire d' Observation de la Terre) with 20 m resolution (10 m panchromatic) may prove better still. Colwell and Poulton (1985) report manual interpretation of color composite SPOT imagery approaches the interpretability of high-altitude photographs. Buchheim et al. (1985) states that manual interpretation to Anderson level II classes (Anderson et al. 1976) was easily obtained. Sadowski et al (1983) report that the proper selection of spectral bands is essential for interpretability of the desired features from the color composite image. The use of such images could greatly reduce the cost of conducting a survey relative to digital analysis.

The Landsat-4 TM offers improvements over the MSS with regard to spectral, spatial and radiometric resolutions. Much work has been devoted to studying the possible effects of these improvements. Although studies indicate that the TM's enhanced spatial resolution results in a larger proportion of pure pixels, this advantage is counteracted by the impact that sensor noise and increased spectral heterogeneity have on TM data. The increased number of quantization levels provides more information per pixel. Therefore, for some studies, a subset of the TM spectral bands may be used. This reduces the amount of time and cost involved in computer processing the data. Digital analysis of TM data has tremendous potential for use in monitoring and inventorying renewable resources.

NOAA

Data from meteorological satellites have been studied for possible use in monitoring large-scale vegetation condition. The advanced very high resolution radiometer (AVHRR) aboard the NOAA series satellites has proved feasible in vegetation mapping (Tucker et al. 1984), agricultural monitoring (Barnett and Thompson 1983), and fire fuel mapping (Miller et al. 1983). Gervin et al (1983) reported accuracy of data for land cover classification to be fair for large homogeneous tracts of land, and poor for areas less extensive and heterogeneous in nature. The advantage and potential importance of meteorological satellites in monitoring and mapping natural resources lies in the low cost for acquisition and processing daily repeated coverage of the earth's surface. The small-scale imagery, while less informative than the LANDSAT satellites (1.1 km resolution), can provide a complete, cloud-free, snapshot view of existing vegetation cover within a much shorter time than LANDSAT'S 18-day repeated coverage.

The use of AVHRR data appears to be ideally suited for assessing broad vegetational trends, particularly over a period of time such as a crop season. Daily coverage by the satellite ensures that cloud-free data will be abundant over a seasonal time frame. The coarse resolution of the AVHRR data, as compared to the LANDSAT data, is practical for mapping such broad ecological conditions as the wide-spread deforestation of tropical areas, global vegetation indexes, and fire fuel status of extensive rangeland. Currently, AVHRR data is being used to produce acceptable maps for all of these applications. However, the coarse resolution is not suitable for classifying finer levels of land cover types. Many important cover classes may occupy areas smaller than the AVHRR resolution could detect. Therefore, the use of AVHRR data for inventorying heterogenous land cover areas such as are found in the Eastern United States cannot be recommended.

OBJECTIVES

Sampling designs are needed to estimate acreage and change in acreage for the land use classes given in Table 1. The level II classes are developed with primary emphasis on the South.

Table 1. Level I and II land use/land cover classes to be estimated. The level I classification scheme is taken from Powell (1981). The level II system was jointly developed by G. Catts of the Rocky Mountain Forest and Range Experiment Station and N. Cost of the Southeastern Forest Experiment Station, Forest Service United States Department of Agriculture.

Level I classes	Level II classes
	7A. Site potential
	7A1. Commercial Timberland
	7A2. Unproductive Woodland
	7A3. Reserved
	7B. Stand Origin
	7B1. Planted
	7B2. Natural
1. Barrenland	7C. Stand Size
2. Cropland	7C1. Sawtimber
3. Grassland	7C2. Poletimber
4. Shrubland	7C3. Seedling/Sapling
5. Urban	7C4. Nonstocked
6. Water	7D. Stand Density
7. Treeland	7D1. Closed
	7D2. Open
	7E. Stand Type
	7E1. >90% Softwoods
	7E2. 50-90% Softwoods
	7E3. 25-50% Softwoods
	7E4. Bottomland Hardwoods
	7E5. Upland Hardwoods

SAMPLING SCHEMES

The requirement of rapid availability of estimates on an annual basis limits the choice to satellite imagery such as thematic mapper (TM) data as a primary source, either in the form of digital or photographic images of the digital data. It is doubtful that the TM data alone can yield all the detailed information needed, so three alternative schemes are presented and assessed. There may well be a need to settle for less than desired to keep costs down.

The alternatives presented describe the general procedures and characteristics unique to each alternative. This paper does not provide detailed description on actual processing techniques and verification measures that would be required in an actual production survey.

Digital analysis of TM data

This alternative would use systematic sampling (on a grid) with a random start and selection of an average of 100 TM plots per state from the digital data, using a plot size of 1000 - 10,000 acres. A sample of 100 plots is rather subjectively chosen as being potentially useful for the more frequently occurring variables listed in Table 1. This figure could be set more realistically after actual data have been collected in a pilot study. The cost of digital analysis should change little with plot size in the above range. Such a large plot size makes accurate measurements of land use/land cover possible on TM. The percentage of each plot in each land use/land cover class would be recorded. Permanent plots would be easily established and maintained. Estimates for large areas can be obtained quickly for broad categories with the high spatial resolution (30 m x 30 m) used. Single date scenes selected for image quality and minimum cloud cover will be used. The amount of cloud cover should be estimated as part of the estimation scheme. If substantial, this may need to be corrected for in the estimation.

The use of digital data alone should yield accurate estimates of acreage in all level I classes, although separating cropland and grassland may be date-dependent. For level II it should be nearly impossible to separate planted and natural stands, nonstocked and nonforested areas, and the bottomland and upland hardwoods. Difficulty in separating the softwood classes can also be expected. The other level II categories could possibly be sorted out, particularly with digital data from different time periods.

With this method, change estimation for appropriate categories should be quite reliable. Analog TM data would probably be needed to understand the nature of the change. Sampling error could only be calculated under the assumption that acreages by land use categories were correct for each plot sampled.

The current cost of this approach is $3300 per scene for obtaining the digital TM data; thus for the 60 scenes in the southern and southeastern states, the acquisition cost would be $198,000 and the processing cost from $100,000 to $200,000 per year. If the only estimates needed are for the population as a whole, a sample of ten scenes might be selected. It is more likely, however, that estimates for each individual state are desired, so that all 60 scenes would be required.

Manual interpretation of TM imagery

This alternative would use manual interpretation of analog TM data at 1:1,000,000 scale (production photographic product from EROS) with a sampling scheme selecting an average of 100 plots per state with a plot size of 1,000 acres. Skilled interpreters would estimate percentage of each plot in each land use class. Permanent plots would be established so that the same locations could be interpreted each year. Although spatial and spectral resolution are reduced relative to the digital data, these losses may be compensated for by the interpretive skill of the interpreter who can more easily bring ancillary information to bear on the estimation of land use acreages (and changes therein over time).

This approach should yield accurate estimates of acreage for the same classes as alternative one. In addition, it should be possible to separate urban with large canopies from other forested land and to increase accuracy in separating pine stand types (50% pine or more versus less than 50% pine), particularly if multitemporal images are used. To distinguish the 0-25% pine, 25-50% pine, and 50+% pine acreages would probably require ancillary information like that obtainable from low altitude (1:3000 or 1:5000 scale) photography.

The permanent plots could be used to determine where change was occurring and what kind. Relatively rare land use and land use change could not be determined or might be estimated inaccurately with the intensity and sample size discussed. Sampling error could only be calculated under the assumption that acreages by land use categories were correct for each plot sampled.

The current cost is $30,000 per year to procure the photographic TM data for 60 scenes and the processing cost would be approximately $60,000 per year. As with the digital analysis, costs would be reduced by decreasing the sampling intensity if interest is in the entire population. Again, it is more likely that estimates for individual states would be desired.

Two-phase sampling using TM imagery with LAP

In this alternative, the 100 TM photo plots per state in alternative 2 would be supplemented with a subsample of low-altitude photo (LAP) plots flown specially for this survey. To minimize cost, it would be best to concentrate acquisition of these photos in specific years, say every fifth year. To give a high degree of confidence that accurate information would be obtained on all land-use classes on each 1,000-acre plot, 1:12,000 scale CIR photography would be vital to this is proper registration, i.e., plot centers on TM and LAP should be at the same locations.

Note that digital plot data as discussed in alternative 1 could be used. We prefer the analog data in alternative 2 because of the lower cost and because it seems intuitively more attractive to use interpreted data at both levels so that a 1:1 correspondence can be established more readily.

Simple linear regressions between corresponding variables on the TM and LAP plots would be computed. If relationships were strong, the LAP plots could be purposively selected to ensure an adequate spread of sampling conditions and to avoid cloud cover. This approach should yield accurate estimates for all desired land use acreages with reliable estimates of error. Since it is likely that the same regressions would hold across states, a sample of 200 LAP photo plots should be adequate to establish the needed regressions. More could probably be available from the LAP photo acquisition program because additional coverage would be relatively cheap. These additional photos could be interpreted in following years if needed.

The cost of this alternative would be the cost of alternative 2 plus $30,000 per year to acquire and interpret the photos and analyze the data. The interpretation of the LAP photography should be done by experienced interpreters familiar with the area, such as from the USDA Forest Service FIA Units.

A pilot study is currently underway in North Carolina to determine whether NHAP 1:58,000 CIR photography flown on a 5-6 year cycle can be substituted for the 1:12,000 CIR photography. Interpretation of photo data for the level I and level II classes is currently underway for the two scales of photography using 1000-acre plots.

SUMMARY

The advantages and disadvantages of the three alternatives proposed emphasizing the use of thematic mapper data for an annual national inventory of land use discussed. The three alternatives are as follows:

1. Digital TM. The principal advantage of this approach is that it could be set up in a production mode at facilities with existing image processing capabilities. Increasing the sampling intensity by going to more samples or a larger plot size will increase cost only slightly. The method is expensive, only part of the desired information is obtained, and it is difficult to understand what the nature of the changes are. This approach is the most expensive of the alternatives discussed.
2. Analog TM. This is the lowest cost alternative. No estimates of reliability and only part of the desired information are obtained. It is easier than in alternative 1 to understand the changes that are occurring although relatively rare conditions will be missed due to the low sampling intensity. Modifications are easy (increased or decreased sampling intensity, studying subpopulations, or adding ancillary information if available).
3. Supplementing alternative 2 with a subsample of LAP photo plots using regression estimation. Accurate estimates of all detected land use classes and statistical estimates of reliability are obtained. A good understanding of change is gained subject to the limitations of the sample size. The LAP subsample could likely be selected purposively so that particularly interesting conditions on the TM photos can be studied in detail. Relatively rare conditions will be missed, especially on the LAP photos, because of the lower sampling intensity. But modifications are easy (increased or decreased sampling intensity, shifting work from one year to the next for budgetary reasons, studying subpopulations, getting any supplementary information of interest). Precise registration of plot centers on both the LAP and TM is vital for the success of this approach.

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