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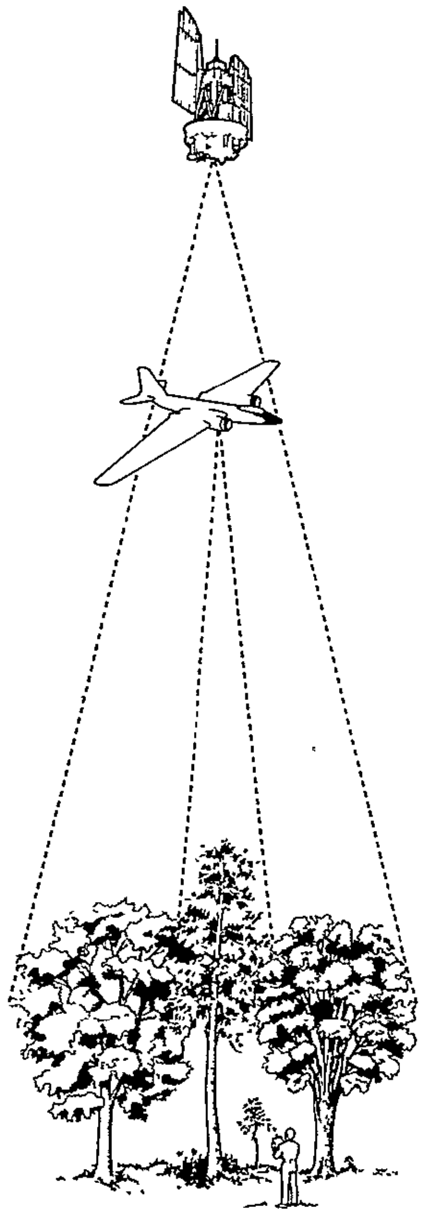

A LITERATURE REVIEW OF MAJOR REMOTE SENSING PROJECTS MAPPING FOREST LAND IN THE UNITED STATES, USING SATELLITE DATA AND AUTOMATIC DATA PROCESSING

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NOTE: In 1976, the Nationwide Forestry Applications Program was expanded from a Regional project by cooperative agreement between the Forest Service, U. S. Department of Agriculture, and the National Aeronautics and Space Administration (NASA). The Program is designed to sponsor research and development on the application of remote sensing analysis techniques to problems arising from the need to inventory, monitor and manage forests and rangelands, including the assessment of impacts on forest stands from insect and disease damage.

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16 Abstract

This paper summarizes the findings of 19 selected major projects that are representative of satellite remote sensing and lists the conclusions which may influence the design of future test projects for mapping renewable resources. Fourteen of these projects used automatic data processing analysis methods, and 15 investigated forestry landscapes.

The following subjects are discussed for each selected project: objectives, scope, methodology, major conclusions and output, and special comments and notes.

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PREFACE

In the last few years, many forestry investigations, both large and small, have been performed using automatic data processing (ADP) techniques to analyze Landsat,* Skylab, and Apollo data. Forestry experiments using photointerpretation techniques alone, as well as numerous nonforestry studies using a combination of ADP and photointerpretation techniques, have also been conducted. The conclusions from many of these investigations will influence the design of future remote sensing test projects for mapping renewable resources.

This paper is intended to be an informal working document and an easy and useful cross-reference for future test project planners. It summarizes the findings of 19 major representative projects in and related to the forestry discipline under the following topics: objectives, scope, methodology, major conclusions and output, and special comments and notes. However, this review should not be considered all-inclusive. It was compiled quickly from research notes prepared intermittently by this author throughout the past few years.

The projects, listed by their most popular names, are discussed in reverse chronological order, as follows:

1. Pacific Northwest Application System and Verification Test (ASVT) — current
2. Ten-Ecosystem Study — current
3. St. Regis/National Aeronautics and Space Administration (NASA) ASVT — current
4. Bureau of Land Management (BLM)/NASA ASVT — current
5. Large Area Crop Inventory Experiment (LACIE) — current

*Landsat - NASA land observatory satellite, formerly called the Earth Resources Technology Satellite (ERTS).

6. Titus' Planning Model Applied to Grays Harbor County, Washington — 1977
7. Mead and Meyer's Mapping in Minnesota — 1977
8. Krebs and Hoffer's San Juan National Forest Mapping — 1976
9. Rhode, Taranik, and Nelson's Flood Inundation Mapping — 1976
10. Susanville ASVT — 1976
11. Williams and Haver's Intralab Forest Mapping — 1976
12. Aldrich's Skylab Study — 1975
13. Langley's Skylab Study — 1975
14. Colwell's Skylab Study — 1975
15. Hoffer's Skylab Study — 1975
16. Aldrich's ERTS-1 Study — 1975
17. University of California at Berkeley, Sam Houston National Forest Inventory — 1975
18. University of California at Berkeley, Plumas National Forest Inventory — 1973
19. Langley's Apollo Study — 1971

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CONTENTS

ABBREVIATIONS

ADP	Automatic data processing
ASCS	Agricultural Stabilization and Conservation Service (USDA)
ASVT	Application System and Verification Test
BLM	Bureau of Land Management
CAMS	Classification and Mensuration Subsystem
CAS	Crop Assessment Subsystem
ECHO	Spatial classifier program developed by the Laboratory for Applications of Remote Sensing
EREP	Earth Resources Experiment Package
EROS	Earth Resources Observation System
ERTS	Earth Resources Technology Satellite
ESL	Electromagnetic Science Laboratory
FSH	Forest Service Handbook
Image 100	Interactive Multispectral Image Analysis System, Model 100
ISA	Intensive study area
JSC	Lyndon B. Johnson Space Center
LACIE	Large Area Crop Inventory Experiment
Landsat	NASA land observatory satellite
LARSYS	Laboratory for Applications of Remote Sensing System
MDAS	Multispectral Data Analysis System
MSS	Multispectral scanner
NASA	National Aeronautics and Space Administration
NCIC	National Cartographic Information Center
NOAA	National Oceanic and Atmospheric Administration

PCC Probability of correct classification

PPP Probability proportional to predicted ________;
e.g., probability proportional to forest-predicted proportion or PPP to forest proportion

PPS Probability proportional to size

PSU Primary sampling unit

PSW Pacific Southwest

SSU Secondary sampling unit

TSU Tertiary sampling unit

USDA U.S. Department of Agriculture

USDI U.S. Department of Interior

YES Yield Estimation Subsystem

1. PACIFIC NORTHWEST ASVT

Nichols, J. D.*; Harding, R. A.†; Scott, R. B.†; and Edwards, J. R.†: Forest Inventory of Western Washington by Satellite Multi-Stage Sampling. Interim Report, August 1977.

Objectives

This project was designed to inventory forest parameters (including the basal area, density, and volume) and categorize them by age class, site class, and ownership, using ADP analysis of Landsat, aircraft, and ground sampling data.

Scope

1. Site: 8 093 740 square hectometers (20 million acres) in western Washington
2. Landsat coverage: nine Landsat scenes for three dates, used to produce one set of complete coverage
3. Ownership: State of Washington, national forest, other public, forest industry, and other private
4. Cover types: old growth conifer, second growth conifer, second growth hardwood, regeneration, nonstocked commercial forest, and nonforest
5. Remote sensing and ancillary data:
   a. Landsat multispectral scanner (MSS) data
   b. Aerial photography from U-2 flights, from Department of Natural Resources (State of Washington) flights,

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*Electromagnetic Science Laboratory (ESL), Inc.; Sunnyvale, California.

†Department of Natural Resources; State of Washington; Olympia, Washington.

and from USDA Forest Service flights at scales of 1:120 000, 1:24 000, 1:15 840, and 1:12 000 in color infrared, color, and black and white

   c. Ground inventory data

6. Participants: NASA Ames Research Center, Department of Natural Resources of the State of Washington, Pacific Northwest Commission, and ESL

<u>Methodology</u>

1. Manual stratification of site by ownership to exclude land not controlled by the State

2. Two-stage sampling with two-phase sampling on the secondary sampling units, SSU's (Regression was used to obtain the second-stage estimate.)

3. Determination of a primary sampling unit (PSU) as 9.7 by 9.7 kilometers (6 by 6 miles), approximately the size of a township

4. Determination of an SSU as 1 Landsat pixel (0.4 square hectometer, 1 acre)

5. Determination of a ground sample (i.e., a two-phase independent sample in a regression estimate) as 0.4 square hectometer (1 acre)

6. Approach:

   a. Test of areas to calculate the coefficient of variation and to determine the PSU size

   b. Data handling, preprocessing/mosaicing, and cleaning by averaging, registration, and ownership digitizing

   c. Determination of the sampling design

   d. ADP classification and sample allocation

e. Performance of photography and ground work and estimation of regression

f. Data compilation and analysis

g. Transfer of technology

Major Conclusions and Output

1. Output: A tabulation of the statistics, classification maps registered to Washington's State plane coordinate system, documentation, and recommendations will be produced. They are not available at this publication date.

2. Reviewer's assessment of project's conclusion: This project used a state-of-the-art approach, is feasible, and attained the desired goals.

Special Comments and Notes

1. ADP classification: Signatures were developed for 22 intensive study areas (ISA's), 512 by 512 pixels each, amounting to about 30 percent of the study site; there were fewer than 35 training samples per ISA, each 2 to 20 pixels. Clustering was used to determine the signature subclasses of mixed hardwood-conifer, with 17 signatures determined for 6 cover types.

2. Sample allocation: Fifty PSU's with probability proportional to forest-predicted proportion (PPP), 3000 SSU's and 325 ground SSU samples, and a ground sample PPP to site class and age class were selected.

3. Optimal PSU size: The following PSU sizes were analyzed: 1.6 by 1.6, 3.2 by 3.2, 4.8 by 4.8, and 9.7 by 9.7 kilometers (1 by 1, 2 by 2, 3 by 3, and 6 by 6 miles). The 9.7-by-9.7-kilometer PSU gave the best (i.e., the smallest) coefficient of variation.

4. Image-to-ground registration: One control point was selected per township.

5. SSU registration on photographs: A zoom transfer scope or sketchmaster was used, with a claimed precision of ±30.48 meters (±100 feet).

6. SSU photograph-to-ground correlation: Two methods of photointerpretation were used:

   a. Direct interpretation of basal area, density, and stem diameter

   b. Indirect estimation by crown closure, crown diameter, height, etc.

7. Evaluation of ADP classification: There was no overall map accuracy (probability of correct classification, PCC). The evaluation of 25 percent of each ISA was subjective; hence, approximately 25 percent by 30 percent reflected a 7.5-percent evaluation.

2. TEN-ECOSYSTEM STUDY

Kan, E. P.; and Weber, F. P.: The Ten-Ecosystem Study: Landsat ADP Mapping of Forest and Rangeland in the United States. Proceedings of the Twelfth International Symposium on Remote Sensing of Environment, sponsored by the Environmental Research Institute of Michigan, held at Manila, Philippines, April 20-26, 1978.

Objectives

The Ten-Ecosystem Study was developed to analyze Landsat and aircraft sampling data with ADP techniques in order to uniformly assess the following:

1. The information content in Landsat MSS data
2. The success of Landsat classification over large areas for the 10 generalized forest and rangeland ecosystems in the United States

Scope

1. Site: nine sites throughout the United States, each with 303 515 square hectometers (750 000 acres)
2. Ecosystems: Coastal Range and Rocky Mountain Conifer, Northern Hardwood, Northern Conifer, Pinyon-Juniper, Southeastern Pine and Oak-Pine, Boreal, Rangeland, Pacific Coast Conifer, and Central Hardwood
3. Administrative boundaries: counties, township, etc.
4. Cover types:
    a. Level II: softwood, hardwood, grassland, water, and other
    b. Level III: softwood, hardwood, and grassland subcategorized by species; water subcategorized into

census (greater than 16.2 square hectometers, 40 acres) and noncensus (less than 16.2 square hectometers)

5. Remote sensing and ancillary data: Landsat MSS data, 1:120 000 scale aerial photography, and data from cursory field trips
6. Separability study: training field spectral discrimination for maximum information content in Landsat MSS data
7. Simulated inventory study:
    a. Development of signatures from the 10-percent site without benefit of a ground check
    b. Classification of the entire site (extending signatures)
    c. Check of map accuracy (PCC) and areal estimate precision
    d. Determination of the success of Landsat classification over large areas
8. Participants: NASA/Lyndon B. Johnson Space Center (JSC), USDA Forest Service, and Lockheed Electronics Company, Inc.

Methodology

1. Masking of administrative boundaries
2. Interactive signature development by training fields; supervised classification
3. Evaluation and areal estimates:
    a. Determination of a PSU as 50 by 50 pixels (1 pixel equals 0.3 square hectometer, 0.8 acre)
    b. Determination of an SSU as 2 by 2 pixels, with nine possible configurations at or about each
    c. Determination of the PCC and accuracy of the areal estimates

4. Two-phase regression estimation of area proportions for investigating the utility of Landsat classification as auxiliary information to improve the areal estimate obtained by simple random sampling of photoplots

5. Postprocessing for remapping classifications such that each object has a minimum prespecified size

6. Approach:

   a. Preliminary image analysis: selection of Landsat data for ADP

   b. Site analysis: field trips and ancillary data

   c. Preprocessing: image-to-image and image-to-ground registration, as well as the identification of training fields

   d. Processing: preparation of separability study and simulated inventory study

   e. Postprocessing: minimum area mapping and output products

   f. Evaluation: statistical evaluation of PSU and SSU used to calculate PCC, areal estimate accuracy, and precision and regression estimates

   g. Transfer of technology

Major Conclusions and Output

1. Feasibility conclusions, sample classification maps, and statistics were output.

2. A Landsat Level II classifier was used.

3. ADP classification using 10-percent contiguous areas for signature development provided a PCC similar to the PCC calculated for the signatures developed throughout the site.

4. The direct area tabulation from simulated inventory studies was fairly accurate. Area estimates were unbiased at the 0.9 confidence level for homogeneous sites where the PCC was greater than 80 percent.

5. Landsat classification was used as auxiliary information to improve areal estimates obtained by the random sampling of photoplots. The area estimate variance was reduced by 55 to 97 percent, depending on whether the PCC was low or high.

6. Routine ADP analysis and minimum area mapping was conducted.

7. Workshops were conducted and there was much contact with the users.

Special Comments and Notes

1. Special effort was devoted to defining and confining the extent of ground-truth data as they were related to the time and manpower constraints. A 10-percent limited area was used in the simulated inventory for developing signatures to be extended to the rest of the site.

2. A uniform assessment over 10 diverse ecological and physiographic sites of the United States has not been achieved before. The conclusions were similar to conclusions from other studies, but the uniform assessment was made possible by the design of the project.

3. Two phase sampling for areal proportion estimates was demonstrated with Landsat data used for auxiliary information.

4. A rigorous classification evaluation procedure was used. Historical statistics were not relied on since a comparison with them might not always be fair. The PCC calculation and area were compared against aircraft photointerpreted ground truth.

5. The SSU location was given nine possible configurations to minimize misregistration error and decision logic weakness. This relaxed the Landsat-to-photograph registration requirement to within a 1-pixel error, which is readily achievable.

6. No more than 25 PSU's (50 by 50 pixels) were used for evaluation and area estimation, and ten 2-by-2-pixel SSU's were used per PSU. This resulted in a total area of 1000 by 1000 pixels and an SSU sampling of 0.1 percent of the total area.

7. Minimum-area mapping was demonstrated to be operational.

3. ST. REGIS/NASA ASVT

Mroczynski, R. P.: Forest Resource Information System Project. Laboratory for Applications of Remote Sensing, Purdue University, NASA Contract NAS 9-15325 Quarterly Report, January 1978.

Objectives

This project was designed to investigate the contribution of Landsat MSS data in an industrial, operational forest resource information system, to investigate several levels (platforms) of imagery, and to analyze the correlation between measurements using these platforms in order to develop the following capabilities:

1. An effective multilevel sampling system that uses Landsat and aircraft data
2. A change detection capability
3. A method of transferring ADP technology to the paper industry

Scope

1. Site: land holdings of the St. Regis Paper Company (Southern Timberland Division)
    a. Site I: in the Lower Coastal Plain in Georgia (87 008 square hectometers, 215 000 acres)
    b. Site II: in the Piedmont Upper Coastal Plain in Georgia (24 281 square hectometers, 60 000 acres)
    c. Site III: in the Middle Coastal Plain in Mississippi (28 328 square hectometers, 70 000 acres)
    d. Site IV: in the Alluvial Bottomland in Florida (32 375 square hectometers, 80 000 acres)

2. Land units:

   a. Plots: 1 to 2 square hectometers (2.5 to 5 acres)

   b. Operating areas: 8.1 to 121.4 square hectometers (20 to 300 acres)

   c. Administrative units: 485.6 to 2023.4 square hectometers (1200 to 5000 acres)

3. Cover types:

   a. Conifer: natural pine, planted pine, seeded pine, atypical pine, and cypress-cedar

   b. Deciduous: bottomland, upland noncommercial, and upland commercial

   c. Mixed: upland and bottomland

   d. Nonstocked: forest and noncommercial brush

   e. Nonforest: pasture, crops, and habitation

   f. Water

   g. Possibly density classes in a more detailed level of analysis

4. Remote sensing and ancillary data: Landsat MSS data, as well as color and color-infrared photography at 1:4800, 1:15 840, and 1:60 000 scales

5. Participants: NASA/JSC, St. Regis Paper Company (Southern Timberland Division), and the Laboratory for Applications of Remote Sensing (Purdue University)

Methodology

1. Stratification of forest resources using Landsat ADP analysis

2. Further detailed interpretation using aerial photography at increasing scales

3. Comparison against ground plots, acreage evaluation, and some qualitative evaluation

Major Conclusions and Output

1. Maps, tables, and feasibility conclusions on cover type mapping and parameter inventories were produced.
2. The correlation between measurements made on different scales of imagery was analyzed.
3. Change detection was demonstrated and conclusions were reached.
4. Technology transfer was accomplished with instruction courses, learning packages, and "hands-on" demonstrations.
5. Landsat technology was integrated into an ongoing information management system.

(The interim conclusions are pending.)

Special Comments and Notes

None.

4. BLM/NASA ASVT

Wildland Vegetation Resources Inventory System Integration and Demonstration. ESL Proposal Number Q2089 (Sunnyvale, California), February 1977. (Also Project Plan, JSC-11632, October 1976.)

Objectives

This project was designed to produce an inventory of wildland resources, a feasibility study of what and how much can be mapped, a demonstration of Landsat aircraft and ground sampling ADP technology, and a demonstration of change detection and technology transfer.

Scope

1. Site:
    a. Site I: Denali Planning Unit, Alaska (809 374 square hectometers, 2 million acres), 1977-78
    b. Site II: Shivwits Planning Unit, Arizona (809 374 square hectometers), 1978 (ongoing)
    c. Site III: Owyhee Planning Unit, Idaho (809 374 square hectometers), 1978 (ongoing)
2. Approach: multistage sampling
3. Planning model: developed by S. Titus of the University of California at Berkeley (see section 6); applied to site II for optimal resource allocation
4. Cover types for Site I:
    a. Wet tundra: water sedge, saline meadow, and marsh
    b. Mesic tundra: grass-sedge-herb, shrub, and tussock

c. Dry tundra: open, closed, mat, cushion, closed shrub, and open shrub

5. Remote sensing and ancillary data: Landsat MSS data, U-2 photography, small-aircraft large-scale 35-millimeter photography at scales of 1:10 000 to 1:16 000 with stereo doublets, and ground survey data

6. Participants: NASA, BLM (Denver Service Center), and ESL

Methodology

1. Formation of the final stratification from vegetation strata and "convenience" strata (i.e., accessibility zones)

2. Two-stage sampling with two-phase sampling on SSU's (regression estimation in conjunction with two-phase sampling)

3. Determination that there would be 300 PSU's, consisting of low-altitude flight lines less than 0.8 by 3.2 kilometers (0.5 by 2.0 miles); collection of 35-millimeter photography over these PSU's at 1:10 000 to 1:16 000 scales

4. Determination that SSU's would be 18 cluster points, approximately 0.1 square hectometer (0.25 acre); collection of photography with stereo doublets at 1:1200 to 1:2000 scales

5. Approach:

   a. Preprocessing: correction for Landsat data banding and line drop, geometric and some radiometric correction, registration, and electronic mosaicing (site I covered in four Landsat frames)

   b. Processing: supervised and unsupervised classification

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c. Postprocessing: smoothing (not minimum-area mapping as in the Ten-Ecosystem Study) to remove salt-and-pepper appearance in classification

d. Statistical testing

6. Special output map presentation by algebraically combining (overlaying) topographic data on classification data and topographic data furnished in digital tapes by the National Cartographic Information Center (NCIC), formerly known as the Defense Mapping Agency

7. Change detection by differencing two classification images

8. Signature extension (method developed by the Environmental Research Institute of Michigan) to develop similar classification signatures

Major Conclusions and Output

1. Output: Feasibility conclusions, tabulations of statistics, photointerpretation keys, technology transfer workshops, and a "hands-on" demonstration were produced during this project.

2. Reviewer's assessment of project's conclusions: The project used a state-of-the-art approach, is feasible, and attained the required precision.

Special Comments and Notes

1. ADP classification was used on six to eight 512-by-512-pixel ISA's per Landsat scene, approximately 20 to 30 percent of the study site. The ISA's were used to develop signatures.

2. A subjective iterative evaluation of each ISA was made to determine the adequacy of signatures for a whole Landsat frame (or stratum).

3. The image registration precision was within 0.5 pixel.

5. LACIE

MacDonald, R. B.; and Hall, F. G.: LACIE, A Proof of Concept Experiment in Global Crop Monitoring. Proceedings of Midcon 77, IEEE Electronics Show and Convention (Chicago, Illinois), November 8-10, 1977.

Objectives

The LACIE project was designed to develop, implement, test, and evaluate operational remote-sensing Landsat ADP technology in order to develop the following capabilities:

1. Classification and determination of multicountry wheat acreage
2. Estimation of wheat yield by using meteorological and climatological data
3. Estimation of wheat production in the early growth season, during the growth season, and postharvest

Scope

1. Countries: United States, U.S.S.R., Canada, China, India, Argentina, Brazil, and Australia
2. Sampling: 5000 segments, 9.3 by 11.1 kilometers (5 by 6 nautical miles) each; multiple acquisitions per segment (average of five to six acquisitions per segment) to study the progression in biostages; and 3 consecutive years of wheat-watching (three phases)
3. Statistics summation: categorized by crop-reporting districts, states, and nation
4. Accuracy and precision goal: 90/90 criterion (i.e., within ±10-percent true wheat production for 90 percent of the time)

5. Cover types: wheat, nonwheat, small grain, and non-small grain

6. Remote sensing and ancillary data:

   a. LACIE operation: Landsat MSS data only

   b. Sideline test, evaluation, and development studies: supplementary aerial and ground data only

7. Major analysis subsystems: Classification and Mensuration Subsystem (CAMS), Yield Estimation Subsystem (YES), and Crop Assessment Subsystem (CAS)

8. Participants: NASA, USDA, National Oceanic and Atmospheric Administration (NOAA), many universities, and Lockheed Electronics Company, Inc. (the principal contractor)

Methodology

1. Agrophysical stratification

2. Probability proportional to size (PPS) sampling in wheat-growing area (probability obtained from history and/or preliminary image analysis)

3. Cluster sampling, where each cluster is 9.3 by 11.1 kilometers (5 by 6 nautical miles)

4. Development of agrometeorological model for calculation of yield; i.e., hectoliters per square hectometer (bushels per acre)

5. Determination of production as area times yield

6. Procedure 1 ADP classification:

   a. Interpretation and labeling of cluster-selected grid dots (subset of 209 dots)

   b. Classification of a whole scene of wheat acreage, based on cluster statistics

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c. Bias correction from checking the classification against the labels of a subset of 30 to 60 dots from the original 209 grid dots and the labels from another 209 selected grid dots

7. Estimation without the use of aerial photographs or ground-truth data (except for ISA's which were used as evaluation yardsticks)

8. Multitemporal classification on an average of five to six acquisitions per segment (i.e., a 9.3-by-11.1-kilometer cluster segment)

9. Extensive research, test, and evaluation to support the mainstream LACIE operation

10. Transfer of the technology and ADP system to the USDA

Major Conclusions and Output

1. Data were output on wheat acreage, yield, and production during the entire growing season throughout 3 years (1974-77).

2. Many ancillary output products, a new technology, and the transfer of technology resulted from this project.

3. The 90/90 criterion for production estimates was met in the United States and the U.S.S.R.

4. The project demonstrated large data analysis and production turnaround; improved ADP classification, sampling technology, early season production estimation, and first-generation yield estimation; and defined new technological issues.

5. The throughput rate was 30 days from the time the digital tape of the segment was received until processing was completed for each segment. (The 30 days included 8 days of weekend, 13 days of true processing, and 9 days of holding for subsequent processing.)

Special Comments and Notes

1. LACIE was the first multicountry proof-of-concept experiment that utilized only satellite remote-sensing ADP technology to monitor an important agricultural commodity (wheat and small grains). No aerial photographs or ground-truth data were used.
2. Much new technology was developed, tested, and adopted.

6. TITUS' PLANNING MODEL APPLIED TO GRAYS HARBOR COUNTY, WASHINGTON

Wensel, L.; Colwell, R.; and Titus, S.: Development of Sampling Design for Use with Remotely Sensed Data for Natural Resources Inventory. University of California at Berkeley, NASA Research Grant 16-640-CA, June 1977. (Discussed in the NASA Contract NAS 9-14452 Final Report, University of California at Berkeley, September 1976.)

Objectives

The objectives of this project were to test the utility of Titus' Planning Model in its optimal allocation of statistical samples and in its analysis of the choice of sampling schemes, as applied to the forest resource inventory of Grays Harbor County, Washington.

Scope

1. Test data: used data from the Grays Harbor County, Washington, portion of the Pacific Northwest ASVT (see section 1) to set up the model.
2. Approach: used different combinations of cost parameters, sampling strategy, and sensitivity analysis to determine optimal choices.

Methodology

1. Formulation of the optimality criterion, which is a function of the sampling cost subjected to the variance requirement.
2. Selection of a sampling strategy (e.g., single-stage sampling, two-stage sampling, or two-stage stratified with double sampling)

3. Selection of the size of the clusters, the allocation strategy (e.g., PPS or just simple random), the correlation coefficient, and the precision requirement

4. Simulation of a spatial layout of the statistical data, such as the Landsat two-dimensional imagery

5. Application of a nonlinear programming computer algorithm to determine the optimal number of samples and the associated cost (satisfying all the prespecified constraints)

6. Performance of the same optimization to generate a series of allocation strategies with their associated cost and to generate a sensitivity analysis to determine the best choice of strategy and sample allocation

Major Conclusions and Output

1. The use of stratified two-stage sampling with double sampling (i.e., two-phase sampling) was recommended over the other schemes.

2. The use of cluster sample blocks larger than a 0.4-square-hectometer (1-acre), 10-point cluster sample in the double-sampling strategy was also recommended.

Special Comments and Notes

1. The development of the Planning Model was a pioneering effort in conceptualizing, formalizing, developing, and implementing computer software to optimize sample allocation and strategy decisions. The software was developed previously in and outside the University of California at Berkeley. A nonlinear programming technique was used.

2. Potential weaknesses of the model resulted from the assumption of the optimality criterion, the nonconsideration of physical

and social factors, and the dependence on prior statistical data and the spatial layout of the data.

7. MEAD AND MEYER'S MAPPING IN MINNESOTA

Mead, R. A.; and Meyer, M. P.: Landsat Digital Data Application to Forest Vegetation and Land-Use Classification in Minnesota. NASA Contract NAS 5-20985 Final Report, University of Minnesota, June 1977.

Objectives

This project was designed to produce the following:

1. Feasibility study on the detection of land-cover types by Landsat ADP techniques and on the degree of accuracy that can be expected
2. Technology transfer opportunities
3. Determination of the usability of Landsat ADP classification

Scope

1. Site: selected blocks of Minnesota forest land (less than 404 687 square hectometers, 1 million acres)
2. Cover types: water, lowland conifer, upland conifer, mixed forest, brush and shrub, grassland and open, agriculture, mined land, sedge meadow, urban, and sphagnum/leatherleaf
3. Evaluation: utility of classification output evaluation at 1.24 000, 1:125 000, and 1:250 000 scales
4. ADP systems:
    a. Interactive Multispectral Image Analysis System, Model 100 (Image 100) at the Earth Resources Observation Systems (EROS), University of Colorado (Ft. Collins)

b. Laboratory for Applications of Remote Sensing System (LARSYS)/Bendix Multispectral Data Analysis System (MDAS)

5. ADP system comparison: results of the analyses of the ADP systems to be compared (will not be all-inclusive)

Methodology

1. Straightforward ADP classification

2. Attempted multidate analysis

3. Evaluation of classification using three methods: training field accuracies, test field accuracies, and pixel-by-pixel evaluation against interpreted aerial ground-truth and ground-checked data

Major Conclusions and Output

1. The accuracy of the classification of the 11 cover types was assessed as follows:

   a. Training field accuracies: 91 to 100 percent

   b. Test field accuracies: 0 to 100 percent

   c. Pixel-by-pixel accuracies: 0 to 64 percent with the exception of water (95 percent) and sedge meadow (83 percent)

2. An output classification map with a scale no larger than 1:125 000 was recommended for the field users, but larger scales were considered useful for evaluation.

3. The conclusions on multidate analysis were not consistent.

4. The study concluded that water can be reliably detected.

5. ADP Landsat maps were recommended for extensive or intensive use by field-level resource managers.

6. Landsat digital data were determined to have doubtful utility for forest resource mapping in areas having complex vegetation covers.

Special Comments and Notes

1. This project used a straightforward ADP analysis.
2. No area estimation was made.
3. No conclusion was drawn on the amount of ground-truth data needed for operational use.
4. There was good interaction with the users.

8. KREBS AND HOFFER'S SAN JUAN NATIONAL FOREST MAPPING

Krebs, P.; and Hoffer, R.: Multiple Resource Evaluation of Region 2 U.S. Forest Service Lands Utilizing Landsat MSS Data. NASA Contract NAS 5-20948 Final Report, July 1976.

Objectives

This project had the following objectives:

1. Development of an ADP feasibility study on the detection of land-cover types and on the degree of accuracy that can be expected
2. Presentation of topographic and other supporting data and determination of their utility
3. Comparison between different evaluation techniques
4. Geomorphic mapping, using manual interpretation

Scope

1. Site: portion of San Juan National Forest, Colorado (194 250 square hectometers, 480 000 acres)
2. Cover types:
   a. Generalized level: coniferous, deciduous, mixed, grassland, sparsely vegetated, bare rock, and water
   b. Community type level: dense conifer, sparse conifer, coniferous/deciduous mix, deciduous/coniferous mix, aspen, oak, wet and mesic grassland, grassland, sparsely vegetated, bare rock, and water
3. Remote sensing and ancillary data: Landsat MSS data, aerial color photography at 1:60 000 and 1:120 000 scales, color-infrared photography, ground data, and topographic data tapes from the NCIC

4. Participants: NASA, the Institute of Arctic and Alpine Research (University of Colorado at Boulder), and the Laboratory for Applications of Remote Sensing (Purdue University)

Methodology

1. Use of a modified clustering approach (i.e., clustering selected 40-by-40-pixel sample blocks, as many as necessary)

2. No attempt to extend signatures beyond one 7.5-minute quadrangle sheet (turned out to be unfeasible)

3. Registration and overlaying of topographic data onto the Landsat classification image (Different algebraic combinations were used to give different presentations; the topographic data were comprised of elevation, slope, and aspect.)

4. Evaluation methods:

   a. Test field analysis with Landsat versus ground-field data

   b. Test field analysis with Landsat versus interpreted aircraft photography

   c. Systematic samples of 2 by 2 pixels as test samples, comparing Landsat versus interpreted aircraft photography

5. Tabulations of area, which are not evaluated

Major Conclusions and Output

1. Presentations were obtained by algebraically combining topographic data and Landsat classification data useful to the Forest Service. For example, a big game winter range could be considered as grassland with slopes less

than 30°; with an aspect restricted to south-southeast, south, and south-southwest; and with elevations between 2286 and 2743.2 meters (7500 and 9000 feet).

2. Feasibility conclusions were reached on what land cover types could be mapped on Landsat imagery using ADP techniques. The overall accuracies using test fields (Landsat versus interpreted aircraft photography) were 74.4 percent and 79.8 percent for the generalized level and the community type level, respectively.

3. The three evaluation techniques were comparable to one another.

Special Comments and Notes

1. Topographic data were used in the final presentation of classification data but not in developing the classification.

2. The method used for this project was a large type-separability study (see the Ten-Ecosystem Study, section 2).

3. The area tabulation was not checked statistically.

9. RHODE, TARANIK, AND NELSON'S FLOOD INUNDATION MAPPING

Rhode; Taranik; and Nelson: Inventory and Mapping of Flood Inundation Using Interactive Digital Image Analysis Techniques. Proceedings of the Second Annual William T. Pecora Memorial Symposium (Sioux Falls, South Dakota), October 25-29, 1976.

Objectives

The objective of this project was to demonstrate the feasibility of using Landsat ADP technology in estimating inundated agricultural areas.

Scope

1. Site: 607 030.5 square hectometers (1.5 million acres) in the Red River Valley, North Dakota
2. Remote sensing and ancillary data: Landsat data and 1:120 000 scale aerial photographs taken during the summer of 1975
3. Cover types: partial inundation and complete inundation
4. Participants: U.S. Department of Interior (USDI)/EROS and Technicolor Graphics, Inc. (Sioux Falls)

Methodology

1. Manual stratification into three agrophysical strata
2. Double sampling (i.e., two-phase sampling with sampling in both phases); regression estimation for area estimates
3. Determination of the PSU cluster sample size as 40 by 40 pixels

4. Determination of the number of samples to be used in the first and second phases, based on the precision required of totally inundated land: ±10 percent at the 0.95-percent level.

5. Location of second-phase cluster samples, also at 40 by 40 pixels, on 1:120 000 scale photographs; area estimation by the grid-dot method, using 200 dots per square inch

6. Determination of the optimal size of the PSU by plotting the coefficient of variation of inundated land versus the PSU size (PSU sizes of 10 by 10, 20 by 20, 40 by 40, and 60 by 60 pixels were tried.)

Major Conclusions and Output

1. Regression estimates:

   a. Partial inundation was estimated as 148 020 square hectometers (365 757 acres) with a 5.4-percent sampling error (i.e., a 10.8-percent error at the 0.95-percent level).

   b. Complete inundation was estimated as 236 835 square hectometers (585 219 acres) with a 6.1-percent sampling error (i.e., a 12.2-percent error at the 0.95-percent level).

   c. Total inundation was estimated as 379 165 square hectometers (936 917 acres) with a 3.9-percent sampling error (i.e., a 7.8-percent error at the 0.95-percent level).

2. A total of 200 first-phase samples and 30 second-phase samples were needed, assuming correlation between phases at 0.8 and (unreported) cost parameters

4. The optimal sample size was determined to be 40 by 40 pixels, at a 0.33 coefficient of variation.

Special Comments and Notes

1. The method of area estimation was similar to that used in the Ten-Ecosystem Study (section 2).

2. A total of 200 first-phase samples at 40 by 40 pixels resulted in a 17.5-percent sampling (total area roughly 1350 by 1350 pixels). A total of 30 second-phase samples at 40 by 40 pixels resulted in a 2.6-percent sampling. (Compare these rates with the 0.1-percent sampling of the second-phase samples used in the Ten-Ecosystem Study.)

3. Double sampling was used. The 200 cluster units in the first phase of the Landsat classification data did not need to be sampled because the whole area was classified by ADP. Better use was made of the naive estimate; that is, the variance was reduced by using a total count of inundation in the Landsat data rather than an estimate from 200 cluster samples.

4. Area was estimated in each 40-by-40-cluster unit, using approximately 125 dots (at 200 dots per square inch on 1:120 000 scale photographs).

5. According to the project conclusions, the registration of cluster samples in the photographs was precise to within ±0.5 pixel.

10. SUSANVILLE ASVT

DeGloria, S. D.; Davis, S. J.; and Thomas, R. W.: The Utilization of Remote Sensing Data for a Multidisciplinary Resource Inventory and Analysis Within a Rangeland Environment. Project Report, University of California at Berkeley, 1976.

Objectives

The Susanville ASVT project was conducted to determine the utility of remotely sensed imagery for the BLM's unit resource analysis of vegetation-type mapping, generalized land-unit mapping, sensitive-area mapping, and range-productivity estimation. (Both ADP and manual interpretation of Landsat, small-scale, and medium-scale imagery were used.)

Scope

1. Site: representative area of range and forested land in northeastern California and northwestern Nevada (the Susanville District of the BLM); total study area of 1 011 717.5 square hectometers (2.5 million acres); five planning units with individual analysis of one or more units (e.g., ADP multistage analysis over 505 858.8 square hectometers, 1.25 million acres)
2. Landsat coverage: two Landsat frames over 2 consecutive days to make up the Landsat study frame
3. Landsat interpretation:
    a. Enlargement of Landsat color imagery to 1:250 000 scale for interpretation
    b. Manual interpretation of Landsat imagery for four major units: alluvial and flood plain land, basin land, terrace and plateau land, and upland
    c. Area estimation

4. Photointerpretation: manual interpretation of small-scale and medium-scale photographs (1:120 000 and 1:30 000 scales) to produce vegetation-type mapping (e.g., mapping semiarid land vegetation into sagebrush, juniper, and grass); 4.9 to 10.1 square hectometers (12 to 25 acres) minimum area mapping to generalize these detail maps

5. Sensitive area analysis: manual interpretation of 1:30 000 scale imagery for following features: wet and dry meadows, reservoirs, springs, moist sites, and brown areas

6. Estimation of range productivity: ADP Landsat analysis and multistage sampling

Methodology

1. Use of conventional photointerpretation methods in the three interpretation tasks

2. Use of ADP analysis to cluster the spectral signatures and label the clusters by vegetation classes

3. Multistage sampling of three stages:

    a. PSU's of 40 by 30 pixels

    b. Six SSU's per PSU with an SSU size of 40 by 5 pixels

    c. Ten tertiary sampling units (TSU's) per SSU with a TSU size of 4 by 5 pixels

        (1) TSU's covered by stereo triplets at 1:800 scale and wide angle at 1:3000 scale

        (2) Approximately 16.8 meters (55 feet) between samples on the ground transect of a TSU

        (3) Regression analysis for the TSU and ground two-phase sampling

4. Range productivity estimation using each level of imagery alone, without multistage expansion

Major Conclusions and Output

1. Output: Vegetation map overlays, land unit (unit resource analysis) maps, statistics, and area and productivity estimates were produced.

2. Landsat manual interpretation: The land unit generalized map was not useful. (However, "The knowledge gained via this analysis has direct utilization for a number of resource disciplines.")

3. Aerial photography interpretation: "Smaller scale (i.e., 1:120 000) photography was suitable for mapping purposes, e.g., for vegetation type mapping, but not for determining species composition and density. The 1:30 000 photography is more accurate for detailed mapping, but···further detailed evaluation is required."

4. Sensitive area analysis: Difficulty was encountered in this analysis because of confusion between different categories.

5. ADP Landsat analysis: The cluster classification map produced 35 cluster classes corresponding to 8 vegetation types; confusion resulted from a physiographic variation in the site. The classification map proved to be useful for a multistage sampling base.

6. Multistage sampling for range productivity: The relative standard errors in two planning unit estimates were estimated as 20 percent and 33 percent. ("Quantitative estimates of productivity···are efficiently determined utilizing multistage sampling products which use Landsat, highflight photography and ground data.")

Special Comments and Notes

None.

11. WILLIAMS AND HAVER'S INTRALAB FOREST MAPPING

Williams, D. L.; and Haver, G. F.: Forest Land Management by Satellites. Intralab (Project 75-1), NASA Goddard Space Flight Center (Greenbelt, Maryland), December 1976. (Also in the proceedings for the fall convention of the American Society of Photogrammetry and the American Congress on Surveying and Mapping held in Seattle, Washington, September 28 through October 1, 1976.)

Objectives

The objectives of this project were to use temporal analysis and ADP methods to develop the following:

1. A study of the feasibility of forest mapping in the North Carolina Southern Pine Region
2. A transfer of technology in cooperation with the forestry industry (Weyerhauser Company)

Scope

1. Site: 24 281.2 square hectometers (60 000 acres) in North Carolina, 32.2 kilometers (20 miles) southwest of Phelps Lake
2. Cover types: hardwood, pine (open, partial, and closed canopy), regeneration, clearcut, and change (vegetation to clearcut)
3. Temporal analysis: one summer scene (August) and one winter scene (February)
4. Aerial ground-truth data interpretation: color and color-infrared photography for evaluation of the agreement against Landsat ADP classification

Methodology

1. Straightforward ADP supervised classification
2. Temporal analysis
3. Evaluation of classification by randomly located pixels of an approximate 1-percent sampling
4. Evaluation of acreage against the Weyerhauser inventory

Major Conclusions and Output

1. Feasibility conclusions:
    a. The mapping of pine, hardwood, and clearcut had an overall 90-percent accuracy (96 percent for pine, 94 percent for hardwood, and 54 percent for clearcut).
    b. The separation of pine into three crown-closure subcategories and one regeneration subcategory resulted in 56-percent, 56-percent, 98-percent, and 59-percent accuracy, respectively.
    c. An overall clearcut mapping accuracy of 54 percent was achieved. A 3-percent acreage deviation from the Weyerhauser inventory acreage was evident on further evaluation of four carefully chosen clearcut areas.
4. Pine and hardwood were more separable in winter than in midsummer. Temporal analysis was recommended.
5. A cost analysis (under oversimplifying assumptions) showed a 15-percent higher cost than for a conventional inventory.

Special Comments and Notes

1. This project was an encouraging joint demonstration between NASA and private industry.

2. Straightforward ADP processing was used, and no new conclusions were reached.

12. ALDRICH'S SKYLAB STUDY

Aldrich, R. C.; Roberts, E. H.; and Greentree, W. J.: Forest Inventory: Forest Resource Evaluation, Sampling Design and Automated Land Classification. Evaluation of Skylab (EREP) Data for Forest and Rangeland Surveys, USDA Forest Service Research Paper PSW-113, 1976.

Objectives

Aldrich's Skylab Study had the following objectives:

1. To evaluate S-190A and S-190B 1:250 000 scale mono photographs, S-190A and S-190B 1:500 000 scale mono photographs, and S-190B stereo photographs
2. To evaluate the utility of Earth Resources Experiment Package (EREP) imagery in land-use classification
3. To evaluate the utility of EREP imagery in forest area estimation
4. To evaluate forest sampling schemes with variations in sampling intensities
5. To evaluate the ADP classification of digitized EREP data

Scope

1. Site: four counties near Augusta, Georgia (not all used for each objective):
    a. Objective 1: one-county analysis
    b. Objective 2: four-county analysis
    c. Objective 3: one-county analysis
    d. Objective 4: one-county analysis
    e. Objective 5: 20 234.4 square hectometers (50 000 acres)

2. Cover types:

   a. Objectives 1 and 2: categorized into forest, cropland, pasture, idle land, other agriculture, urban, census water, and noncensus water; forest subcategorized into pine, hardwood, and mixed

   b. Objective 3: forest, urban, census water, noncensus water, and other

   c. Objective 4: pine, hardwood, nonforest, and water

   d. Objective 5: forest subcategorized into pine, hardwood, and cutover; nonforest subcategorized into grassland, cropland, bare soil, wild vegetation, and urban; and water

3. Remote sensing and ancillary data:

   a. Skylab S-190A and S-190B color, mono, and stereo photographs

   b. 1:120 000 scale color-infrared aerial photographs

   c. 1:20 000 scale USDA Agricultural Stabilization and Conservation Service (ASCS) aerial and ground survey data

   d. USDA Forest Service ground data

Methodology

1. All objectives: photointerpretation and ADP

2. Objective 1: evaluation of different interpretations by checking forty 16-point cluster samples

3. Objective 2: evaluation of 210 16-point cluster samples

4. Objective 3: estimation of proportions from twenty-five 16-point cluster samples (subsamples were 40 ground plots); determination of the bias in the estimated forest proportion; analysis of regression

40

5. Objective 4: testing of three sampling schemes (simple random, systematic, and systematic with postsampling stratification) using ADP classification maps; variation of sampling intensities from 50-by-50-grid to 2-by-2-grid sampling

6. Objective 5: use of half of the study area (one of two contiguous blocks) to develop spectral signatures and use of the other half to test the classification; evaluation of area proportion accuracy and location accuracy. The location accuracy was checked by overlaying 480 ground-truth grid points

Major Conclusions and Output

1. Objective 1: The S-190B stereo photography was the best choice.

2. Objective 2: Mixed pine-hardwood could not be separated from pine or hardwood. By combining pine with pine and hardwood mix and combining upland hardwood with bottomland hardwood, the overall accuracy was 73 percent—for pine and 69 percent for hardwood

3. Objective 3: The EREP forest area estimate was 8.6 percent relatively higher than the ground-truth data (ASCS inventory) after the estimate was adjusted using the regression equation. The standard error of this estimate was 3.5 percent.

4. Objective 4:

   a. The biases and variances of the estimates decreased as the sampling became more intensive, as the theory predicts.

   b. The method of systematic sampling with postsampling stratification (using ADP classification) was best; it gave the least variance, with equally small (or negligible) bias.

5. Objective 5:

   a. Forest area was classified on the EREP data to within 96-percent accuracy.

   b. A classification map was found to be usable for stratification. However, the location accuracy was only 50 percent; this low accuracy was attributed to Landsat imagery distortions.

6. Overall conclusion: The study proved that manual interpretation or the ADP classification of EREP data will provide a data base for Level I and Level II land-use and broad forest type stratifications. (The Level I categories were forest, nonforest, and water. The Level II categories were conifer, deciduous hardwood, grassland, cropland, bare soil, wild vegetation, urban, and water.)

Special Comments and Notes

The method for objective 2 is a type-separability study, while the method for objective 3 is a simulated inventory study. (See the Ten-Ecosystem Study, section 2.) Note the similarity in the use of regression analysis for area estimates.

2. The utility of the imagery was directly related to the season when the data were collected. Temporal composites produced a higher contrast.

3. There was no significant difference between the different types of color imagery, as determined by the correlation analysis.

4. High-flight photography proved to be more useful than EREP space imagery. A higher resolution was needed for forest inventories.

5. The use of Skylab S-190 data reduced the sampling variance of forest volume estimates by as much as 43 percent when compared to simple random sampling. Regression sampling proved to be the best of the three sampling schemes (stratified, PPS, and regression).

Special Comments and Notes

1. The choice of space imagery at the highest level of a multistage sampling scheme was again confirmed to be useful, reinforcing Langley's conclusion in 1969 on the Apollo study (section 19).

2. See the conclusion on the utility of EREP data by Colwell (section 14).

14. COLWELL'S SKYLAB STUDY

Colwell, R. N. (principal investigator): Skylab Data as an Aid to Resource Management in Northern California. NASA Contract NAS 9-14420 Final Report, University of California at Berkeley, October 1975.

Objectives

The primary objective of Colwell's Skylab Study was to use manual interpretation to test the utility of S-190A imagery for discriminating timber volume classes in a multistage sampling scheme.

Scope

1. Site: 50 585.9 square hectometers (125 000 acres) in Plumas National Forest, California; 19.2 by 25.6 kilometers (12 by 16 miles)
2. Estimation parameters: gross timber volume in the study area
3. Remote sensing and ancillary data: S-190A color-infrared photography, 1:60 000 scale high-flight (RB-57) color-infrared photography, low-altitude 1:7500 wide-angle and 1:1000 stereo 35-millimeter photography, and ground survey and dendrometer measurements

Methodology

1. Division of study area into forty-eight 3.2-by-3.2-kilometer (2-by-2-mile) PSU's
2. Random selection of six PSU's, as defined by some variance calculation
3. Determination of each PSU as five SSU strips, 3.2 by 0.6 kilometers (2 by 0.4 miles) each

4. Random choice of one SSU from the chosen PSU

5. Collection of low-altitude photography at 1:7500 and 1:1000 scale stereo triplets at 10 equally spaced TSU locations along the SSU

6. Performance of ground work in two TSU's, each 0.2 square hectometer (0.4 acre), with an approximate plot radius of 22.9 kilometers (75 feet)

7. Analysis of S-190A photography by three photointerpreters:

   a. Separation into four timber volumes: none, 0 to 23.6 cubic meters (0 to 10 000 board feet), 23.6 to 47.2 cubic meters (10 000 to 20 000 board feet), and above 47.2 cubic meters (20 000 board feet)

   b. Combination into timber/nontimber classification

   c. Testing for between-interpreter correlation

8. Use of a multistage scheme for estimating the timber volume in the 19.3-by-25.7-kilometer (12-by-16-mile) area using simple random sampling and straight expansion, estimating the ratio using the area of timber as the independent variable, and estimating the ratio using the volume estimate as the independent variable; analysis of the standard error of the final total estimate (The ratio estimators used Skylab-interpreted information at the highest level stage.)

Major Conclusions and Output

1. Timber volume classes on S-190A color-infrared imagery were not reliably distinguished by human interpreters. The correlation between the different interpretations was very poor.

2. A random sampling scheme with a straightforward expansion estimator was more precise than the ratio estimator using the Skylab-interpreted information (i.e., area or estimated volume) because the correlation of the Skylab interpretation to the ground-truth data was too low (less than 0.3 correlation).

3. "The purely manual interpretive process in the multistage sampling inventory was demonstrated to be timely and cost effective." No computer data processing was performed.

4. General conclusion: "It appears that Skylab S190A imagery is not of significantly high resolution to provide timber volume information for inventory purposes."

Special Comments and Notes

Although Langley's Skylab investigation (see section 13) concluded that Skylab's imagery did not have sufficient resolution for inventory purposes, a gain of 43 percent in precision was reported using S-190 data in the first stage of a multistage sampling scheme. However, Colwell's work reported no benefit in using S-190 data. No explanation was obtained for this apparent conflict.

15. HOFFER'S SKYLAB STUDY

Hoffer, R. M.; and staff: Computer-Aided Analysis of Skylab Multispectral Scanner Data in Mountainous Terrain for Land Use, Forestry, Water Resources, and Geologic Applications. NASA Contract NAS 9-13380 Final Report, Information Note 121275, Laboratory for Applications of Remote Sensing (W. Lafayette, Indiana), December 1975.

Objectives

Hoffer's Skylab Study had the following objectives:

1. Development of an ADP feasibility study on land-use mapping and forest-cover-type mapping using S-192 MSS data
2. Evaluation of the spectral bands on the S-192: seven visible bands in the 0.41 to 0.98 micrometer range, three near-infrared bands in the 0.98 to 1.30 micrometer range, two middle-infrared bands in the 1.55 to 2.35 micrometer range, and one thermal band in the 10.2 to 12.5 micrometer range
3. Development and testing of data-handling techniques to overlay topographic data onto MSS data (The topographic data included elevation, slope, and aspect.)
4. Evaluation of the quality of S-192 data
5. Hydrological and geological analyses (These are not discussed here.)

Scope

1. Site: San Juan Mountains and surrounding areas of south-western Colorado; also an area over and west of La Sal, Utah (The size of the study site varied for different phases of the investigation but was approximately 75 000 square hectometers, 185 325 acres.)

2. Cover types:

   a. ADP land cover mapping: water, exposed rock and soil, grassland, deciduous forest, coniferous forest, tundra, and snow; deciduous and coniferous forests further divided into oak, aspen, ponderosa pine, Douglas and white fir, Englemann spruce, and alpine.

   b. Band selection study: same cover types as for land cover mapping (item a)

   c. S-192 data evaluation: forest and water classifications

3. Remote sensing and ancillary data: Skylab S-190A and S-190B photography, S-192 MSS data, Landsat MSS data, RB-57 1:120 000 color-infrared photography, NC-130 color-infrared photography, NC-130 MSS data, small aircraft photography, and ground data

4. Participants: NASA, Laboratory for Applications of Remote Sensing (Purdue University), and Institute of Arctic and Alpine Research (University of Colorado at Boulder)

Methodology

1. Use of modified clustering approach: clustering preselected 40-by-40-pixel sample blocks, as many as necessary

2. Evaluation of classification results:

   a. Qualitative evaluation against aerial photography

   b. Statistical sampling of 4-by-4-pixel blocks, and

   c. Acreage comparison in 7.5-minute quadrangle areas

3. Spectral band evaluation: ranking of classification accuracies

4. Overlaying of topographic data: reformatting, resampling, and registering NCIC topographic digital data

5. Evaluation of S-192 data quality:

   a. Qualitative evaluation

   b. Examination of noise in the calibration data in each channel by examining the standard deviation over 1300 samples

   c. Performance of Fourier analysis by obtaining auto-correlation functions and the power spectrum of samples of calibration data

6. Advanced spatial data analysis: evaluation of the utility of the ECHO spatial classification program for cover-type mapping

Major Conclusions and Output

1. Level II land cover maps from this Skylab S-192 study had 85-percent overall accuracy, while vegetation cover maps had a 71-percent overall accuracy. Stand density was shown to influence spectral characteristics significantly.

2. The best bands in the classification of the S-192 data included the 0.46 to 0.51, 0.78 to 0.88, 1.09 to 1.19, 1.55 to 1.75, and 10.2 to 12.5 micrometer wavebands. The classifications using four bands were almost as good as those using more bands.

3. The acreage estimates for forest cover types were highly correlated to the photointerpreted acreage (0.93 correlation).

4. The Skylab S-192 data had better spectral resolution than the Landsat-1 MSS system and caused improvement in cover-type mapping accuracies.

5. Data-handling techniques were developed to successfully pre-process and overlay topographic data onto Skylab or Landsat

MSS data. Such overlaid data offered extra discrimination in the classification of land cover types or vegetative cover types.

6. The modified clustering procedure and ECHO program were demonstrated to be useful in MSS data analysis. The ECHO program provided classifications that more closely resembled the cover type maps.

7. The preprocessing and digital filtering of the S-192 data caused noise problems in the data; both low frequency and high frequency noise existed along and across the scan lines. A ranking of the 13 channels showed that channels 11, 3, 7, and 8 were the best overall, in that order.

Special Comments and Notes

1. A significant point about this project was the simultaneous availability of cloud-free coverage from Skylab, Landsat, high-altitude WB-57, and low-altitude NC-130 digital and photographic data on June 5 and 6, 1973. An extra set of Skylab, WB-57, and NC-130 data was also acquired during August 4 through 8, 1973. This permitted excellent multisensor and multiplatform comparison, overlaying, and evaluation.

2. This effort was one of the first that analyzed the implications of overlaying topographic data onto satellite imagery.

3. This effort was also one of the first that used ADP techniques to analyze satellite MSS data over rugged terrain.

16. ALDRICH'S ERTS-1 STUDY

Aldrich, R. C.; Norick, N. X.; and Greentree, W. J.: Forest Inventory: Land Use Classification and Forest Disturbance Monitoring. Evaluation of ERTS-1 Data for Forest and Rangeland Surveys, USDA Forest Service Research Paper PSW-112, 1975.

Objectives

The objectives of this project were the following:

1. To evaluate 1:1 000 000 scale false-color composites from ERTS-1 for land-use classification, using photointerpretation methods
2. To evaluate ERTS-1 1:1 000 000 scale false-color composites for mapping forest disturbances, using photointerpretation methods
3. To evaluate ERTS-1 digital data analysis for land-use classification and area determination

Scope

1. Site: all study areas near Atlanta, Georgia (same site as that in Langley's Apollo study, section 19), covering over nine counties, which are approximately 80.5 by 96.6 kilometers (50 by 60 miles) each, as follows:
   a. Objective 1: entire study site
   b. Objective 2: one county in the site
   c. Objective 3: only three ISA's, 3237.5 to 4046.9 square hectometers (8000 to 10 000 acres) each, less than 32.2 kilometers (20 miles) from one another.

2. Cover types:

   a. Objective 1:

      (1) Level I: forest, nonforest, and water

      (2) Level II: conifer, deciduous hardwood, grassland, cropland, bare soil, wild vegetation, urban, and water

   b. Objective 2:

      (1) Type of disturbance: no disturbance, harvesting, land clearing, natural regeneration, artificial regeneration, and other (undecided)

      (2) Land-use trend: no change, forest to agriculture, forest to urban, forest to water, and agriculture to forest

      (3) Size of land-use trend: approximately 0.5 to 2 square hectometers (1 to 5 acres), 3 to 10 square hectometers (6 to 25 acres), 11 to 20 square hectometers (26 to 50 acres), 21 to 40 square hectometers (51 to 100 acres), 41 to 202 square hectometers (101 to 500 acres), and above 202 square hectometers (500 acres)

   c. Objective 3:

      (1) Level I: forest, nonforest, and water

      (2) Level II: pine, hardwood, grazed grassland, undisturbed grassland, plowed fields/barrow pits, idle, abandoned, transitional, and water

3. ERTS-1 false-color composites: standard ERTS color composites at a 1:1 000 000 scale on an International Imaging System color additive viewer using bands 4, 5, and 7

4. Remote sensing and ancillary data:

   a. Two NASA high-altitude underflights: June 1972 and October 1972

b. Three ERTS scenes: October 1972, April 1973, and June 1973

c. Ground checking (approximately 150 ground points)

Methodology

1. Objective 1: classification of 292 random points on imagery using two temporal composites (April and June, and April and October): evaluation against ground-truth data

2. Objective 2: classification of 245 points, consisting of 209 disturbance points, on an April scene; evaluation against ground-truth data compiled by comparing 1:120 000 scale aerial photographs for June 1972 against 1:63 360 scale USDA panchromatic photographs for 1966, also compiled from ground checks

3. Objective 3:

   a. Selection of the training areas from two of the three ISA's

   b. Classification of all three ISA's by the ADP system at the Laboratory for Applications of Remote Sensing and at the Forest Service's Pacific Southwest (PSW) Forest and Range Experiment Station in Berkeley, California

   c. Evaluation by three methods: determination of training field accuracies, determination of area measurement accuracies, and random point evaluation by 1-pixel evaluation or 3-by-3-pixel proportion evaluation

   d. Extension of the signatures from the first and second to the third ISA (24.1 to 32.2 kilometers, 15 to 20 miles)

Major Conclusions and Output

1. Objective 1:

   a. A 96-percent accuracy was achieved for forest/nonforest classification

   b. The Level II classification accuracies were as follows: 7 percent to 85 percent for nonforest categories, 100 percent for water, and 50 percent for pine-hardwood

   c. There was a nominal variation of classification accuracies between the ERTS dates.

2. Objective 2:

   a. Forest disturbances were detected 90 percent of the time and properly identified 80 percent of the time.

   b. Spring ERTS data were best for discriminating disturbances; late fall and winter data were the second choice.

   c. Clearcuts and forest-to-nonforest disturbances were identified if they were larger than 0.8 to 1.2 square hectometers (2 to 3 acres).

   d. At least 3 years of change were required before detection of nonforest-to-forest disturbances was possible.

3. Objective 3:

   a. Training field accuracies of 95 percent were experienced for forest-nonforest classifications.

   b. Forest land area was underestimated with less than 15-percent relative error.

   c. Nonforest area categories experienced a relative error larger than 25-percent.

   d. For a point-by-point evaluation, there was a 7-percent PCC for Level II classifications.

e. The ADP extension of Level II signatures to within 24.1 to 32.2 kilometers (15 to 20 miles) worked as well as the use of local signatures.

4. General conclusion: "ERTS-1 appears useful to provide an up-to-date area sampling base to measure forest area by county," and to help inventory forest-to-nonforest disturbances.

Special Comments and Notes

The method for objective 1 was a type-separability study. The method for objective 3 was similar to the simulated inventory study of the Ten-Ecosystem Study (see section 2).

17. UNIVERSITY OF CALIFORNIA AT BERKELEY, SAM HOUSTON NATIONAL FOREST INVENTORY

Titus, S. J.; and Thomas, R.: Timber Volume Inventory Investigation, Sam Houston National Forest. NASA Contract NAS 9-14452 Final Report, University of California at Berkeley, July 1976.

Objectives

This project was designed to test the effectiveness of using Landsat MSS data as a first stage in a multistage sampling inventory scheme in a typical forest in the Southeastern Pine Ecosystem of the United States.

Scope

1. Site: less than 81 000 square hectometers (200 000 acres) in the Sam Houston National Forest in Texas
2. Forest parameters: volume, growth, mortality, number of trees, and areal estimate; categorized by softwood and hardwood and by diameter classes
3. Remote sensing and ancillary data: Landsat MSS data; aerial photography in color infrared, 1:60 000 and 1:24 000 scales; low-flight MSS data (Bendix 24-channel MSS); small-craft low-altitude photography; ground survey and dendrometer measurements
4. Data processing: ADP in Landsat analysis and computer data compilation

Methodology

1. ADP classification of Landsat MSS data as the first stage of the multistage sampling technique (see section 18)

2. Sampling in lower level photography and in ground survey data

Major Conclusions and Output

1. Statistics tables of the different forest parameters were output (see Scope, item 2).
2. The relative errors in the stocking volume estimates (7.76 percent) and growth estimates (6.84 percent) were close to Forest Service survey requirements (5 percent).
3. The Landsat data were verified to be ineffective in providing a first-stage stratification for the Sam Houston inventory because of the intrinsic homogeneity of forest types in the forest.
4. A detailed subcategorization by species under softwood and hardwood was not achieved due to the claimed lack of knowledge of the forest by the Berkeley field crews, as well as the lack of adequate Forest Service support during the field survey.

Special Comments and Notes

1. Tabulated statistics constituted 8 of the 28 sets of statistics required by the USDA Forest Service in its national inventories (Forest Service Handbook FSH-4809).
2. According to the project's conclusions, the remaining 20 sets of statistics were derivable from the 8 generated sets if additional ancillary information, such as administrative boundaries and projection models, was available. (This information was not available during the project.)
3. The multistage sampling scheme was again demonstrated to be viable in large area inventories (areas larger than 20 234.4 square hectometers, 50 000 acres).

4. The nonutility of Landsat data was explained as the consequence of the complexity of the forest/ecosystem and not as the fault of the methodology.

18. UNIVERSITY OF CALIFORNIA AT BERKELEY, PLUMAS NATIONAL FOREST INVENTORY

Nichols, J.; and Thorley, G.: An Integrated Study of Earth Resources in the State of California, Based on ERTS-1 and Supporting Aircraft Data. Progress Report on NASA Contract NAS 5-21827, University of California at Berkeley, July 1973. (Also see Kan, E. P.: Some Thoughts on the Multistage Sampling Design to Inventory Timber Volume, LEC-3259, Lockheed Electronics Company, Inc., April 1974.)

Objectives

The objective of this project was to demonstrate the use of Landsat MSS data as a first stage in a multistage sampling inventory scheme in a typical forest in California.

Scope

1. Site: 87 007.7 square hectometers (215 000 acres) in the Quincy Ranger District of the Plumas National Forest in California
2. Estimation parameters: gross timber volume in the study area
3. Remote sensing and ancillary data: Landsat MSS data; aerial photographs in color and color infrared, 1:120 000, 1:7500, and 1:1000 scales; and ground survey data
4. Data processing: ADP in Landsat analysis and computer data compilation

Methodology

1. Manual edit of the boundary of the Quincy Ranger District on ERTS-1 data

2. Selection of training areas that correspond to four volume classes on the ERTS-1 data with the aid of 1:120 000 scale color-infrared photography [The volume classes were none, 0 to 23.6 cubic meters (0 to 10 000 board feet), 23.6 to 47.2 cubic meters (10 000 to 20 000 board feet), and above 47.2 cubic meters (20 000 board feet).]

3. ADP classification of Landsat data into the four volume classes

4. Separation of the data into nonoverlapping PSU's of 40 by 5 pixels; accumulation of the volume within each PSU

5. Determination of the number and location of the PSU's, using PPS sampling (Four PSU's were chosen.)

6. Collection of 1:7500 and 1:1000 scale photography over four selected PSU's

7. Division of the PSU's into 10 equal SSU's; placement of one circular plot of 0.2 square hectometer (0.4 acre) at the center of each SSU

8. Interpretation and estimation of the volume in the circular plot (i.e., the TSU)

9. Determination and location (PPS) of two TSU's for subsampling and ground work

10. Performance of a ground survey and selection (PPS) of four trees to be measured in each TSU

11. Mathematical expansion of the estimates to the entire Quincy Ranger District

Major Conclusions and Output

The gross timber volume was estimated with a relative standard error of 8.2 percent.

Special Comments and Notes

This was the first demonstration of Landsat in a multistage sampling inventory. A similar approach has been used since then in the large areas ASVT (see section 1).

19. LANGLEY'S APOLLO STUDY

Langley, P. G.; Aldrich, R. C.; and Heller, R. C.: Multistage Sampling of Forest Resources by Using Space Photography — An Apollo 9 Case Study. Volume 2: Agriculture, Forestry and Sensor Studies. Proceedings of the Second Annual Earth Resources Aircraft Program Review, NASA Manned Spacecraft Center (Houston, Texas), 1969. (Also see Aldrich, R. C.: Space Photos for Land Use and Forestry. Photogrammetry Engineering, 37(4), 1971, pp. 389-401.)

Objectives

Langley's Apollo Study was designed to test the utility of Apollo spacecraft photography as a first stage in a multi-stage sampling scheme to inventory timber volume.

Scope

1. Site: 2 023 435 square hectometers (5 million acres) in the Mississippi Valley covering the Louisiana, Mississippi, and Arkansas Oak-Pine ecosystem (128.7 by 128.7 kilometers, 80 by 80 miles)

2. Estimation parameters: gross timber volume in the study area

3. Remote sensing and ancillary data:

   a. Apollo color-infrared photography

   b. Aerial photography: high-flight Polaroid, 1:60 000 scale, using a 3.8-centimeter (1.5-inch) lens; low-flight 70-millimeter, 1:12 000 scale, using a 3.8-centimeter (1.5-inch) lens; and stereo triplets at 70 millimeters, 1:2000 scale, using a 22.9-centimeter (9-inch) lens

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c. Ground survey data and dendrometer measurements

4. Data analysis: photointerpretation of all photography

Methodology

1. Manual division of the study area into 400 6.4-by-6.4-kilometer (4-by-4-mile) grid cells, each constituting a PSU
2. Photointerpretation of the forest area in each PSU; stratification of the area into forest and nonforest PSU's
3. Determination of the number and location (PPS) of the PSU's to be subsampled in the forest stratum
4. Collection of high-flight Polaroid photography, 1:60 000 scale, over the selected PSU's; development of a mosaic of the Polaroid photography over the PSU's
5. Division (onboard the aircraft) of each PSU and 10 equal SSU strips; interpretation of the imagery for the relative amount of timber in each SSU
6. Selection (PPS) of two SSU's and collection of low-flight photography: 1:12 000 scale photography along the SSU strip and ten 1:2000-scale stereo triplets, equally spaced, in the SSU strip
7. Interpretation (in the laboratory) of the timber volume in a 0.2-square-hectometer (0.6-acre) TSU plot, at the center of the stereo-triplet photograph, using the parameters of tree height, crown coverage, and crown diameter; determination of the ratio area between the 0.2-square-hectometer plots and the SSU strip
8. Performance of field work in the selected TSU and measurement of the selected trees
9. Mathematical expansion of the estimates to the entire study area

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Major Conclusions and Output

1. The sampling error was reduced by 58 percent when compared to an inventory using the same multistage sampling scheme but without using Apollo data in the first stage.

2. The following sampling errors were experienced:

   a. Simple random sampling without using Apollo data: 30.7 percent

   b. Simple random sampling using the stratification of Apollo data into forest and nonforest: 22.5 percent

   c. PPS sampling using the stratification of Apollo data and volume interpretation: 13.0 percent

Special Comments and Notes

1. The reduction in the sampling error was not as encouraging as in a similar survey over Georgia. This was attributed to the poor correlation between the volumes (in terms of area) interpreted from the aerial data and from the ground survey data.

2. This was a classic example of the use of space photography for multistage sampling inventories.