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ANALYSIS OF RECREATIONAL LAND USING SKYLAB DATA

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16. Abstract
The goal of this project was to evaluate the use of S190A and S190B photography and S192 multispectral scanner data acquired by the Earth Resources Experiment Package of the SKYLAB mission during 1973. S192 data collected on 5 August 1973 was processed by computer to produce a classification map of a part of the Gratiot-Saginaw State Game Area in south central Michigan. A 10-category map was prepared for an area consisting of diverse terrain types, including forests, wetlands, brush, and herbaceous vegetation. An accuracy check indicated that 54 percent of the pixels were correctly recognized. When these ten scene classes were consolidated to a 5-category map, the accuracy increased to 72 percent. The accuracy of the 5-category map can be further increased to 82 percent, if the required output consists of summary statistics for a square-mile grid, since omission and commission errors tend to counterbalance each other. S190A, S190B, and S192 data can be used for regional surveys of existing and potential recreation sites, for delineation of open space, and for preliminary evaluation of geographically extensive sites.

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PREFACE

The goal of EREP Investigation 443 was to analyze and evaluate the use of earth resources data obtained during the SKYLAB program for the analysis and evaluation of recreational land. The investigation was carried out under NASA Contract NAS9-13283, with Mr. Rigdon E. Joosten acting as NASA Technical Monitor for the project. Mr. Irvin J. Sattinger, Research Engineer at the Environmental Research Institute of Michigan, was Principal Investigator. Mr. Franklin G. Sadowski was responsible for field data collection and computer processing and analysis of the S192 data. Mr. Norman E.G. Roller determined the S192 data classification performance.

The investigation was conducted in close cooperation with people and organizations who could view the work from the standpoint of the ultimate user of the data. Mr. George Skrubb, Director of the Oakland County Planning Commission, and Mr. Shan G. Topiwalla of the Oakland County Planning Commission assisted in evaluating the S190A photography. Mr. Larry Peterson, Outdoor Recreation Planner at the Lake Central Regional Office of the Bureau of Outdoor Recreation, was consulted on the utility of the S190B photography. Mr. Gary Boushelle, Assistant Regional Wildlife Biologist, for Region III (Southern Michigan), Mr. Marv Johnson, and Mr. Richard Elden, all of the Michigan Department of Natural Resources, provided us with valuable data and advice during our analysis of S192 data for the Gratiot-Saginaw State Game Area. However, the conclusions and recommendations contained in this report do not necessarily reflect the views of the organizations mentioned above.

Finally, we would like to acknowledge Mrs. Nancy J. Moon and Miss Debbie Compton, who provided valuable secretarial support.

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1 INTRODUCTION AND SUMMARY

1.1 PROJECT OBJECTIVES

One of the major goals of the SKYLAB program was the demonstration of the use of advanced spaceborne sensors to acquire data needed for many problems in earth resource management and environmental protection. During the SL2, SL3, and SL4 missions, the Earth Resources Experiment Package collected large quantities of earth resources data which now constitute a comprehensive data bank for continuing use. The objective of the SKYLAB investigation conducted by the Environmental Research Institute of Michigan was to analyze and evaluate the use of this space-acquired data for particular application to recreational land analysis. In addition, the results of the project can be considered applicable to data that might be acquired by similar sensors carried on future missions, where the opportunity will exist to obtain additional coverage of areas of particular interest.

A number of studies have shown potential uses of remote sensing data for recreational analysis and planning. Potential applications of the LANDSAT multispectral scanner were specifically covered by Sattinger, Dillman and Roller [1]. More general studies of recreational applications have been undertaken by other investigators [2,3].

Although the S190A and S190B photographic systems and the S192 multispectral scanner all have application to the study of recreational land, the primary emphasis of this study was on the processing and interpretation of the S192 multispectral scanner data.

In order to demonstrate a specific use of SKYLAB data, this investigation concentrated its effort on a test area primarily of value as wildlife habitat. Although this demonstration of the use of

SKYLAB data concentrated on wildlife habitat analysis, the results can be adapted to many of the other recreational land analysis tasks discussed in Section 5.

1.2 SUMMARY

S190A photography of southern Michigan was obtained during each of the three SKYLAB missions. Coverage of the area during June 1973 was examined to determine the amount of detail contained in the imagery (Section 2.1). S190B photography collected in August 1973 was also examined (Section 2.2). The S190B photography contains sufficient detail to map Level I and Level II categories of land use and land cover. This capability makes it potentially useful for such purposes as mapping existing recreational facilities, identifying open space suitable as recreational land, initial selection of recreation sites, and site planning of geographically extensive sites.

Major emphasis of the study was placed on processing and evaluation of S192 multispectral scanner data collected during August 1973. We selected as a test site a part of the Gratiot-Saginaw State Game Area in south central Michigan. This 5,300-hectare state game area is managed mainly for woodland species of wildlife such as deer, ruffed grouse, woodcocks, and squirrels. The ability to map major categories of land use and land cover of this type of recreational area would, therefore, be of major value to wildlife planning and management.

Processing of the S192 data was based on the technique of maximum likelihood ratio processing (Section 3). Processing of the data began with an assessment of S192 data quality. S192 data were found to have a relatively limited signal-to-noise ratio. Some misregistration of pixels from various spectral bands is also believed to limit classification performance. For the classification process, a total of 35 training sets were selected representing such diverse terrain types as wetlands, brush, and wooded areas of varying tree crown density. Training sets were also selected for pine and for regenerated aspen, the latter being of particular interest in deer habitat studies. Based on ground truth collected during field checks and photo-interpretation of available aerial photography, the 35 training sets were subsequently combined to form 10 major scene classes. The digital data for the test site was subjected to maximum likelihood ratio processing, using six spectral channels determined by computer analysis to be the optimum channels for scene classification.

An accuracy check was conducted on three one-square-mile sections of the test site (Section 4). We found that a 10-category map could be produced in which 54 percent of the pixels were correctly recognized. When these ten scene classes were consolidated to a 5-category map, the accuracy increased to 72 percent. Because of the predominance of the forest category in these sections (constituting about two-thirds of the total area), its accuracy of classification was as high as 85 percent, while the accuracy of recognizing herbaceous, brush, and non-forested wetland categories ranged from 24 to 52 percent. The accuracy of the 5-category map can be further increased to 82 percent, if the required output consists of summary statistics for a complete square mile, since omission and commission errors tend to counterbalance each other. It should be noted that these accuracy characteristics were for a case in which a relatively complex test area was classified using data acquired in late summer. This particular season has been found in other studies not to be optimum for terrain and vegetation classification. Also, the predominance of one type of terrain (forest) tends to reduce the accuracy with which other less dominant classes can be determined. Therefore, under other circumstances, improved classification results might be obtained.

We believe that S192 data can be used for regional surveys of existing and potential recreation sites, for delineation of open space, and for preliminary site evaluation of geographically extensive sites. S192 data in combination with S190A and S190B photography can be used for more detailed studies of regional areas (Section 5).

2
EVALUATION OF EREP PHOTOGRAPHY

Photography obtained by the S190A and S190B cameras has considerable potential for various purposes in the analysis of recreational land. In order to assess this potential, S190A and S190B coverage of sections of Southeast Michigan during the SL2, SL3, and SL4 missions was examined to determine its usefulness for land use and land cover mapping. Since the major emphasis of this project was on the development of computer processing techniques for use with the S192 system, the analysis of photographic data was not carried out in as complete detail as was warranted.

2.1 S190A PHOTOGRAPHY

Coverage of Southeast Michigan with the S190A system was obtained during all three missions. Coverage of the area was obtained on 12 June 1973 during the SL2 mission, on 5 August 1973 during the SL3 mission, and on 12 January 1974 during the SL4 mission.

S190A photography from the SL2 mission was examined in some detail. This examination was performed by the Principal Investigator and by Mr. Shan G. Topiwalla, a member of the staff of the Oakland County Planning Commission.

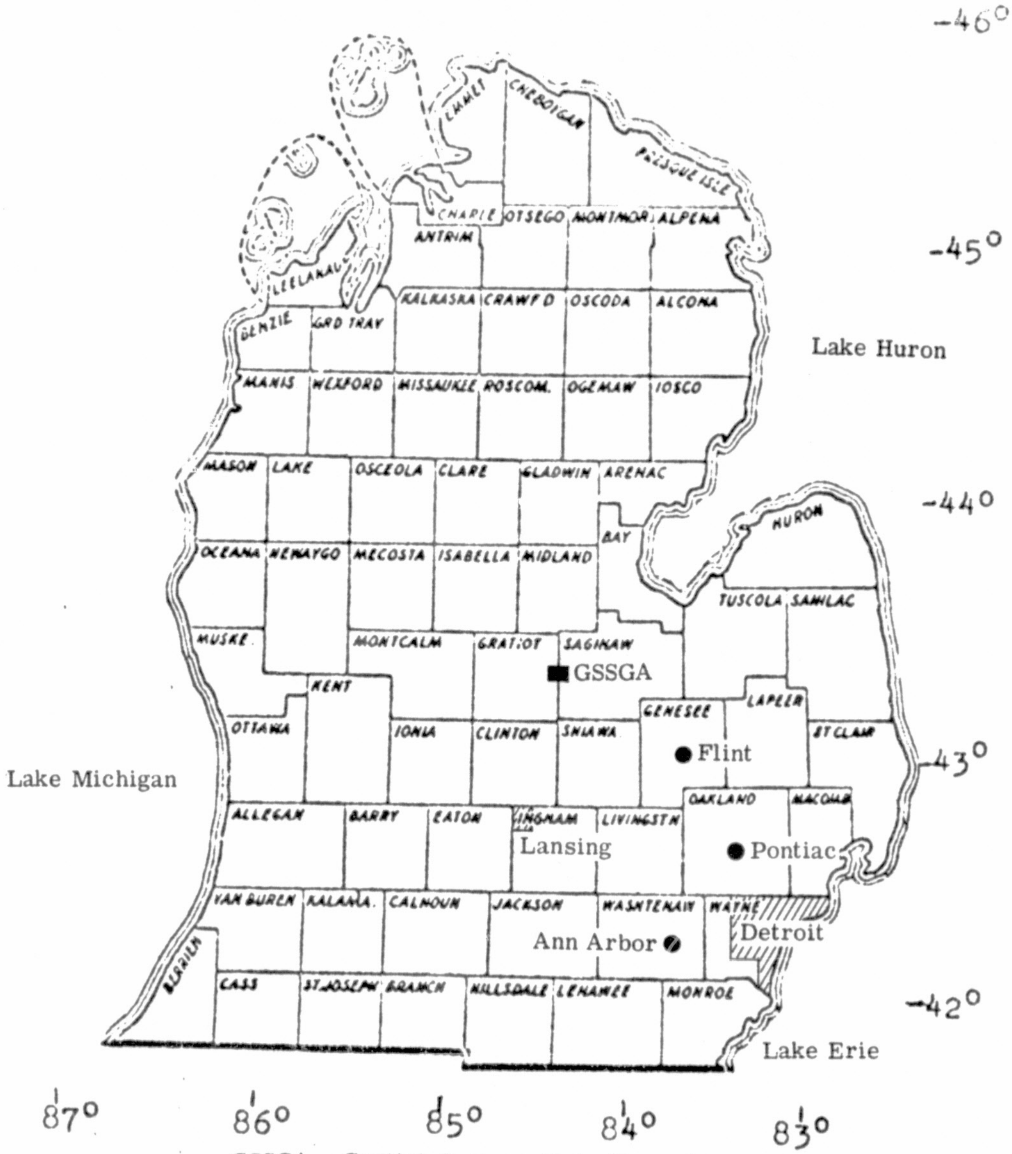
The S190A photography was interpreted in the form of 4X transparencies (1:712,500) with the aid of an 8X magnifier. The purpose was to determine which urban and natural resource features can readily be detected but not identified, and which features can be identified without use of ground truth.

The image interpretation exercise was mainly concentrated on one frame of the data. The coordinates of the center of this frame are 42:6.5 deg. N. latitude and 83:31.8 deg. W. longitude. The photography was taken on 12 June 1973 at approximately 9 a.m. EDT. This frame includes the western shoreline of Lake Erie and areas inland from the shoreline to a distance of about 100 km. About 30 percent of the northwest part of Oakland County is cloud-covered, and there appears to be a light haze over the remainder of the county. Some other sections of the frame also exhibit cloudiness or haze, but certain sections are clear, notably in Washtenaw County (see Figure 1).

Film/filter combinations at the various camera stations are listed in Table 1. From Camera Station 3 or 5, such linear features as major highways, major traffic arteries, and airport runways can be clearly identified. It is also possible to determine the general outlines of subdivisions, agricultural fields, golf courses, shopping centers, industrial complexes, sand and gravel pits, and central business districts. However, these features cannot be completely identified without auxiliary sources of information. Bare soil is easily distinguished from vegetation cover, but Station 3 does not have enough spatial detail to separate crops, woodlands, or other major classes of vegetation, at least for the sizes of these features found in Southeast Michigan.

Station 5 provides the sharpest spatial definition of natural and cultural features. Although water bodies are relatively difficult to distinguish on the basis of tonal variations in this band, other features stand out sharply. For example, individual streets in subdivisions and bridges over the Maumee River at Toledo can be distinguished.

The extent of strip developments consisting of industrial, commercial, and some multi-family residential establishments can be delineated from Station 2 imagery. Major arteries appear to be defined by dark gray linear features. These features are not continuous as major road arteries would be. A comparison of the Station 2 imagery with the land use map reveals that the dark gray linear returns match those sections of major arteries that have strip developments along



GSSGA - Gratiot-Saginaw State Game Area

FIGURE 1. LOWER PENINSULA OF MICHIGAN

TABLE 1

FILM/FILTER COMBINATIONS OF EREP PHOTOGRAPHY
S190A Photography (SL2, 12 June 1973)

CAMERA STATION	FILM TYPE	FILTERS	DESIGN BANDWIDTH, μm	FILM DEFINITION
1	EK2424	CC	0.7 to 0.8	IR B&W
2	EK2424	DD	0.8 to 0.9	IR B&W
3	EK2443	EE	0.5 to 0.88	IR Color
4	SO-356	FF	0.4 to 0.7	Aerial Color
5	SO-022	BB	0.6 to 0.7	PAN-X B&W
6	SO-022	AA	0.5 to 0.6	PAN-X B&W
S190B Photography (SL3, 5 August 1973)				
	SO-242	S	0.4 to 0.7	Aerial Color, High Resolution

TABLE 2

GENERAL CHARACTERISTICS OF EREP PHOTOGRAPHY

S190A CAMERA STATION	WATER CONTRAST	VEGETATION CONTRAST	COLOR DISCRIMINATION	SPATIAL RESOLUTION
1	H	L	-	L
2	H	L	-	L
3	M	H	H	L
4	M	M	L	M
5	L	H	-	H
6	L	M	-	M
	L	M	M	V

V = Very High
H = High
M = Medium
L = Low

them, for example, along Telegraph Road in Oakland County between Eight Mile and Twelve Mile Roads. The segment of Telegraph Road between Twelve Mile and just south of Fifteen Mile Roads, where there is no strip development, is not defined on the imagery.

Large scale new construction is identifiable on Station 3 and Station 5 imagery. The I-275, I-696, I-96 interchange in Novi in Oakland County is in its early phases of construction. The lighter tonal returns on Station 3 and Station 5 imagery define the general design of the interchange. The large Briarwood Shopping Center being built at the south edge of Ann Arbor is also clearly visible, but cannot be identified without ground truth.

Thirteen golf courses were detected in Oakland County on Station 2 imagery. A county land use map shows fifteen golf courses within the area interpreted. All golf courses in urbanized areas can be distinguished by their comparatively light tonal returns. The two golf courses not identified are in rural areas surrounded by open fields and woodlands.

Water bodies are clearly defined on Station 2 imagery. Wetlands can be detected with intensive interpretation, but their presence requires separate confirmation. Major streams can be observed. Lakes as small as 1 hectare can be detected and the general shape of individual lakes as small as 2 hectares can be delineated.

For each S190A camera station, a subjective evaluation was made with respect to four characteristics: water contrast, vegetation contrast, color discrimination, and spatial resolution. The qualitative results are shown in Table 2. The subjective evaluation of spatial resolution is consistent with reported resolution data [4]. Evaluation of the water contrast characteristics is consistent with known spectral characteristics of water bodies. The evaluation of vegetation contrast and color discrimination characteristics is largely subjective and attempts to indicate the ease of distinguishing various categories of vegetation on the basis of contrast or color. No attempt was made to evaluate combinations of more than one band of the multiband S190A photography.

2.2 S190B PHOTOGRAPHY

We also studied S190B photography for several areas of southeastern Michigan, including Detroit, Flint, Pontiac, Ann Arbor, and Lansing. This area was photographed during the SL3 mission on 5 August 1973 and is covered by Frames 83-149, 83-150, and 83-151.

Film/filter characteristics of photography are shown in Table 1. The S190B photography was studied in the form of 2X transparencies (1:475,000), examined with the aid of an 8X magnifier.

Figure 2 is a sample of S190B photography for a portion of Oakland County northwest of Pontiac. The figure has appreciably poorer spatial resolution and color discrimination than the positive transparency from which it was produced and which was used for detailed photointerpretation. In comparison with S190A photography, S190B photography has much better spatial resolution. However, the use of aerial color film results in relatively low color discrimination and vegetation contrast compared to S190A Station 3 or 5.

On the transparency, a wide variety of individual natural and cultural features can be detected and identified, including features as small as private horse tracks, individual subdivision streets, and section line roads. Four lane roads can be identified by detection of the median. Discrimination of vegetation and water bodies is relatively limited, but wooded areas and water bodies can be distinguished and delineated.

2.3 CONCLUSIONS

Table 3 summarizes the capabilities of S190A and S190B photography to detect or identify individual cultural features or types of land cover, indicating which S190A camera stations are the most useful for each class. The table provides a comparison of S190A and S190B capabilities.

The examination of S190A imagery indicates that a number of urban features and natural resources can be grossly identified in conjunction with varying amounts of supplementary information. Although the S190A photography can provide some rough information on recreation sites, the information is not sufficiently detailed for any but the most general reconnaissance of an area. It should be noted, however, that our study did not attempt to combine imagery from more than one camera station.

S190B color photography has adequate resolution to detect or identify many natural and cultural features which are significant for the evaluation of recreational land and open space. Many of these features were recognized in the 5 August 1973 photography. Since the photographic detail is adequate to detect but not identify many features within the scene, such as buildings or vegetation categories, these features can be identified most effectively by interpreters familiar with the territory. The effectiveness of the interpretation could be further improved if coverage were obtained at two or three different seasons so that such indicators as seasonal changes in vegetation cover or snow enhancement could aid the interpretation of land use and land cover.

The analysis of the S190B photography just described was reviewed by Mr. Larry Peterson of the Lake Central Region, Bureau of Outdoor Recreation. Possible applications of the S190B photography listed below include several suggested by him.

- The photography can be used to good advantage to obtain general familiarity with an area of one or more counties, and to study interrelationships of major natural and cultural features within the area, such as forests, water bodies,

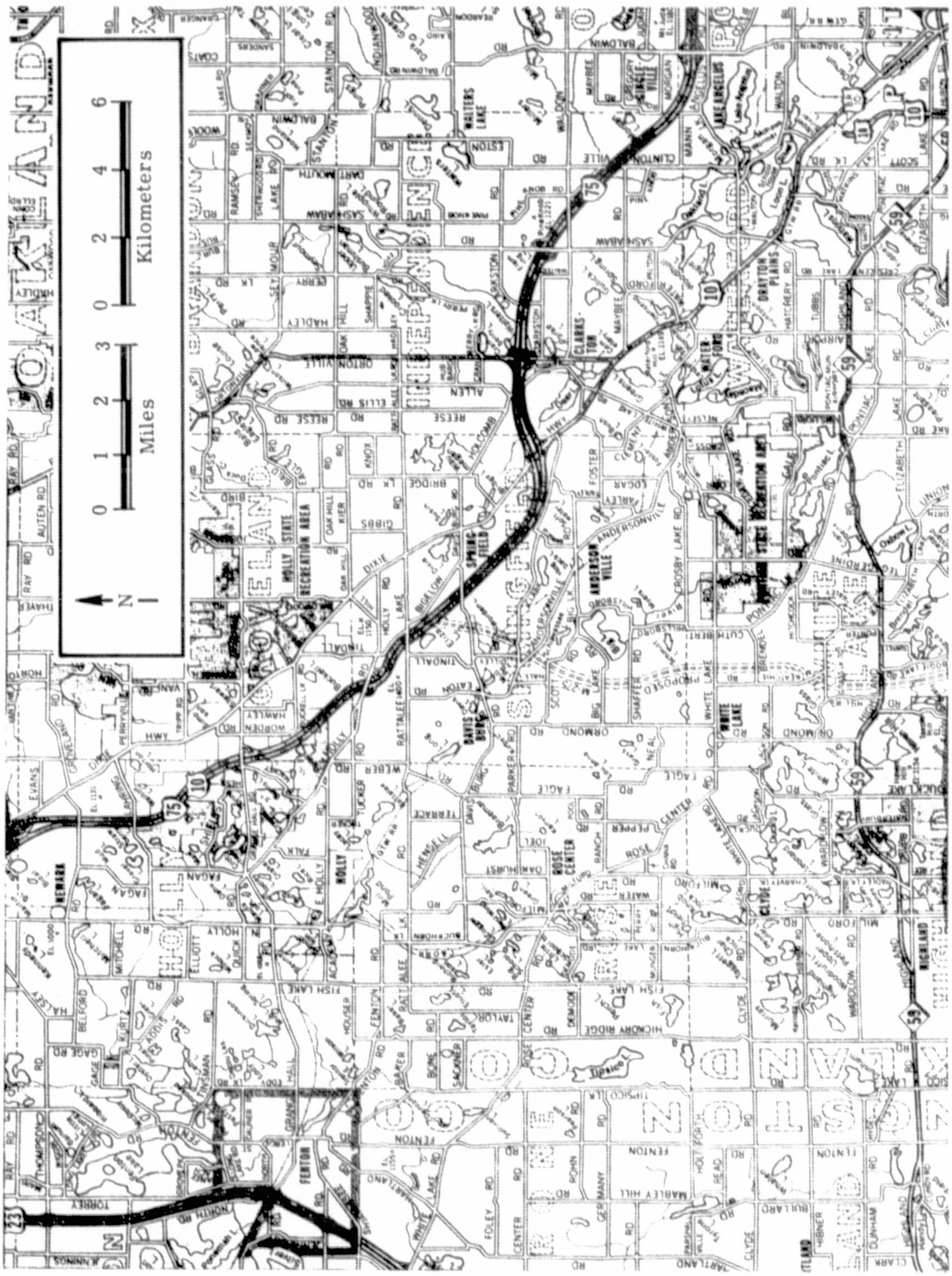


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FIGURE 2. S190B PHOTOGRAPH OF AREA IN OAKLAND COUNTY, NORTHWEST OF PONTIAC, MICHIGAN

TABLE 3

DETECTION AND IDENTIFICATION CAPABILITIES OF EREP PHOTOGRAPHY

	S190A		S190B	
	CAPABILITY	BEST CAMERA STATIONS	CAPABILITY	REMARKS
Urban and Cultural Features				
Central business district			I	
Shopping center			D	
Commercial strip development	I	5	I	
Subdivision streets	I	5	I	
Trailer court			D	
High school			D	
Parking lot			D	
Individual building			D	
Factory			I	
Power plant			D	
Light industrial park			D	
Rural/urban boundary			I	
Sanitary landfill			D	These categories may be confused
Sand and gravel pit	D	3,5	D	
Dike			I	
Village	D	3	I	
Rural and Natural Areas				
Agricultural fields	I	5	I	
Bare soil	I	5	I	
Farmstead			D	
Woodlots	D	3,5	I	Cannot distinguish deciduous from coniferous in August
Wetlands	D	2,3	I	

Water Features				
Rivers and streams	I	1,2,3	I	
Lakes	I	1,2,3	I	
Shallow water			D	These categories may be confused
Sediment			D	
Water circulation patterns	I	1,2,4	I	
Shoreline development			I	
Transportation				
Major urban traffic artery	I	5	I	
Major highway	I	5	I	
Interchange			I	
Two-lane vs. four-lane			I	
Section line road			I	
Railroad			I	
Airport	I	5	I	
Bridge			I	
Recreational Features				
Golf course	I	2,3	I	
Large urban park	D	5	I	
Football stadium			I	
Racetrack	I	5	I	
Private horse track			I	

D = Detect
I = Identify

urban areas, and transportation networks. In the absence of other sources of up-to-date photography, S190B coverage of the entire area of responsibility of a recreation agency would be valuable for general reference purposes, and this value would increase with the size of the agency's area of responsibility.

- Existing recreational facilities, such as golf courses, parks, stadiums, race tracks, and marinas can be detected and identified. If this interpretation is performed by someone familiar with the territory, the identification of individual sites is quite reliable and serves as an inventory of existing recreation supply.

- Repeated coverage of an area at intervals of about one year would make it possible to observe and measure land use trends. Such measurement would indicate open space potentially suitable as recreational land which is threatened by development pressure. It would also indicate trends in population growth, which constitute one type of information needed in estimating the growth of recreation demand.

- The photography can be used for initial selection of recreation sites. It provides necessary detail to identify significant vegetation and water features and to relate them to urban areas and transportation networks. In addition, it is possible to detect and in many cases identify specific industrial or commercial installations, sewage treatment plants, and some types of air and water pollution which influence the suitability of adjacent recreation sites.

- The photography has only limited use for individual site planning of parks, golf courses and other recreation facilities. For geographically extensive sites, such as river valleys or scenic trails, however, it can provide useful information.

- S190B photography can be used in the computer processing and analysis of S192 data. The selection of training sets is an important part of S192 automatic interpretation procedures. Because S190B photography is collected concurrently with S192 data, it provides a timely record of scene class appearance or condition that may be lacking from ancillary sources of information collected before or after the scanner data. The resolution and timeliness of the photography allows the assessment of general characteristics of potential training sets. As indicated in Section 3.4, S190B photography was used to observe such characteristics as the homogeneity and current boundaries of major vegetation features in the test site and surrounding agricultural fields. However, it is essential to supplement the examination of S190B data with ground truth obtained by field trips. This was found to be true even for the high-altitude aerial photography also used in training set selection.

3
ANALYSIS AND PROCESSING OF MULTISPECTRAL SCANNER DATA

3.1 DATA PRODUCTS

Data products used for the study of the S192 Multispectral Scanner were collected by the Earth Resources Experiment Package on board Skylab 3 during revolution 1197 on 5 August 1973. The track 61 overpass was made from a northwest to southeast direction over southern Michigan at approximately 11:00 a.m. EDT. Data that were collected included multi-band photography from the S190A camera system, color photography from the S190B earth terrain camera, and computer-compatible multispectral data from the S192 multispectral scanner.

High-altitude aerial photography of southeast and south central Michigan was acquired on 11 August 1973 by the NASA/ARC Earth Resources Aircraft Project in support of the EREP project. The photography is of excellent quality. However, as a result of the change in test site discussed below, it was necessary to use high-altitude color-infrared photography of south central Michigan that had been acquired on 10 June 1972 by the NASA/ARC Earth Resources Aircraft Project. The photography is at a contact scale of 1:120,000, is also of excellent quality, and was used in the analysis of S192 data.

3.2 TEST SITE SELECTION AND DESCRIPTION

We had originally intended to concentrate our S192 analysis effort on Test Site 819522 (Oakland County, Michigan), which had been the site for much of our work in a similar investigation of LANDSAT-1 data. Examination of the SL3 screening imagery supplied by NASA indicated that cloud cover existed over parts of Oakland County. The northwest part of the county was clear, but possibly subject to slight haze cover. It was therefore decided to select an alternative site that would still fulfill the objectives of determining the utility of S192 and other types of Skylab data for the analysis of recreational sites in southern Michigan.

A major form of outdoor recreation in southern Michigan consists of hunting, with much of this type of activity taking place in managed state game areas. Personnel of the Wildlife Division of the Michigan Department of Natural Resources (DNR) had shown genuine interest in our remote sensing work during previous contacts. Since their participation in the present project would contribute to the significance and usefulness of the results achieved, we visited the Wildlife Division on 21 February 1975 to discuss our program and ask for their advice and assistance in obtaining ground truth and reviewing project results. Our primary contact was with Gary Boushelle, Assistant Regional Wildlife Biologist, Region III (southern Michigan). Also present at the meeting were John Byelich, Deer Range Management Specialist and L. A. Davenport, Senior Wildlife Executive.

We learned that a state game area in Gratiot and Saginaw Counties (see Figure 1) is of particular interest to the Wildlife Division and is included at the northern edge of the S192 data coverage of 5 August 1973. The Gratiot-Saginaw State Game Area consists of a total of 13,097 acres (5,300 hectares) that are managed for the production of woodland species of wildlife such as deer, ruffed grouse, squirrels, and woodcock. The topography is predominantly flat with undulations in elevation of a few feet that are caused by the post-glacial beach ridge geomorphology of the terrain. Much of the area is timbered with predominantly even-aged stands of oak, oak-aspen, aspen, and mixed hardwoods. Conifers exist only in isolated small patches and one pine plantation. Some wetlands occur in areas of poor drainage. The remainder of the area consists of small parcels of brushy and herbaceous vegetation. A few fields are sharecropped; but the soil is sandy and not very productive. Habitat management has included small wildlife cuttings and plantings. Several commercial timber cuts were made as clearcuts for aspen reproduction.

Twelve contiguous square-mile sections of near-complete state ownership were designated as the test site for S192 data analysis.

3.3 DATA QUALITY ANALYSIS

Computer tapes of scan line straightened S192 data were first converted from 9-track NASA format to 7-track ERIM format. During that process, it was necessary to reduce the 22 channel NASA tapes to the maximum of 20 tape channels allowed by the ERIM IBM 7094 computer system. Since the thermal infrared spectral channel had been recorded in both a single- and double-sampled mode, we decided to delete two tape channels (SDO's 15 and 16) which comprised the doubly-sampled thermal channel and retain the thermal channel information of SDO 21.

Our procedure for analyzing data quality involved assessments of the dynamic range and noise properties of all spectral channels in order to determine their utility for further processing. Dynamic range in this case is defined as the range of integers over which data values representative of total scene variability are distributed. Dynamic range for the area of the Gratiot-Saginaw State Game Area (GSSGA) was assessed by histogramming the data values in each spectral channel. The area histogrammed covered the GSSGA and included some of the surrounding agricultural fields — a total of 31959 pixels.

Dynamic range varied by spectral channel, being as low as 30 integer values in SDO's 3 and 4 (0.56 - 0.61 μm) and as large as 63 integer values in SDO 19 (0.98 - 1.03 μm). Data values in SDO 18 (0.46 - 0.51 μm) were distributed throughout the total range of 0 - 256, perhaps indicating the presence of many bad scan lines. Table 4 indicates the ranges for all 20 SDO's. Some dissimilarities existed between the ranges of data values for even-numbered and odd-numbered SDO's in most of the doubly-sampled spectral channels. For example, zero data values occurred in several even-numbered SDO's. In addition, maximum and minimum histogram limits varied by a few integers between even- and odd- numbered SDO's of the same spectral channel.

TABLE 4

SIGNAL-TO-NOISE COMPARISON OF S192 DATA

SDO	Spectral Band (μm)	Range of Integer Values Over Which 99% of Pixels are Distributed	RMS "Noise" Fluctuations (integer values)	Signal-to-Noise Ratio
22	0.41 - 0.46	37	5.6	6.6
18	0.46 - 0.51	*	14.1	
1	0.52 - 0.56	31	2.6	11.9
2	0.52 - 0.56	31	2.4	12.9
3	0.56 - 0.61	30	3.0	10.0
4	0.56 - 0.61	30	3.1	9.7
5	0.62 - 0.67	45	4.7	9.6
6	0.62 - 0.67	42	4.9	8.6
7	0.68 - 0.76	48	4.3	11.2
8	0.68 - 0.76	47	4.5	10.4
9	0.78 - 0.88	56	4.5	12.4
10	0.78 - 0.88	59	20.0	2.9
19	0.98 - 1.03	63	5.9	10.7
20	1.09 - 1.19	47	4.0	11.7
17	1.2 - 1.3	46	5.6	8.2
11	1.55 - 1.75	45	2.8	16.1
12	1.55 - 1.75	45	3.0	15.0
13	2.10 - 2.35	47	3.5	13.4
14	2.10 - 2.35	46	3.8	12.1
21	10.2 - 12.5	34	4.5	7.5

*see text

A rough measure of system "noise" was obtained by inspecting integer values in each SDO from a matrix of 150 pixels on a lake surface of assumed uniform reflectance. The rms fluctuations in integer value are stated for each SDO in Table 4. High "noise" values were noted for SDO's 10 and 18. By dividing the previously determined dynamic range for each SDO by the corresponding rms "noise" fluctuations, a measure of signal-to-noise can be stated (Table 4).

The results of Table 4 indicate generally better signal-to-noise ratios for the odd-numbered SDO's of all doubly-sampled spectral channels except for the 0.52 - 0.56 μm channel (SDO's 1 and 2). The odd-numbered SDO's had also been devoid of zero data values. Therefore, in order to reduce the cost and simplify the analysis of subsequent data processing, all even-numbered SDO's of the doubly-sampled spectral channels were deleted. In addition, because of the histogram and noise problems associated with SDO 18, we decided to delete the spectral channel of 0.45 - 0.51 μm from further processing efforts.

3.4 TRAINING SET SELECTION

Digital graymaps of the Gratiot-Saginaw State Game Area (GSSGA) were generated for several SDO's in order to determine the SDO which would allow for an optimum visual display of major scene classes. We found that the best display was achieved by a level slice of SDO 11 (1.55 - 1.75 μm). Also, this SDO provided the best subjective delineation of the perimeter of the GSSGA by separating forested areas from the surrounding agricultural fields. This graymap was subsequently used as a base onto which a one-square-mile section grid was transferred. Section lines were traced from the 1:120,000 color infrared transparency that had been spatially registered to the graymap with the aid of a Bausch and Lomb Zoom Transfer Scope. This section grid served as a locational reference in the S192 data for the location of training sets.

Areas designated as training sets were representative of the major terrain and vegetation classes. A visit was made to the GSSGA with personnel from the DNR in order to review management objectives that would help define information parameters of operational interest. With that information in hand, training sets were located on the high-altitude RB-57 color infrared photography of the area acquired in June 1972. These training sets included such diverse terrain types as non-forested wetlands, brush, and wooded areas of varying tree crown density. Training sets were also selected for a pine plantation, for a forested area that had been flooded by beaver dam construction, and for regenerated aspen, the last-named being of particular interest in deer habitat studies. A total of 35 separate training sets were designated in an effort to encompass the inherent variability of the scene classes.

The S190A and S190B photography was checked for additional information of a concurrent nature that might influence the choice of training sets. The low resolution of the S190A photos provided little assistance for assessing the nature of individual training sets. The S190B photo, when examined under 8X magnification, provided sufficient detail to enable locating many boundaries of agricultural fields and major vegetation features such as forest, brush and herbaceous areas, and sparsely vegetated wetlands. In addition, large variations in vegetation density could be detected within the boundaries of such areas, thus providing some assessment of homogeneity. As a result of checking the S190B photo, the location of three training sets were adjusted to conform with current field boundary positions.

Groups of S192 pixels corresponding to each training set designated on the RB-57 photography were delineated on the digital graymap by superimposing the photography onto the graymap with the zoom transfer scope. Boundary pixels around each training set were excluded from delineation. The signature for each training set was then extracted from the S192 digital tapes. Such signatures include the means and standard deviations of data values in each spectral channel and a covariance matrix for all spectral channels.

3.5 PRELIMINARY SIGNATURE ANALYSIS

All signatures were analyzed as to their statistical uniqueness by computing the probability of misclassification for all possible pairs of signatures. Each pairwise probability of misclassification (PPM) provides a measure of the separability between two multi-dimensional statistical distributions. It represents an average of the probabilities that samples from distribution A will be mistakenly classified as distribution B and that samples from distribution B will be classified as distribution A. The result varies between zero (the two distributions are well separated) and 0.5 (the two distributions lie on top of each other). The classification rule used is the same best linear decision rule used to classify multispectral data [5, p. 100].

The 35 signatures were aggregated into a small set of composite signatures by combining groups of signatures having high probabilities of misclassification. Table 5 lists the resulting composite signatures for the S192 data set along with scene classes identified on the high-altitude, color-infrared photography. Computer separation of forest density classes seemed to be poor. High probabilities of misclassification were noted to occur for many forest signatures regardless of tree density. This was disappointing since the photo-interpretation of high-altitude color infrared photography had shown promise for discriminating three forest density classes. The separation of only two wetland classes was not disturbing since such scene classes are of limited areal extent in the test site, making accurate establishment of training sets difficult. In addition, because the extent and physical characteristics of wetlands can vary dramatically from year to year, the separation of only two wetland classes by S192 data may be

TABLE 5

PHOTOINTERPRETED SCENE CLASSES AND STATISTICALLY AGGREGATED COMPOSITE SIGNATURES FOR THE GRATIOT-SAGINAW STATE GAME AREA

Scene Classes Identified on RB-57 Color-Infrared Photography Collected on 10 June 1972	Composite Signatures of S192 data Collected on 5 August 1973
NON-FORESTED WETLANDS 1	NON-FORESTED WETLANDS 1
NON-FORESTED WETLANDS 2	NON-FORESTED WETLANDS 2
NON-FORESTED WETLANDS 3	
FLOODED FOREST	FLOODED FOREST
BRUSH FIELDS	BRUSH FIELDS
FOREST 1 (sparse crown cover)	ALL FOREST
FOREST 2 (intermediate crown cover)	
FOREST 3 (dense crown cover)	
ASPEN REGENERATION SITES	ASPEN REGENERATION SITES
PINE PLANTATION	PINE PLANTATION

indicative of the actual situation that existed a year after the photography had been collected.

The composite signatures from the S192 data were then analyzed to determine the ranking of spectral channels for computer separation of the scene classes. Although the separation of forest density classes seemed poor, we were nevertheless interested in identifying spectral channels of importance for forest and brush signatures. Therefore, we performed optimum channel selection separately for two groups of composite signatures as shown in Table 6: (a) a set of 4 signatures corresponding to brush, cutover forest having less than 25 percent crown cover, sparse forest with 30-70 percent crown cover, and dense forest with greater than 70 percent crown cover, and (b) a set of all major separable signatures, with the three forest density classes in (a) as a single signature.

Table 7 illustrates the resulting channel selections for both sets of signatures. The channels have also been ranked according to the previously determined signal-to-noise (S/N) ratio (Table 4). Note that the first two optimum channels (0.78-0.88 μm and 1.55-1.75 μm) are the same for both sets of signatures. The high S/N ratio for these two channels may have had a dominant influence on their selection. However, the 2.10-2.35 μm channel, which also had a high signal-to-noise ratio, ranked low for both sets of signatures. This would appear to indicate a real spectral significance for the first two optimum channels in separating the vegetation categories in this particular data set. The remaining optimum channel sequences differ for the two sets of signatures and show less correspondence with the channel S/N ranking. Note that three of the first four optimum channels for each set of signatures fall in the spectral range of the LANDSAT system.

TABLE 6

COMPOSITE SIGNATURES FROM S192 DATA USED FOR THE DETERMINATION OF OPTIMUM SPECTRAL CHANNELS

Signature Name	4 Brush and Tree Signatures	7 Major Signatures
Wetlands 1		X
Wetlands 2		X
Flooded Forest		X
Brush	X	X
Sparse Forest	X	
Intermediate Forest	X	X
Dense Forest	X	
Aspen Regeneration		X
Pine Plantation		X

TABLE 7

SELECTION OF OPTIMUM CHANNELS FOR COMPOSITE SIGNATURES FROM S192 DATA

Spectral Channel (μm)	Signal-to-Noise Ranking*	Ranking of Channels: 7 Major Signatures	Ranking of Channels: 4 Brush and Tree Signatures	LANDSAT Channel Corresponding to S192 Channel
0.41 - 0.46	12	9	6	
0.52 - 0.56	4	4	8	Band 4
0.56 - 0.61	8	11	12	
0.62 - 0.67	9	10	4	Band 5
0.68 - 0.76	6	7	3	Band 6
0.78 - 0.88	3	1	1	
0.98 - 1.03	7	3	5	Band 7
1.09 - 1.19	5	5	10	
1.20 - 1.30	10	6	11	
1.55 - 1.75	1	2	2	
2.10 - 2.35	2	8	7	
10.20 - 12.50	11	12	9	

*highest signal-to-noise ratio is ranked 1

In order to evaluate the classification capability of data derived from LANDSAT and SKYLAB for various combinations of channels, pairwise probabilities of misclassification were computed for composite signatures using four separate combinations of data source and number of channels:

1. Four channels of LANDSAT data acquired on 8 June 1973 for the GSSGA area.
2. Four channels of S192 data most nearly corresponding to the LANDSAT channels (see Table 7).
3. Four channels of S192 data shown in Table 7 as optimum channels for the 7 major categories.
4. Twelve channels of S192 data.

For each of the four combinations, the single forest signature was replaced with the three signatures from Table 6 that represented the three forest density classes and probabilities of misclassification were computed.

The comparative performance of various sources and numbers of channels of image data can be seen from Table 8. This table shows probabilities of misclassification of nine different scene classes. The names of each class have been made consistent with final selection of classes discussed in Section 3.6 below. Each entry represents the averaged probability of confusing the individual scene class with all of the other scene classes listed. The values shown should be used only for relative comparisons of the various data sources. The absolute magnitudes of these values will be much lower than real classification results to be shown later, since these values have been derived by comparing signatures of pure training sets and are not affected by the complexities introduced in the actual classification process.

Direct comparison of the performance of LANDSAT data and of S192 data is not possible, since LANDSAT and S192 data are not available for the same date. LANDSAT data acquired on 8 June 1973 were available

TABLE 8

AVERAGE PROBABILITIES OF MISCLASSIFICATION OF EACH SCENE CLASS

SCENE CLASS	DATA SOURCE LANDSAT1 (June,1973)	S192 LANDSAT4	S192 OPT4	S192 ALL12
Deep/Shallow Marsh	.0133	.0594	.0244	.0004
Shrub Swamp	.0939	.1126	.0571	.0079
Brush	.0783	.1290	.0416	.0416
Aspen Regeneration	.0701	.0706	.0143	.0086
Sparse Forest With Understory	.0683	.1081	.0787	.0581
Int. to Dense Forest with Understory	.0931	.1594	.1116	.0801
Dense Forest without Understory	.0796	.1647	.1135	.0839
Flooded Forest	.0522	.0733	.0452	.0095
Pine	.0224	.0595	.0087	.0003
Average	.0714	.1170	.0625	.0363

TABLE 9

AVERAGE OF ALL PAIRWISE PROBABILITIES OF MISCLASSIFICATION FOR INCREASING NUMBERS OF S192 CHANNELS

SCENE CLASSES	NUMBER OF CHANNELS* 1	4	6	12
7 Major Signatures	.1118	.0286	.0194	.0112
4 Brush and Tree Signatures	.2688	.1810	.1592	.1439

*Channels used are optimum channels shown in Table 7 for the GSSGA area, two months earlier than the SKYLAB SL3 pass used for S192 processing. Hence, seasonal differences may have affected the ability of the computer processing to distinguish various classes of terrain and vegetation. Table 8 indicates that the LANDSAT June data give consistently lower probabilities of misclassification than the four equivalent channels of S192 August data. It is believed that the earlier date for the LANDSAT data would favor the discrimination of wetland and vegetation classes. The increased discriminability might also be due to the higher signal-to-noise ratios typically observed for LANDSAT data. In addition, the better spatial location of pixels in LANDSAT data helps to ensure the extraction of signatures uncontaminated by misregistered pixels. Another difference in the two sets of data is the fact that the S192 equivalent channels are narrower in bandwidth than the LANDSAT channels. It is unlikely that this would explain any of the poorer performance of the S192 data.

Considering the performance of various combinations of S192 channels, it can be seen that the optimum four channels of S192 data as listed in Table 8 is considerably superior to the four channels selected to simulate the LANDSAT channels. Since the 1.55-1.75 μm channel constitutes the major difference of the optimum channels from the LANDSAT bands, the indication is that this channel is the most significant factor in improving performance.

The optimum four channels are roughly comparable in performance to the June LANDSAT data. It is reasonable to conclude that the comparable performance is achieved due to the inclusion of a near infrared band in the four optimum channels and possibly the narrower bandwidth of the S192 channels. These factors would offset the fact that June is likely to be at least as good as, if not better than, August as a season for vegetation discrimination, and the fact that the signal-to-noise ratio of the S192 data is generally less favorable than the LANDSAT data.

The table also shows appreciable improvement in classification performance of 12 channels of data over four channels of data, as well as over the use of LANDSAT data. Further information on the comparison of various numbers of channels of S192 data is contained in Table 9. This table shows results of computer calculations of average pairwise probability of misclassification for two combinations of signatures: seven major signatures and four signatures of brush and wooded areas. The table shows that continued improvement is obtained by going to additional channels, although the rate of improvement with the addition of each channel slows down as the total number of channels increases. Because of the increasing cost and time for classification associated with large numbers of channels, it seems likely that in practice a total of four or six channels would prove to be optimum. The actual determination of this optimum would depend on the particular circumstances of individual equipment performance and classification requirements. For this study, we performed classification studies using the optimum six channels of S192 data.

The 10.5-12.5 μm thermal infrared channel had a low rating in the choice of optimum channels. This may be a result of the low S/N ranking of this channel. Therefore, no general conclusion about the utility of the thermal channel should be reached on the basis of this analysis.

3.6 TRAINING SET VERIFICATION

At this stage of the procedure a second visit was made to the test site. The visit was made in mid-June 1975 when vegetation foliage had progressed to its full stage of seasonal development. The intent was to document the physical characteristics of many of the training sets under phenological conditions that would have existed during the 5 August 1973 overpass. Such on-site observations were desired in order to ascertain the physical characteristics of the training sets and resolve several uncertainties regarding the combination of previously extracted signatures into composite signatures.

Twenty of the 35 originally designated training areas were visited. At each area, observations were recorded that included a general description of the site, recent disturbances, the physiognomic characteristics of the vegetation, and major species present. Many of the areas were documented with photographs. Subsequent analysis of the recorded observations provided the additional ground truth information that enabled a more perceptive reassessment of the procedure for combining signatures.

Eight forested training areas were visited. Although the observed tree crown densities of each area were in general agreement with the photointerpreted density classes, an additional physical characteristic proved to be of importance in describing each area. This characteristic concerned the existence of a lower tree/woody shrub understory within the forest canopy. Figures 3 and 4 illustrate the presence and absence of such an understory for two dense forest areas having similar overstory crown densities (estimated as 70 percent in the field). Areas of intermediate crown densities were typically characterized by a lower tree/woody shrub understory of reproduction. Thus, the presence of such an understory constituted a forest stand characteristic that was not necessarily correlated with crown density class.

We again analyzed the signatures of the forest areas that were visited and found that for crown density classes previously designated as "intermediate" and "dense", the signatures were somewhat separable into two groups on the basis of the presence or absence of a lower tree/woody shrub understory. Accordingly, three signatures were combined to create a composite signature representative of forest areas comprised of dense (at least 60 percent) crown cover over a predominantly

FIGURE 3. FOREST AREA OF ESTIMATED 70% CROWN COVER WITH UNDERSTORY OF LOWER TREES AND WOODY SHRUBS

FIGURE 4. FOREST AREA OF ESTIMATED 70% CROWN COVER WITH NO LOWER TREE/WOODY SHRUB UNDERSTORY

herbaceous vegetation and litter background. Four signatures were combined to represent forest areas having intermediate to dense (approximately 40 percent or greater) crown cover over a lower tree/woody shrub understory.

The remaining signature of the eighth area visited represented a forest area having sparse overstory crown cover (less than 40 percent) over a dense lower tree/woody shrub understory. This area had recently been selectively cut and was not typical of most of the test site. However, it was retained as a separate signature (Sparse Forest) because it represented a class of forest cover that appeared to be spectrally separable.

Visits to several wetland training areas confirmed the earlier signature analysis results that had indicated two spectrally distinct classes of non-forested wetlands. One such class was characterized by a mixture of open water and emergent herbaceous vegetation that we chose to call Deep/Shallow Marsh (Figure 5). The other consisted of dense woody shrub growth in water that we referred to as Shrub Swamp (Figure 6).

A third photointerpreted wetlands class was characterized by intermediate aspen and oak tree crown cover over a predominantly herbaceous vegetation and water background (Figure 7). Such areas occur on small, low hummocks that are dispersed around the wetlands areas. One such area was large enough to permit the extraction of a signature which was found to be quite similar to the signature of the forested area flooded by beaver dam construction. This area had an overstory of lowland forest species that included red maple, oak, elm and birch over a background of standing water that supported a lush bloom of duckweed (Figure 8). These two signatures were combined into a composite signature that we called Flooded Forest.

Areas of aspen regeneration represented predominantly aspen forested areas that had been clearcut to promote the growth of aspen reproduction

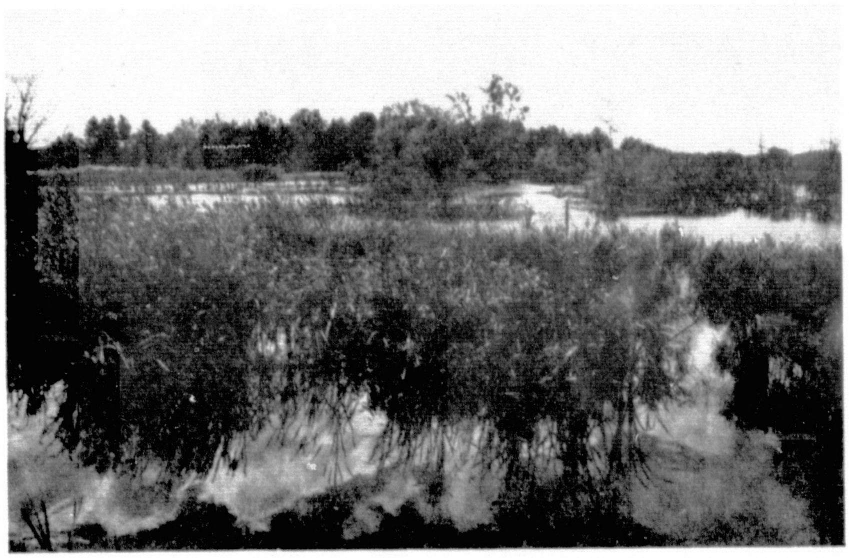


FIGURE 5. WETLAND CLASSIFIED AS DEEP/SHALLOW MARSH

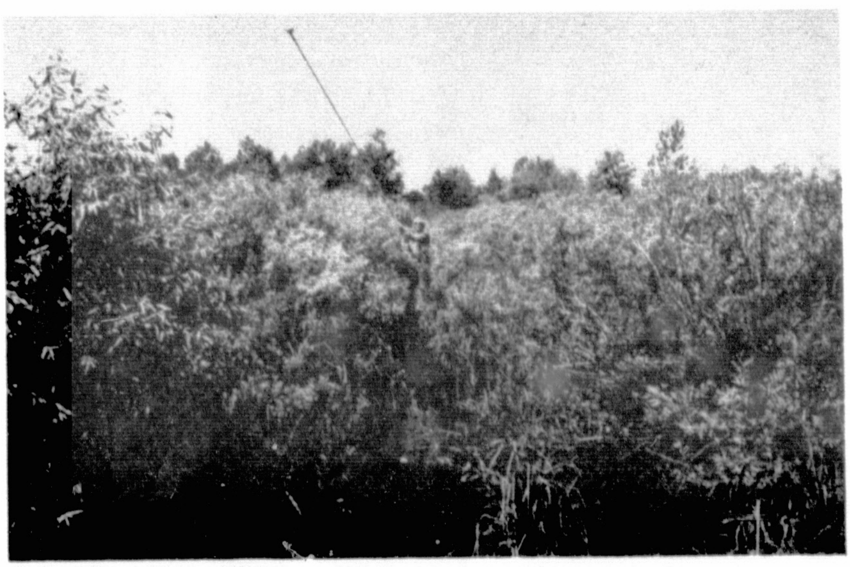


FIGURE 6. WETLAND CLASSIFIED AS SHRUB SWAMP

FIGURE 7. SWAMP FOREST OF INTERMEDIATE ASPEN AND OAK TREE CROWN COVER OVER A PREDOMINANTLY HERBACEOUS VEGETATION AND WATER BACKGROUND

FIGURE 8. LOWLAND FOREST INUNDATED WITH WATER CAUSED BY BEAVER DAM CONSTRUCTION. Water surface covered by duckweed.

FIGURE 9. FORESTED AREA RECENTLY CLEARCUT AND BURNED TO PROMOTE ASPEN REGENERATION

FIGURE 10. ASPEN REGENERATION ON A SITE THAT WAS CLEARCUT AND BURNED SEVERAL YEARS PRIOR TO THE SITE IN FIGURE 7

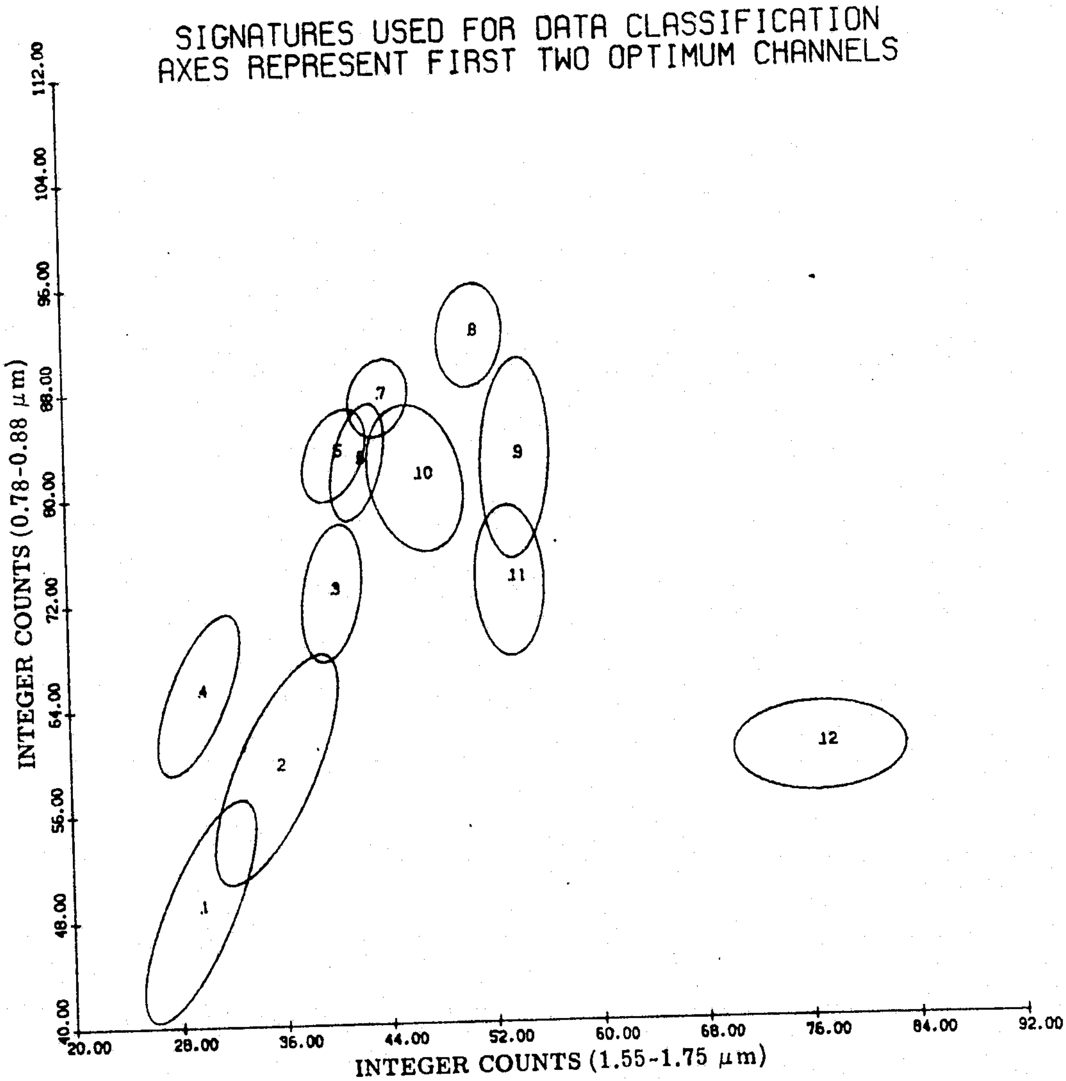
for deer browse. These areas displayed great variability in the amount and height of reproduction depending on the time since they had been cut (Figures 9 and 10). Nevertheless, signatures of four such areas were combined to form a composite signature for a scene class (Aspen Regeneration) that appeared to be spectrally separable.

As a result of the field visit to the test site, three additional scene classes were defined for classifying the data. These included a scene class we called Herbaceous that was intended to account for small parcels of land that constituted old fields, plots of small grains planted for wildlife, and forest openings. The other two were Agriculture and Bare Soil scene classes that typified much of the farmland surrounding the test site.

3.7 FINAL SIGNATURE ANALYSIS AND DATA CLASSIFICATION

The statistical separability of the resulting composite signatures were again assessed by computing classification probabilities for each of the signatures. In this case, the distribution of each signature in turn was compared to the distributions of all other signatures to generate a matrix that showed the expected classification performance for ERIM's best linear-rule classifier (see Appendix A). Figure 11 illustrates a two-channel Gaussian representation of the signatures (at the same chi square value) that generally confirms the separability shown by the matrix.

The channels illustrated are the first two channels previously identified in Table 7 as optimum for separating both forest density classes and major scene classes. In this figure, the relative location, shape, and orientation of the distributions provides a graphic illustration of the statistical uniqueness of each of the signatures that is provided by the two best spectral channels. Although considerable overlap exists between the two forest signatures, they nonetheless offered some promise of separating two forest scene classes where only one was previously indicated in Table 5.



Distribution Number	Scene Class
1	Deep/Shallow Marsh
2	Shrub Swamp
3	Flooded Forest
4	Pine Plantation
5	Dense Forest w/out Understory
6	Intermediate to Dense Forest with Understory

Distribution Number	Scene Class
7	Sparse Forest with Understory
8	Aspen Regeneration
9	Agriculture
10	Brush
11	Herbaceous
12	Bare Soil

FIGURE 11. TWO CHANNEL GAUSSIAN REPRESENTATION OF THE TWELVE COMPOSITE SIGNATURES USED FOR DATA CLASSIFICATION

The signatures were finally used to classify all pixels in the test site using ERIM's best linear decision rule. Because of great disparities in the frequency of occurrence of scene classes throughout the test site, we weighted the signatures according to the observed dominance of scene classes on the color-infrared photography. Thus, forested areas were more favored in the classification procedure than other scene classes. Signatures were assigned a threshold exponent value that corresponded to 0.001 level of rejection for six degrees of freedom. Pixels having exponent values exceeding the threshold were unclassified.

Since the previous computations of optimum channels had shown only marginal classification improvement beyond the use of six channels, we used only six channels for classification. The choice of six channels was made by including those channels which had previously constituted the optimum four channels for each of the two sets of signatures in Table 7. These channels are listed in Table 10.

TABLE 10

SPECTRAL CHANNELS USED TO COMPUTE THE EXPECTED-PERFORMANCE MATRIX FOR THE FINAL SET OF COMPOSITE SIGNATURES AND TO CLASSIFY THE DATA

0.52 - 0.56 μm
0.62 - 0.67 μm
0.68 - 0.76 μm
0.78 - 0.88 μm
0.98 - 1.03 μm
1.55 - 1.75 μm

4
EVALUATION OF S192 CLASSIFICATION RESULTS

In this section the results of our computer processing are presented and evaluated. The accuracy of classification is analyzed using several different procedures and its relationship to the characteristics of the S192 sensor and the terrain are indicated.

4.1 ANALYSIS OF CLASSIFICATION ACCURACY

Figures 12 and 13 illustrate high altitude color-infrared photographic coverage and the resulting digital classification map for that portion of the Gratiot-Saginaw State Game Area that constituted the test site. For orientation purposes, a square mile section grid has been drawn on the classification map.

For accuracy evaluation, three sections (3, 22, and 28) were chosen for a pixel-by pixel check of the computer-mapped scene classes against ground truth. The sections chosen contained a diversity of scene classes in order that some assessment of most scene classes could be accomplished. However, no bare soil and very little agriculture appeared in the three sections.

Ground truth data were obtained from Game Division field sheets supplied by the Michigan Department of Natural Resources. Each field sheet provides a planimetric map of a 40 acre parcel and contains a great deal of accurate detail on cover-type identity and location that is obtained by ground survey. Although they vary as to their date of preparation, with some being as old as 10-15 years, they are kept updated by management personnel for major manipulative changes.

Our procedure in using the field sheets consisted of mosaicing the appropriate 16 field sheets for each of the three test sections. The location of major scene class boundaries on each mosaic was verified by reference to the RB-57 photography that had been acquired on 10 June 1972. Thus, the recent RB-57 photography provided the necessary spatial accuracy in determining scene class boundaries, while the field sheets provided reliable identification of cover type.

Each mosaic was then reduced to the scale of the classification map and overlaid on it to provide a pixel-by-pixel comparison. We believe the overall accuracy of the ground truth assembled in this manner to be quite good, and conclusions reached in the accuracy analysis would not have been substantially changed had ground truth been assembled by other methods.

Table 11 summarizes the results for all three sections on a percentage basis. Because of the difficulty in establishing the presence or absence of an understory within intermediate to dense forested areas, classification accuracy is reported for a single Intermediate to Dense Forest scene class. The occurrence of this scene class typifies most of the game area and accounts for two-thirds of the three-section area for which classification accuracy was checked. Note that it has the highest classification performance.

In general, classification performance is poor for the ten scene classes reported. In many cases, omission errors and commission errors are understandable in that confusion occurs among scene classes that typically portray overlapping ranges of biological and physical characteristics. For example, very sparse and very dense brush are classified as herbaceous and forest classes, respectively. Large omission errors for herbaceous and agriculture classes are explained by the classification of such areas as brush. Varying densities of reproduction within areas of aspen regeneration give rise to classification as forest and brush.

Table 12 presents the classification results for a consolidated set of scene classes. Scene classes were consolidated according to Table 13. Errors of omission and commission that previously existed

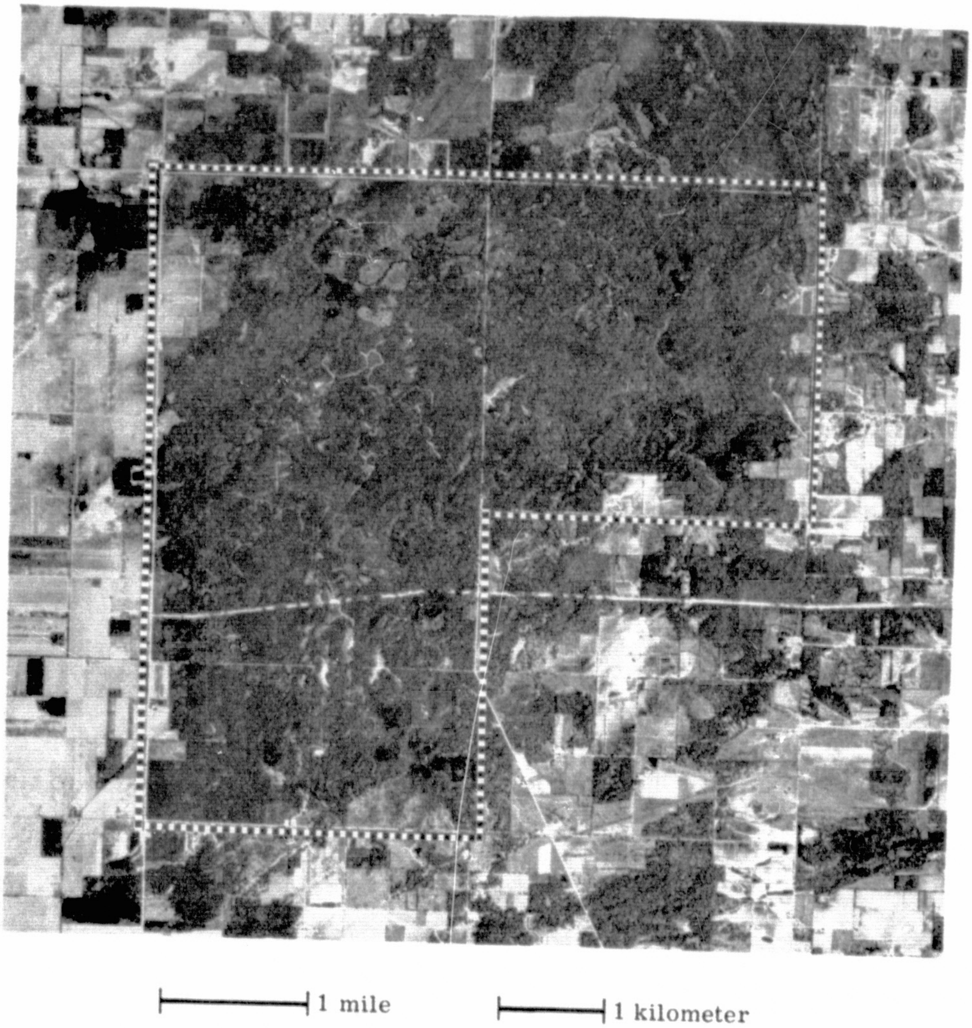
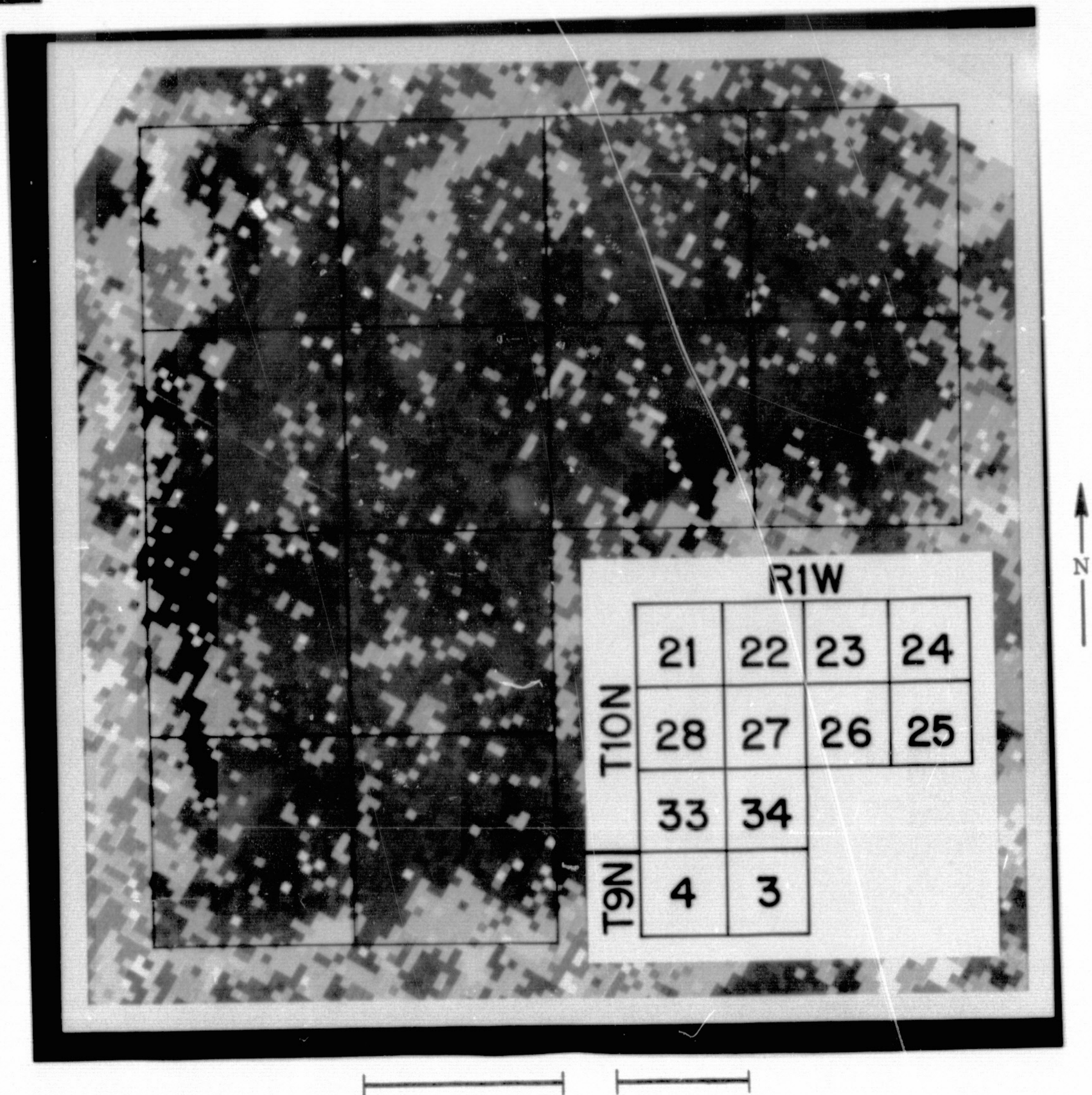


FIGURE 12. RB-57 PHOTOGRAPH OF THE GRATIOT-SAGINAW STATE GAME AREA OBTAINED ON 10 JUNE 1972



COLOR LEGEND

Blue	Deep/Shallow Marsh	Yellow-Green	Sparse Forest	Orange	Brush
Blue-Green	Shrub Swamp	Purple	Flooded Forest	Yellow	Herbaceous
Black	Dense Forest w/out Understory	Violet	Pine	Brown	Agriculture
Green	Intermediate to Dense Forest with Understory	Red (Magenta)	Aspen Regeneration	Aqua	Bare Soil
				White	Unclassified

FIGURE 13. DIGITAL CLASSIFICATION MAP OF THE GRATIOT-SAGINAW STATE GAME AREA TEST SITE

between similar scene classes are now counted as correct classifications for fewer scene classes of more differentiable physiognomic structure. Although the breakdown of scene classes is general and less informative from a resource inventory viewpoint, the results are presented in a more concise and easily interpretable format. Some confusion still exists between scene classes that overlap in their physical descriptions. For example, much herbaceous and some forest are misclassified as brush. It is interesting to note that the omission error for each scene class is inversely related to the frequency of occurrence for that scene class and that much of the misclassification is recorded as forest - the dominant scene class. This point is further discussed in Section 4.2.

4.2 EFFECTS OF S192 DATA CHARACTERISTICS

Several characteristics of the S192 data itself account for much of the limitation in classification accuracy. Limited dynamic range and high noise values resulted in relatively low signal-to-noise ratios for most of the spectral channels. Signal-to-noise values were determined to be no higher than 16 while most SDOs were at 10 or lower. Computer selection of optimum channels for signature discriminability appears to have been influenced by signal-to-noise values since two channels having high signal-to-noise ratios were chosen as the first two optimum channels for two separate sets of signatures. These channel selections may not be totally indicative of channels which would have been optimum purely from the standpoint of establishing the spectral separability of signatures of different scene classes. It is, therefore, difficult to state general findings regarding the best spectral channels for use.

The six channels used, which included the optimum four channels for two separate sets of signatures (Table 10), contain spectral regions which have proven to be useful in other studies of vegetation

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TABLE 11

SUMMARY CLASSIFICATION PERFORMANCE FOR THREE SECTIONS OF THE GRATIOT-SAGINAW STATE GAME AREA (10 scene classes)

Ground Truth \ Classification Results (percent)	Number of Pixels	Percent Correct	Deep/Shallow Marsh	Shrub Swamp	Flooded Forest	Pine	Intermediate to Dense Forest	Sparse Forest	Aspen Regen	Brush	Herbaceous	Agriculture	Unclassified
Deep/Shallow Marsh	59	44.1		32.2	11.9		5.1						6.8
Shrub Swamp	168	32.1	11.9		31.5	1.2	14.9	0.6		3.6	0.6		3.6
Flooded Forest	11	45.4		27.3			27.3						
Pine	6	0					66.7			33.3			
Intermediate to Dense Forest	1006	65.9		2.9	14.4	0.2		4.9	2.6	6.7	0.6	0.1	1.7
Sparse Forest	45	53.3			2.2		33.3		2.2	4.4			4.4
Aspen Regeneration	103	42.7			4.8		35.9	4.8		11.6			
Brush	48	20.8			20.8	2.1	29.6	2.1			8.3	2.1	4.2
Herbaceous	88	17.0			5.7		14.8	4.5	2.3	50.0		5.7	
Agriculture	17	0			11.8		5.9			52.9	29.4		
Total Pixels	1551												

Percent accuracy in individual pixels: 841 out of 1551 or 54 percent.

TABLE 12

SUMMARY CLASSIFICATION PERFORMANCE OF THREE SECTIONS OF THE GRATIOT-SAGINAW STATE GAME AREA. TEN SCENE CLASSES HAVE BEEN CONSOLIDATED INTO 5.

Ground Truth \ Classification Results (percent)	NUMBER OF PIXELS	PERCENT CORRECT	NON-FORESTED WETLANDS	PINE	DECIDUOUS FOREST	BRUSH	HERBACEOUS	UNCLASSIFIED
NON-FORESTED WETLANDS	227	52.4		0.9	39.2	2.6	0.4	4.4
PINE	6	0			66.6	33.3		
DECIDUOUS FOREST	1062	85.2	3.0	0.2		9.1	0.6	1.8
BRUSH	151	43.7		0.7	51.0		3.3	1.3
HERBACEOUS	105	23.8			23.8	52.4		
TOTAL PIXELS =	1551	percent accuracy in individual pixels: 1115 out of 1551 or 72 percent						

TABLE 13

CONSOLIDATION OF SCENE CLASSES

ORIGINAL SCENE CLASS	CONSOLIDATED SCENE CLASS
Deep/Shallow Marsh	Non-forested Wetlands
Shrub Swamp	
Pine	Pine
Intermediate to Dense Forest	Deciduous Forest
Sparse Forest	
Flooded Forest	
Aspen Regeneration	Brush
Brush	
Herbaceous	Herbaceous
Agriculture	

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scene class discrimination. Five of the six channels fall within the four spectral channels of the LANDSAT sensor. The sixth channel identifies the mid-IR region as desirable. This region also proved to be optimum in a previous study that incorporated high-altitude aircraft MSS data for classifying forest vegetation categories [6]. Evidence concerning the utility of the thermal channel was inconclusive, since it had low signal-to-noise and low optimum channel rankings for signature discrimination.

Another type of limitation of the S192 data is that inherent in its resolution of about half a hectare. We are attempting to apply this resolution to an area of considerable complexity. With the exception of the forest class, most other scene classes occur as small parcels of varying irregular shapes that are interspersed throughout the area. Such parcels typically have high ratios of boundary length to area. In addition, they have the effect of dividing the forest area into parcels, thus increasing the ratio of boundary length to area for the forest scene class.

To illustrate this parceling effect, separate parcels within the three sections studied were counted and divided by the total area of the sections. The average parcel was found to have an area of approximately 6 hectares. For one of the sections, a count of pixels falling on parcel boundaries indicated that about a third of the pixels contain mixtures of two or more of the ten scene classes used to classify the data. Thus, the presence of many pixels containing mixtures of scene classes may offer an explanation for many of the omission and commission errors indicated in Table 12. Small, isolated patches of pine less than a pixel size in area had little chance of being correctly classified. As a scene class becomes more frequent in occurrence, a larger percentage of pure pixels will be available for classification. This favored the accuracy of recognizing forest classes.

An additional complication to spatial resolution concerns the band-to-band spatial misregistration of pixels within the data. Because we utilized all odd-numbered SDOs of doubly sampled spectral channels, we avoided the one-half pixel misregistration that exists between even-and odd-numbered SDOs. However, spatial misregistration of pixels is still inherent to the data because of errors introduced by the scanner electronics and tape recorder and by the scan line straightening algorithm that is applied to the data. This misregistration can be as great as 2 pixels. Such misregistration will cause pixels to be mislocated in the data relative to their true ground position and will more than likely increase the number of pixels containing mixtures of scene classes. Thus, the previously stated classification results include omission and commission errors that are influenced by the mislocation of pixels in the data relative to their true ground position and the large number of mixture pixels.

4.3 ANALYSIS OF SECTION SUMMARY STATISTICS

To minimize the effect on classification performance of pixel locational inaccuracies, we performed another type of accuracy check. Instead of checking the percentage of the individual pixels of each scene class that correctly matched the ground truth, as discussed in Section 4.1, we compared the proportion of each scene class in a one-square-mile section as determined from the computer analysis with the correct proportion as indicated by ground truth. By avoiding the pixel-by-pixel matching of computer output and ground truth, we do not penalize the classification accuracy for instances where an element of terrain was correctly recognized but was misplaced in the data relative to its true ground position.

The results of this analysis are shown in Tables 14, 15, and 16 for each of the three sections for which accuracy checks were made. For each class of terrain, the number of pixels in the one square mile area as indicated by ground truth (Column 1) was compared with two corresponding quantities. In one case, the comparison was made with the number of pixels correctly identified by the computer as belonging to that class (Column 3). In the second case, the comparison was made with the total number of pixels correctly or incorrectly identified by the computer as belonging to that class (Column 6).

For example, Table 14 shows that ground truth indicated a total of 63 pixels of wetlands in Section 3 out of a total of 526 pixels. Of these 63 pixels, 42 were correctly identified as wetlands. However, the total number of pixels classified as wetlands totaled 53. More than one reason may explain the increase. It may have been due to commission errors for other classes -- conditions where the signature of another class was confused with the signature of wetlands. It may have been due to the classification of boundary pixels, in which case the recorded digital data was a mixture of two or more scene classes. Or it may have been due to pixel mislocation, either in the ground truth map or in the computer map.

The discrepancies in classification for the two methods of comparison are shown in Table 14 for each of the consolidated scene classes previously identified in Table 13. These discrepancies are also expressed as percentage errors of the total number of pixels, 526 in this case. Thus, for wetlands, the individual pixel check is 4.0 percent less than the ground truth figure, while the computer aggregate number is only 1.9 percent less. In general, the computer aggregate percentage errors tend to be less in absolute magnitude than the individual pixel percentage errors. At the bottom of Table 14, an overall figure for accuracy by the two methods indicates that the computer

TABLE 14

ACCURACY COMPARISON FOR SECTION 3

CLASS	GROUND TRUTH		INDIVIDUAL PIXEL			COMPUTER AGGREGATE		
	(1) PIXELS	(2) PERCENT OF TOTAL	(3) PIXELS	(4) PERCENT OF TOTAL	(5) PERCENT ERROR (4)-(2)	(6) PIXELS	(7) PERCENT OF TOTAL	(8) PERCENT ERROR (7)-(2)
WETLANDS	63	12.0	42	8.0	- 4.0	53	10.1	- 1.9
PINE	0	0	0	0	0	3	0.6	+ 0.6
DECIDUOUS FOREST	363	69.0	309	58.7	-10.3	355	67.5	- 1.5
BRUSH	34	6.5	8	1.5	- 4.9	83	15.8	+ 9.3
HERBACEOUS	66	12.5	14	2.7	- 9.8	24	4.5	- 8.0
UNCLASSIFIED	0	0	8	1.5	+ 1.5	8	1.5	+ 1.5
TOTAL	526	100.0	381			526	100.0	

Percent accuracy in individual pixels: 373 out of 526 or 71 percent

Percent accuracy in computer aggregate: $(526-\Sigma|(1)-(6)|)$: 414 out of 526 or 79 percent

TABLE 15

ACCURACY COMPARISON FOR SECTION 22

CLASS	GROUND TRUTH		INDIVIDUAL PIXEL			COMPUTER AGGREGATE		
	(1) PIXELS	(2) PERCENT OF TOTAL	(3) PIXELS	(4) PERCENT OF TOTAL	(5) PERCENT ERROR (4)-(2)	(6) PIXELS	(7) PERCENT OF TOTAL	(8) PERCENT ERROR (7)-(2)
WETLANDS	89	17.0	58	10.1	- 5.9	73	14.0	- 3.0
PINE	4	0.8	0	0	- 0.8	2	0.4	- 0.4
DECIDUOUS FOREST	308	58.9	239	45.7	-13.2	324	61.9	+ 3.0
BRUSH	114	21.8	58	11.1	-10.7	115	22.0	+ 0.2
HERBACEOUS	8	1.5	0	0	- 1.5	0	0	- 1.5
UNCLASSIFIED	0		9	1.7	+ 1.7	9	1.7	+ 1.7
TOTAL	523	100.0	364			523	100.0	

Percent accuracy in individual pixels: 355 out of 523 or 68 percent

Percent accuracy in computer aggregate: $(523-\Sigma|(1)-(6)|)$: 480 out of 523 or 92 percent

TABLE 16

ACCURACY COMPARISON FOR SECTION 28

CLASS	GROUND TRUTH (1) PIXELS	(2) PERCENT OF TOTAL	INDIVIDUAL PIXEL (3) PIXELS	(4) PERCENT OF TOTAL	(5) PERCENT ERROR (4)-(2)	COMPUTER AGGREGATE (6) PIXELS	(7) PERCENT OF TOTAL	(8) PERCENT ERROR (7)-(2)
WETLANDS	75	15.0	19	3.8	-11.2	25	5.0	- 10.0
PINE	2	0.4	0	0	- 0.4	0	0	- 0.4
DECIDUOUS FOREST	391	77.8	357	71.1	- 6.7	421	83.8	+ 6.0
BRUSH	3	0.6	0	0	- 0.6	28	5.6	+ 5.0
HERBACEOUS	31	6.2	11	2.2	- 4.0	14	2.8	- 3.4
UNCLASSIFIED	0		14	2.8	+ 2.8	14	2.8	+ 2.8
TOTAL	502	100.0	401			502	100.0	

Percent accuracy in individual pixels: 387 out of 502 or 77 percent

Percent accuracy in computer aggregate: $(502-\Sigma|(1)-(6)|)$: 378 out of 502 or 75 percent

aggregate accuracy is 79 percent as compared with 71 percent for individual pixels.

Tables 15 and 16 present similar information for Sections 22 and 28 respectively. For Section 22, computer aggregation increased the accuracy substantially (from 68 to 92 percent). For Section 28, computer aggregation actually reduced the accuracy slightly (from 77 to 75 percent). This was primarily due to the fact that the section had a relatively high percentage of deciduous forest (77.8 percent) and almost no brush (0.6 percent). The tendency of some deciduous forest to be recognized as brush was not counterbalanced by the tendency of brush to be recognized as deciduous forest.

5
CONCLUSIONS AND RECOMMENDATIONS

5.1 S190A AND S190B EVALUATION

The S190A photography has some limited application to recreational land analysis and the S190B photography has more general use for many applications, limited primarily by its resolution. The S190B Earth Terrain Camera has resolution approaching that obtainable from high-altitude aerial photography and will be capable of use for many of the same applications.

Terrain relief is a characteristic of considerable importance in recreational land evaluation. Although the camera images have some capability for studying topography through stereo viewing, the amount of topographic relief in southern Michigan, where this study was conducted, is insufficient to take advantage of this capability.

S190B photography is useful by itself for many applications of recreational land analysis. The photography contains sufficient detail to map Level I and Level II categories of land use and land cover. A specific use of S190B data is to map existing recreational facilities. It is possible to detect and in many cases identify such recreational facilities as parks, golf courses, stadiums, race tracks, playgrounds, ski slopes, and snowmobile trails. It can also be used for general reconnaissance of the recreation potential of an area, for identifying open space potentially suitable as recreational land, for initial selection of recreation sites, and for individual site planning of geographically extensive sites, such as river valleys or scenic trails.

5.2 S192 EVALUATION

S192 multispectral scanner data were used for mapping a test site in the Gratiot-Saginaw State Game Area in south central Michigan, consisting largely of forest, brush, herbaceous, and wetland areas. The classification map was prepared by use of six spectral bands indicated by computer analysis as being optimum for scene classification. Listed in approximate order of preference, these were 0.78-0.88 μm, 1.55-1.75 μm, 0.98-1.03 μm, 0.68-0.76 μm, 0.52-0.56 μm, and 0.62-0.67 μm.

An accuracy check made for three one-square-mile sections of this test site showed that for a 10-category map, 54 percent of the individual pixels were correctly recognized. When these ten scene classes were consolidated to a 5-category map, the overall accuracy increased to 72 percent. However, the accuracy of recognizing the herbaceous, brush, and non-forested wetland categories ranged from 24 to 52 percent. The accuracy can be further increased to 82 percent if the required output consists of summary statistics for a complete square mile, since omission and commission errors tend to counterbalance each other.

Classification accuracy was limited by certain characteristics of the S192 data. These included the relatively low signal-to-noise ratios of certain spectral bands, the gross spatial resolution of the data, misregistration of pixels, and geometric distortions in the digital map resulting from the scan-line straightening process. These characteristics prevented us from reaching definitive conclusions regarding the utility of individual spectral channels in the classification process. The computer selection of optimum channels was probably influenced by the signal-to-noise ratios of these channels as well as by the spectral separability of individual terrain types.

Some of the factors limiting classification accuracy in our study are not inherent in the S192 system. We were limited to the use of data acquired in August. Other studies of multispectral techniques indicate this is a relatively poor season for discriminating vegetation terrain classes. A study of the use of LANDSAT data for similar purposes [1] found that March and June data were effective dates for land cover analysis, and that combining data from both dates substantially increased classification accuracy over that available from either date alone.

The character of the terrain used as our test site also influenced the classification performance. We attempted to study a complex scene made up of parcels of widely varying size and irregular shape. In the case of one square-mile section, mapping of this type of terrain at the resolution of the S192 sensor resulted in the processing of one-third of the pixels as border elements with mixed signatures. This limitation affects the accuracy of identifying the class of individual pixels, but as indicated in the accuracy figures quoted above, individual errors tend to cancel out when statistical summaries are obtained for areas as large as one square mile. Errors in pixel-by-pixel identification that result from geometric distortions of the S192 data also tend to be substantially reduced when statistical summaries of the data are produced.

5.3 APPLICATIONS OF EREP SENSORS

A general description of the use of EREP sensors for land use mapping and inventory and land resource evaluation has been presented in Reference 4. The conclusions reached in that reference apply to many of the applications of remote sensing for analysis of recreational land. In the following discussion, the emphasis is placed on specific types of information needed for recreational land analysis.

Based on previous studies of potential uses of remote sensing for recreational analysis and planning [1,2,3], Table 17 is a listing of the more important types of land use or recreation activity that are adaptable to remote sensing analysis.

The S190A, S190B, and S192 sensors are capable of observing or measuring these terrain features in varying degrees of detail, as discussed in previous sections. Based on our evaluation of the individual sensors, we believe that they provide a capability of performing the general functions listed in Table 18.

The accuracy evaluation indicates that the S192 system will be best adapted to applications involving mapping or inventory of large areas and statistical summaries of major categories of land use and land cover. The data can be used for general reconnaissance of such areas to make preliminary assessments of their recreation potential. The ability to use automatic processing methods on the S192 data makes it adaptable to efficient studies of large areas. For example, Reference 1 describes the possible use of space-acquired multispectral scanner data for general evaluation of wildlife habitat. The digital nature of the output data allows the user to make quantitative measurements of certain attributes of a given area which are significant indicators of habitat quality.

The value of the S192 data may be enhanced by combining it with LANDSAT coverage of the same area. The LANDSAT data may be used both for updating the SKYLAB data base and for extending recognition results by combining data from more than one season.

The higher resolution S190B data obtained on the same pass provides assistance to the training set selection process for S192 processing by providing information on current boundaries and homogeneity of major vegetative and terrain types.

TABLE 17.

TYPES OF RECREATION SITES FOR REMOTE SENSING ANALYSIS

Existing recreation facilities (parks, golf courses, stadiums, race tracks, etc.)

Open space (agricultural and natural areas, urban development)

Water-oriented recreation (water circulation, thermal pollutants, pollution sources and concentrations, aquatic vegetation, coastal wetlands, shoreline development, aesthetic appearance, adjacent land use)

Inland lakes
Streams and rivers
Great Lakes shoreline

Wild and scenic rivers (existing land use, stream size, visual appearance)

Sites for parks, camping, picnicking (total area, vegetation, adjacent land use, nearby water bodies, access)

Wildlife habitat (land use class and vegetation type and distribution

Scenic trails [existing rights-of-way (e.g., abandoned railroad lines), adjacent land use]

Ski areas (vegetation cover, topography, snow cover)

TABLE 18

GENERAL FUNCTIONS OF REMOTE SENSING

	S190A	S190B	MSS S192
Regional survey of existing and potential recreation sites	x	x	x
Delineation of open space	x	x	x
Preliminary site evaluation		x	x
Recreation demand analysis		x	
Planning site acquisition and development		x	
Environmental impact assessment		x	
Monitoring and managing recreation areas		x	
Information dissemination to the public	x	x	x

5.4 RECOMMENDATIONS

A large data base of SKYLAB data is now available for use in specific project studies. The capabilities of S190A and S190B photography are fairly well understood at this time and they are ready for applications to such projects.

In order to make the most effective use of computer-processed S192 data, however, continuing studies will be needed. Additional work beyond that reported in this study is desirable to determine optimum channels for terrain and vegetation classification under varying combinations and distribution of land use and land cover, and for other seasons of the year. Continuing studies will be needed to establish the accuracy of such data, and possible methods of increasing accuracy through the application of systematic error corrections. For example, detailed data on the biasing of classification results by the size of individual parcels of land cover could lead to practical means of applying corrections to counteract this bias.

These future studies should be application-oriented. They are most effectively performed if they are tied to a study of the recreational potential of a specific area and involve the active participation of the user community -- federal, state, or local agencies or private organizations with the responsibility for recreational project planning and implementation.

A specific use of SKYLAB data which should be further developed is the combined use of S192 data with S190B data for multi-stage inventories of wetlands, woodlands, and other natural areas with recreation potential. The S192 data provides a capability for automatic classification of large areas, while the S190B camera provides data for sampling the area at higher resolution. Further investigation should also be made of combining the advantages of the broad spectral range of the S192 data with LANDSAT data which has more limited spectral range, but provides coverage of the same area at other seasons.

Looking further ahead, advanced development of multispectral scanners for future manned missions should reduce the restrictions on classification performance that resulted from the signal-to-noise and registration characteristics of the S192. The operational use of the system should stress greater flexibility in selecting season and time of day for data acquisition to meet the user's requirements for processing and analysis.

APPENDIX A

Table 19 shows the expected classification performance for the final composite signatures used to classify the data. Each row represents a test signature and each column represents a signature class. For each test signature taken in turn, 1000 pixels were generated at random according to the multivariate normal distribution specified by the test signature. The pixels were classified and the fraction of pixels going into each signature class were tallied to give the probability that pixels from the test signature will be classified (or misclassified) into each signature class. Pixels falling outside the threshold exponent value for each of the signature classes were unclassified.

The table thus provides a simulation of data classification performance for a given set of signatures that are assumed to encompass the variability of the data set. For the simulation to be complete, all signatures contained the same six spectral channels and were assigned the same threshold exponent value and weights that were used to classify the real data (see Section 4).

TABLE A-1

EXPECTED CLASSIFICATION PERFORMANCE FOR THE FINAL SET OF COMPOSITE SIGNATURES

TEST SIGNATURE \ SIGNATURE CLASS	WEIGHTING FACTOR	Deep/Shallow Marsh	Shrub Swamp	Flooded Forest	Pine Plantation	Dense Forest Without Under-story	Intermediate to Dense Forest With Understory	Sparse Forest With Understory	Aspen Regenera-tion	Agriculture	Brush	Herbaceous	Bare Soil	Unclassified
Deep/Shallow Marsh	.05	.746	.212	.011	.004	.000	.000	.000	.000	.000	.001	.000	.000	.026
Shrub Swamp	.05	.178	.692	.086	.004	.000	.013	.000	.000	.001	.009	.000	.000	.017
Flooded Forest	.05	.000	.086	.706	.002	.074	.113	.000	.000	.000	.013	.000	.000	.006
Pine Plantation	.025	.005	.004	.028	.956	.007	.000	.000	.000	.000	.000	.000	.000	.000
Dense Forest Without Understory	.2	.000	.000	.020	.000	.642	.267	.056	.001	.000	.013	.000	.000	.001
Intermediate to Dense Forest with Understory	.2	.000	.000	.017	.000	.226	.632	.070	.007	.000	.039	.000	.000	.009
Sparse Forest With Understory	.1	.000	.000	.000	.000	.182	.165	.601	.009	.000	.042	.000	.000	.001
Aspen Regeneration	.1	.000	.000	.000	.000	.000	.006	.024	.912	.015	.039	.003	.000	.001
Agriculture	.05	.000	.000	.000	.000	.000	.000	.000	.037	.652	.047	.259	.001	.004
Brush	.1	.000	.000	.003	.000	.061	.145	.036	.043	.029	.613	.063	.000	.007
Herbaceous	.05	.000	.000	.000	.000	.000	.000	.000	.003	.014	.015	.914	.000	.054
Bare Soil	.025	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.000	.000

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