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PROPOSAL FOR A STUDY OF COMPUTER MAPPING OF TERRAIN USING MULTISPECTRAL DATA FROM ERTS-A FOR THE YELLOWSTONE NATIONAL PARK TEST SITE

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16. Abstract

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Techniques were devised for quantitatively comparing the recognition map of the park with control data acquired from ground inspection and from analysis of side-looking radar (SLAR) images, a thermal IR mosaic; and black and white, color, and color IR aerial photos of several scales. Quantitative analyses were made in ten 40 km^2 test areas. Comparison mechanics were performed by computer with the final comparison results displayed on line-printer output.

Forested areas in Yellowstone Park were mapped by computer using ERTS data for less than one-fourth the cost of the conventional forest mapping technique for topographic base maps. Additional potential uses of computer mapping from ERTS data include production of maps of plant community types, examination of changes in surface cover types (such as forest fire burns or wildlife habitat) as a function of time, and use of recognition maps as "data layers" in a computerized resource information storage and retrieval system.

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COLOR TERRAIN MAP OF YELLOWSTONE NATIONAL PARK,

COMPUTER-DERIVED FROM ERTS MSS DATA*

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ABSTRACT

A terrain map of Yellowstone National Park was made by a digital computer using the Earth Resources Technology Satellite (ERTS) multispectral scanner (MSS) data obtained August 7, 1972. This color map shows plant community types and other classes of ground cover in what is basically a wildland. The map comprises 12 classes, 6 of which were mapped with accuracies of 70 to 95 percent. The remaining 6 classes had spectral reflectances that overlapped appreciably, and hence those were mapped less accurately. Maps made from ERTS data obtained at different stages of plant growth should enable these classes to be accurately mapped also.

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Forested areas in Yellowstone Park were mapped by computer using ERTS data for less than one-fourth the cost of the conventional forest mapping technique for topographic base maps. Additional potential uses of computer mapping from ERTS data include production of maps of plant community types, examination of changes in surface cover types (such as forest fire burns or wildlife habitat) as a function of time, and use of recognition maps as "data layers" in a computerized resource information storage and retrieval system.

INTRODUCTION

Purpose and Goals

The stability of regional and local economics of areas surrounding large tracts of wildlands are often closely tied to the intrinsic values and multiple-use management of the resources within these areas. Such extensively-managed natural areas commonly provide essential watersheds, wildlife habitat and outdoor recreation while, with the exception of our National Parks, simultaneously yielding a steady flow of forest products, minerals and forage. Unfortunately, the increasing resource requirements of our society are making it increasingly difficult to accomodate these uses while preserving the natural values of these wildlands from which these benefits are derived. In the case of the National Parks, there is a dichotomy between making the parks available for use by steadily increasing numbers of visitors, and preserving them as naturally functioning areas unaffected by man.

Proper administration of these areas requires an increased awareness of the condition of a greater number of complex environmental variables. The availability of quantitative information, characterizing the nature of various terrain cover-types, greatly facilitates meaningful analyses. Yet, the cost of obtaining such data by field survey techniques has always been high, and is not always possible--particularly in rugged terrain, or wilderness that must not be disturbed.

An investigation was made of the accuracy and usefulness of computerized surface-cover mapping of the entire park and surrounding area using the 4-channel multispectral scanner (MSS) data from ERTS-1. Previous studies in the north central part of the park using low-altitude aircraft MSS data demonstrated the feasibility of accurately mapping a wide variety of terrain classes automatically by computer (Smedes, 1971).

Regional Setting

Yellowstone National Park (figure 1) is the oldest national park in the world and the largest in the United States. Established just a little over a century ago (March 1, 1872) it encompasses nearly 9,000 square kilometres (3,472 sq. mi.) of Wyoming, Montana, and Idaho. It contains a wide range of climatic and vegetation zones, wildlife, relief, land forms, and soil and rock types. It is the only known place in the world where scientists can study the primal "plumbing" system of hot springs and geysers--elsewhere such systems have been affected by man's intervention and have changed or adjusted in response to that intervention.

The park is a broad plateau of young (Quaternary) volcanic rocks bordered on the north, east, and south by an arcuate complex of ridges and dissected highlands of older volcanic rocks and deformed prevolcanic sedimentary and metamorphic rocks. Yellowstone Lake, about 350 square kilometres (137 sq. mi.) in area, dominates the southeastern part of that plateau, and is one of the largest natural mountain lakes in the U.S.

The major part of the plateau marks the site of ancient calderas which formed by collapse as a result of the rapid expulsion of large volumes of ash flows whose remnants form the fringe of the plateau (Keefer, 1972). Lava subsequently spread across the floor of the caldera to form a coalesced mass of lava domes and flows some of whose toe-like projections can be seen on the Pitchstone Plateau (shown by the arrows at f, figure 2).

Previous Data

Topographic maps, geologic maps, and conventional aerial photographs have provided important bases for planning and management of this large, basically primitive area, but ERTS images provide for the first time a comprehensive pictorial view of the entire park and its environs. Yellowstone Park occupies the central part ofthe ERTS image shown in figure 2. This cloud-free image acquired August 7, 1972 documents the terrain during late summer. Other images capture the changes in ground cover in response to seasonal differences, but were not analysed by computer in this study.

Prior to ERTS images, the only complete pictorial base of the entire park was a mosaic compiled from more than 80 high-altitude color aerial photographs taken by NASA in 1969 (figure 3). Flights on three different days were required in order to obtain this relatively cloud-free photographic coverage. Even so, large clouds can be seen north of Hayden Valley near the center of the park, and along the central eastern edge. In contrast, ERTS provides a synoptic view in a few seconds, in one image.

Approach and Techniques

Two recognition maps of Yellowstone National Park and its surroundings were prepared from ERTS MSS data as a part of this study. Both maps were created by a computerized analysis technique known as the gaussian maximum likelihood ratio technique. This statistical decision-making algorithm assigns probability-density functions to desired mapping classes using statistical data from "training" areas for each mapping class. Ratios formed from these probability density functions are evaluated by computer for selection of the most likely mapping class for each picture element (pixel) in the ERTS data over Yellowstone National Park.

A simple recognition map was prepared initially to identify five general classes of surface-cover: forest, rock and bare soil, grassland, lowland, and water. A colored computer printout (figure 4) was used to display this map at a scale of approximately 1:50,000 (Thomson and Roller, 1973). Information gained from analysis of this map was used to subdivide the five initial classes into a second, more sophisticated set of classes for creation of a second recognition map whose categories represent principal vegetation community types and other surface cover types related to park management needs and land-use planning.

SELECTION OF MAPPING CLASSES

The initial five-class recognition map of Yellowstone National Park demonstrated that it was possible to map basic types of ground cover such as forest, rock and bare soil, water, and grass or lowland with reasonable accuracy by computer. Subdivision of these five mapping classes was initially proposed, as shown in figure 4, to produce 22 specialized mapping classes. These mapping classes were selected on the basis of (1) the naturally occurring terrain association units in Yellowstone Park, (2) greatest probable difference in spectral reflectance to attain the greatest likelihood of being mapped separately, (3) ecological significance, and (4) importance to the user--those who are responsible for managing and making decisions on land-use planning and alternative policies. Training areas were selected for each of these 22 mapping classes to obtain radiance histograms plus mean and standard deviation radiance values in each of the four ERTS-1 MSS channels. Topographic variation in any given mapping class was taken into account by selecting training areas with differing slope and aspect. No measures were taken in this study to either determine or compensate for effects of atmospheric attenuation. Examples of radiance histograms are given in Appendix D. Included is one histogram of coniferous forest with 40 to 100 percent canopy cover, three histograms for three density levels of forest with a grass understory, and four histograms of surface-cover types with similar spectral characteristics. Examination of the statistics for each of the 22 mapping classes suggested that many were too similar spectrally at that season (late summer) to be reliably mapped by the computer. Four of these 22 classes were dropped after initial examination of the spectral statistics. Another six were eliminated after examination of several small recognition maps which were produced over selected parts of the park. Figure 5 illustrates how selection of the final twelve mapping classes relates to the initial five mapping classes. The FOREST class on the final recognition map is a combination of all coniferous tree species for which training areas were selected. Crown cover for this class varies from 40 to 95 percent. Spectral statistics for lodgepole pine, douglas fir, and spruce-fir, although slightly different for each species, were masked by spectral "noise" coming from understory vegetation which varied within and between the tree species. It was also found that stands of coniferous trees infested with insects did not have markedly different spectral statistics than healthy stands, again because of the influence of understory vegetation. Only those forested areas with 25 percent or more dead and bare trees had noticeably different spectral signatures. A winter ERTS frame may permit accurate computer mapping of conifers by species, as well as of insect-infested conifers if the understory vegetation were uniformly covered by snow. (Visual examination of winter images indicate that saturation of signal would not occur.) Two grass units (figure 4) were combined and renamed GRASS 3 (figure 5) when it was found that they were both very similar spectrally to the initial GRASS 3 mapping class. Two light rock classes were similarly combined and renamed LIGHT ROCK 3. GRASSLAND and LOWLAND, which should have been combined on the initial five-class recognition map, were separated into a GRASS MEADOW or SLOPE class, and a GRASS/BRUSH class after determining that LOWLAND GRASS, UPLAND GRASS, and ALPINE MEADOW were all spectrally similar to GRASS MEADOW or SLOPE, and that GRASS/BRUSH was separable spectrally from the GRASS MEADOW or SLOPE class. The initial ROCK and BARE SOIL class was subdivided into LIGHT ROCK (felsic) and DARK ROCK (mafic) classes, plus THERMAL DEPOSITS which have unusually high spectral radiance. Water and shadow were both found to have very low radiance in all channels, but shadows were consistently higher than water. However they were combined and classed as water because their spectral envelopes overlapped in all four channels. An "unclassified" category was added as the twelfth mapping class in order to handle situations where a ground resolution element could not be identified by the computer as any of the eleven classes for which it was trained. This turned out to be largely shallow water and muddy water. Appendix A contains a description of each of the mapping classes used to produce the final recognition map. Detailed descriptions of representative training areas for each of the final mapping classes is given in Root and Smedes, 1974b (in preparation).

CREATION AND DISPLAY OF THE FINAL TWELVE-CLASS RECOGNITION MAP

Training areas for the 11 mapping classes discussed above were used to produce the final recognition map of Yellowstone Park via automatic image analysis of ERTS MSS data obtained 7 August, 1972, using the previously described maximum-likelihood decision algorithm.

Two types of output display were used. The first (figure 7) is direct computer line-printer output, where each printed character represents an ERTS ground resolution element. By printing alternate cells in both rows and columns the final map product consisted of ten strips of line printer output 2.4 metres long mosaiced together to produce a 2.4 by 2.6 metre map with an approximate scale of 1:50,000. This map display was used primarily for evaluating the accuracy of the computer map. Its large dimensions limit its practical usefulness in a typical office environment. Consequently a second type of display technique, a color ink-squirter map, was used to produce a map more compatible with other existing maps of Yellowstone Park_/ Figure 8 is a reduced copy of the original colored map. Each ground resolution element on this display version of the recognition map is represented by a microscopic color dot. Groups of ecologically similar mapping classes were coded in similar colors to highlight natural relationships among mapping units.

_/This map was prepared by Mead Corporation of Dayton, Ohio from tapes supplied by the Environmental Research Institute of Michigan. The original product was prepared with 36 resolution elements to the inch and was about 1 x 1.5 metres in size.

A significant distortion of scale (an apparent east-west stretching) was introduced into the ink-squirter map as a result of the ERTS pixel (the cell, or ground resolution element) with dimensions of 57 x 79 metres being displayed as a square. The problem has since been resolved between the Environmental Research Institute of Michigan and Mead Corporation and relatively undistorted color ink-squirter maps can now be produced.

CONTROL DATA

Several types of aerial photographs and maps were used as ground reference data for checking the accuracy of the computer recognition map. These data consisted of the 1:125,000 color mosaic (figure 3) of the entire park, 1:110,000 and 1:55,000 stereo color infrared photos over the entire park, surficial and bedrock geologic maps at a scale of 1:125,000, topographic maps at scales of 1:250,000, 1:125,000 and 1:24,000, and a control reference map created by interpretation of all of the above data over the southern half of the park. Several east-west and north-south 1:20,000 flight strips of low altitude color photos were also used as a close-up spot-checking reference when questions arose about composition of surface material. On-site field spot-checking was done initially before the control map was created. A detailed discussion of the quality and usefulness of the control data may be found in Root and Smedes, 1974a (in preparation).

EVALUATION TECHNIQUES

Because the 12-class recognition map of Yellowstone Park was produced by the computer through a statistical decision-making process, the map must be examined to determine accuracy of identification for each mapping class. Two basic methods were used to analyse mapping accuracy. First, the 12-class map was compared qualitatively with the control data to examine general terrain features and the overall accuracy performance of each mapping class. Second, 10 test areas were selected throughout the park in which detailed computerized comparisons were made between the recognition map identifications, the control map and the corresponding control data obtained from 1:110,000 NASA high altitude color infrared photography. Each of the accuracy analysis methods is described in detail below.

Qualitative Analysis

General terrain features on the 12-class recognition map (figure 7) were compared with the control data of Yellowstone Park and the following observations were made.

The major mountain ranges, drainage patterns, major stream channels, and forest clearings (meadows, rock outcrops, and forest fire burns) greater than 2.4 h.a. (6 acres) are sharply and accurately portrayed on the ink-squirter version of the recognition map.

Three levels of coniferous forest canopy density (40-95%; 15-40%; and 0-15%) can be distinguished on the recognition map. The two lower-density forest classes can be further distinguished by the presence or absence of understory vegetation. Subtle differences in density of forest canopy resulted in a delicate mottling on the computer map, which shows these differences more accurately than was possible on the control map.

Overall, WATER, CONIFEROUS FOREST, LIGHT ROCK 3, and GRASS 3 were most accurately classified. Less accurate were GRASS, LIGHT ROCK, and GRASS 2. Least accurate were THERMAL DEPOSITS, LIGHT ROCK 2, GRASS/BRUSH, and BRUSH/DARK or SHADOWED ROCK, for reasons discussed above.

Each of the mapping classes was examined individually by making qualitative comparisons with the control data. A summary of observations for each class is recorded in Appendix C of Root and Smedes, 1974b (in preparation).

Outlines of forest fire burns as much as 20 years old can be pinpointed on the recognition map, but the burns could not be mapped as a unique category because each burn is a different age and consequently is at a different stage of plant succession. The forest fire burn areas consist of varying amounts of GRASS, GRASS/BRUSH, BRUSH/DARK or SHADOWED ROCK, GRASS 2, and LIGHT ROCK 2, depending on their age.

Large water bodies (lakes) were virtually 100 percent correctly classified. Shorelines for the most part are sharply defined, but are affected in places by boundary effects. Some ground resolution cells falling over shoreline were left unclassified because the watershore spectral mixture did not appear similar to any existing mapping classes. Some shoreline cells containing light colored sandy beaches or felsic rock outcrops were classified as BRUSH/DARK or SHADOWED ROCK, because the spectral mix of WATER and LIGHT ROCK very closely approximates the spectral signature for BRUSHDARK or SHADOWED ROCK. It is possible, at additional computer processing expense, to estimate the proportions of each ground cover type in an individual cell (Nalepka and others, 1972).

Long narrow water bodies and those with areas less than 2.4 h.a. (6 acres) frequently were not classified as water, again because of boundary effects. In rare instances deep shadows cast by steep, rugged terrain were classified as water. Shallow water and streams from 50 to 150 metres wide most frequently were not classified as WATER but as BRUSH/DARK or SHADOWED ROCK. This was due largely to the combined effect of the spectral signatures of WATER and stream bed gravel, sand, silt and mud forming a signature nearly identical to BRUSH/DARK or SHADOWED rock. Occasionally ground resolution units falling over shallow water did not have spectral signatures similar to any of the 12 mapping classes, and consequently were coded as unclassified on the recognition map.

Roads <u>per se</u> were not detected on the recognition map, but roadbed clearings greater than 150 metres wide through dense coniferous forest provided enough spectral contrast to be shown on the computer map.

Developed areas were preponderantly shown as BRUSH/DARK or SHADOWED ROCK on the recognition map. Dark-colored roof tops and bituminous paving surfaces are the major contributors to this relatively dark mapping class.

Turbid Lake was not classified as any of the 11 mapping classes used for recognition training because its signature is unique, due to the extremely turbid water carrying suspended particles from numerous hot springs surrounding the lake. It and many areas of shallow water comprise the 12th class. Turbid Lake could be automatically identified as an additional TURBID WATER mapping class if it were considered an important enough category to be recognized separately.

The majority of misclassifications, with two exceptions, were due to boundary effects. Three types of boundary effects were noticed upon close examination of the recognition map. The first was two ground-cover materials combining to form an unrecognized signature, and the second was two types of ground-cover materials combining to form a recognizable but erroneous signature. The third and most common boundary effect was the combination of two ground-cover materials to form a signature correctly identifying the two materials as a mixture. An example of the first type of boundary effect is an unrecognized combination of WATER and CONIFEROUS FOREST; the second, water combined with light sandy beach being identified as BRUSH/DARK or SHADOWED rock; and the third, solid grass and solid coniferous forest being recognized as though grass with a thin, evenly dispersed coniferous tree cover.

The two misclassification exceptions were caused by an overlapping of spectral signatures of three particular mapping classes (see radiance histograms in Appendix D). Signature envelopes of LIGHT ROCK 2, GRASS/BRUSH, and BRUSH/DARK or SHADOWED ROCK overlapped each other within all four data channels, causing larger numbers of false alarm and false dismissal errors than were anticipated. LIGHT ROCK 2 and GRASS/BRUSH were especially similar in spectral character and were frequently mistaken for each other by the recognition routines. These two mapping classes should have different spectral signatures during late spring or early summer when the brush cover is verdant and in bloom, increasing the likelihood of its separability from LIGHT ROCK 2. A second problem was the similarity between thermal deposits and snow and, less frequently, very light colored felsic rock or pure limestone. Consequently the THERMAL DEPOSIT mapping class occurs frequently in the major mountain ranges depicting snow and highly reflective rock outcrops. Fortunately the true thermal deposits in Yellowstone Park are restricted to lower altitudes, below timberline. Therefore the true THERMAL DEPOSITS and associated thermally altered rock can be accurately separated from snow and highly reflective rock by human interpretation of the recognition map in terms of the altitude and location (relative to major mountain ranges) of the point in question, using ERTS data obtained in late summer.

Quantitative Analysis

Ten test areas were selected throughout the park in which to perform a quantitative check on recognition map accuracy. These test areas are all approximately 5 by 8 kilometres in size (40 square kilometres). This size was chosen after examining overall patterns formed by individual mapping units throughout the park. These overall patterns were considered desirable to check in their entirety because they represent identifiable ecological units, such as alpine mountain ranges, subalpine montane forests, extensive grasslands (e.g. Hayden Valley), large water bodies, areas of thermal activity, etc. Test areas were not randomly placed, but rather situated throughout the park so as to include representative examples of all 11 types of mapping units.

Test area shape was chosen as a rectangle in order to sample the greatest amount of variation in ground cover types with the greatest efficiency as demonstrated by Oosting (1956:42). Test areas were oriented with the long axis either parallel or perpendicular to the orbital path of the ERTS satellite, depending on the extent and shape of the pattern of ground-cover types being sampled.

Recognition map data for each test area were obtained from the computer line-printer output version of the recognition map which represents identification symbols for every other ERTS pixel (both in rows and columns). Each test area thus contained approximately 2,500 pixels. Test areas oriented perpendicular to the satellite orbital path were 68 pixels long and 37 pixels wide. Those oriented parallel to the orbital path were 49 pixels wide and 53 pixels long.

As an example, test area 10 located 4 kilometres south of Heart Lake is shown in the form of a black and white photograph (figure 9), control map (figure 10), computer line-printer recognition map (figure 7), and color ink-squirter map (figure 11). Appendix B is a listing of all test areas used, including their locations and a general description of the terrain cover in each test area.

With the help of ERTS gray-scale computer maps, boundaries of each test area were positioned as carefully as possible to match ground terrain features with corresponding spatial patterns on the recognition map. Symbols on the recognition map representing ERTS pixels were then coded on punched computer cards for each test area. In test areas 1 and 10 the control maps were coded to represent the control mapping classes as separate colors. Using a TV level slicing system the total area of each mapping class was given in digital readout. These data were used as a control comparison for point-count area estimates made in each of the ten test areas.

The recognition map and control data for each test area, coded on punched computer cards, were analysed by a computer program written to perform the mechanics of comparing recognition map data to corresponding control data. The program performs three types of data comparisons. First it compares, pixel for pixel, the recognition map data with the corresponding control data, tallying correct and incorrect identifications. Second, an area comparison is made, with a tally of percent area correctly identified for each mapping class. Figures 12 and 13 represent conceptual illustrations of point and area comparisons respectively. Third, a pairwise analysis is performed using the point comparison data. For each test area the pairwise analysis indicates the amount and frequency of errors of commission and omission, both of which are helpful in evaluating the overall recognition map accuracy. Appendix C contains, for test area 10, an example of the output data for these three comparisons, plus a map of the test area indicating where misclassifications occurred, according to the point comparison analysis. A more detailed explanation of the computer program and a program listing are provided in Ranson, Root, and Smedes (in preparation).

The final results of the quantitative analysis are summarized in Table 1. Point comparison results for all test areas are consistently lower than area comparison results for two reasons. First, it was difficult to assure that recognition map and control data were properly registered. Misregistration of ± one pixel significantly compounded the effect of boundaries, as pixels located near boundaries were tallied as misclassifications when in fact they were correctly identified on the recognition map. Second, in areas of rugged topography, relief displacement also caused local misregistration between the recognition map and control data. Area comparisons showed markedly higher identification accuracies because the effects of misregistration and relief displacement were minimized. However the area comparison figures must be considered in light of false alarm errors. The area comparison computes the percent area correctly identified by dividing the area of a given class on the recognition map by the control data area for that class as obtained from a point count on the control data. If the percent correctly identified is greater than 100 percent the excess over 100 percent is tallied as false alarm error. A particular class may be shown as 100 percent accurate areawise, but occurrence of false alarm (commission) errors for that mapping class suggests the likelihood of corresponding errors of omission. Therefore the accuracy of that mapping class is less than that indicated in the area comparison, by approximately the amount of the false alarm error.

Overall, the quantitative results have closely substantiated the qualitative examination of the recognition map. With some exceptions the same approximate order of identification accuracies is shown by the quantiative comparison results. The order of decreasing recognition accuracy changed between point and area comparisons,primarily because mapping classes with small areas and/or long, thin shapes tended to be overlooked in the point comparison analysis because of misregistration problems. Especially affected were LIGHT ROCK, GRASS 2, THERMAL DEPOSITS, and CONIFEROUS FOREST.

According to area-comparison results, mapping accuracies most frequently ranged from 40 to 100 percent, with 6 mapping classes showing accuracies better than 70 percent in most test areas--WATER, CONIFEROUS FOREST, LIGHT ROCK 3, GRASS 3, GRASS 2, and BRUSH/DARK or SHADOWED ROCK. The identification accuracy of BRUSH/DARK or SHADOWED ROCK was rated considerably lower in the qualitative analysis because of the observance of numerous false alarm errors, particularly along streams and shorelines. As expected, the mapping classes which are spectrally similar to each other, especially GRASS/BRUSH and LIGHT ROCK 2, had lower recognition accuracies. THERMAL DEPOSITS also had a low recognition accuracy because of the previously discussed spectral similarity to snow and outcrops of highly reflective rock. Altogether, the mapping accuracies obtained from the quantitative analysis are believed to be lower than the actual mapping accuracies because of misregistration, boundary effect, and relief displacement problems in the comparison techniques.

The problem of reducing boundary effects in the quantitative analysis procedure was addressed by making point counts a second time in test areas 1, 4, and 10,directly from 1:110,000 NASA high altitude color infrared photos. Test areas 4 and 7 contained virtually flat terrain, but test area 10 contained more than 300 metres of relief. Table 2 shows that area-comparison accuracies for test areas 4 and 7 were higher using the photo as control data rather than the control data reference map. Point-comparison results were lower however, because using the photo rather than the control data map effectively introduced additional boundaries as more detail was extracted from the photo. This additional detail permitted a more accurate area estimate of control data mapping units, hence the better area-comparison results, but the introduction of more boundary effects resulted in even lower accuracy figures in the point comparison. Test area 10, with 305 metres of relief, did not show an improvement in area comparison accuracies. The control map was corrected for relief displacement, but the photo control data were not. Differences in the point-comparison results are probably due to relief displacement effects, and differences in the area-comparison results are probably due to relief displacement effects on the photo control data around the borders of the test area. Minor relief displacement within the ERTS imagery is undoubtedly contributing to misregistration problems in the point-comparison analysis for this test area and other containing rugged terrain. Orthophotos used as control data may solve this problem. Misregistration errors would still be likely to affect point-comparison results, but more-accurate area comparisons could be obtained if point counts were made directly from photos corrected for relief displacement. This procedure would eliminate the need for producing the control map, which is a costly and time-consuming step in the accuracy analysis process--six man-months were required to produce a control map for the southern half of Yellowstone National Park. A further aid in obtaining better comparison results would be geometric correction (rectification) of the ERTS image before creation of the recognition map. The use of completely rectified ERTS data would greatly facilitate the process of locating corresponding boundaries of the test areas, and would produce a product that could be used as a precision map, singly or as an overlay with other maps of an identical scale. However, in areas of exceptionally high relief, a minor amount of relief displacement may still be evident on the rectified map.

COST COMPARISON OF MAPPING FORESTED AREAS

A comparison was made between the cost of producing a green forest overprint by conventional photogrammetric mapping techniques and the cost of obtaining a computer-interpreted forest map using ERTS data. The CONIFEROUS FOREST mapping class was chosen for this cost comparison because of its importance as a land-cover type and because of readily available and accurate data on the cost of conventional mapping of woodland. The cost comparison demonstrates that a forest versus nonforest map can be produced by computerized interpretation of ERTS data for less than one fourth the cost of conventional mapping techniques.

The computer-interpreted forest map can be produced in a matter of one or two weeks and contains timely information which can be frequently updated to account for alterations of forest cover resulting from forest fires, avalanches, landslides, and (for application outside Yellowstone Park) changes due to lumbering, road construction, or development. The computer FOREST map is produced by using a consistent statistical decision-making algorithm which assures the use of uniform identification criteria throughout the entire map. In contrast, the conventional forest mapping technique is subject to possible inconsistencies in human interpretation.

Another advantage of the computer-interpreted FOREST map is its ability to show vast numbers of small clearings, down to the minimum resolution of the sensing system used (0.44 hectare for ERTS data). A delicate mottling of forest and non-forest classes can be mapped to reflect natural growth patterns of vegetation. It is presently too costly and time consuming to map this kind of detail by conventional means.

The final 12-class recognition map of Yellowstone Park demonstrated the ability of the computer mapping technique to distinguish not one, but three levels of forest density, indicating that it is possible and cost-effective to produce more than just a forest versus non-forest map.

POTENTIAL USES OF THE YELLOWSTONE PARK RECOGNITION MAP

The 12-class computer generated map of Yellowstone Park has numerous potential applications which could aid in the planning, management, and scientific research within the park. These possible applications are discussed below in detail.

Plant Community Map

The classes on the existing Yellowstone Park recognition map and the additional cover types that could be separated using winter, late spring, and/or early summer ERTS frames demonstrate the feasibility of producing maps of plant community types for wildland areas such as Yellowstone Park. Such maps would be a valuable contribution to the basic data information which the National Park Service has been collecting over national parks before comprehensive planning, design, environmental impact analysis, or development are undertaken.

Future Applications

Examination of Surface Cover as a Function of Time

A computer-generated recognition map indicates not only the location of individual mapping categories, but also the total area occupied by each. Such information is obviously of great value over agricultural areas, but also may be of use in a national park for inventory purposes. If recognition maps containing identical mapping classes are produced at given time intervals, changes in the areas of mapping classes as a function of time may permit valuable insights into such processes as (1) average surface area burned annually by forest fires, (2) analysis of wildlife habitat via dynamic changes in vegetation types used for food and cover, (3) trends in snowpack accumulation and water levels in lakes and streams, (4) changes in hydrothermal geologic activity as reflected in changes of surface thermal deposits and vegetation, and (5) changes in areas of insect-infested timber.

THE RECOGNITION MAP AS A DATA LAYER IN A RESOURCE INFORMATION SYSTEM

A digitized multi-layered resource information grid utilized for land-use planning must contain data on the character of the surface cover. A computer-generated recognition map could provide this type of information, in a form readily entered into the grid storage system. In addition to the surface cover type each grid point in the resource information system might contain digitized information on topography, precipitation, geology, soils, and socio-economic data, among others (Smedes and others, 1974). The National Park Service envisions such a multi-layered information storage and retrieval system for major areas of the National Park System that require new or redirected planning, design, and development with concurrent analysis of environmental impacts.

LITERATURE CITED

Keefer,W. R., 1972, The geologic story of Yellowstone National Park: U.S. Geol. Survey Bull. 1347, 92 p.

Nalepka, R. F., Horowitz, H. M., and Hyde, P. D., 1972, Estimating proportions of objects from multispectral data, Report No. 31650-73-T: Willow Run Laboratories of the Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan.

Oosting, H. J., 1956, The study of platn communities; An introduction to plant ecology: Second Edition, W. H. Freeman, San Francisco.

Ranson,K. J., Root, R. R., and Smedes, H. W., 1974c (in preparation), A computerized method for comparing control data with automatically interpreted recognition maps produced from digital multispectral scanner output: U.S. Geol. Survey

Root, R., and Smedes, H. W., 1974a (in preparation), Relative quality and value of imagery types used for compiling control data information in Yellowstone National Park: U.S. Geol. Survey

Root, R., and Smedes, H. W., 1974b (in preparation), Eleven class recognition map, classification, display, accuracy, and potential uses: U.S. Geol. Survey

Smedes, H. W., 1971, Automatic computer mapping of terrain: in Proceedings of the International Workshop on Earth Resources Survey Systems, v. 2, p. 345-406.

Smedes, H. W., Nez, George, Salmen, Larry, Turner, A. K., Lutzen, E. E., and Reed, J. C., Jr., 1974, Land-use planning aided by computer cellular modelling/mapping system to combine remote sensing, natural resources, social and economic data: Proceedings of the Ninth International Symposium on Remote Sensing of the Environment, Ann Arbor, Michigan.

Thomson, J., and Roller, N., 1973, Terrain classification maps of Yellowstone National Park, Symposium on Significant Results Obtained from the Earth Resources Technology Satellite - 1, Volume 1: Technical Presentations, Section B, p. 1091-1095.

U.S. Geological Survey, 1972, Surficial geologic map of Yellowstone National Park: U.S. Geol. Survey Misc. Geol. Inv. Map I-710.

U.S. Geological Survey, 1972, Geologic map of Yellowstone National Park: U.S. Geol. Survey Misc. Geol. Inv. Map I-711.

TABLE I. SUMMARY OF MAPPING ACCURACY RESULTS OBTAINED BY QUANTITATIVE POINT AND AREA COMPARISONS

Area comparison results are consistently higher because errors introduced by misregistration and relief displacement were minimized. Means were weighted in proportion to the area of each mapping class in each test area. All figures are expressed in percent accuracy of computer identification.

POINT COMPARISON SUMMARY - ACCURACY TABULATION

MAPPING CLASS	TEST AREA 1	2	3	4	5	6	7	8	9	10
FOREST	67	22	59	47	65	60	82	79	77	30
LT ROCK 3	21	17	--	65	--	40	38	--	19	4
LT ROCK 2	12	22	0	--	--	--	--	--	16	8
LIGHT ROCK	--	3	--	--	18	33	--	--	38	0
GRASS 3	17	12	50	--	18	17	--	--	24	40
GRASS 2	--	17	24	--	21	6	--	--	6	28
GRASS	--	17	20	7	23	6	--	--	4	42
GRASS/BRUSH	6	23	29	--	42	18	--	--	--	--
BRUSH/DK RK	35	--	--	51	--	--	--	--	38	18
THERMAL DP	--	--	--	--	50	31	--	--	--	--
WATER	--	--	--	--	16	13	--	99	--	--

AREA COMPARISON SUMMARY - ACCURACY TABULATION

MAPPING CLASS	TEST AREA 1	2	3	4	5	6	7	8	9	10
FOREST	91	64	67	70	100	66	83	93	100	44
LT ROCK 3	100	100	--	100	--	100	100	--	100	100
LT ROCK 2	37	100	100	--	--	--	--	--	100	100
LIGHT ROCK	--	14	--	--	91	100	--	--	44	53
GRASS 3	100	68	100	--	100	100	--	--	56	79
GRASS 2	--	100	100	--	100	100	--	--	98	100
GRASS	--	39	35	8	74	10	--	--	27	98
GRASS/BRUSH	29	48	100	--	55	100	--	--	--	--
BRUSH/DK RK	100	--	--	70	--	--	--	--	100	68
THERMAL DP	--	--	--	--	100	43	--	--	--	--
WATER	--	--	--	--	22	42	--	100	--	--

TABLE II. COMPARISON OF ACCURACY RESULTS OBTAINED FROM THE CONTROL DATA REFERENCE MAP VERSUS HIGH ALTITUDE AERIAL PHOTOGRAPHS

All numbers are expressed in percent accuracy of computer identification.

POINT COMPARISON SUMMARY

MAPPING CLASS	TEST AREA 4	4(PHOTO)	7	7(PHOTO)	10	10(PHOTO)
FOREST	47	37	82	83	30	33
LT ROCK 3	65	49	38	23	4	31
LT ROCK 2	--	--	--	--	8	7
LIGHT ROCK	--	--	--	--	0	2
GRASS 3	--	--	--	3	40	41
GRASS 2	--	--	--	--	28	25
GRASS	--	--	--	--	42	35
GRASS/BRUSH	--	--	--	--	--	--
BRUSH/DK RK	51	40	--	--	18	--
THERMAL DP	--	--	--	--	--	--
WATER	--	--	--	--	--	--

AREA COMPARISON SUMMARY
(Corrected for false alarm error)

MAPPING CLASS	TEST AREA 4	4(PHOTO)	7	7(PHOTO)	10	10(PHOTO)
FOREST	70	76	83	97	44	87
LT ROCK 3	84	100	85	97	91	96
LT ROCK 2	--	--	--	--	99	36
LIGHT ROCK	--	--	--	--	53	18
GRASS 3	--	--	--	100	79	94
GRASS 2	--	--	--	--	96	96
GRASS	--	--	--	--	98	73
GRASS/BRUSH	--	--	--	--	--	--
BRUSH/DK RK	70	95	--	--	68	--
THERMAL DP	--	--	--	--	--	--
WATER	--	--	--	--	--	--

APPENDIX A. DESCRIPTION OF MAPPING CLASSES FOR FINAL 11 CLASS RECOGNITION MAP

CLASS NAME	CODE NAME	DESCRIPTION
CONIFEROUS FOREST	CF	40 to 95% coniferous tree canopy consisting of lodgepole pine, spruce-fir, douglas fir, white-bark pine, and other less common species. Also includes shadowed forests on north facing slopes.
LIGHT ROCK 3	LR-3	15 to 40% coniferous tree canopy cover with non-vegetated understory consisting of rock outcrops, rock rubble, talus, or coniferous litter mat. Locally includes dead trees or cured vegetation understory.
LIGHT ROCK 2	LR-2	5 to 15% coniferous tree canopy with non-vegetated understory consisting of rock outcrops, rock rubble, talus, or cured grass.
LIGHT ROCK	LR-1	Light colored rock outcrops, rubble, or talus slopes with bare soil, and very sparse infrequent vegetation representing most life forms. Locally includes cured herbaceous vegetation on dark rock.
GRASS 3	G-3	15 to 40% coniferous tree canopy with grassy understory. Infrequent shrubs, bare soil, and rock exposures may be present.

GRASS 2	G-2	5 to 15% coniferous tree canopy with grassy understory. Locally includes sagebrush, willows, or small tree reproduction. Rock exposures and bare soil are locally present but are infrequent.
GRASS	G-1	Consists mostly of grass and other herbaceous forbs. Isolated trees, shrubs, brush, bare soil, and rock exposures may be present in insignificant amounts.
GRASS/BRUSH	GS	Consists of approximately equal amounts of grass and brush cover. Bare soil is present but not frequent.
BRUSH/DARK OR SHADOWED ROCK	B/DR	Consists of two classes that are similar spectrally, but are very different genetically. 1. 70 to 90% brush cover, most commonly big sagebrush or bitterbrush. Grass and bare soil account for the remaining cover. 2. Dark colored rock outcrops and related rubble, or lighter colored rocks or rock rubble which is darkened by shadow in areas of high relief. Also may contain very sparse infrequent or cured vegetation representing most herbaceous life forms. Locally includes sand, gravel, and clay exposures on steep and south facing slopes.
THERMAL DEPOSITS	TD	Consists mostly of siliceous sinter, travertine, and associated weathering products. Lesser contributions come from sparse meadow grasses and occasional shrubs and coniferous trees.
WATER	W	Lakes, ponds, and streams with clear water more than 10 feet deep. The signature of shallow clear water is significantly affected by the bottom material, and turbid water is affected by the spectral signature of the suspended particles.

APPENDIX B. LOCATION AND GROUND-COVER DESCRIPTION FOR THE 10 TEST AREAS USED FOR COMPARING THE FINAL 11 CATEGORY RECOGNITION MAP WITH CONTROL DATA.

Each test area is approximately 5 by 8 kilometres (3 by 5 miles) or 40 km^2 (15 mi^2) in area. For each test area principal ground cover types are listed in order of decreasing abundance.

TEST AREA	LOCATION	DESCRIPTION OF GROUND SURFACE COVER
1	10 km (6.2 mi) northeast of Saddle Mountain in the northeast portion of the park.	Subalpine timber and grassland with 490 metres (1,600 feet) of relief. Principal ground cover types are coniferous forest, light rock 2, grass/brush, and grass 3. Traces of light rock 3 and dense brush are present.
2	11 km (6.8 mi) east of Tower Junction in the northwest portion of the park.	Meadows and wetlands associated with the Lamar River floodplain, and grass/brush slopes north and south of the Lamar River valley. Total relief is 640 metres (2,100 feet). Principal ground cover types are grass/brush and grass. Less common are grass 3, light rock, coniferous forest, grass 2, and light rock 2.
3	10 km (6.2 mi) southeast of the town of Mammoth in the northwest portion of the park.	Coniferous forests and woodlands intermixed with grass and grass/brush meadows. Total relief is 610 metres (2,000 feet). Principal ground cover types are coniferous forest, grass, grass 3, grass 2, and less commonly grass/brush.

4	Madison Valley immediately northwest of West Yellowstone in the west central portion of the park.	Open coniferous woodland intimately intermixed with dense brush cover on flat, nearly level terrain. Principal ground cover types are brush, coniferous forest, and light rock 3.
5	Hayden Valley, in the central portion of the park.	Rolling grassland and brushland bordered by coniferous forest. Total relief is 122 metres (400 feet). The Yellowstone River flows through the northeast portion of the test area. Principal ground cover types are grass/brush, grass, and coniferous forest. Less common are water and thermal deposits.
6	Lower Geyser Basin and immediate surroundings in the west central portion of the park.	Thermal deposits and associated meadows, wetlands, and lakes, surrounded by coniferous forest. Total relief is 92 metres (300 feet). Principal ground cover types are coniferous forest, grass, and thermal deposits. Less common are grass 3, light rock, light rock 3, and water.
7	10 km (6.2 mi) west of Lower Geyser Basin in the west central portion of the park.	Entirely coniferous timber, with a total relief of 153 metres (500 feet). Principal ground cover types are coniferous forest and light rock 3. A trace of grass 3 is present.
8	Central portion of Yellowstone Lake, including Frank Island.	Entirely composed of water except for Frank Island, which has a relief of 23 metres (74 feet) and is composed of coniferous forest, light rock, grass 3, and grass 2.
9	The Trident, in the extreme southeast portion of the park.	Subalpine and alpine forests, meadows, tundra, and rock outcrops. Total relief is 610 metres (2,000 feet). Principal ground cover types are light rock, coniferous forest, grass 3, dark and/or shadowed rock, and light rock 3. Less common are light rock 2, grass, and grass 2.
10	4 km (2.5 mi) south of Heart Lake, in the south central portion of the park.	Coniferous forests and woodlands with high relief, grasslands, and wetlands of the Snake River flood plain. Total relief is 305 metres (1,000 feet). Principal ground cover types are grass 3, coniferous forest, grass, and grass 2. Traces of dark rock, light rock, light rock 2, and light rock 3 are also present.

APPENDIX C. RESULTS OF POINT, AREA, AND PAIRWISE COMPARISONS BETWEEN THE RECOGNITION MAP AND CONTROL DATA FOR EACH OF THE 10 TEST AREAS

The computer program which performs the comparison mechanics prints four pages of output. The first is a map of the test area on which symbols represent misclassified ground resolution elements according to point comparison results. The second page is a class by class summary of point comparison results. The third page is a similar summary of area comparison results. The fourth page is a pairwise array, in which the diagonal is the number of ground resolution elements correctly identified for each class according to point comparison results; rows represent false alarm (commission) errors for each class; and columns represent false dismissal (omission) errors for each class.

MAP OF CORRECTLY IDENTIFIED GROUND TRUTH UNITS FOR TEST AREA 10

BLANK=CORRECTLY CLASSIFIED POINT
CLASS SYMBOL=MISCLASSIFIED POINT

```
     3333333333333333333333333333333444444444444444444
     3444445555566666777778888899999000001111122222333
     9135791357913579135791357913579135791357913579135

1864 EIXIXSXIISOEOOEXO= XXX        0 0  0  0     XOX OS
1866 IIX M X  OISSEOOE= MMM 0000000  OO  0         OOEI
1868 EOXXXXSISXXXIISSS IMMM OO 0 X 0   XOO OO     OOSSI
1870  C+.=.=$IXXII=I=== MMOXXXX X     X X 0 0000  OSSXI
1872 S EI====IOOI=II==IMOO OOXOO 0  0 CI     0 OO+=III
1874 X=S==S= SXXXI II=IO OOOO  0 0 0 MIXX XIOOOS==  IO
1876 ==I= S IX  IS ISIXX XOOX     OOM OCOXXO 0 SIII   0
1878 II==SSESIISIII=O OXOOOEOOOOOOMM  0 0 OE  I    OO
1880 =I  ==    III  SSOOOOOOOOOOOOO OO XOOSSIS I  0 SX
1882  S XI=       I=I OOOOOSOOOSO SO  OCXII=  I   I=  X
1884 = SEE ==  III IOXOEIOIEESOXSSSO OCXXX  II=I== XX+
1886 ==SS.        SX=O I IOSIS  S XOSXXCO   I=   ..+SSX
1888 S==E+  =   S=IXI OI ISIX SSSXXX  CO  I==   ESS  X
1890 IS=OS  =   I=ISOIIOXXI  =  S EX =C SI  IIS+ OX=X
1892 OSSSS .==== X  IXXXISS== =   SX  C M  IE++XXOXXM
1894 S.=.S  = == IIIIMXXIS===  X=  I M  O XS   X   X
1896 ...SSE==. =     XX IIIEI==   SIMMIM OXXE XXM MXX X
1898 S     I==   S    XXX IS   MI   SMM MIOOXXSIIOX =X
1900  =SSIOIS=       OXX  SI O I   I  X    MXE==IIIIM
1902  =I=SI =   IICXSMI O SI  XXII   X M XO=SIIIII    I
1904 XSI = II II    X XM    I=X  =XXXIXXXXSS=I X X X= I
1906  =    SI =    IXX   I=== X  I IXXXXXOS=SX   IXIXSS
1908        III= IMMSXX   ISXXII  XIX O    +OX    XI=XI
1910 =      =II=IOMX I    =XIS   IX  SS  XOXX XIXX I= =I
1912 ==  S   = SI=ISIIIEEI   =      I  SSSIIIXOXXSX S I I
1914 I=     II  IIIIIIMM    IX   II I =   IIOII XX I
1916 ====        = I  IM SSS=    XXII  == ==SOXOSXI=
1918 I===X  II=   OOOE=S.S.S==  XIXXIX      IOOSOI    M
1920 II=I======IEM EEESE.ES= I  XXIIXXXIIIIO MI I   I I
1922  S I= ==    IXC =X==OXX=S==  X X  XXMXX S M
1924    I=       =III  XXXI=IS   =I XII XX=XMIS OI MX
1926 IISSSES       IXXX M IIIIS      OIIIXXI XIIOOS I   I
1928 IS= OE        I IXXXXISS   I===  IIXI XSXS ISI   X
1930 SSOOOEI     ===IX  SSES= = SO== XXIII=XSISSSXOX MM
1932 EEEEEE    X  =I=    =  S ==E =         X S===  OXX
1934 SOEESSEI    XXXX    SXSSX    =S II= ==XXXSSS==EO MM
1936 SS EEEE     XXXI IIII ISI S==      ==I SSSS==SSIX
1938 OSSOOXII              O XXXI =S S== XX =I=S  ISSSSXM
1940 X  XI I          II   I OOSSOS=X IX XXXX =SIIX SS=I
1942 IX       I       I=          S IIXX O XXXXX XXXX S==I
1944 III I      II  IIIIO   II        SIII  X    XXII=++X I
1946 I               II II I IXII II OS  O   II  SAIX IE+E X
1948       SOO    III I I SOISI=I=III    II      XXXXX==S+
1950  XXOOS+S =I   I  M =O =S==    X XX XX    IXXIXS=IIXI
1952 XX= OOOSIS I       OMI====I==SII IIIIAX  III   XX XS
1954 IXXO OOSESIII II SSSOS==I=  ==IIIIII= XX   X XOX E
1956 XXMOOOOCEI=IICII==E E==   ==I===II=I=IIXXX   MMMMXX
1958 O XMOOOCOES=S I= XIXOS =X = ISSX ==XM XI      XMMMM
1960 MMXXO XXOOEXXX  I=.= SSS  = II XOM X              MM
1962  M +XXIXOOOOI  II==IX X X == XIX  XI              XX
1964  MMXXOISXE SE  I=I=XX     I=  XXX   X        OX X= O
1966  O S   XO   II IX=II XX      X  I   XXXXX OOXX SSX
1968 MM IM   XXS X M   IIII   XXIMMXX I XXXISXISIM IXIXXX
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POINT COMPARISON TABLE--TEST AREA 10

CLASS ON RECOGNITION MAP		TOTAL NUMBER OF EGUIVALENT GROUND TRUTH CELLS	NUMBER OF CORRECTLY CLASSIFIED CELLS	PERCENT CORRECTLY CLASSIFIED CELLS	90 PERCENT CONFIDENCE LIMITS
FOREST	M	592.0	179.0	30.2	27.1, 33.3
LT. ROCK 3	O	25.0	1.0	4.0	0.0, 10.5
LT. ROCK 2	E	52.0	4.0	7.7	1.6, 13.8
LIGHT ROCK	+	29.0	0.0	0.0	0.0, .0
GRASS 3	X	971.0	391.0	40.3	37.7, 42.9
GRASS 2	I	441.0	125.0	28.3	24.8, 31.9
GRASS	=	449.0	187.0	41.6	37.8, 45.5
GRASS/BRSH	S	0.0	0.0	-----	
BRSH/DK RK	S	34.0	6.0	17.6	6.9, 28.4
THERMAL DP	.	0.0	0.0	-----	
WATER	W	4.0	0.0	0.0	0.0, .1
UNCLASSIF.	U	0.0	0.0	-----	

ORIGINAL PAGE IS OF POOR QUALITY

AREA COMPARISON TABLE--TEST AREA 10

CLASS ON RECOGNITION MAP		PERCENT AREA OF EQUIVALENT GROUND TRUTH UNITS AS ESTIMATED FROM THE GROUND TRUTH MAP	PERCENT AREA OF EACH CLASS IDENTIFIED ON THE RECOGNITION MAP	PERCENT AREA CORRECTLY IDENTIFIED	FALSE ALARM ERROR (EXPRESSED AS PERCENT OF TOTAL AREA MAPPED)
FOREST	M	22.7	9.9	43.8	
LT. ROCK 3	O	1.0	9.5	100.0	8.5
LT. ROCK 2	E	2.0	2.6	100.0	.6
LIGHT ROCK	+	1.1	.6	52.5	
GRASS 3	X	37.4	29.5	78.8	
GRASS 2	I	17.0	21.4	100.0	4.4
GRASS	=	17.3	16.9	97.9	
GRASS/BRSH	S	0.0	8.1	0.0	8.1
BRSH/DK RK	S	1.3	.9	68.1	
THERMAL DP	.	0.0	.6	0.0	.6
WATER	W	.2	0.0	0.0	
UNCLASSIF.	U	0.0	0.0	-----	

PAIRWISE CLASSIFICATION ARRAY FOR TEST AREA 10

		M	O	E	+	X	I	=	$	S	.	W	U
FOREST	M	179	0	1	2	43	23	10	0	0	0	0	0
LT. ROCK 3	O	112	1	3	1	89	19	11	0	10	0	0	0
LT. ROCK 2	E	7	2	4	3	20	9	13	0	9	0	0	0
LIGHT ROCK	+	5	0	2	0	0	3	4	0	1	0	0	0
GRASS 3	X	152	3	5	9	391	115	84	0	4	0	2	0
GRASS 2	I	82	2	12	4	236	125	95	0	0	0	0	0
GRASS	=	27	10	11	7	117	80	187	0	0	0	1	0
GRASS/BRSH	$	24	6	13	2	66	62	34	0	4	0	0	0
BRSH/CK RK	S	2	0	0	0	7	4	3	0	6	0	1	0
THERMAL DP	.	2	1	1	1	2	1	8	0	0	0	0	0
WATER	W	0	0	0	0	0	0	0	0	0	0	0	0
UNCLASSIF.	U	0	0	0	0	0	0	0	0	0	0	0	0

FIGURE 1. INDEX MAP. Yellowstone National Park shown in black.

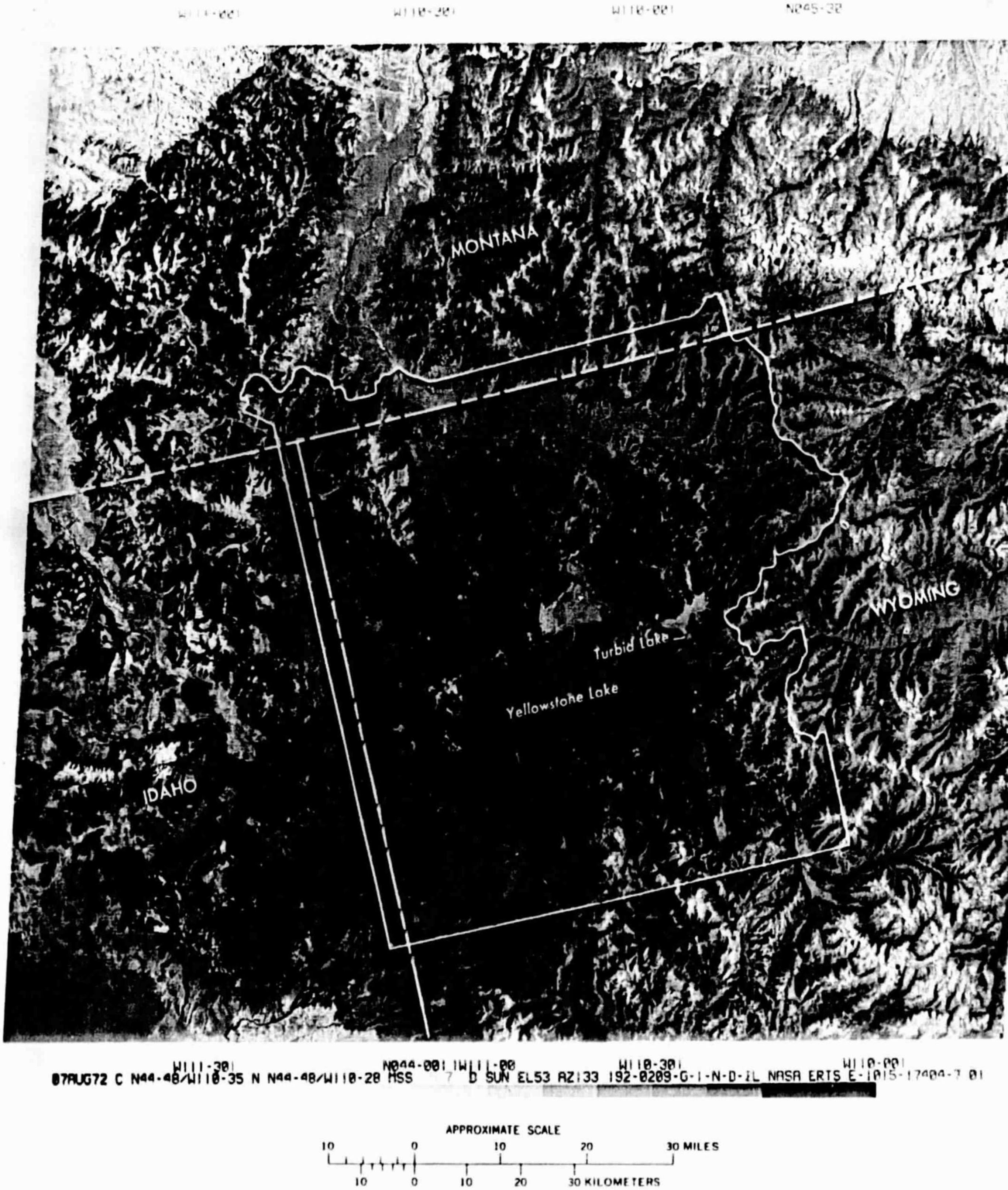

FIGURE 2. LANDSAT-1 (ERTS-1) COLOR COMPOSITE IMAGE OF YELLOWSTONE NATIONAL PARK AND VICINITY. Park boundary shown by white line. Image 1015-17404, August 7, 1972. Copied from Smedes (1976, p. 313).

FIGURE 3. AIRPHOTO MOSAIC. Compiled from high-altitude aerial color photos furnished by NASA in 1969. Boundary of Yellowstone National Park shown by thin line and bottom edge of mosaic. Copied from Smedes (1976, p. 314).

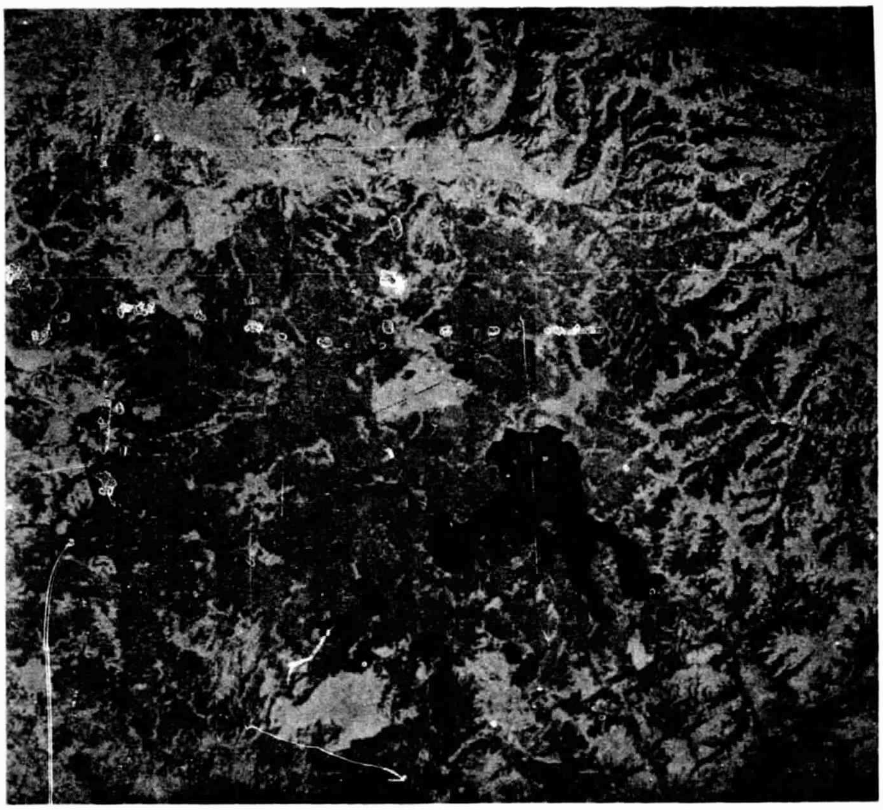

FIGURE 4. FIVE-CLASS RECOGNITION MAP. In order of decreasing gray tone the classes are water, forest, rock, grass, and lowland. Photo reduced from original color printout about 8 x 8 feet.

Forest	Lodgepole pine (mature stand) Lodgepole pine (immature stand) Lodgepole pine infested by bark beetles Douglas fir Spruce-fir 40-65% forest with grass understory 40-65% forest with rock or bare soil understory
Grass	Brush Grass-brush Upland grass Grass +5-15% trees Grass +15-40% trees
Lowland	Lowland grass Lowland shrub Alpine meadow
Rock	Light rock Dark rock Thermal deposits Rock +5-15% trees Rock +15-40% trees
Water	Shadow Water

FIGURE 5. SUBDIVISION OF FIVE INITIAL MAPPING CLASSES INTO 22 SPECIALIZED MAPPING CATEGORIES. These categories were selected on the basis of (1) natural occurrence, (2) differences in spectral character, (3) ecological significance, and (4) importance to the user.

MAPPING CLASSES ON INITIAL FIVE CLASS RECOGNITION MAP	MAPPING CLASSES ON FINAL TWELVE CLASS RECOGNITION MAP
FOREST	FOREST (40-100% coniferous tree canopy) GRASS 3 (15-40% coniferous tree canopy with grass understory) GRASS 2 (5-15% coniferous tree canopy with vegetated understory) LIGHT ROCK 3 (15-40% coniferous tree canopy with non-vegetated understory) LIGHT ROCK 2 (5-15% coniferous tree canopy with non-vegetated understory)
GRASSLAND	GRASS/BRUSH
LOWLAND	GRASS MEADOW OR SLOPE
ROCK AND BARE SOIL	LIGHT ROCK THERMAL DEPOSITS DARK ROCK/BRUSH
WATER	WATER
	UNCLASSIFIED

FIGURE 6. RELATIONSHIP OF FIVE INITIAL MAPPING CLASSES TO THE 11 FINAL MAPPING CATEGORIES SELECTED AFTER ANALYSIS OF ALL SPECIALIZED MAPPING CATEGORIES. A twelfth category, "unclassified", represents those ground resolution units whose spectral-signature was unlike any of the 11 mapping categories used on the final recognition map.

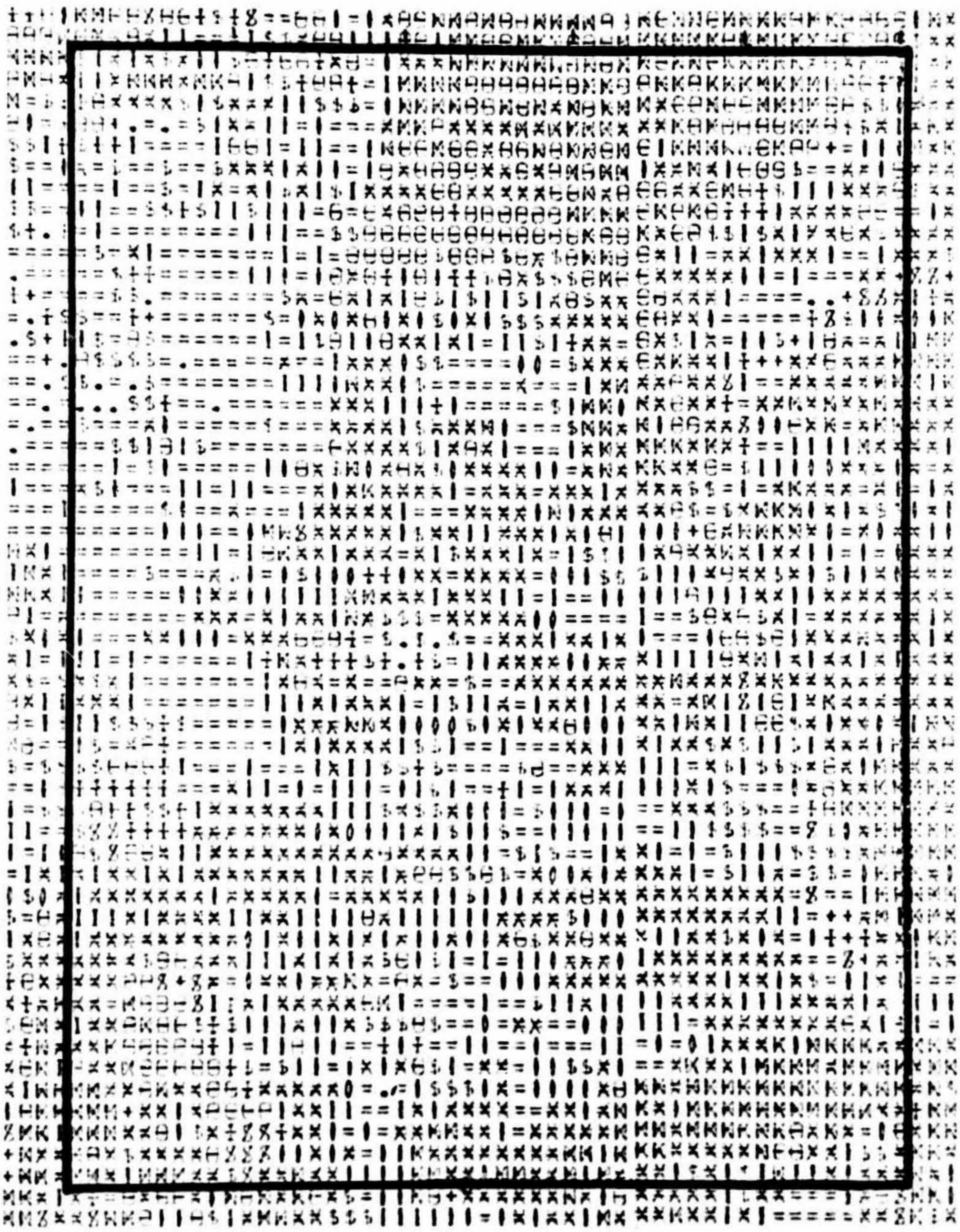

FIGURE 7. RECOGNITION MAP DATA FOR TEST AREA 10. Location: four kilometres south of Heart Lake. Approximate scale: 1:50,000. ERTS data obtained 7 August, 1972.

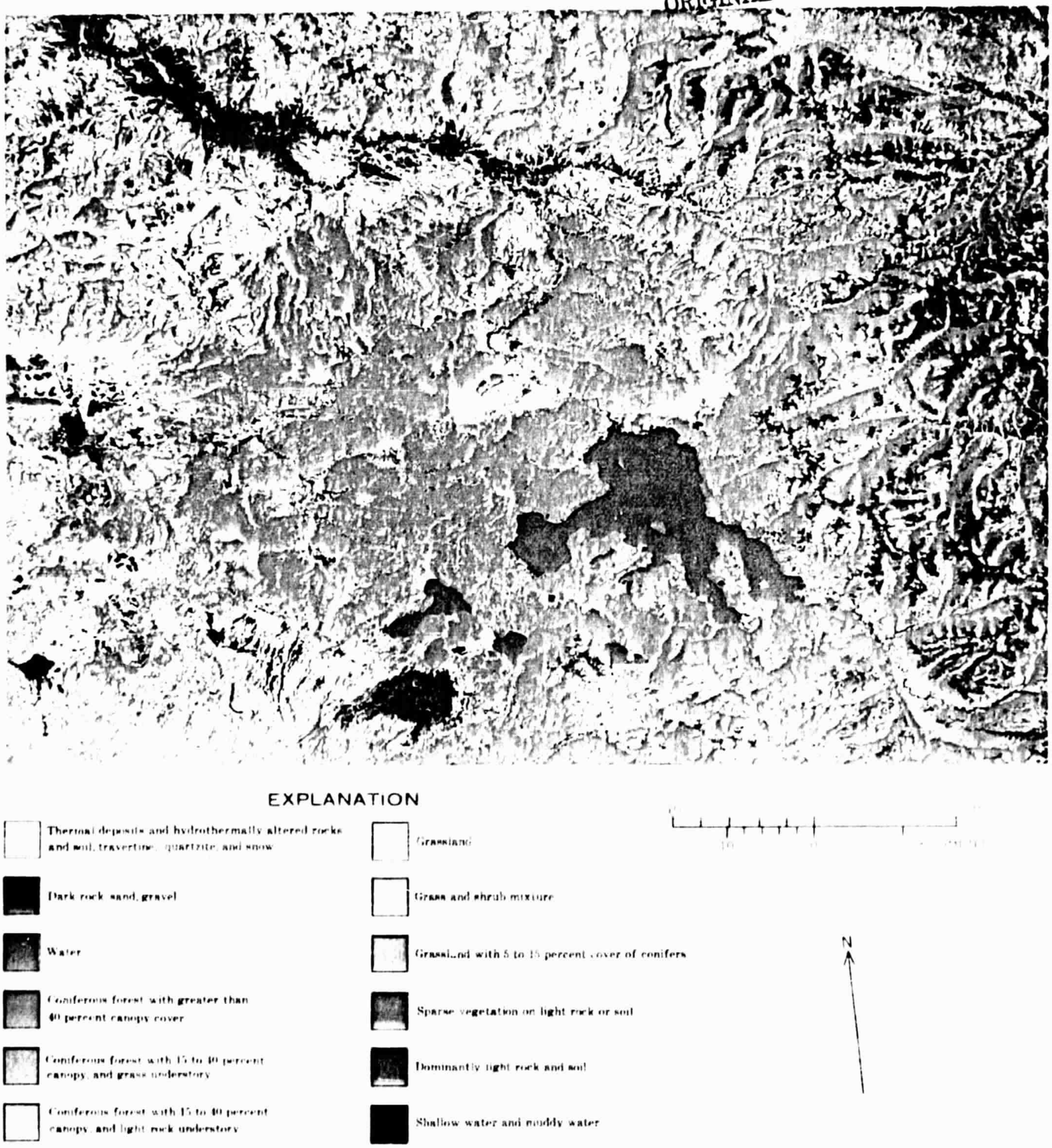

FIGURE 8. COMPUTER-GENERATED RECOGNITION MAP OF YELLOWSTONE NATIONAL PARK AND VICINITY. Made from computer-compatible tapes for LANDSAT-1 (ERTS-1) image 1015-17404 of August 2, 1972. Color map copied from Smedes (1976, p. 315).

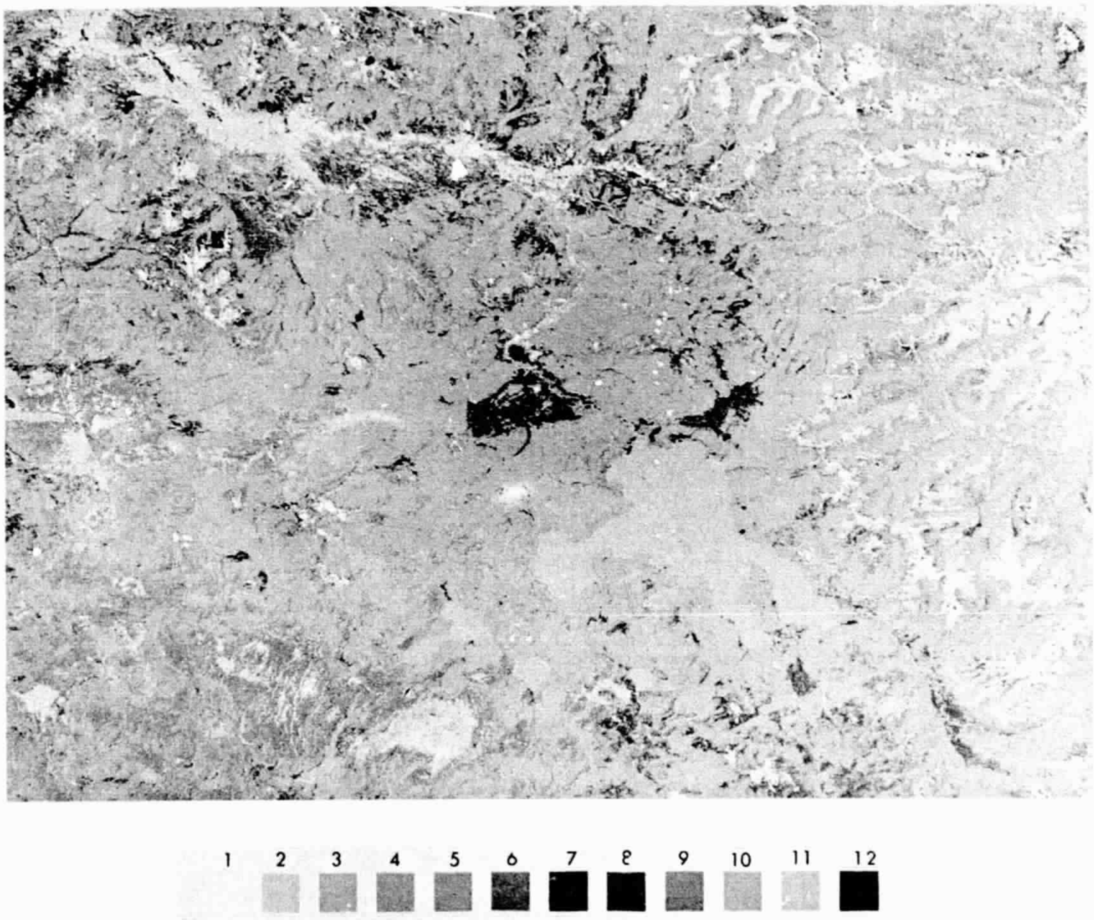

FIGURE 8. COMPUTER-GENERATED RECOGNITION MAP OF YELLOWSTONE NATIONAL PARK AND VICINITY. Photo reduction of original colored ink-squirter map depicting the 12 categories described in the text. Apparent east-west stretching results from the rectangular ERTS pixel being printed as a square. ERTS-1 data of August 7, 1972. Map code, starting from left of row of squares (colored on original):

1. Thermal deposits and snow
2. Brush/dark rock
3. Water
4. Coniferous forest
5. Grassland with 15 to 40% forest canopy
6. Light rock with 15 to 40% forest canopy
7. Grassland with 5 to 15% forest canopy
8. Grassland
9. Grass/brush
10. Light rock with 5 to 15% forest canopy
11. Light rock
12. Muddy and/or shallow water

FIGURE 9. AERIAL PHOTOGRAPH OF TEST AREA 10.

ORIGINAL PAGE IS
OF POOR QUALITY

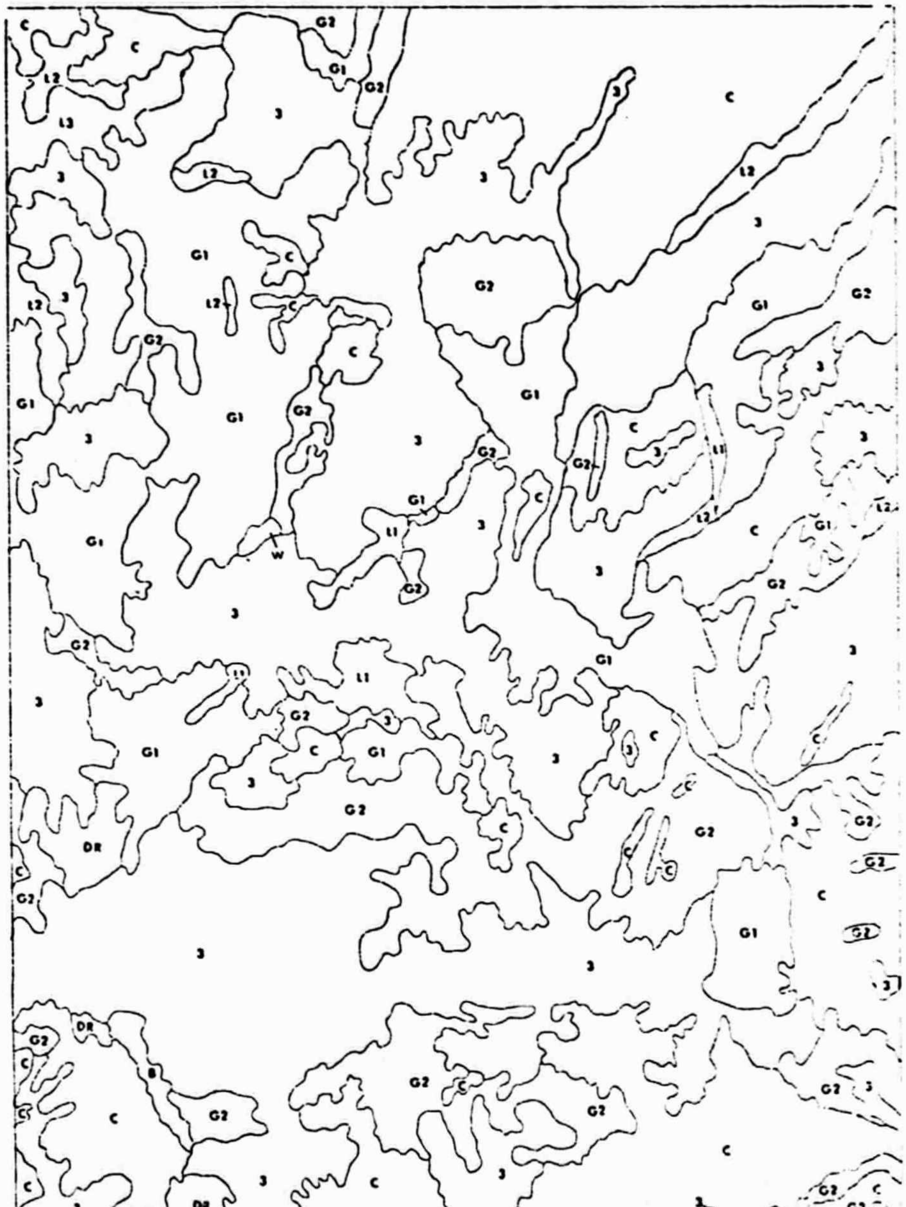

FIGURE 10. MAP SHOWING CONTROL DATA FOR TEST SITE 10. Site is located about 4 km south of Heart Lake. Approximate scale 1 50,000. Classes, described in text, are:

C	CONIFEROUS FOREST	L2	LIGHT ROCK 2
G1	GRASS	L3	LIGHT ROCK 3
G2	GRASS 2	B	BRUSH
3	GRASS 3	DR	DARK ROCK
		W	WATER

FIGURE 11. ENLARGED SEGMENT OF THE INK-SQUITER MAP, SHOWING APPROXIMATE AREA OF TEST AREA 10. Reproduced from the original color map. Approximate scale 1:42,000.

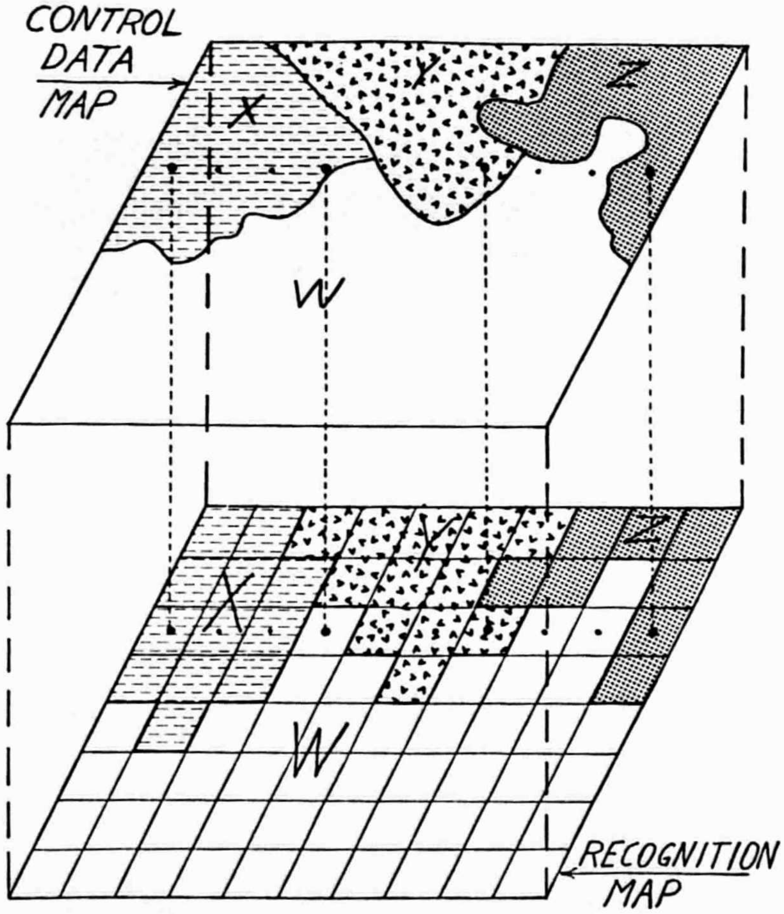

FIGURE 12. CONCEPTUAL ILLUSTRATION OF POINT-COMPARISON TECHNIQUE. Each square on the recognition map represents an ERTS pixel, or ground resolution element. W, X, Y, and Z are hypothetical mapping classes, shown as they would appear on the control data map (top) and the recognition map (bottom). Large dots on each layer represent point comparisons of individual recognition map pixels with the corresponding control data. The fourth dot from the left indicates the potential effect of boundaries on the accuracy of point comparison results.

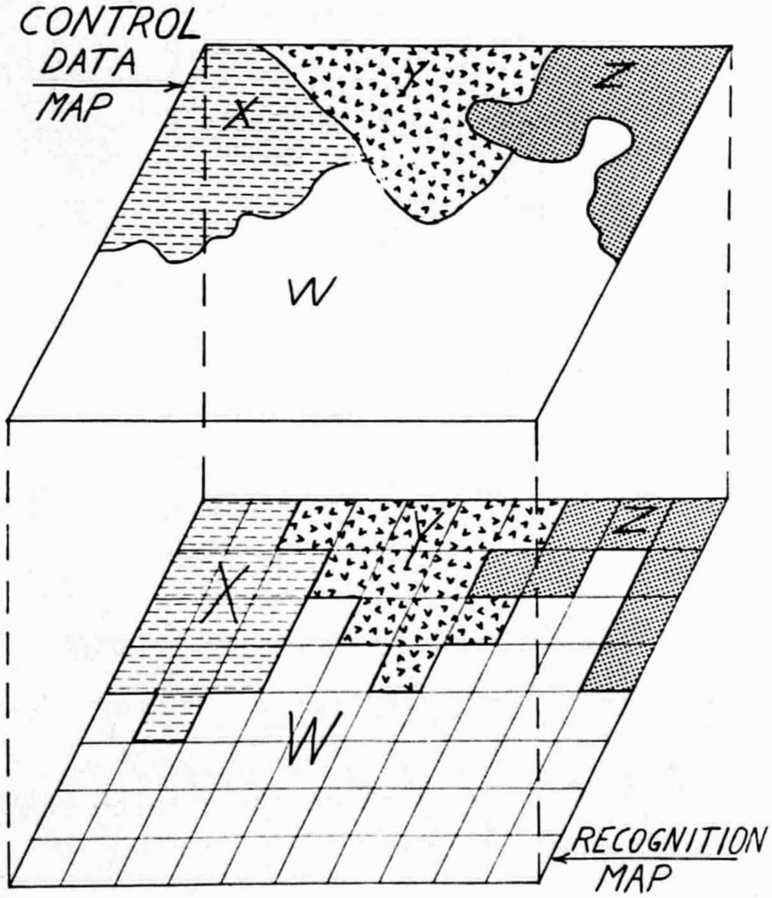

FIGURE 13. CONCEPTUAL ILLUSTRATION OF AREA-COMPARISON TECHNIQUE. Each square on the recognition map represents an ERTS pixel, or ground resolution element. W, X, Y, and Z are hypothetical mapping classes, shown as they would appear on the control data map (top) and the recognition map (bottom). Total areas for each mapping class are determined by point counts on both the control data map and recognition map, and are utilized for calculation of area comparison mapping accuracies.