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AN EVALUATION OF SATELLITE DATA FOR ESTIMATING THE AREA OF SMALL FORESTLANDS IN THE SOUTHERN LOWER PENINSULA OF MICHIGAN

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AN EVALUATION OF SATELLITE DATA FOR ESTIMATING THE AREA OF SMALL FORESTLANDS IN THE SOUTHERN LOWER PENINSULA OF MICHIGAN

By

Michael Apostolos Karteris

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ABSTRACT

AN EVALUATION OF SATELLITE DATA
FOR ESTIMATING THE AREA OF SMALL FORESTLANDS
IN THE SOUTHERN LOWER PENINSULA OF MICHIGAN

By

Michael Apostolos Karteris

This study evaluated the use and potential of Landsat images for mapping and estimating acreage of small scattered forestlands in Barry County, Michigan. Four Landsat images, two from late winter and two from early fall, were tested. Three of these images, the winter black-and-white band 5, the winter color and the fall color, were employed without modification. The fourth image was a diazo color composite of the fall scene produced by manipulating a black-and-white transparency of each Landsat band to enhance the appearance of the forest resources.

Forestlands as small as 2.5 acres were mapped from each Landsat data source. The maps for each image were then compared with a detailed forest type map that had been previously prepared by another investigator using color infrared photography and extensive ground truth information. Comparison of the Landsat maps with this source detected mapping errors, which were categorized as those of commission and omission, and then further classified into boundary or identification errors. The commission errors were usually higher than those of omission, and most of the error cases were

boundary errors of less than five acres. The most frequently misclassified areas were agriculture lands, treed-bogs, brushlands, and lowland and mixed hardwood stands, while stocking level affected interpretation more than stand size. The overall level of the interpretation performance was expressed three ways, through the estimation of classification, interpretation and mapping accuracies. These accuracies ranged between 74 and 98 percent.

The overall recommendation of the study is that, considering errors, accuracy, and cost, winter color imagery is the best Landsat alternative for mapping small forest tracts. However, since the availability of cloud-free winter images of the study area is significantly lower than images for other seasons, a diazo enhanced image of a fall scene is recommended as the next best alternative.

To

My Parents, Apostolos and Mersina;

My Wife, Kaity

and

My Son, Apostolos

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It would have been impossible to conduct a study of this nature without the assistance, cooperation and understanding support of many individuals.

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CHAPTER I

INTRODUCTION

A. General

Sound management of forest resources entails three phases of activities: 1) resources inventory, 2) the development of improved plans or programs and 3) the adaptation and application of these programs.

A complete and detailed selection of current data during the inventory process is the primary input and basic prerequisite for a justifiable forest management decision-making process. A well designed and intelligent inventory system provides valuable, extensive, quantified and qualified information on the forest to be managed. Information such as forest location, acreage, volume, type and stand condition, land productivity, areas suitable for new plantations, geological characteristics of the area, surface and subsurface water and ownership should be included in the inventory output which will be considered by the forest manager.

On the other hand, forestlands (especially small private tracts) are continuously shifted to other uses, such as agriculture. Also, other more rapid changes in the forest environment are caused naturally by fires, insect and/or disease epidemics and by cultural and technological developments such as air pollution. To keep track of all these changes, and to update the information about the condition of forest resources, requires repeated inventories. All this information will be used by the forest manager to amend managerial programs, to improve management practices and policies and/or adjust the regional and local programs according to policy changes.

A sound inventory system requires efficient and cost-effective data collection techniques and methods. It is the forest manager's responsibility to investigate, adopt and utilize those which best fit the conditions of his forest area and to give the required information. Forest inventories using conventional techniques and methods are the best way of acquiring the desired information, but they are very expensive and time-consuming procedures. Such considerations become important with budget constraints; however, data should be kept up-to-date by taking new inventories at short intervals (perhaps five years) even though costs continue to increase.

Remote sensing techniques -- especially vertical aerial photography using various film types and scales -- are an integral part of many forest activities. This is due to high image quality, the development of photointerpretation and photogrammetric techniques, the availability of qualitative and quantitative keys and tables and the forester's familiarity and acceptance of the new element. Most importantly, aerial photography can be used as a tool for gathering information about forest resources, increasing the accuracy at a given cost and/or achieving the predetermined level of accuracy with less labor and time.

However, aerial photography cannot completely replace field work in forest inventories. Only a combination of photo and ground information will give the desired results. Furthermore, the dynamic state of the forest environment and the extended acreage of the forest resources require a synoptic view on a repetitive basis at short intervals. With an airborne photographic system it is almost impossible to fulfill these requirements because of the high cost and effort involved.

B. Landsat System

A new dimension in remotely acquired information (synoptic view, repetitive coverage, multispectral imagery, digital data format) about the earth's resources and their changes over time was initiated with the Landsat (Land Satellite) program in July of 1972. At that time NASA (National Aeronautics and Space Administration) launched the first unmanned satellite, ERTS-1 (Earth Resources Technology Satellite-1) which was later named Landsat-1. Since then, two more satellites identical to Landsat-1 have been launched. They are the only ones operational to date. All these satellites have been specifically designed on an experimental basis to collect information on the various features and conditions of the surface of the earth from an altitude of

570 miles (920 kilometers).

The primary remote sensing system on board the satellites, the Multispectral Scanning System (MSS), records the reflected radiation from an area of 79 x 79 meters of the earth's surface in our different spectral bands, two in the visible and two in the reflected infrared portion of the electromagnetic spectrum.[1] To improve the quality of the received MSS data, several operations (e.g., radiometric and geometric corrections and edge and contrast enhancement techniques) are applied. The processed data are available in a photo-like[2] and digital[3] format from the EROS Data Center.[4]

Landsat technology appears to offer an alternative approach to solve some forest inventory problems. Synoptic view, repetitive coverage and multispectral imagery are desired characteristics of data employed for forestry purposes. However, several questions have been raised concerning

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[1] Electromagnetic spectrum is a series of electromagnetic radiations arranged according to wavelength or frequency. The spectrum extends from the shortest cosmic rays through the visible and infrared radiation to the radio energy.

[2] Photo-like data are images produced from the digital satellite data by applying certain procedures at the EROS Data Center. They are available in print and transparency (positive-negative format).

[3] Digital data are whole integers representing the brightness values of the picture elements. They range from 0 to 127 for bands 4, 5 and 6 and 0 to 63 for band 7 and they are recorded on computer compatible tapes (CCT's).

[4] EROS Data Center, Sioux Falls, South Dakota 57198.

Landsat by forest managers and scientists: 1) what information does Landsat imagery contain for forestry; 2) how much of this information can be extracted; 3) what level of accuracy can be reached when extracting this information; and 4) what is the cost?

Since the introduction of the Landsat program, forest scientists have been involved in various investigations trying to answer these four basic questions. However, the problem is very complicated as many factors are involved (i.e., season of acquiring data, vegetation types, geomorphology, ground resolution of the system, radiometric resolution). Because of this, more research is needed in order to determine the potentials and drawbacks of the Landsat system. The Michigan Department of Natural Resources, Forest Management Division, has posed the same general questions. The Department wants to know the efficiency of employing the new technology in various forest activities in the state, and the requirements in terms of personnel, experience and equipment to utilize Landsat data. This study was conducted to answer some of the questions and construct a comprehensive framework for using Landsat technology for forestry in Michigan.

C. Objectives

This study assessed the use of spaceborne remote sensing technology to detect, identify and delineate scattered forestlands. It examined various types of Landsat images to determine the extent to which they could provide the desired information to the forest manager. Of main interest in this study was the inventory of scattered small forestlands. The difference between this type of spatial distribution and an extensive contiguous forest of the same acreage is that, in the case of scattered small forestlands, the ratio of total length of tract boundaries to the actual forest acreage is very high. In terms of photointerpretation and mapping, this situation means that the interpreter has to detect, locate and trace many more boundaries which implies a higher probability of making locational errors. This, in turn, increases the probability of making classification errors negatively affecting the overall interpretation performance and utility of the system.

The specific objectives of the study were to:

1. Develop a methodology for manual interpretation of scattered small forestlands on Landsat images for two alternative seasons.
2. Assess the accuracy of the interpretation performance.
3. Analyze and evaluate the various interpretation errors qualitatively and quantitatively.
4. Evaluate the effect of the seasonal factor on the interpretation.
5. Evaluate Landsat based technology and procedures in terms of time, cost, personnel and equipment requirements for forest inventory purposes in Michigan.

Based on the information obtained and conclusions drawn from this study, the Michigan Department of Natural Resources, Forest Management Division, will decide whether Landsat technology is a reliable and promising alternative to be integrated into the periodic inventories of the state's forest resources.

CHAPTER II

LITERATURE REVIEW

Since the initiation of the Landsat program eight years ago (1972), professional foresters have expressed considerable interest in this new technology. Many investigations have been conducted to evaluate the capability and disadvantages of Landsat data. Special consideration has been given to spatial,[5] spectral[6] and radiometric[7] resolutions and other characteristics in an attempt to solve certain forestry problems. Researchers have been trying to determine the efficiency with which MSS data provides necessary information to the forest manager. In an effort to accurately determine the degree of detail which can be extracted from Landsat data,

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[5] Spatial resolution is a measure of the smallest identifiable feature. In Landsat it is called a "pixel" (for picture element) and it covers an area of 56 x 79 meters or 1.1 acres (0.44 hectares).

[6] Spectral resolution is a measure of the discreteness of the spectral band widths (spectral band width is an interval in the electromagnetic spectrum which is defined by two wavelengths). Three of Landsat's sensors are sensitive over 0.2 μm wavelength range, whereas the fourth one is sensitive over 0.3 μm range.

[7] Radiometric resolution is the sensitivity of the sensor to distinguish between gray levels. Three of Landsat's sensors can distinguish among 128 gray levels, whereas the fourth one can distinguish among 64 gray levels.

several individuals have conducted many studies covering a whole range of forest activities. In many instances emphasis has been placed on obtaining a quantitative expression (percentage) of estimation accuracy by comparing findings with available ground observations. These studies have entailed either manual interpretation of Landsat imagery, which is similar to conventional photointerpretation of aerial photography, or to more sophisticated computer-assisted analysis and classification of digital Landsat data. A few studies have looked at both.

Studies were conducted to investigate, evaluate and demonstrate the feasibility, advantages and disadvantages of using Landsat technology in detecting, identifying, locating and mapping forest resources. Findings of the more significant findings are highlighted as follows.

Tueller et al. (1973) reported that the minimum density for identifying the pinyon/juniper ecotone on Landsat-1, false color composite imagery, taken in July, was as low as 16.4 trees per acre provided the trees were close and continuous. Furthermore, areas of 55-60 acres with an acreage density of 30 trees or more per acre could be easily identified.

In a computer-assisted analysis of Landsat-1 data taken in August to classify agricultural crops and forests in Michigan, Safir et al. (1973) found that forests could be classified correctly about 85 percent of the time.

Lauer et al. (1973) noted that a skilled interpreter could identify and distinguish forestland from non-forestland with more than 86 percent accuracy on Landsat-1 summer false color composite imagery. They also reported that this interpretation was done nearly 20 times faster in comparison to the use of black-and-white photography at a scale of 1:15,840.

Erb (1973) reported that pine timber stands of ten acres and larger in size could be detected visually on black-and-white and color composite images, provided that contrast with the surrounding area was good. Furthermore, the area measurement of large forest stands (on classification maps), using supervised computer-assisted classification,[8] differed by 11 percent from corresponding data selected from aircraft photography.

Benson and Lauer (1973) conducted a series of quantitative, manual interpretation tests on various image types (black-and-white, false color, enhanced color, etc.), taken in late August to determine which image provided the maximum amount of information for an optimum forest classification. The three-band (4, 5, 7) digitally enhanced images and two-band (5, 7) photographically made color composites gave the

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[8] Computer-assisted classification is a computer-implemented process of assigning individual pixels of a multispectral imagery to a class according to a pre-specified rule. If the classes have been defined based on inherent data characteristics, the classification is called <u>unsupervised</u>, whereas if the classes have been defined based on representative training areas of known characteristics, the classification is called <u>supervised</u>.

best results. Classification with accuracies of 52 and 50 percent respectively were obtained.

Hoffer et al. (1974) used computer-assisted techniques to identify and map forest cover types in mountainous areas of southwestern Colorado, from Landsat-1 digital data. An overall correct classification performance for coniferous and deciduous trees of about 94.3 percent was obtained. Results obtained from the use of only two channels (5 and 7) and all four channels were almost the same. Furthermore, acreage estimates of the various forest cover types with the actual values yielded a correlation coefficient of 0.982 at the 0.95 probability level.

Heath (1974) investigated the applicability of various image and digital Landsat data to classify timber types on the Sam Houston National Forest in Texas. He reported that computer-assisted analysis gave better mapping results than manual interpretation 74 percent of the time.

Lee (1974) tested the suitability of August and September Landsat imagery for monitoring forest management operations. Detailed mapping was difficult because of the relatively low resolution of the system. The minimum area delineated was ten acres, although this depended on the contrast with the surroundings. It was pointed out that Landsat data are best for broad forest resource inventory and extensive management activities.

Jobin and Beaubien (1974) mapped broad vegetation cover types by a manual interpretation of Spring (April 2) and

Fall (October 4) Landsat imagery. They reported that satellite imagery is a promising tool, especially if photographic or computer enhancement techniques are employed.

Eller and Ulliman (1974) concluded that maps of conifer-hardwood delineations, based on manual interpretation of a band 5 winter scene (snow covered), were not accurate. Attempts to interpret forested areas from a combination of winter and summer scenes using an additive color viewer with color coded density level slice analysis of selected scenes did provide significant improvement.

Aldred (1974) discussed how an experimental design should be planned to determine the reliability of Landsat imagery for interpretation and mapping of forest resources. Accuracy and cost should be the bases for evaluating various methods of extracting information from Landsat data. A preliminary trial of operator/band combinations indicated that manual interpretations of bands 5 and 6, combined and photographically enhanced by an experienced interpreter, gave the best results (6.68 mean square error of the areal proportions between trial and standard). The interpretation of a standard false color composite print gave a mean square error of 7.28.

Lee (1975a, 1975b) evaluated the reliability of manually identifying and measuring clear-cut areas on September 1972 and August 1973 imagery. He used a multidate, enhanced color print, a black-and-white band 5 of the September scene and a computer-compatible tape (CCT) of the August scene. The interpretation of band 5 and the computer-assisted analysis were not successful because the forest boundaries were not always clear. On the other hand, interpretation and mapping using color prints was more successful.

Kan and Dillman (1975) reported that temporal analysis, using early and late spring Landsat data, improved by up to 11 percent the classification accuracy of forests as opposed to single-season analysis. Furthermore, they found that two channel analyses were more effective, performing as well as the three or four channels for simple seasonal or temporal analysis.

Kalensky and Scherk (1975) examined the applicability of Landsat data in computer-compatible tape format for forest mapping. They found that for single-date imagery, the September 5 imagery yielded the best overall classification (81 percent) and mapping (72 percent) accuracies, whereas the March 1 imagery was least satisfactory. Classification based on channels 5 and 7 gave the same accuracies as when all four channels were used. Multidate image processing increased only marginally the classification and mapping accuracies; however, the pictorial outputs had a better display quality.

Messmore et al. (1975) conducted a study to evaluate the forest mapping capability of summer (August 30) Landsat-1 MSS digital data. Using an unsupervised technique, followed by a supervised maximum likelihood classification[9] they found that training data were classified with an accuracy of 95 percent based entirely on the analysis of channels 6 and 7.

Lee (1976) evaluated the feasibility of Landsat digital data (August 12, July 20) for forestland classification. The unsupervised classification was very poor; however, a supervised one was very successful. He noted that enlargement of each pixel four times gave more information but was probably not economical because of the computer time involved. He recommended that operational information regarding logged and burned-over areas can be updated using the Image 100 computer system[10] or photographic enhancement techniques. He also pointed out that pixel by pixel classification is suitable as the first stage in a multistage forest sampling design.

Santos et al. (1975) tried to verify the capability of the Landsat system as a means of monitoring deforestation in the Amazon region. Manual interpretation and computer-assisted

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[9] Supervised maximum likelihood classification is based on the performance of the maximum likelihood rule which quantitatively evaluates both the variance and correlation of the spectral response patterns of each preselected training set when it classifies an unknown pixel.

[10] Image 100 computer system is an interactive image analysis system designed for classifying multi-spectral scanner data. It was developed by the General Electric Company and consists of both hardware and proprietary software.

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classification of the data taken in July and August gave almost the same results. However, the manual approach was much faster. Channels 5 and 7 were found to be the most appropriate for an exact outline of the deforested areas.

Heller et al. (1975) evaluated Landsat image and digital data taken during three seasons. They applied conventional photointerpretation methods and computerized classifications. The LARS (Laboratory for Application or Remote Sensing) and the PSW (Pacific Southwest Forest Experiment Station) classification systems were used. Manual interpretation accuracies of 98-99.4 percent were obtained. When computerized analyses were made the LARS system gave results within 15 percent of the ground truth, whereas the PSW, with less sophisticated hardware, gave results within 25 percent. The team concluded that Landsat is a Level I land-use sensor system.[11]

Dodge and Bryant (1976) reported no significant differences in forest acreage for two counties in New Hampshire when comparing estimates based on Landsat data with U.S. Forest Service figures. The differences between Landsat and Forest Service estimates of the forest resources of the two counties were -6.8 and +0.4 percent.

Bedfort et al. (1977) reported that on Landsat color

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[11] Level I is the most general grouping in the hierarchical categorization of land cover-use for use with remotely sensed data. It is based primarily on surface cover and is designed for use with small scale imagery, e.g., Landsat imagery (Anderson et al., 1976).

composites the darker tones of forestlands made them distinguishable from agricultural regions in Idaho. They also found that fall imagery was best to separate forestlands from range.

Mead and Meyer (1977) used Landsat digital data taken on May 23 and July 17 to map forest cover classes in north central Minnesota, employing alternative processing systems with various pattern recognition routines. They found that the maximum likelihood routine requires less training sets than the parallelepiped routine. May imagery gave better classification than July. However, natural resource managers who evaluated the resulting maps observed the classification accuracies were not accurate enough to meet the level of information needed by forest managers.

Dietrich and Lachowski (1977) reported that, by applying digital processing to Landsat CCT data, they were able to map forestlands in the Philippines and obtain an acreage estimate in four months.

Hoffer et al. (1978) conducted a study covering 158 counties in four states to compare estimates of gross forest resource acreages obtained by computer-assisted analysis of Landsat data with estimates obtained by conventional procedures. The results were very promising.

Hardy and Agar (1978) tried to distinguish and inventory commercial or potentially commercial forestlands from non-forestland areas in Britain, as well as estimate their acreage by using CCT data obtained in March. The computer classification was found to be 84 percent accurate. Manual revision of the original classification increased the accuracy to within four percent of the manual estimate. They also noted difficulty in correctly classifying such areas as suburban wooded gardens, clear cut and/or recently planted areas on mountainous steep slopes, heathlands and orchards.

Bryant et al. (1978) investigated the possibility of mapping forestlands in northern Maine using Landsat digital data taken in early July and August. One of the goals of the study was to map forests using minimum ground truth data. Initial results showed many discrepancies among softwood, hardwood and mixed forests, whereas the total forest acreage agreed quite closely (97 percent) with conventional inventory data. With more intensive use of the ground truth data the differences between computer and conventional inventory data fell within 5 percent for the forest types and 1.6 percent for the total forest acreage. However, the percent difference increased substantially for forests under 100,000 acres. Furthermore, the locational agreement between the computer classification map and the 1:15,840 scale forest type map was only about 54 percent.

Chaudhery et al. (1978) investigated the application of Landsat digital data in inventorying forest classes in Bangladesh. They reported that the accomplished level of accuracy, about 70 percent, was not high enough to justify the integration of Landsat data in this type of inventory work.

Danjoy and Sadowski (1978) applied manual interpretation and computer-assisted techniques in classifying forest resources in the Peruvian Amazon region. They found that digital processing techniques were more accurate than manual approaches in identifying and locating forests and mapping their boundaries. Multi-element classification contributed to better illustration of the forest boundaries than the classification based on information from one element at a time.

Morain and Klankamsorn (1978) discussed various uses and applications of Landsat imagery for mapping and inventorying forest resources and their changes in Thailand. Diazo false color imagery using only bands 5 and 7 formed the basis for the accomplishment of the various programs.

Bryant et al. (1979) reported that with computer-assisted analysis of Landsat digital data, it was possible to identify and map clear-cut areas as small as three hectares (7.5 acres) in northern New Hampshire. Also, some differences in stages of regrowth in the clear-cut areas were identifiable. Acreage measurements were found to be within about 15 percent of the Forest Service figures.

Townshend et al. (1979) conducted a preliminary evaluation of Landsat-3 RBV (Return Beam Vidicon) data taken on August 3 for forest discrimination and mapping in an intensively dissected area in south Italy. They interpreted the imagery manually with the aid of a video density slicer. The overall correct interpretation of forestlands, with more than 35 percent coverage, was about 94 percent with errors of omission and commission less than ten percent.

All studies included in the preceeding literature review were unique in terms of geographical area, date, vegetative cover and condition and climatological, geomorphological and geological parameters. However, accuracy determination was not standardized to allow comparison and evaluation of studies conducted under similar conditions and using different approaches and methodology. Because of that, it is difficult to determine the utility of Landsat data as an integral part in forest management, and only inferences are possible for cases conducted under similar conditions and characteristics. Based on statements and conclusions made by the authors, only general evaluations can be made about the overall status of Landsat technology to assess various forest parameters. The results of several additional studies which were conducted to evaluate the usefulness of Landsat technology to various forestry aspects are summarized in Appendix B.

CHAPTER III

THE STUDY AREA

A. General

The study area was Barry County in southwestern Michigan (Figure 1). There were several reasons for selecting this county. It contains many scattered forested areas of various sizes and shapes. Detailed maps were available, showing up-to-date information about the location, distribution, composition and condition of the forest resources. Almost all the major forest cover types found in Michigan are present in the county. Both good quality color infrared photography at various scales ranging from 1:24,000 to 1:120,000 and black-and-white panchromatic photography were available. The transportation system of the county permitted quick and inexpensive access for the collection of ground truth data. Finally, the area is located close to Michigan State University.

Barry County is located approximately between the geographic coordinates, north latitude 42° 25' to 42° 47' and west longitude 89° 05' to 89° 33'. It covers an area of about 559 square miles (144,780.3 hectares).

The terrain varies from level in the east to gently rolling in the west. Some areas have steep slopes but

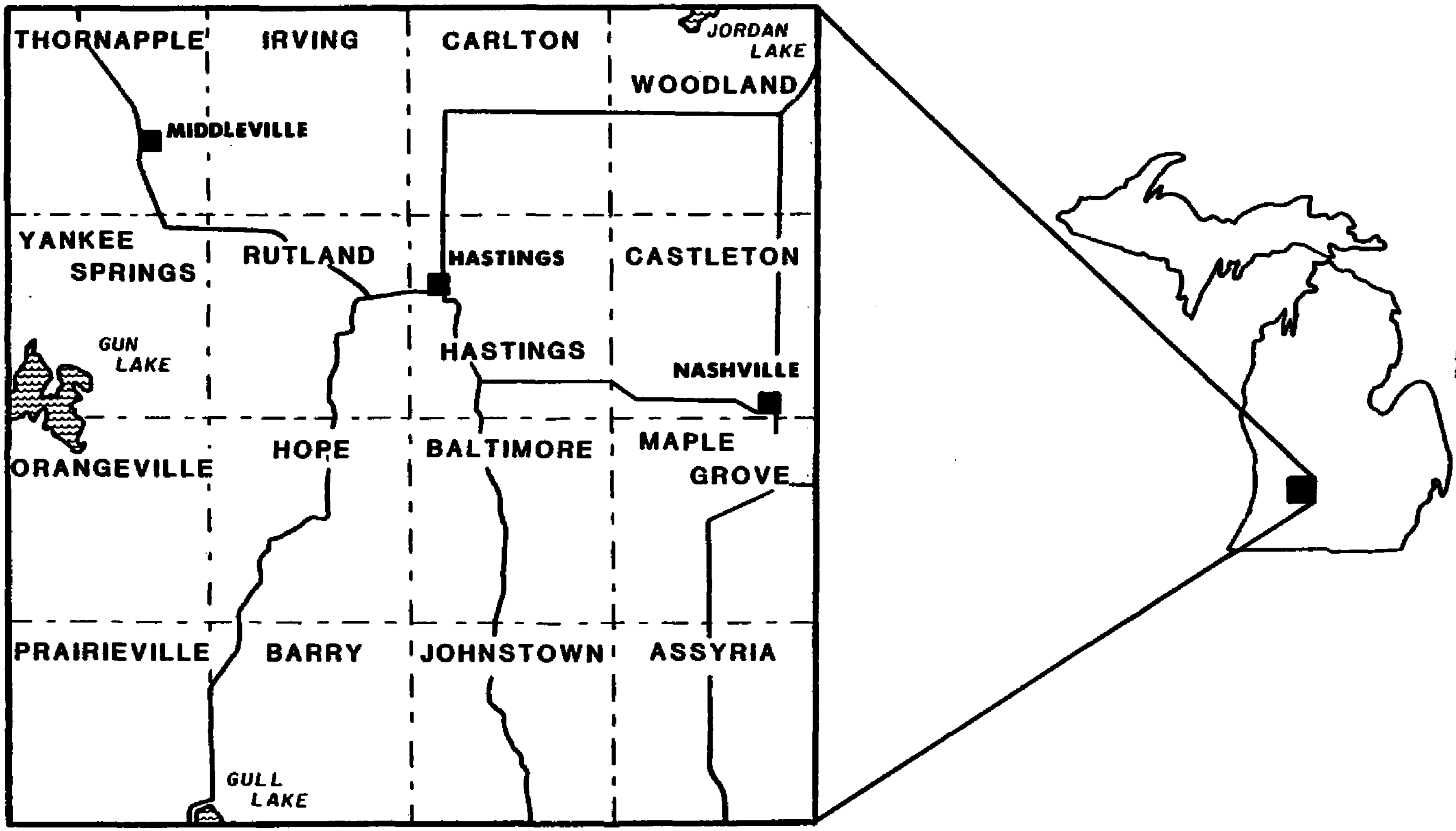

Figure 1. Barry County, Michigan, showing its subdivision into 16 townships and location in the state.

elevations are not high. The average elevation is about 850 feet (259 meters) above sea level and 260 feet (79 meters) above the level of Lake Michigan. Over 300 lakes of various sizes occur in the county. Gun Lake, the largest with 2,611 acres (1,057) hectares) is located in the western part of the county. The Thornapple River traverses the county diagonally across the northern townships. There are a number of wetlands, although well-drained soils predominate throughout the county. Bellefontaine sandy loam and Miami loam soils constitute 58 percent of the county (Deeter, 1928). The level areas are glacial sandy plains, whereas the hilly areas are glacial till plains and moraines, respectively.

Agriculture land covers 198,205 acres (80,210 hectares) or 55.4 percent of the county, mostly the eastern part. Agricultural activities include general farming, livestock feeding, dairying and poultry production. Major crops are corn, wheat, oats, soybeans, and dry beans.

About 26.5 percent of the county area (93,600 acres or 37,878 hectares) is covered by forestland, mostly in the western part. Of these forestlands, 99.2 percent is capable of producing commercial timber. Less than 1.0 percent is incapable of producing commercial timber because of restrictions due to site conditions or administrative regulations. The growing stock (excluding limbs or cull trees) totals 64.2 million cubic feet (1,797,600 cubic meters) of which 61.5 million cubic feet (1,722,000 cubic meters) are hardwood (Chase, 1970).

Two-thirds of the forestland is in private ownership, whereas the state owns approximately 23,000 acres (9,303.7 hectares). Most of the state forestlands are managed primarily for recreational uses. Yankee Springs State Recreation Area is the focal point of public recreation use in the county. There are two game areas. Many lakes and the Thornapple River are also used for recreational activities. A recreation inventory (Parkins, 1978) shows that the county contains many private campgrounds, municipal parks, public school and organizational camp facilities and two state-owned parks.

The transportation system of the county is good. There are many miles of federal and state highways and county and municipal roads which provide ready access to all parts of the county.

The climatological conditions of the county are similar to the typical midwest climate, but Lake Michigan is a great influence. The average temperature is about 48°F (27°C); the annual precipitation is about 33 inches (84 cm) of which half falls during the growing season (May-September). During the winter season the total snowfall is about 40 inches (102 cm). The prevailing winds are south to southwest.

B. Major Forest Cover Types in Barry County

North America is divided into five forest regions: Boreal, Northern, Central, Southern and Tropical (Society of American Foresters, 1954). Michigan is almost exclusively within the Northern Region, except for the very southern part which is within the Central Region. Michigan's forests are classified into six major forest cover types,[12] all of which are found in Barry County.

1. White-Red-Jack Pine

   Forestlands consisting of white pine (_Pinus strobus_), red pine (_Pinus resinosa_) and jack pine (_Pinus banksiana_), are sub-typed as white, red, jack pine or combination of them, where one or two of the species are predominant. This type usually occupies dry sandy soils, but may also be found in more moist areas. In Barry County almost all of the pine stands are plantations, of which about one-fifth are red pine.

2. Oak-Hickory

   White oak (_Quercus alba_), northern red oak (_Quercus rubra_), black oak (_Quercus velutina_), bitternut hickory (_Carya cordiformis_), pignut hickory (_Carya glabra_) and shagbark hickory (_Carya ovata_) are the predominant species. There are also many combinations with other oaks, hickories and associated hardwoods (elm, walnut, maple, etc.).

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[12] Forest cover type is defined in the Forest Terminology (Ford-Robertson, 1971) as a "descriptive term used to group stands of similar character as regards composition and development due to given ecological factors, by which they may be differentiated from other groups of stands."

This type occupies well drained upland soils. It is the most common type in Barry County.

3. Elm-Ash-Maple

This type is also called "lowland hardwoods" as it is found in moist to wet soils, swamps, gullies and other poorly drained areas. It consists of American elm (Ulmus americana), black ash (Fraxinus nigra) and red maple (Acer rubrum). The three species occur in various proportions, but in Barry County, red maple is the predominant species.

4. Maple-Beech-Cherry

This is one of the forest cover types included in "northern hardwoods." It consists of sugar maple (Acer saccharum), American beech (Fagus grandifolia) and black cherry (Prunus serotina). This type generally occupies fertile, moist, well drained upland soils. In Barry County this type consists of well stocked stands. The species in this type are also the predominant understory species in other types.

5. Aspen

This is a sub-type of the aspen-birch forest cover type, consisting of bigtooth aspen (Populus grandidentata), quaking aspen (Populus tremuloides) and balsam poplar (Populus balsamifera) in various combinations. It is found on all kinds of soils except those with very high moisture content. It is a pioneer species on clear-cut or burned areas, and is not an important forest type in Barry County.

6. Spruce-Fir

This type contains white spruce (Picea glauca), black spruce (Picea mariana) and balsam fir (Abies balsamea), is found mainly on upland loamy soils, and in Barry County it consists only of plantations.

7. Mixed Hardwoods

In Michigan, and more specifically in Barry County, there are many forest areas occupied by mixtures of various hardwood species. They are simply mixed forests difficult to classify. This forest type is found on many soil types, and has various stocking levels and stand classes.

8. Northern Conifer Swamps

The principal species are tamarack (Larix laricina) and eastern hemlock (Tsuga canadensis). The type is found on low, poorly drained soils spread throughout the southern part of Barry County. It covers only a small percentage of the total forest acreage in the county.

9. Locust

Locust is found only in planted stands in the county. These consist of black locust (Robinia *pseudoacacia*) and honey locust (*Gleditsia triacanthos*). It is not important in the county because it occupies a small acreage.

CHAPTER IV

DATA ACQUISITION

A. Landsat Data

The selection of the best available imagery is an important and fundamental step in employing Landsat data. However, what is considered as the "optimal" imagery varies among the different disciplines which make use of this type of information. It is further influenced by the particular objectives being sought. The characterization of imagery as "optimal" depends on many factors. For clarification these can be divided into two categories. The first includes factors which are standard for all types of tasks, whereas the second includes factors which vary according to the project.

The following factors are included in the first category:

1. Good radiometric quality. Sometimes one or more of the Landsat spectral bands are poorly detected and transmitted to the receiving stations. With the exception of band 6 (which is not commonly used), the other three bands are usually of good radiometric quality.

2. The extent and location of clouds. A cloud-free study area is a prerequisite for nearly every investigation, especially in cases where intensive and detailed analysis of small areas is required.
3. Data from the new EDIPS (EROS Digital Image Processing System) system. Since February 1, 1979 standard processing routines (radiometric and geometric corrections, haze removal and edge enhancement) have been applied to the data on an operational basis. This has been done to improve the spatial and radiometric resolution of the products and increase the interpretability of various ground features.

The following factors are included in the second category:

1. The specific purposes and objectives of the study. Specific cases require special selection of images. For example, quick and accurate mapping and acreage estimation of burned or insect/disease-damaged forested areas require images acquired just after the event. On the other hand, the recording of changes in the forest environment occurring over time requires the acquisition and analysis of multitemporal data.
2. The time of the year. The specific features or conditions of interest are sometimes spectrally

more distinguishable from their surrounding areas at a specific time of the year.

3. The availability of funds. If enough money is available, there is a flexibility in acquiring complementary images and maximizing the degree of extracting the desired information.

All of these factors were taken into consideration in selecting the Landsat images utilized in this study. A search was carried out of all available Landsat images of the area (i.e., nominal center of path 23 and row 30 of the Worldwide Reference System)[13] (Figure 2). Although the reference forest cover type maps were constructed from the interpretation of aerial photographs flown in 1974, the Landsat images were selected from the 1979-80 collection (after February 1, 1979). This made use of the improved quality of the new EDIPS system product. Changes in the forest resources of the county during the period between 1974 and 1979 were recorded and considered during the various calculations.

Based on objectives of the study it was concluded that "optimal" imagery would be a cloudless winter scene with

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[13] Nominal center is the theoretical geographical (longitude, latitude) center of a scene.

Path is the theoretical longitudinal center line of a scene, corresponding to the center of an orbital track.

Row is the theoretical latitudinal center line of a scene.

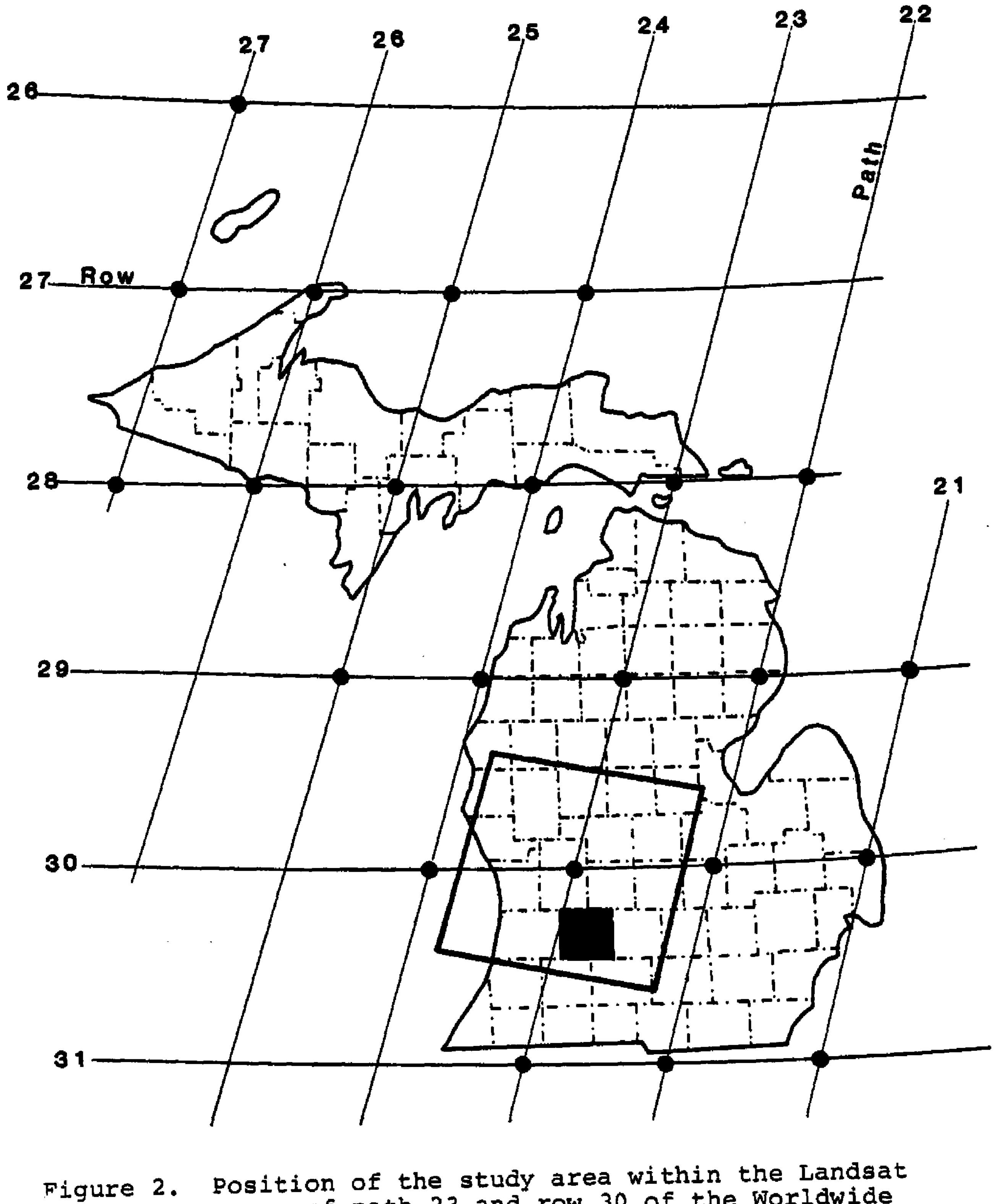

Figure 2. Position of the study area within the Landsat scene of path 23 and row 30 of the Worldwide Reference System and location of the centers of the scenes required to cover the whole state.

snow cover on the ground. Usually there is no snow on the trees with the exception of the first two to three days following snowfall. Under this condition, although there is snow cover on the ground (especially in the leafless hardwoods forest areas), the tonal contrast between woodland areas and their surroundings is very high. The reason is evident: part of the high spectral reflectance of the snow is obscured by the woody and branching part of the trees resulting in a lesser amount of radiation reflected from these areas and recorded by the Landsat sensor system. Two scenes which were taken on February 17 and 26, 1979 from Landsat 2 and 3, respectively, were found to fulfill the foregoing basic requirement. The second scene was eventually selected for evaluation because the tonal contrast of the forestlands with the snow covered surroundings was higher.

For completeness and for comparison purposes, an additional Landsat scene, taken during the growing season, was selected. Investigation showed that the only cloud-free scene of the study area was taken on September 12, 1979. Figure 3 shows the standard false color composite of the selected fall scene with the boundaries of the study area delineated.

Black-and-white positive and negative, 9 x 9 inches (225 x 225 mm) transparent imagery of all four bands and standard false color composites of both February 26 and September 12 scenes were purchased from EROS Data Center. Table 1 shows the identification number of the selected

Figure 3. Barry County study area delineated on a false color composite scene imaged by Landsat-3, September 12, 1979.


W040
W045+
W050+
W055+
12SEP79 C N43-05/W085-31 USGS-EDC N N43-02/W085-21 M 5 7 D SUN EL43 A139 G3H-CP-N L2 NASA LANDSAT E-30556-15460-5

Landsat-3 scenes, the date of acquisition and also includes a qualitative description of each scene.

Table 1. Characteristics of the selected Landsat scenes.

Identification #	Date	Qualitative Description
E-30358-15475-5	February 26, 1979	winter scene, snow covered, hardwoods leafless, no agricultural activities, good radiometric quality, high contrast, cloud free
E-30556-15460-7	September 12, 1979	fall scene, no snow, hardwoods with foliage, agricultural activities, low radiometric quality, low contrast, few clouds

An additional comment on the selection of Landsat imagery can be offered. It is difficult, sometimes impossible, to find scenes which meet the specific requirements of an investigation. Occasionally researchers must compromise their needs or deviate from initial objectives or goals in order to use available Landsat data.

B. Reference Data

One of the most important and fundamental needs of remote sensing research is accurate reference data. The reference data required depends on the characteristics and objectives of the particular research project and on the characteristics of the remote sensor (type, radiometric resolution, spatial fidelity and spectral sensitivity). Ground information, ground truth or surface observation are some other terms for reference data. However, these terms imply on-the-ground acquisition of the data which sometimes is impossible or not economically feasible. It is generally understood that information extracted from aerial photography should not be referred to as ground data.

In this study the primary source of reference data was a recently completed forest cover type inventory of the county (Tatem, 1978). As stated before, the forest cover types were mapped from color infrared aerial photography at a scale of 1:31,680 flown in 1974. Four such maps were compiled, each containing four townships. The maps may be subject to some error in the interpreter's delineation of forest boundaries vis-a-vis ground conditions as all areas were not verified in the field. In cases where discrepancies in delineation of the boundaries between the forest cover maps and the maps created from manual interpretation of the Landsat data (interpretation maps) were found, supplementary information was used. The major type of supplementary information was 1:24,000 color infrared photography flown in 1978 which were provided by the Office of Land Resource Programs in the Michigan Department of Natural Resources.

CHAPTER V

STUDY MATERIALS, DESIGN AND DATA COLLECTION

A. Study Materials

Four Landsat images from two seasons (late winter and early fall) were employed in this study; all were positive film transparencies. Three of the images were standard Landsat products and the other was an enhanced image of the forest resources using the diazo process. They were: 1) a black-and-white image of band 5 (winter scene); 2) a standard false-color composite (winter scene); 3) a standard false-color composite (fall scene); and 4) a diazo false-color composite (fall scene). A discussion of these film products follows.

1. Standard Images: winter black-and-white; winter color; fall color.

The first Landsat image to be analyzed and evaluated was a black-and-white band 5 image (1:1,000,000 scale) taken on February 26, 1979. All the available band images, both positives and negatives, for this date were subjectively evaluated to determine the best band image for forest identification. The negative images were considered inferior because the forest boundaries appeared fuzzier than on the positive, the possibility of misclassifying water areas as forests was higher, and the interpreter lacked familiarity and experience with the appearance of tones on negative imagery.

A different approach was followed for the selection of the best positive band. All four black-and-white band positive images were projected at a scale of 1:50,000. For each image a quick interpretation of the forest resources within the training townships was conducted. A subjective evaluation of the four bands showed that band 5 (Figure 4) most clearly and accurately depicted forestlands because of the high spectral contrast between forestlands and surrounding snow-covered areas. The high contrast was due to the low reflectivity of the wooded areas in comparison to the high reflectivity of the snow. Because of snow and above-freezing temperatures prior to the winter image, the reflectance of the snow cover was at a maximum (O'Brien and Munis, 1975) in band 5. In addition, water areas were more clearly differentiated from coniferous forests.

Standard false-color composites of both late winter (Figure 5) and early fall (Figure 3) were evaluated next. A false-color composite of a scene is generated by printing three MSS bands onto a color film. The printing is typically done through blue, green and red filters for bands 4, 5 and 7, respectively. The product is referred to as "false" color because it simulates the color appearance of color infrared film. False-color composites were included in the

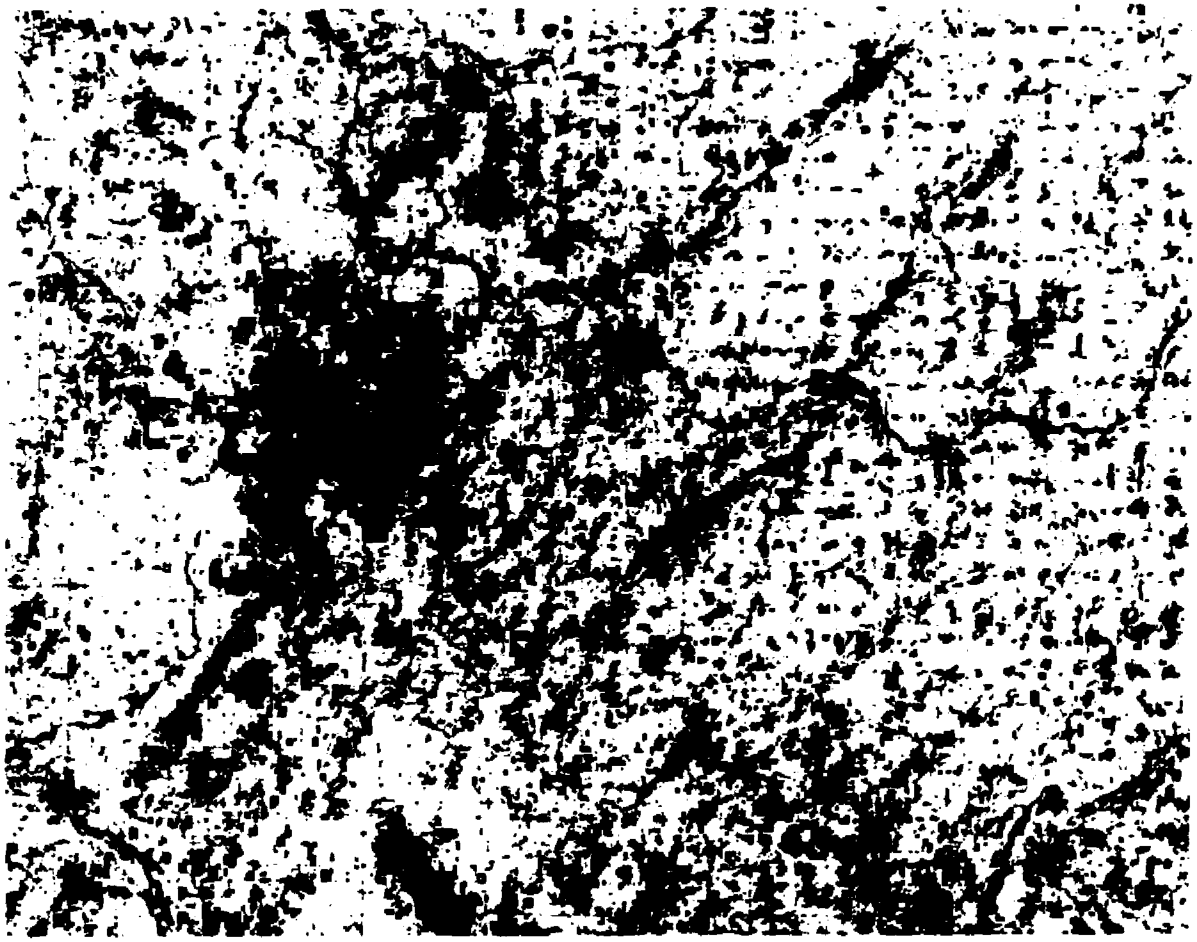

Figure 4. Landsat black-and-white band 5 subimage of Barry County, Michigan taken on February 26, 1989.

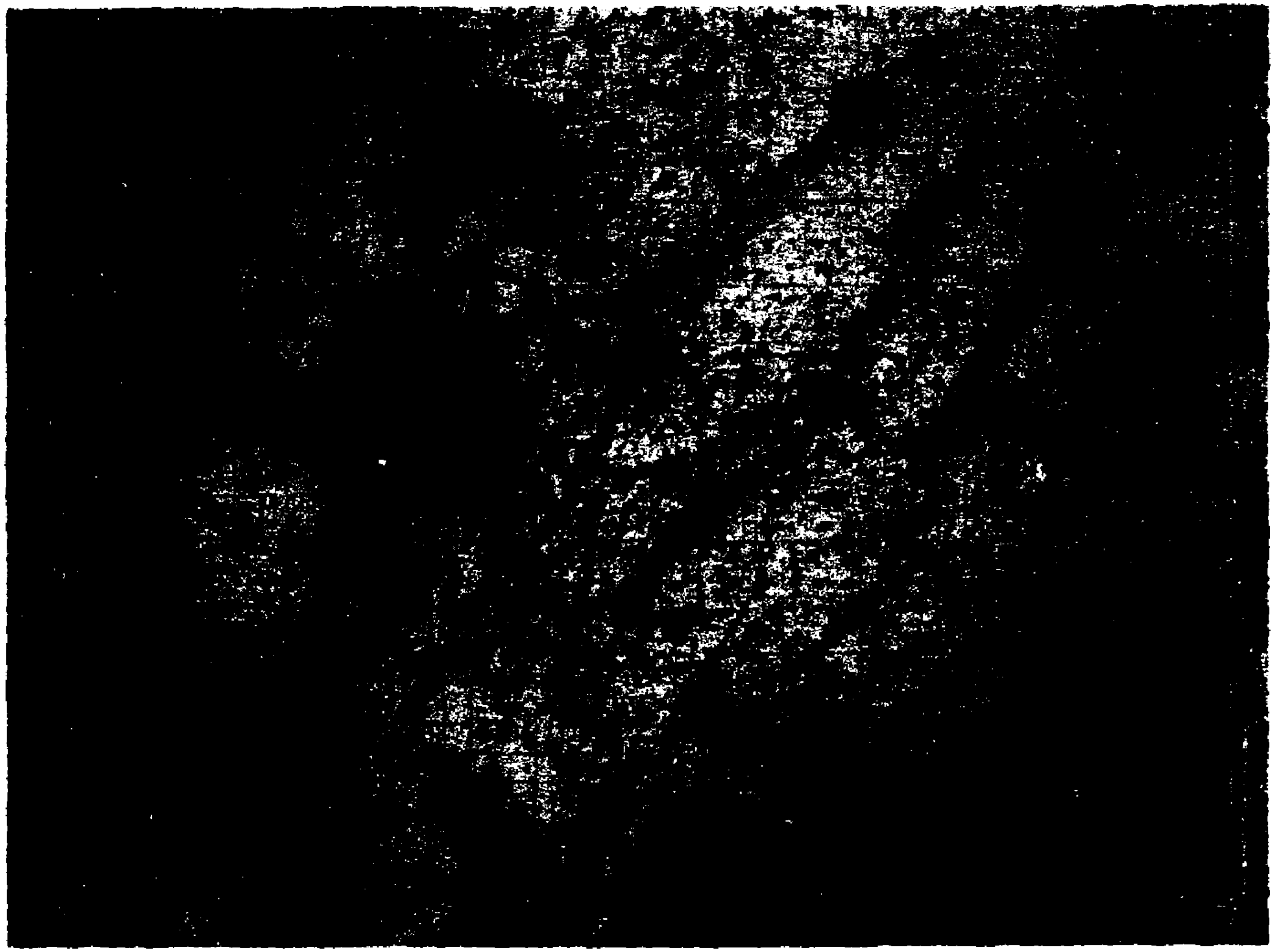

Figure 5. Landsat false-color composite subimage of Barry County, Michigan taken on February 26, 1979.

evaluation because they are a standard Landsat product. Also, a composite, as a color multiband product, combines and complements the information which exists in each band and improves the ability to distinguish the identity and condition of various features because the eye can distinguish many more color variations than gray shades.

2. Diazo Color Composite

Although Landsat data provides a large amount of information, it is difficult and sometimes impossible to extract all the information in a scene from standard images (black-and-white and false-color composite). Landsat data can, however, be enhanced to increase the appearance (contrast) of particular areas of interest such as forests.

There are two types of contrast enhancement methods: digital, where the digital data from the Landsat computer compatible tapes (CCT's) are employed; and optical, where the photographic Landsat images are used. Only the optical enhancement method was used in this study because digital methodology was too costly.

There are two major alternative optical contrast-enhancement methods: photographic processing and diazo processing. Diazo processing was selected since photographic processing is also a relatively costly procedure requiring a photographic laboratory and experienced technical personnel. The diazo process is, however, capable of producing results similar to those produced by photographic processing or digital methodology.

Diazo color composites are made by superimposing two, three and sometimes more diazo film copies of different spectral band images. The copies are produced by exposing Landsat black-and-white transparencies onto diazo films of different colors. The process and the equipment used in this procedure are described in Appendix C.

The imagery taken on September 12, 1979 was used for the diazo processing. Positive and negative transparencies of all four bands were used in the process. These procedures were followed to determine the best diazo color composite to enhance the forest resources in the study area. Density measurements were taken with a densitometer on forest areas clearly defined on all black-and-white band positive and negative images. Five density measurements were taken on bands 4 and 5 and seven measurements were taken on bands 6 and 7. More density measurements were taken on bands 6 and 7 in order to cover the whole density range of the forest resources because coniferous species have different reflectivity than hardwoods. To get reliable density measurements the selected forest targets were considerably larger than the aperture diameter of the densitometer which was one millimeter. At the Landsat image scale of 1:1,000,000 this represents an area of 200 acres (81 hectares).

Most of the density measurements were taken within and directly surrounding the study area in order for the sample values to be representative of the spectral signature[14] of the forests in the area. The average value of each set of these measurements was then calculated and used for the determination of the exposure time based on the sensitometric curves of the specific diazo films. Several combinations of exposure time and image type were used to produce diazo composites. Each diazo composite was then evaluated in terms of interpretability by ocularly comparing the forest boundaries and patterns within the training areas on the diazo color composites and the forest cover type maps.

After a thorough examination of all the diazo products and combinations, the composite chosen consisted of one yellow diazo copy of band 4, three magenta copies of band 5 and one cyan copy of band 7 (Figure 6). The corresponding exposure values were 1400, 1700 and 350 light units.[15] The use of more than one diazo copy of band 5 improved the interpretability of the forest resources on the diazo composite. The color appearance of the diazo composite was similar to the standard false-color composite. The diazo film selected contained linear, regularly spaced stripes which deteriorated

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[14] Spectral signature is the spectral identification (characterization) of an object. It is defined by making quantitative measurements of the properties of the object at several wavelength portions of the electromagnetic spectrum.

[15] The exposure values are represented to show the relative exposure relation between the various diazo films employed. However, they cannot be replicated without the use of the same exposure equipment.

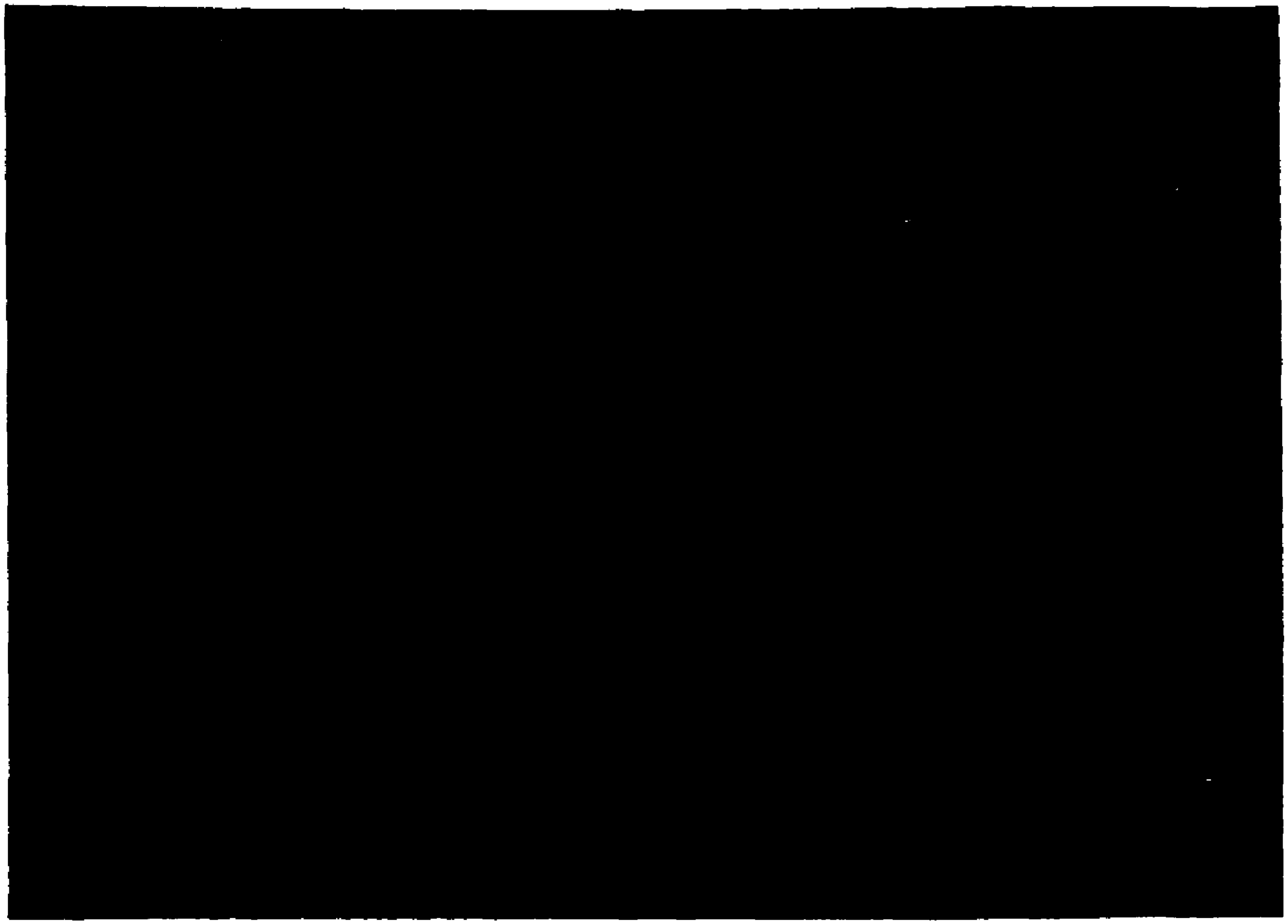

Figure 6. Landsat diazo false-color composite subimage of Barry County, Michigan taken on September 12, 1979.

the quality of the product. The direction of the linear artifacts was either parallel or perpendicular to the long side of the diazo films. The random contact of the diazo films with the Landsat images during the exposures resulted in a random positioning of the stripes on the diazo Landsat images. Thus, the stripping effect could be circumvented by producing multiple diazo copies which would shift the position of these artifacts.

Two important observations were made during the interpretation and storage of the diazo composites. First, although the diazo films were fully developed, after approximately an hour of use, a discoloration of the projected area of the image was noticed. The degree of discoloration increased from the edge to the center of the projected area. To avoid the problem the images were projected in small portions. This was accomplished by putting a black poster board mask with a very small hole between the light source and the diazo image. The projected area was large enough to conduct the interpretation and yet the cumulative amount of light striking the entire image was kept to a minimum. A more expensive alternative would be to photograph the diazo composite with color transparent film. Second, it was also noticed that shelf storage of the diazo composites affected the film layers. Specifically, the tone variation of the yellow and cyan diazo films shifted to lighter densities and the magenta film shifted to lighter densities and turned to a red color. The shifting of the tones to lighter densities was probably due to ultraviolet sunlight in the storage area. It is difficult to determine what caused the magenta color to turn to red. Developed diazo films should be stored in protective envelopes, preferably within cabinets or in other dark areas.

B. Study Design and Data Collection

1. Selection of the Training Set

The amount of training an interpreter receives before actual manual interpretation affects the accuracy of the interpretation. It is very important for the interpreter to know how specific features or conditions on the ground appear on the various Landsat images. The interpreter's interest increases greatly when interpretation decisions are not between abstract code names or numbers but between well-known and defined features.

Basic principles of photointerpretation were used during the visual interpretation of the Landsat images. The bulk of the information was extracted from pre-specified associations between the gray tones (in the case of the black-and-white individual bands), or color renditions (in the case of the false-color composites, and ground features. The shape of the forestlands was another significant factor during the interpretation process because many of the scattered forests had easily recognized geometrical characteristics. Shape was also of great assistance during the interpretation of the winter imagery. Textural differences between forests and non-forests were of greater help in the interpretation of the fall images than the winter ones. Pattern and size were of minor importance in the interpretation and mapping process, but were definitely useful in registering the overlay (called interpretation map) with the projected imagery.

The first step in training was the identification, location and selection of forestlands representative of the overall forest variation in the area. That is, the woodlands sampled should represent stands of all stocking classes and of all forest cover types found in the county. Furthermore, they should be of relatively large acreage with well-defined boundaries for easy visual detection by the interpreter. Various stocking classes should be included because different percentages of ground cover reflect different amounts of solar radiation. Thus, each combination of a forest type and stocking level will be a unique spectral situation. The woodlands selected for training may be spread over the entire county or may be located within a specified area. For procedural reasons, concentrating the training set within the same area is preferred. Thus, for this study, it was decided to use Thornapple and Yankee Springs Townships as training areas. These townships contained many of the forest cover types/stocking levels/stand sizes/acreage size combinations desired. The same townships were also used for the diazo processing experimentation and preliminary evaluation of the interpretability of the diazo color composites.

Training on each set of data was conducted just before the actual interpretation of the specific set. Thornapple and Yankee Springs Townships were excluded from further consideration during the actual interpretation, manipulation and evaluation of the Landsat system data.

2. Interpretation Procedures

In this study the visual interpretation of the forested areas on the standard and diazo Landsat images was done by only one interpreter. The main reasons were: 1) the purpose of the study was to evaluate the interpretability of forest resources from Landsat imagery and not to examine the abilities of different interpreters; and 2) the limitations of time and funds.

The interpretation involved a subjective evaluation and delineation of the boundaries of the forest areas without considering forest type or condition. The main instrument used for the photointerpretation was a back-lighted projector (Appendix D). The scale of the interpreted maps was 1:50,000, because projections at larger scales increased the fuzziness of the boundaries and decreased the overall quality (sharpness) of the imagery. Before interpretation, the interpreter trained himself to recognize the appearance of the forestlands on the imagery. The time spent for training on each type of imagery was unrestricted, but it was recorded for cost considerations. The time spent for the interpretation of the forest resources within each township on each type of imagery was recorded as well. A time lag of approximately a week was scheduled before the interpretation of the subsequent image to reduce possible bias in the interpretation decisions. The boundaries of the county and the corresponding townships were traced on acetate overlays. The Landsat images were projected onto these overlays and carefully registered. The primary features used for registration were water areas and roads.

The black-and-white winter image was interpreted first. The next imagery studied was the standard false-color composite taken in September. The spectral appearance of this imagery and, more specifically, the appearance of the forest areas, were absolutely different from the previous black-and-white winter scene. Because of this, bias in interpretation decisions due to the experience gained from previous interpretation should be minimal. The winter false-color composite was interpreted next followed by the diazo false-color composite to maintain the winter-fall sequence.

The final product of the visual interpretation process was four acetate overlays (interpretation maps), containing the boundaries of all the interpreted forest resources which fell within the study area. These overlays were subsequently used in the data collection and evaluation process to determine the level of performance of visually interpreting the forest resources on the various Landsat images.

3. Verification and Error Types

Making accuracy assessments in the interpretation process is highly dependent, among other factors, on the verification procedure. Verification depends on the type, quality, and the quantity of the auxiliary data collected to assess Landsat classification performance. Sampling techniques are commonly used for the acquisition of data, particularly for large areas, because of the lack of information from other sources, and the high cost involved for the procurement of more detailed data. Several sampling methods have been developed or adapted to satellite technology in order to collect all the information required for a thorough assessment of a Landsat classification. Any sampling approach, however, is subject to sampling errors. Therefore, the most accurate assessment of a classification would consist of a complete enumeration of the features of interest.

In this study the existence of detailed forest cover type maps permitted a complete assessment of the interpretation of forest resources from Landsat images. This was achieved through a full enumeration of the errors committed during the classification process. The process, of course, is subject to non-sampling errors, but these errors are usually very small and have negligible impact.

The evaluation of the interpretation was done by comparing the forest boundary placements on the Landsat interpretation maps with those on the forest cover type maps. The comparison was made by superimposing each interpretation map on top of the forest cover type maps. Registering the two maps was a problem because different geometric projections were used for the Landsat data and the forest cover type maps. The Landsat images were in a Hotine Oblique Mercator (HOM) projection, while the base map of the forest cover map was in a polyconic projection. The different projections caused the location of classification points to differ between the two maps. To compensate for this problem, the registration was done on an individual forest tract basis. Discrepancies between the forest areas depicted on each map were delineated on a third overlay, which also showed county and township boundaries.

These errors were initially classified into two general classes: omission and commission. Omission errors occurred when forest areas were not classified as forests, whereas commission errors were due to the misclassification of non-forest land cover/use classes as forest.

The various omission and commission errors were then further separated into boundary or identification errors. All errors due to misinterpretation of the actual boundaries were classified as boundary errors. On the other hand, errors due to overlooking or missing individual forestlands or to the misinterpretation of individual areas of non-forest cover/use classes as forests were classified as identification errors. Identification errors are the most serious errors because individual parcels of land of a certain class are absolutely lost by assigning them to another class. Omission errors were classified based on the forest types shown on the reference forest cover maps. On the other hand, commission errors were categorized from 1:24,000 scale color infrared photography taken in 1978 using a specifically developed land cover/use classification system. Table 2 shows both classification systems.

The omission errors were first characterized in terms of forest type. Nine forest type categories representing the forest resources found in the county were included in the system. Subsequently, each forest type was divided into ten subcategories, each of which represented a specific stocking level and stand size (Table 3).

The commission errors were divided into seven major land cover/use categories: 1) agriculture areas -- lands utilized for various agricultural activities; 2) treed bog -- adverse sites that support at least ten percent ground cover but of no commercial use; 3) upland and lowland brush -- potentially productive lands which support trees of less than ten percent cover and brush of various species, maturity and stocking (Table 3); 4) scattered trees -- lands supporting only scattered trees with less than ten percent occupancy; 5) urban lands -- classified as urban but with no indication of any type of tree or brush vegetation; 6) urban-trees, a subcategory of urban -- it included urban areas with considerable tree vegetation such as rural, suburban or resort residential areas; and 7) water-marsh -- areas covered permanently or periodically for a significant period of time by standing water.

The second category, upland and lowland brush, was

Table 2. Forest vegetation and land cover/use classification system developed for qualitative evaluation of the interpretation errors.

Error Class	Category	Symbol	Description
Omission	Pine	$P_0 \ldots P_9$	Stands ranging from regeneration to full stocking sawtimber*
	Oak-Hickory	$O_0 \ldots O_9$	"
	Northern Hardwoods	$M_0 \ldots M_9$	"
	Aspen	$A_0 \ldots A_9$	"
	Lowland Hardwoods	$E_0 \ldots E_9$	"
	Mixed Hardwoods	$K_0 \ldots K_9$	"
	Conifer Swamps	$Q_0 \ldots Q_9$	"
	Spruce-Fir	$S_0 \ldots S_9$	"
	Locust	$B_0 \ldots B_9$	"
Commission	Agriculture	A	Areas supporting agricultural crops
	Treed Bog	B_0	Adverse sites supporting trees with more than 10% crown cover
	Upland, Lowland Brush	$B_1 \ldots B_4$	Areas with brush of variable maturity and stocking and trees of less than 10% crown cover*
	Scattered Trees	T	Areas supporting trees with less than 10% crown cover
	Urban	U	Urban areas without trees or other brush vegetation
	Urban-Trees	UT	Urban areas with tree vegetation
	Water-Marsh	W	Areas permanently or periodically covered by standing water

* For further explanation of classes see Table 3.

Table 3. Forest stand size and stocking level categories and brush (upland, lowland) ground cover classes.

Stand Size	Ave. Height of Stand (meters)	Stocking Level	Percent Crown Cover	Code
Regeneration	≤ 1	nonstocked	0	0
Saplings	1-10	Low	10-39	1
		Medium	40-69	2
		High	70+	3
Poletimber	10-20	Low	10-39	4
		Medium	40-69	5
		High	70+	6
Sawtimber	20+	Low	10-39	7
		Medium	40-69	8
		High	70+	9
Brush			0-14	1
			15-29	2
			30-59	3
			60+	4

further divided into four subcategories based upon the percentage of ground covered by brush. In this study some of the land cover/use error categories were similar to the categories employed during the compilation of the forest cover type maps (Tatem, 1978).

Another category was not included in the classification system because it did not represent classification error. This category consisted of individual forestlands that were correctly interpreted on the Landsat images and delineated on the interpretation maps but were not shown on the forest cover maps. These lands were omitted or overlooked in the forest cover type maps for three reasons. First, most of these lands occupied an area of less than the minimum mapping area (5 acres) of the forest cover type maps. Second, some of these stands were missed due to interpretation errors of the other investigator. The third reason were the plantations which have been established since the acquisition of the aerial photographs which were used for the compilation of the forest cover type maps. Forestlands which had been clear cut since the compilation of the forest cover type maps were also included in the interpretation maps (Figure 7).

To calculate the acreage of correctly interpreted forest resources on the various Landsat images, quantification of the various interpretation errors was carried out. For a precise calculation of the areal extent of the errors, a cell-grid was used. The density of the grid cell was 169 cells per square inch (25 cells per square centimeter).

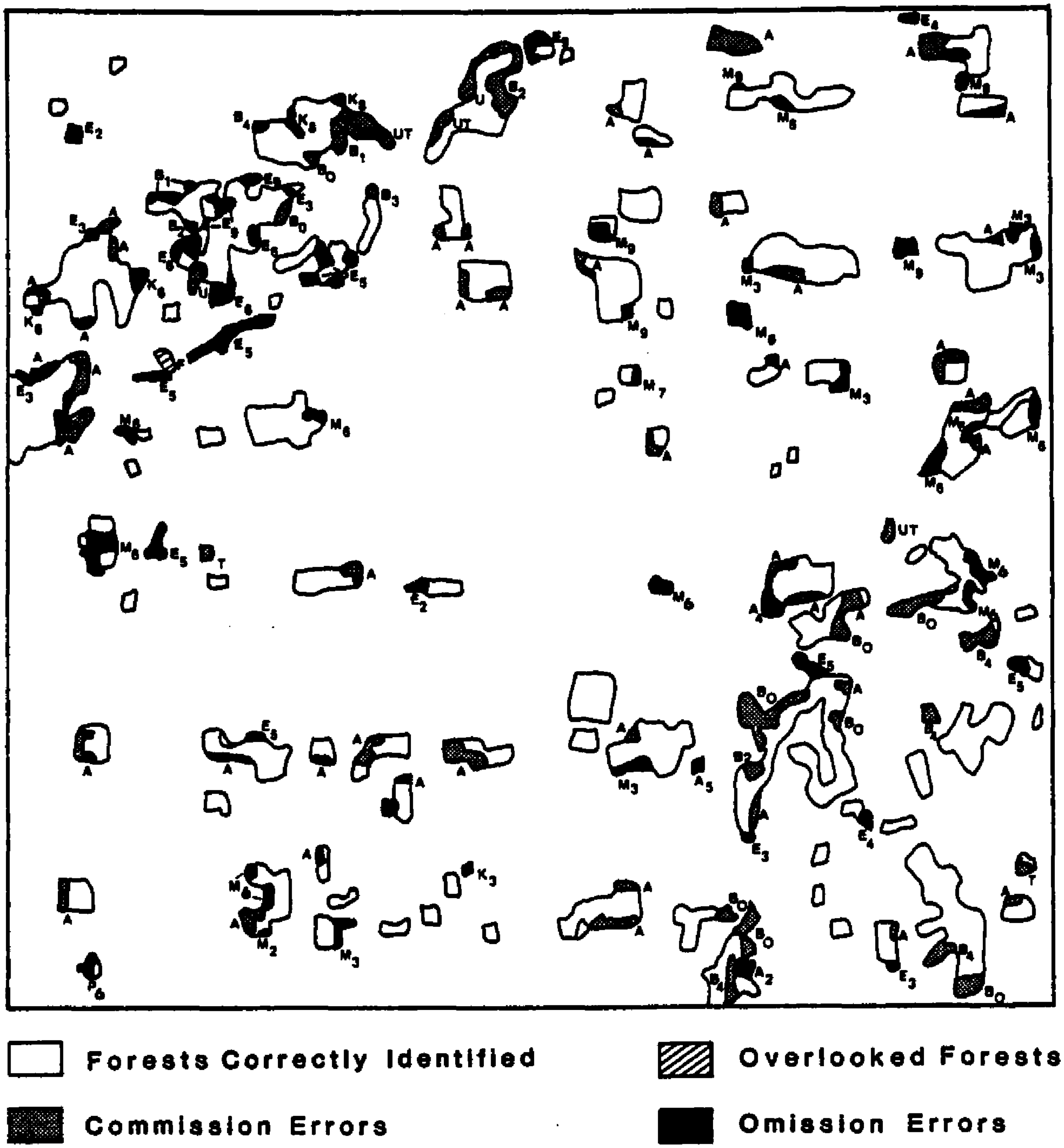

Figure 7. Forest interpretation map from the color fall image of Woodland Township, Barry County, showing commission and omission errors for different forest types. See Tables 2 and 3 for explanation of codes.

At the map scale of 1:50,000 each cell represented 2.5 acres (1.0 hectare) on the ground. To facilitate areal measurements and reduce rounding errors to less than a quarter of a cell (0.625 acres on the ground), which is less than the nominal resolution of the Landsat system (1.1 acres), the counting and recording of the various areal sizes was done on a quarter-cell basis. That is, the actual numbers recorded on the data sheets represented quarters of cells. Recording the various errors was done separately for each type of Landsat image. Commission and omission errors were recorded separately by township on data sheets (Tables 4 and 5).

To extract the required information, several tabulations of the original data were carried out. Tables 4 and 5 are representative examples to clarify the procedures followed. To determine the absolute number of cases assigned to each classification category or subcategory of errors, the cases falling within each column were summed. To determine the percent of cases in each category or subcategory, the corresponding absolute value was divided by the total number of all cases in the township and multiplied by 100. For example, the percent value of the commission boundary error A (agriculture areas) shown in Table 4 was equal to 40.3, that is $\frac{25}{62}$ x 100, whereas the corresponding value of the omission boundary error K_4 (mixed hardwoods) of Table 5 was 6.8, that is $\frac{5}{73}$ x 100. All values were rounded off to one decimal place.

Table 4. An example of a commission error data sheet for winter color scene of Johnstown Township.

Township Johnstown Type of Imagery Winter Color

COMMISSION ERRORS

Error	Boundary: A	B_0	B_1	B_2	B_3	B_4	T	U	UT	W	Total #	Total Acreage
	4*	12	1	8			4	4	8	5	8	28.9
	4	9	7	10			7	3	12		7	12.5
	2	5	12				3	7	4		6	20.8
	3	5	8						12		4	17.5
	5	9							8		3	13.8
	3	4							10		3	15.6
	5								3		2	5.0
	6								5		2	6.9
	3								8		2	6.9
	22										1	13.7
	9										1	5.6
	4										1	2.5
	6										1	3.7
	7										1	4.4
	12										1	7.5
	7										1	4.4
	3										1	1.9
	2										1	1.3
	3										1	1.9
	2										1	1.3
	3										1	1.9
	7										1	4.4
	17										1	10.6
	4										1	2.5
	8										1	5.0
Frequency: Absolute	25	6	4	2			3	3	9	1	53	
Frequency: Percent	40.3	9.7	6.5	3.2			4.9	4.9	14.5	1.6	85.5	
Acreage: Total	95.8	27.6	17.6	11.2			8.7	8.7	48.6	3.1		228.5
Acreage: Mean	3.8	4.6	4.4	5.6			2.9	2.9	5.4	3.1		
Acreage: Standard Deviation	3.8	2.8	2.8	0.9			1.3	1.3	2.9	0		
Acreage: Percent	36.7	10.7	6.8	4.4			3.4	3.5	18.8	1.2		85.2

Error	Identification: A	B_0	B_1	B_2	B_3	B_4	T	U	UT	W	Total #	Total Acreage	Overall Error #	Overall Error Acreage
		16				7		5	4		4	20.0	12	48.9
		6							4		2	6.3	9	18.8
									5		1	3.2	7	67.8
									10		1	6.3	5	23.8
									4		1	2.5	4	16.3
													3	15.6
													2	5.0
													2	6.9
													2	6.9
													1	13.7
													1	5.6
													1	2.5
													1	3.7
													1	4.4
													1	7.5
													1	4.4
													1	1.9
													1	1.3
													1	1.9
													1	1.3
													1	1.9
													1	4.4
													1	10.6
													1	2.5
													1	5.0
Frequency: Absolute		2				1		1	5		9		62	
Frequency: Percent		3.2				1.6		1.6	8.1		14.5			
Acreage: Total		13.9	-			4.4		3.1	17.0			30.3		258.8
Acreage: Mean		6.9				4.4		3.1	3.4					
Acreage: Standard Deviation		4.4				0		0	1.3					
Acreage: Percent		5.3				1.7		1.2	6.6			14.7		

*The unit value is equal to 0.625 acres.

Table 5. An example of an omission error data sheet for winter color scene of Johnstown Township.

Township Johnstown Type of Imagery Winter Color

OMISSION ERRORS

	Error	Boundary K_0	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	Total #	Total Acreage
		2*	14	4	4	4	4	2			5	8	24.4
			4	5		3	3					4	9.4
			4	16		5	3					4	17.5
				11		6	8					3	14.4
						4	18					2	13.7
							4					1	2.5
							2					1	1.3
							4					1	2.5
Frequency	Absolute	1	3	4	1	5	8	1			1	24	
Frequency	Percent	1.4	4.1	5.5	1.4	6.8	11.0	1.4			1.4	32.8	
Acreage	Total	1.3	13.8	22.4	2.5	12.5	28.8	1.3			3.1		85.7
Acreage	Mean	1.3	5.6	5.6	2.5	2.5	3.6	1.3			3.1		
Acreage	Standard Deviation	0	4.4	3.5	0	0.4	3.3	0					
Acreage	Percent	0.5	7.4	9.8	1.1	5.5	12.5	0.5			1.4		37.4

	Error	Identification K_0	K_1	K_2	K_3	K_4	K_5	K_6	K_7	K_8	K_9	Total #	Total Acreage	Overall Error #	Overall Error Acreage
														8	24.4
														4	9.4
														4	17.5
														3	14.4
														2	13.7
														1	2.5
														1	1.3
														1	2.5
Frequency	Absolute											0		24	
Frequency	Percent											0		32.8	
Acreage	Total												0		85.7
Acreage	Mean														
Acreage	Standard Deviation														
Acreage	Percent												0		37.4

Overall Omission Error in the Township	
Number:	73
Acreage:	229.0

*The unit value is equal to 0.625 acres.

In order to determine the various acreage values on the data sheets, the following procedure was used. First, the originally recorded values (number of quarter cells) were transformed to acreage values. Then the mean, the total, and the standard deviation of each category or subcategory were calculated following basic statistical procedures and formulae. The percent value of the total of each category or subcategory for the overall error assigned to each class (commission or omission) in the township was calculated using a similar approach. For example, in the case of the commission errors, A, the percent value of the total acreage over the overall commission error in the township was 36.7, that is $\frac{95.0}{258.8} \times 100$, whereas the corresponding value of the omission error K_4 was 5.5, that is $\frac{12.5}{229.0} \times 100$.

These calculated values were then used to answer various questions and to clarify, to some extent, the utility of the Landsat technology to certain forest management activities.

CHAPTER VI

RESULTS AND DISCUSSION

The data collected from the evaluation of the interpretation of the Landsat images was manipulated in various ways in order to extract the maximum information available. A number of computations, tabulations and graphs were made to: 1) illustrate characteristics and aspects of the forest resources which affected the interpretation performance; and 2) analyze the various sources of interpretation error.

A. Interpretation Errors

Commission and omission errors were probably due to three major factors: the sensor system and image generation process, the interpretation equipment and the interpreter. The spatial, spectral and radiometric resolution of the Landsat sensors places real limits on the accuracy that can be achieved. For example, the probability of detecting forest areas of a size close to or smaller than the spatial resolution of the Landsat system (1.1 acres) is lower than for larger forest tracts. Also, the brightness values of pixels are average reflectance values that represent the mixture of features within each pixel. Therefore, where pixels intercept the forest boundary and the orientation of pixels with respect to the boundary line, affects boundary position and sharpness on the image. Of course, seasonal and atmospheric factors during the recording of the data are also very important. For example, snow on the ground may completely cover young forest regeneration areas and/or may affect the spectral appearance of stands of lower density. Extensive haze may also affect the spectral contrast on the imagery. A certain amount of boundary and interpretation errors in this study were due to the drawbacks of the system and the overall climatic conditions prevailing in the area at the time the data were collected. Projection and magnification of the images by the interpretation equipment affects image geometry and clarity to some extent. Considering the above limits and the inevitability of working within them, the interpreter's experience and background is probably the most important factor.

The first step in the manupulation phase was to summarize the various interpretation errors and present them in tabular form. One table was constructed for each of the four Landsat images (Tables E-1 through E-4 in Appendix E). For each Landsat image, the corresponding table contains the frequency of boundary and identification commission and omission errors and their acreage in the form of absolute and percent values. The percent values refer to the total commission or omission error in the township. Furthermore, the Total Percent column indicates the percent contribution of the commission and omission errors made in each township to the total commission or omission errors of the county.

The summarized commission and omission error results of the whole county in absolute and percent values are shown in Table 6. The absolute values in the table illustrate the number of error cases and the total acreage involved in the errors arranged by type of error and Landsat image.

1. Commission Errors

The smallest total commission error, in terms of number of cases and acreage occurred during the interpretation of the winter standard color composite (henceforth referred to as winter color). Commission errors are shown in Table 6. The second best imagery, in terms of commission error, was the fall diazo color composite (henceforth referred to as diazo), and third was the winter black-and-white image of band 5 (henceforth referred to as black-and-white). The poorest results, in terms of acreage, were given by the standard fall color imagery (henceforth referred to as fall color). The total commission errors of the images expressed in percentages of the total forest acreage in the study area were 5.3, 12.0, 15.5 and 16.3, respectively (Figure 8).

The low commission error of the winter color imagery may be due to two factors:

1. The time of the year the imagery was taken. At that time, February 26, 1979, snow 12 inches deep (Weather Bureau, U. S. Department of Agriculture) covered the whole county. The snow cover increased the spectral contrast of

Table 6. Errors of interpretation performance by type of Landsat image[1] for Barry County, Michigan.

T Y P E   O F   L A N D S A T   I M A G E

		Black-and-White Winter				Color Fall				Color Winter				Diazo Fall			
		Frequency		Acreage[2]		Frequency		Acreage		Frequency		Acreage		Frequency		Acreage	
Error		Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
Commission	Boundary	1255	88.8	7988.9	86.1	1191	92.2	9113.9	93.4	482	87.6	2603.0	83.8	1127	96.1	6957.4	96.9
	Identification	158	11.2	1293.6	13.9	95	7.8	638.6	6.6	68	12.4	503.8	16.2	46	3.9	222.6	3.1
	Total	1413	100.0	9282.5	100.0	1291	100.0	9752.5	100.0	550	100.0	3106.8	100.0	1173	100.0	7180.0	100.0
Omission	Boundary	591	90.8	2670.8	89.1	1017	85.6	7294.4	87.2	878	91.1	3796.8	89.1	936	86.0	5465.1	86.7
	Identification	60	9.2	326.2	10.9	172	14.4	1068.4	12.8	86	8.9	465.5	10.9	152	14.0	839.0	13.3
	Total	651	100.0	2997.0	100.0	1189	100.0	8362.8	100.0	964	100.0	4262.3	100.0	1088	100.0	6304.1	100.0

[1] Total forest acreage: 59,876 acres.

[2] The acreage values represent the number of acres incorrectly interpreted. They are expressed in acres in all subsequent tables and graphs.

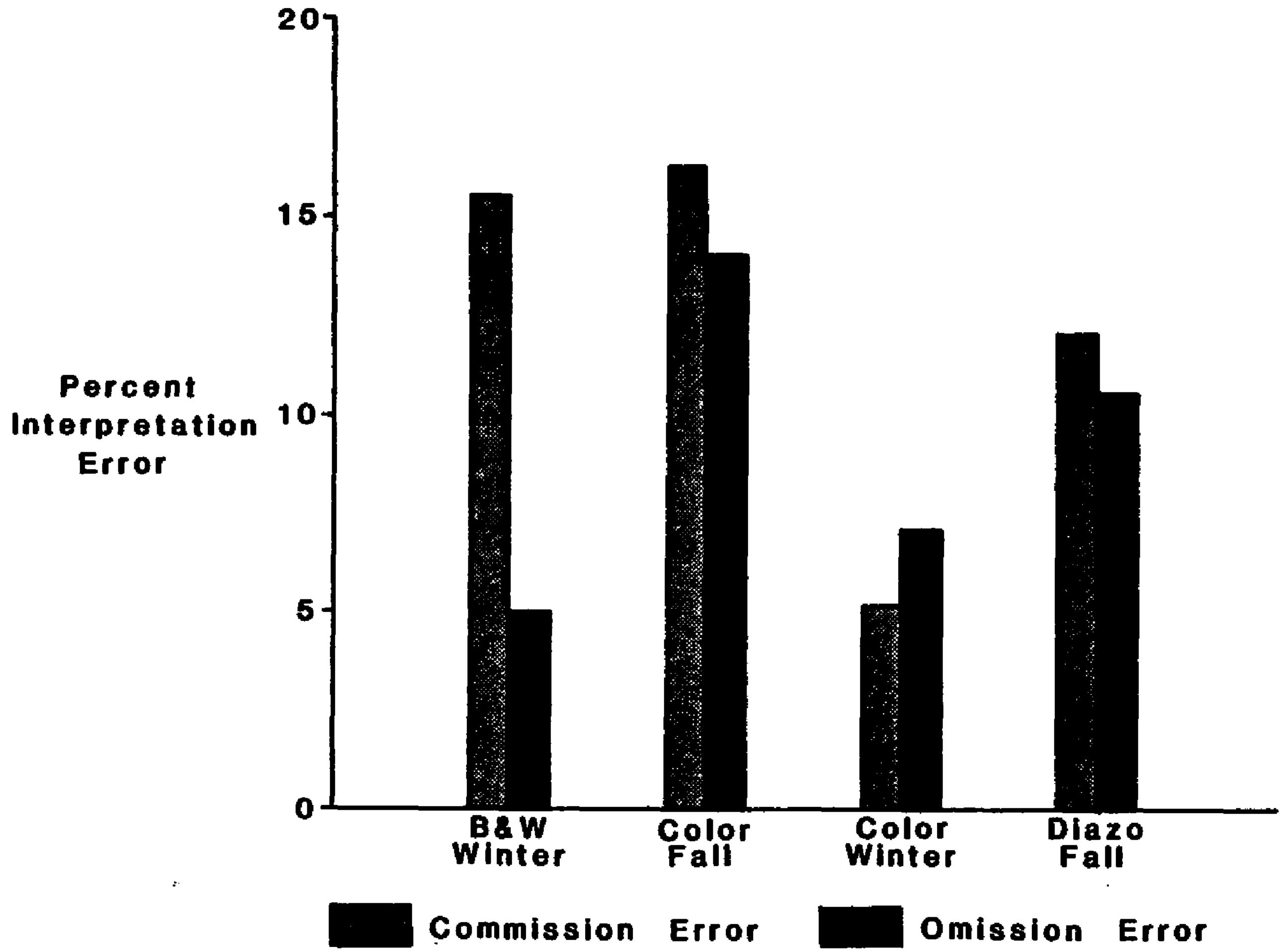

Figure 8. Interpretation commission and omission errors expressed as percentages of the total forest acreage in the study area by type of Landsat image.

the forested areas against the surrounding land cover/use classes. Therefore, the boundaries of many forest tracts appeared very sharp and well-defined on the imagery and, subsequently, were well depicted during the interpretation process. Furthermore, the complete or partial cover by snow of shrub lands, wetlands, brushlands and agricultural lands, resulted in an image in which very few land cover/use categories could be misinterpreted as forests. This fact reduced the possibility of making commission errors and, subsequently, improved the interpretation performance.

2. The color tone variation of the image also contributed substantially to the improvement of the interpretation performance and the reduction of the commission errors. The color factor lessened the misclassification of agriculture, brushland, treed bog, water-iced and marshy areas as forests.

For the black-and-white imagery, the lack of color tone and of multiband depiction was the primary factor which contributed to the substantial increase of the commission errors. Portions of agricultural areas within or adjacent to forestlands and treed bogs and brushlands were often misinterpreted as forests. The misclassification was attributed primarily to the similar gray tone appearance of these areas and forests on the imagery. Most of the commission errors were boundary errors. In most cases non-forest vegetation obscured the high reflectance of the underlying snow to a variant degree, causing misclassifications. The high number of boundary errors may be caused by an agricultural or shrub zone of variant width along the edges of forest tracts. This zone had little or no snow on the ground at the time the imagery was taken. It was distinguishable on the winter color image but not the black-and-white.

The two fall images, color and diazo, had relatively high commission errors in comparison to the winter color scene. The resultant high total commission error during the interpretation of the fall color imagery was due primarily to the low radiometric quality of the scene. The spectral contrast between certain vegetation types (e.g., treed bog, brushlands) and the forest resources was low, a fact which created difficulties during the interpretation process and, in some cases, raised questions concerning decisions for the right classification. A certain degree of improvement was expected through the diazo process. The diazo imagery improved the total commission error by 2,572.5 acres (1,029.0 hectares) over the fall color imagery. In percentage values, the improvement was 4.3 of the total forest acreage in the county. In the case of the Landsat fall imagery, the low radiometric quality of the individual black-and-white Landsat images lowered the effectiveness of the diazo processing. The spectral similarity between the forest areas and other land cover/use types (Brushlands, Urban-Tress and Treed Bog) prevented a complete and absolute visual separation of the forest resources and a sharp definition of forest boundaries. In the final diazo copy some land cover/use classes were recorded in tones similar to those of the forests, and so, differentiating between them was difficult. If a better quality black-and-white Landsat image was used in the production of a diazo color composite, it may significantly reduce the amount of commission error by increasing the separability of the forest resources from the other land cover/use classes.

Separation of the commission error into "boundary" and "identification" revealed very clearly that the former category contributed the most to the total error. In all types of imagery, the boundary error contributed more than 83.0 percent to the total commission error in terms of acreage, and more than 87.0 percent in terms of frequency of error cases (Table 6). The boundary error percentages of the winter images were below 90.0, whereas those of the fall images were larger (Figure 9). Black-and-white and diazo images had the highest percentages in terms of boundary error acreage.

Identification error, on the other hand, was relatively small for all types of Landsat images. The lowest identification error (Figure 9) for both acreage and frequency was accomplished with the diazo imagery. The sequence of the other images in terms of acreage was fall color, black-and-white and winter color.

In summary, the winter color imagery was superior to all other images in terms of frequency and acreage of

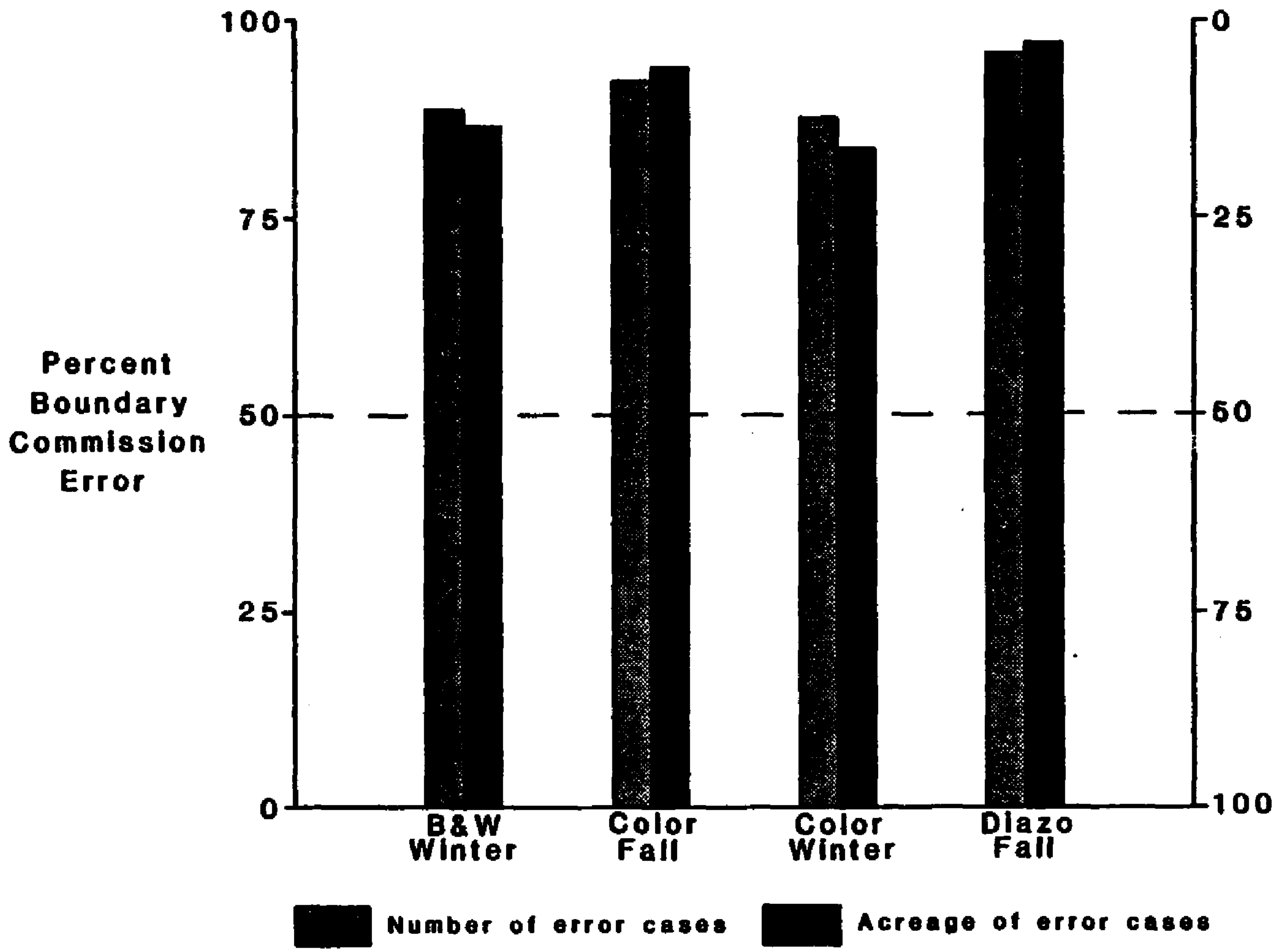

Figure 9. Percent boundary and identification commission errors by type of Landsat image.

commission error. The sequence of the other images was as follows: diazo, black-and-white and fall color. The diazo imagery improved the commission error acreage substantially over the fall color, however, the absolute value was relatively high. It was also seen that the primary source of the commission error during the interpretation of all Landsat images was boundary error, whereas the identification error contributed only marginally.

2. Omission Errors

The second major category of interpretation error was omission error. The smallest total omission error in terms of number of cases and acreage was accomplished by interpreting the black-and-white imagery (Table 6, Figure 8). The total omission error acreage of this imagery was 5.0 percent of the total forest acreage in the county. The corresponding percentages of the other images were 7.1 for the winter color, 10.5 for the diazo and 14.0 for the fall color. Also, the frequence of the error cases increased proportionately to the omission error, in acres, in all images.

The existence of snow on the ground (as in the commission error) improved the spectral contrast of the forestlands and their surroundings in the winter images. Comparison of the omission error acreages of the winter images indicated that the acreage of the winter color imagery was larger than that of the black-and-white image. These results were not expected since a color composite image should have improved interpretability. Examination of the various factors contributing to the creation of the errors showed that color appearance of the forest areas was the primary factor. Actually, the spectral contrast between forested areas and the snow-covered background was higher in the black-and-white than in the color imagery. The number of omission errors of both fall images were almost double those of the black-and-white. In terms of acreage, the error of the diazo was double and that of the fall color almost triple the error of the black-and-white imagery. Thus, in terms of omission errors, the winter images were better than the fall images and the black-and-white had the fewest errors.

Separation of the omission error into "boundary" and "identification" error (Table 6 and Figure 10) show almost the same results as for the commission error. The boundary error acreage was over 86.7 percent of the total omission error acreage for all images. The frequency of boundary omission error cases was over 85.6 percent of the total error for all images. On the other hand, the identification omission error was very small, less than 13 percent for all images, compared to the boundary error.

In summary, the black-and-white winter imagery was the best in terms of frequency and acreage of the omission error. The winter color was the next best, followed by the diazo and fall color. Between the fall images diazo processing improved the total omission error over the fall color. As in the case of the commission error, the boundary

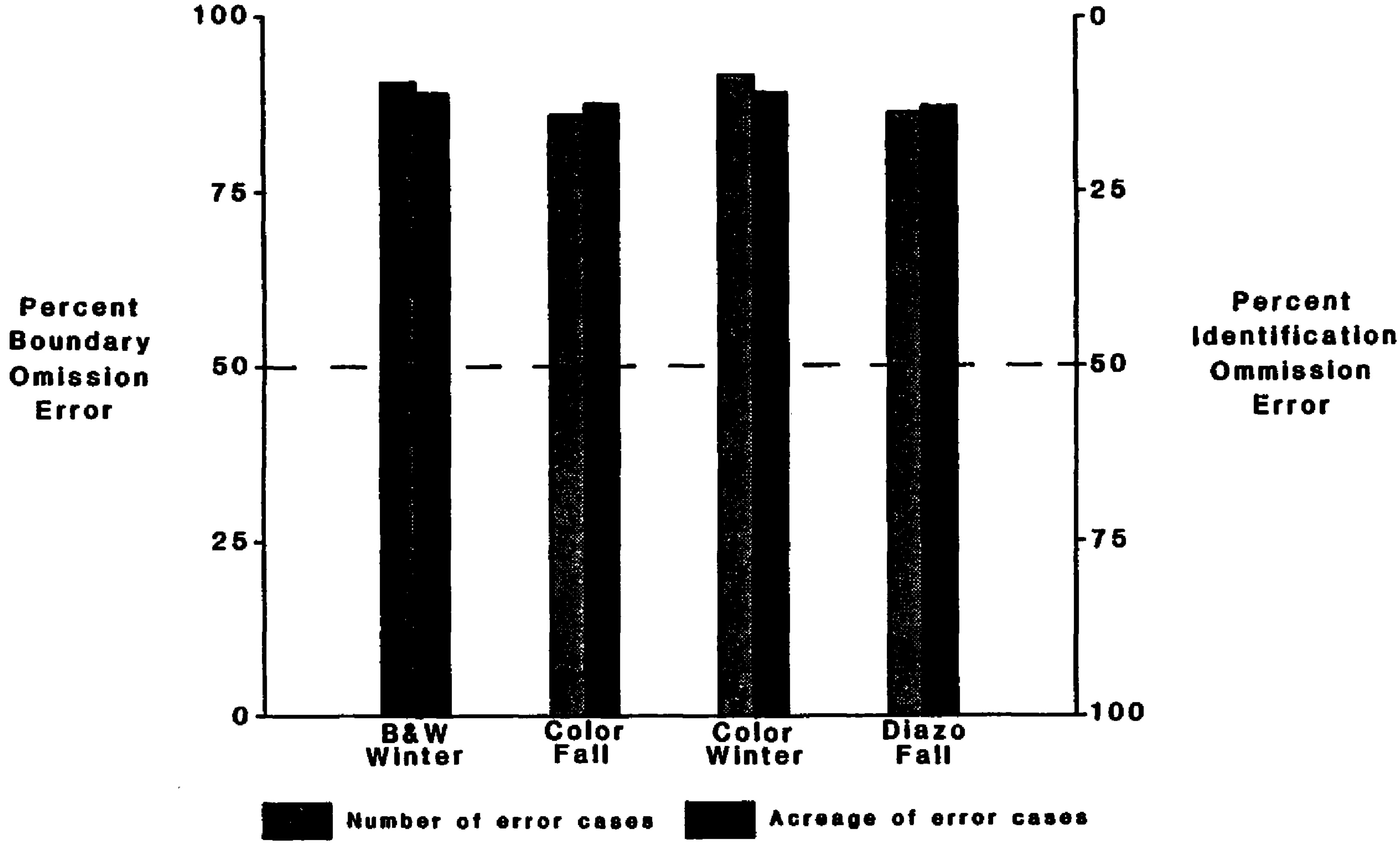

Figure 10. Percent boundary and identification omission errors by type of Landsat image.

error, in terms of frequency and acreage, was the primary source of omission error for all Landsat images. Identification error contributed only marginally which implies that the possibility of missing individual forest tracts during interpretation is very low.

3. Commission and Omission Errors--Combined Effects

So far the commission and omission errors have been discussed separately. However, both types of errors affect the interpretation performance in different ways. Commission-type errors add forest acreage to the actual total forest area, whereas omission errors subtract acreage from the total.

From Table 6 it was seen that the acreage of the total commission error was higher than that of the total omission in all but the winter color image. This indicates that the acreage of the forests in the study area was overestimated in all of the Landsat images, except for the winter color imagery (Figure 11). The large overestimation of the forest resources for the black-and-white is due to the big relative difference between the commission and omission errors with the commission error being the larger. For the other three images, the differences between the two types of errors were relatively small.

So far, from the separate analysis of the commission and omission errors, the winter color and the black-and-white images were recommended as the best images, respectively. However, consideration of both types of error together

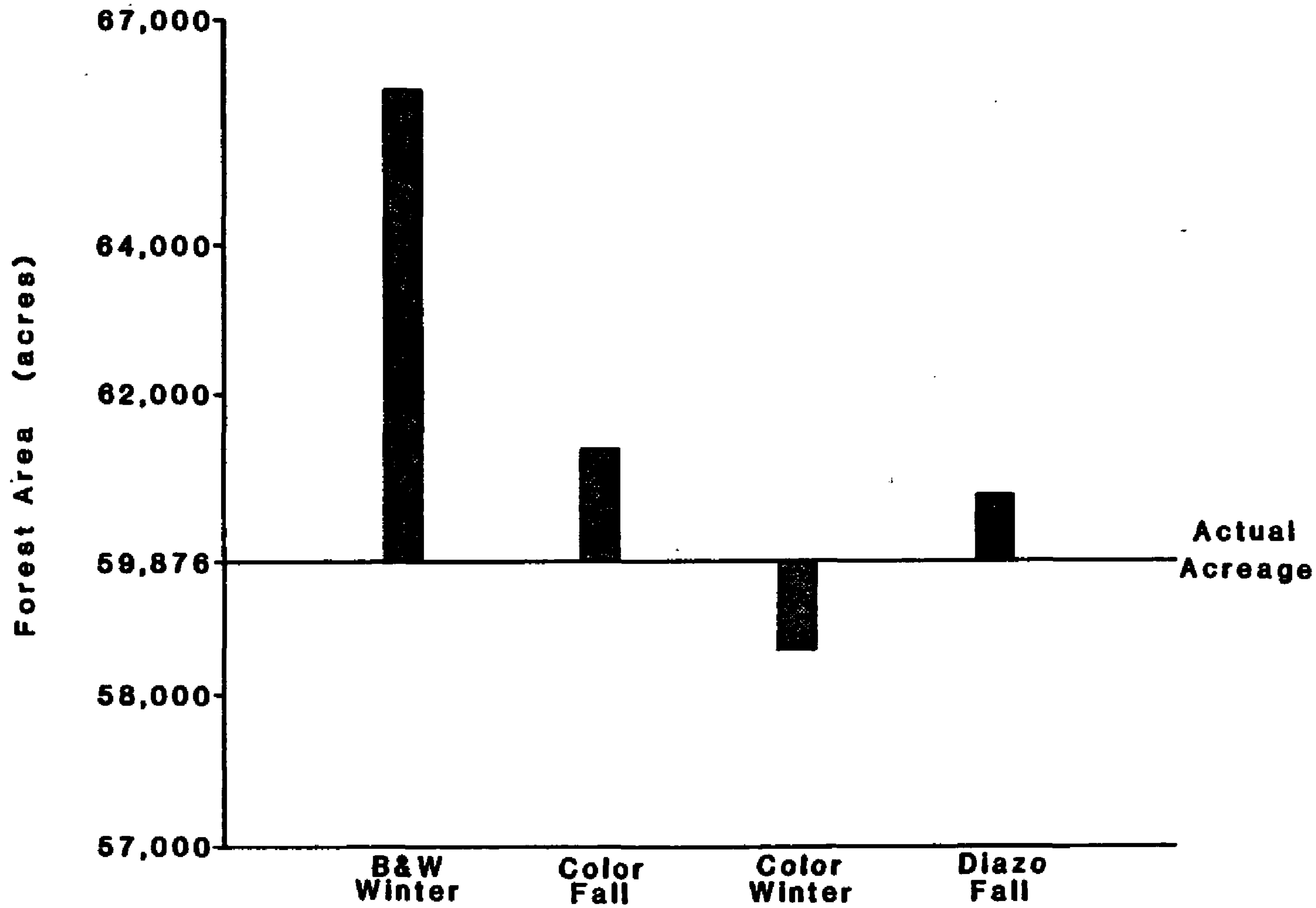

Figure 11. Variation of the estimated total forest area (in acres) by type of Landsat image.

indicates that the black-and-white imagery substantially overestimated the forest resources in the study area compared to the other three images. Examination of the respective errors for the other images revealed the superiority of the winter color imagery over the fall images. Thus, the winter color imagery is recommended as the best overall imagery for the interpretation of forest resources. If this imagery is unavailable, diazo processing of fall imagery is recommended.

B. Accuracy Analysis

So far, the discussion has dealt with the various errors that occurred during the interpretation process. How did these errors affect the overall accuracy of the visual interpretation of the forest resources? Because color infrared photos were often used as ground truth data, "agreement" is a more appropriate term than "accuracy." However, the meaning in terms of the evaluation process is the same so both terms will be used interchangeably.

Three types of accuracy or agreement were defined and calculated in this study: 1) classification agreement which is the percent value of the size of correctly interpreted forest resources over the total reference (actual) resource size; 2) interpretation agreement which is the percent value of the size of correctly interpreted forest resources plus the area of the commission error over the total reference (actual) size of the forest resources; and 3) mapping agreement which is the percent value of the size of correctly interpreted forest resources over the size of the total area displayed on the map after the evaluation. The use of a certain agreement type depends exclusively upon the established objectives, needs and requirements of the forest manager.

1. Classification Agreement

Classification agreement expresses the accuracy of interpretation, taking into account only the omission classification errors. Frequently, a forest manager is interested in how accurately individual forest tracts were identified, without taking into consideration the misinterpretation of non-forest classes as forests (i.e., commission errors).

The formulae for the calculation of classification agreement are given below; K_1 equals absolute acreage agreement, K_2 equals percent agreement:

$$K_1 = T - O$$

$$K_2 = \frac{T - O}{T} \times 100 \text{ where:}$$

K = classification agreement of the forest class
T = total acreage of the forestlands in the county
O = total acreage of the forestlands which were not classified as forests (omission error)

The two expressions of the classification agreement, K_1 and K_2, were calculated and tabulated for all types of Landsat imagery (Table 7).

According to the calculated figures, the classification

Table 7. Classification, interpretation and mapping agreement by type of Landsat image.

T Y P E   O F   L A N D S A T   I M A G E

Agreement	Black-and-White Winter		Color Fall		Color Winter		Diazo Fall		Total Forested Acreage
	Acreage	%	Acreage	%	Acreage	%	Acreage	%	
Classification	56879.0	95.0	51513.2	86.0	55613.7	92.8	53571.9	89.5	
Interpretation	66161.5	89.5	61265.7	97.7	58720.5	98.1	60751.9	98.5	59876
Mapping	56879.0	82.2	51513.2	74.0	55613.7	88.3	53571.9	79.9	

agreement for all types of imagery was over 85 percent (Figure 12). Of them, the best results (95.0 percent) were given by the black-and-white imagery, followed by the winter color (92.8 percent), the diazo imagery (89.5 percent), and the fall color imagery (86.0 percent). The forest acreage of the study area was underestimated in all cases because the value of the omission error was subtracted from the reference value (total) in the formula.

In summary, the black-and-white imagery gave the best classification agreement, followed closely by the winter color imagery. On the other hand, if a 90.0 percent classification agreement is assumed to meet the requirement of a forest inventory, then the diazo imagery almost fulfills this condition. The diazo technique appears to be very promising.

2. Interpretation Agreement

Interpretation agreement expresses the degree with which the forest resources were interpreted on the Landsat imagery, taking into account not only the omission errors but also the commission errors.

The forest manager may be simply interested in getting only a total acreage estimate of the forest resources and not the details of the interpretation errors, the error characteristics (omission-commission) and location. If so, then the interpretation agreement provides the required information. This type of accuracy has been used in many cases in the past; however, the results do not reflect the actual

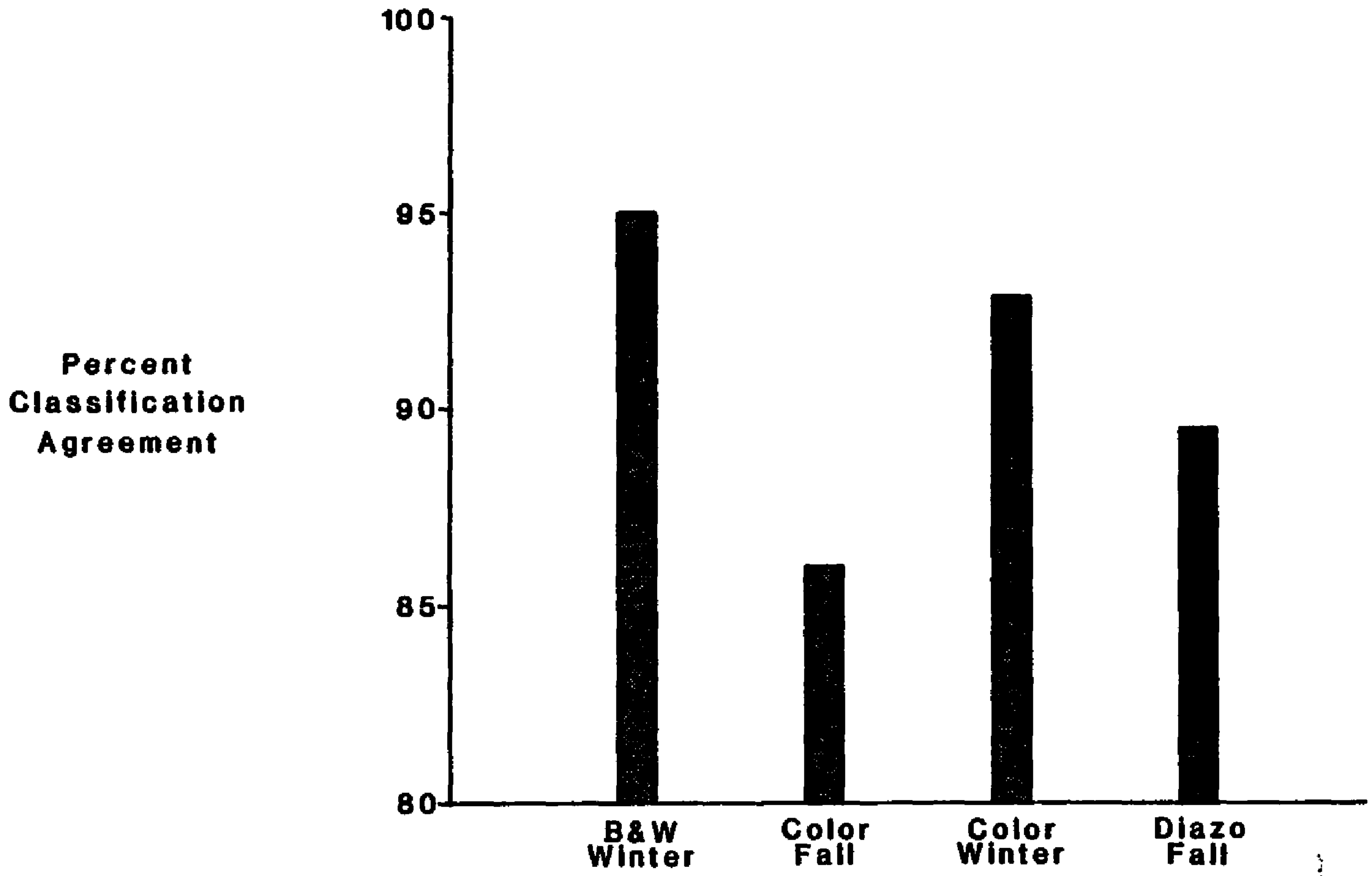

Figure 12. Percent classification agreement by type of Landsat image.

situation of the interpretation performance. Use of both the omission and commission errors to calculate the interpretation agreement (accuracy) usually results in higher agreement values than those for classification agreement.

The formulae to calculate the interpretation agreement are given below. I_1 is the absolute agreement, I_2 is the percent agreement.

$$I_1 = T + C - O$$

$$I_2 = \frac{T - |C - O|}{T} \times 100 \text{ where:}$$

I = interpretation agreement of the forestlands
C = total acreage of non-forest which is interpreted as forest (commission error)
T and O are defined as in classification agreement

Because of the use of both types of errors in the calculations of the interpretation agreement, the forest acreage was either over- or underestimated, depending upon the absolute values of the commission and omission errors. The two errors balance each other so that the percent agreement approaches 100. Therefore, the forest manager should be cautious in using the results of this type of accuracy. If the value of the commission error is bigger than the value of the omission, the interpretation agreement given is an overestimation of the actual acreage, and vice-versa.

Data from Table 6 was used to calculate absolute and percent interpretation agreement by Landsat image (Table 7). The interpretation agreement of all types of Landsat imagery was higher than 89.0 percent (Figure 13). The best interpretation agreement of the forest resources (98.5 percent) was for the diazo imagery, where forest acreage was overestimated by 875.9 acres (350.4 hectares). The winter color image had 98.1 percent agreement and underestimated by 1,155.5 acres (462.2 hectares) the total number of forest acres. This was the only case of interpretation agreement where the forest acreage of the study area was underestimated. The interpretation agreement of the fall color imagery was very close to the above values (97.7 percent), whereas the agreement of the black-and-white imagery was less than 90.0 percent.

Thus, all three images (except the black-and-white) are acceptable when an interpretation agreement of over 90 percent is desired. However, it should be emphasized again that this type of agreement (accuracy) is rather misleading. It does not display the actual affect of the various types of interpretation error on the overall classification condition. Therefore, this agreement or accuracy should be used cautiously and only if a simple number representing the accuracy of the interpretation effort is desired. On the other hand, in operational cases, it is the easiest to calculate because omission and commission errors do not have to be identified. It typically provides the highest accuracy and is, thus, frequently used in demonstrations and other activities related to the transfer of the new technology. It is also applied in extensive regional inventories of natural resources

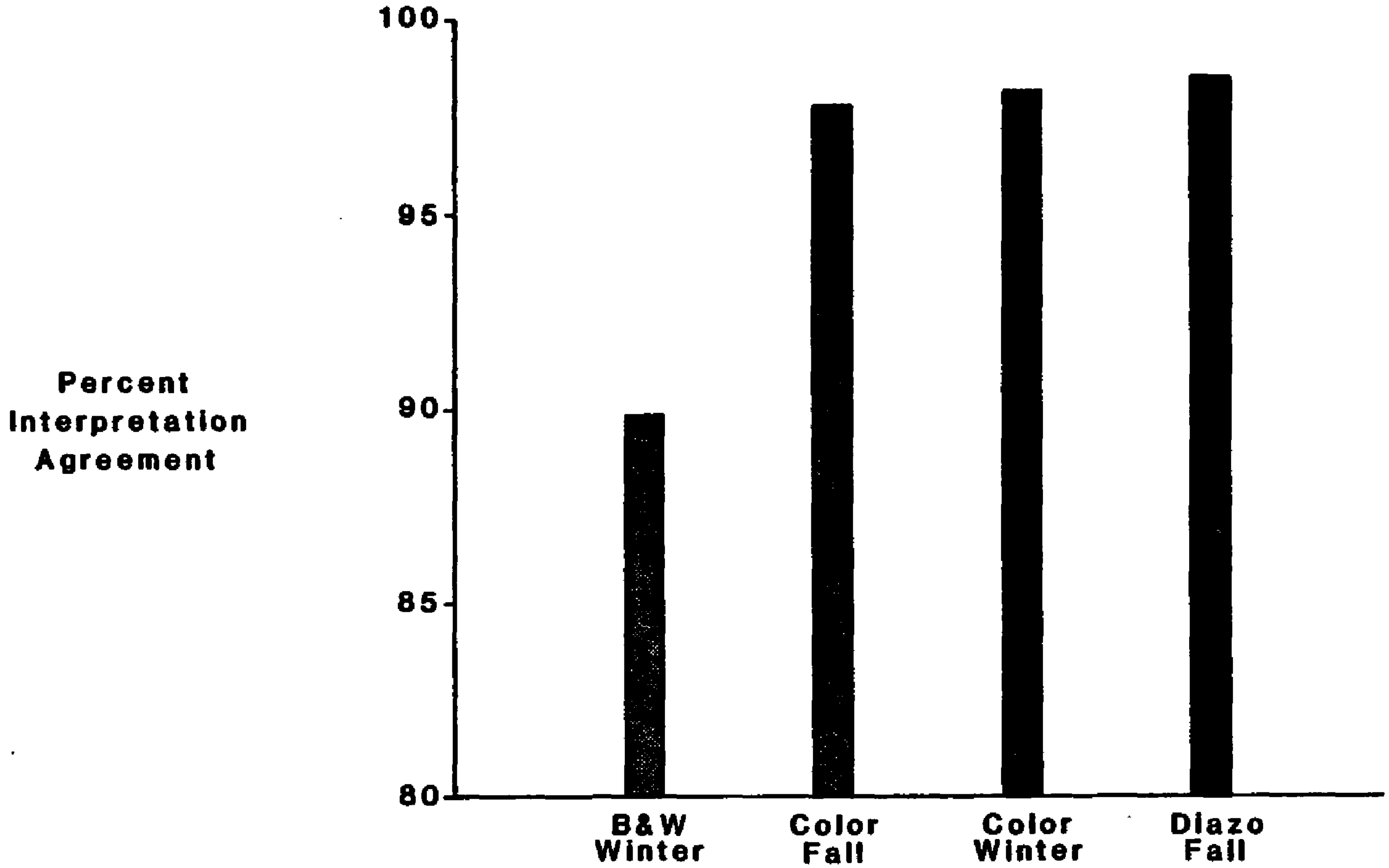

Figure 13. Percent interpretation agreement by type of Landsat image.

where only a simple estimate value is required.

3. Mapping Agreement

If the forest manager requires a value which indicates the locational or positional accuracy of the interpretation map when compared with ground conditions, the mapping agreement or accuracy provides this desired information (Kalensky and Scherk, 1975).

Mapping agreement is expressed by the following formulae where M_1 is the absolute acreage agreement and M_2 is the percent agreement.

$$M_1 = T - O$$

$$M_2 = \frac{T - O}{T + C}$$ where:

M = mapping agreement

T, O and C are defined as before

The absolute values of the mapping agreement were the same as those of the classification agreement so they will not be discussed again (Table 7). Only the percent values of the various images will be discussed. These values best reflect the actual overall situation of the interpretation performance and they appear to be lower than the values of the other two types of agreement. Specifically, all the values of this agreement ranged between 88.3 and 74.0 percent. The best imagery was the winter color, followed by the black-and-white, the diazo and the fall color. Winter color imagery ranked first because the absolute values of both the commission and omission errors of this imagery were relatively small (Figure 14). The second place mapping accuracy of the black-and-white imagery was due, primarily, to the small value of the omission error. Among the fall images the interpretation of the diazo gave better mapping agreement than the fall color because the absolute values of both the commission and omission error of the diazo were lower. Diazo processing improved the mapping agreement by 5.5 percent over the fall color.

Summarizing the conclusions of the analysis, the winter color imagery gave very good results in all types of interpretation performance. It is recommended as the best alternative. However, it may be difficult to find a cloudless winter scene with snow on the ground and, therefore, diazo imagery is recommended as a second alternative.

C. Size of Interpretation Errors

The misclassification problem requires thorough investigation and careful consideration. The various errors which occurred during the interpretation of the Landsat images affected the overall performance, the type and accuracy of the information selected and, finally, the assessment of the potential contribution of the Landsat system to various forest management programs.

Analysis of the errors by size should give a better understanding of the affect of the various images on the interpretation performance. In fact, the size of the errors

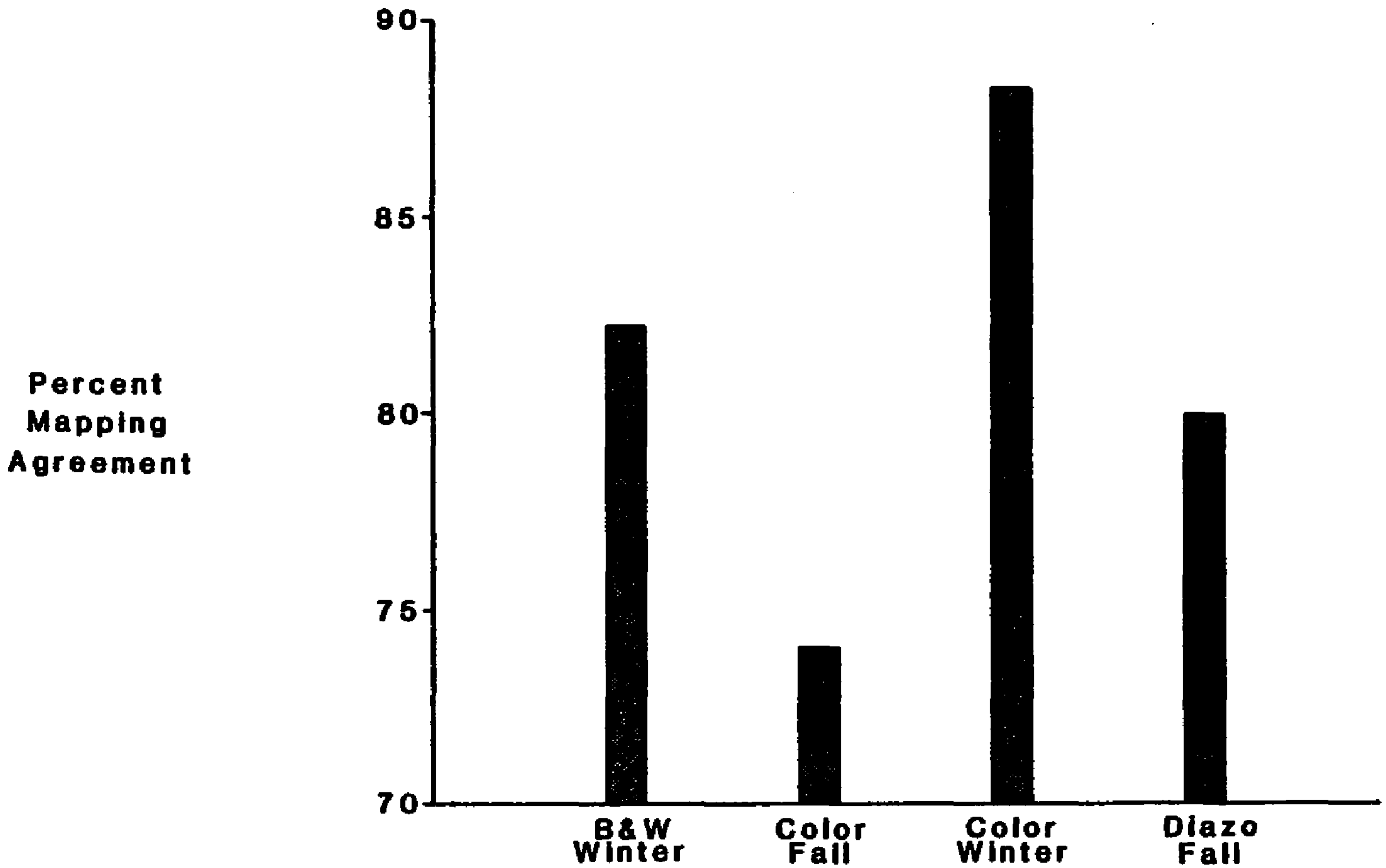

Figure 14. Percent mapping agreement by type of Landsat image.

is probably the most important factor. It is beneficial to know the percentages of the errors assigned to different size classes, because the commitment of a small number of large size errors usually is more important and raises more questions than the commitment of a large number of small size errors. The small size errors can be justified more easily as they approach the spatial resolution limits of the sensor system.

The errors were classified as total error and commission and omission errors subclassed into boundary and identification errors. The errors were then cross-classified into five size classes: 0.1-5.0 acres; 5.1-10.0 acres; 10.1-15.0 acres; 15.1-20.0 acres; and over 20.0 acres. The following is a general discussion of the results (see also Appendix E).

1. Commission Errors

Based on the data (Table E-5) more than half of the total number of commission errors made during the interpretation of each satellite image fell within the smallest size class (0.1 to 5.0 acres). However, the frequency of making commission errors of less than five acres was higher in the winter than in the fall images. Furthermore, the average size of errors of the winter color imagery assigned to this class was the smallest among all images (3.0 acres, or 1.2 hectares). The winter color imagery had the highest among all images and the diazo the highest among the fall images. The corresponding percent acreage values of the smallest error size class varied slightly between the winter color, diazo and black-and-white images (Figure 15). Examination of the percentages of the commission errors of the fall images assigned to the smallest size class indicates that the diazo imagery had the largest percent error in this class. Therefore, diazo processing improved the interpretation of the forest resources over the fall color.

Generally, the total number and acreage of errors of more than five acres in size was smaller in the winter than in the fall images. This implies that the commission errors of the fall images were more significant than those of the winter images. Also, the percentages of error cases and the respective acreage values were smaller in the winter than in the fall images. For the other size classes, as class size increased the percentages of error cases assigned to each size class decreased. In the last class (over 20.0 acres), for all images except the diazo imagery, the percent total error acreage increased. This implies that, except for the diazo imagery, a few of the commission errors were of fairly large size. Both number and acreage of the error cases of all images formed distributions which are skewed toward the smaller values. The bar graph of Figure 15 illustrates very clearly the skewness of the distributions. The figure also shows a second small peak in the last class but this is due to the way the errors were grouped as this class had a much wider class-width. Most of the commission error of the winter color imagery occurred in the smallest size class.

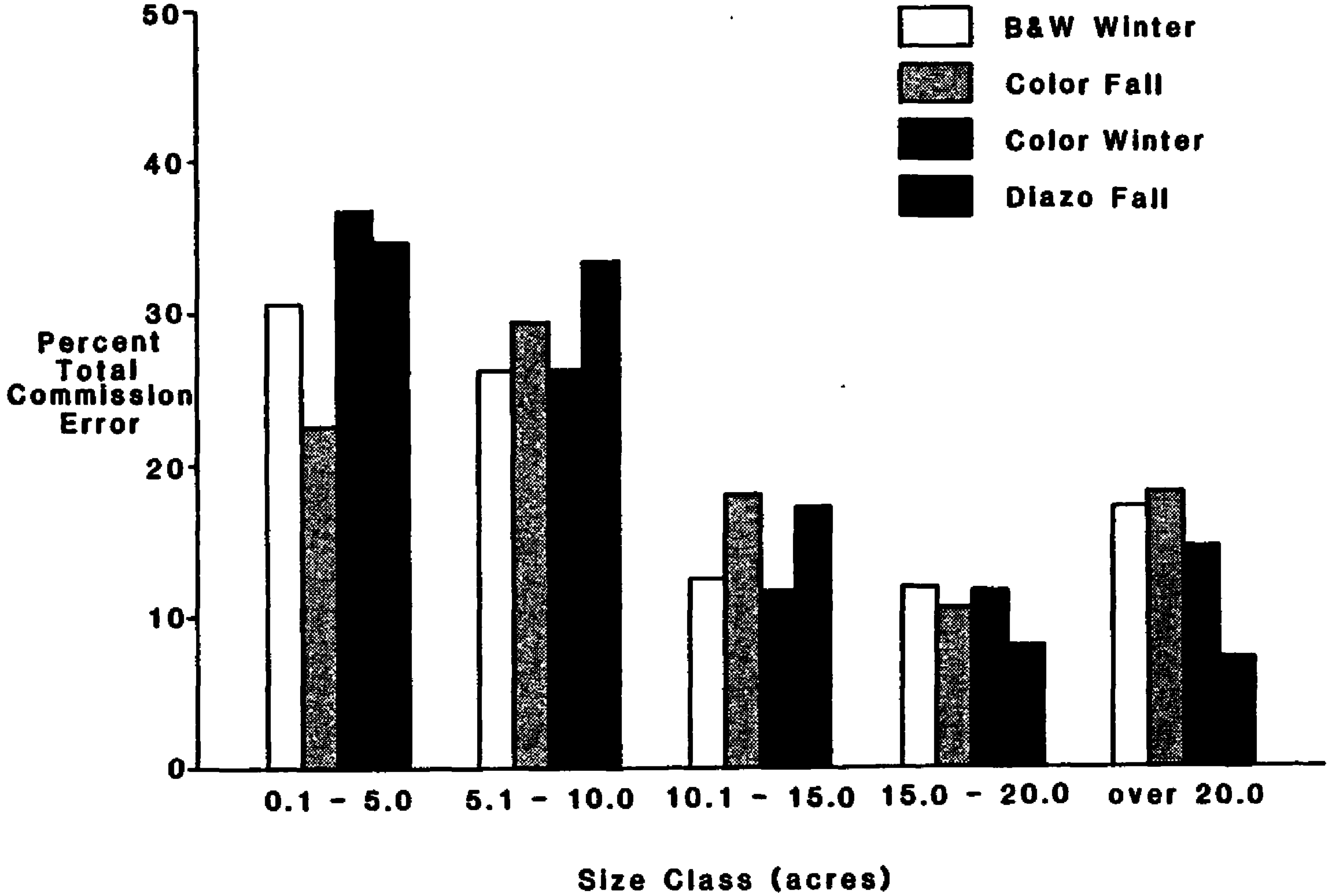

Figure 15. Distribution of total commission error by size class (acres) and type of Landsat image.

However, the diazo imagery was slightly better than the winter color imagery when the two smallest classes were considered together. This implies that the commission errors made during the interpretation of the winter color and diazo images tend to be of smaller size than the corresponding errors of the other images. Because of this, it is concluded that the use of winter color or diazo images is preferable in mapping the forest resources.

The boundary and identification commission errors were also grouped into the same five acreage size classes. Summary tables were constructed and included in Appendix E (Tables E-6 and E-7). Bar graphs of the percentages of the acreage values grouped by size class and Landsat image were created for both types of commission error (Figures 16 and 17). As in the case of the total commission error, over 50.0 percent of the number of boundary errors made during the interpretation of each image were assigned to the smallest size class. The highest percentage was that of the winter color followed by the black-and-white, diazo and fall color. In terms of acreage, the winter color had the largest percent error, followed by the diazo, black-and-white and fall color.

For identification commission error, as in the case of boundary commission errors, over 50.0 percent of the number of the identification errors had a size of less than 5.0 acres. Figure 17 illustrates the distribution of the acreage of the errors by size class. It is seen that the larger part

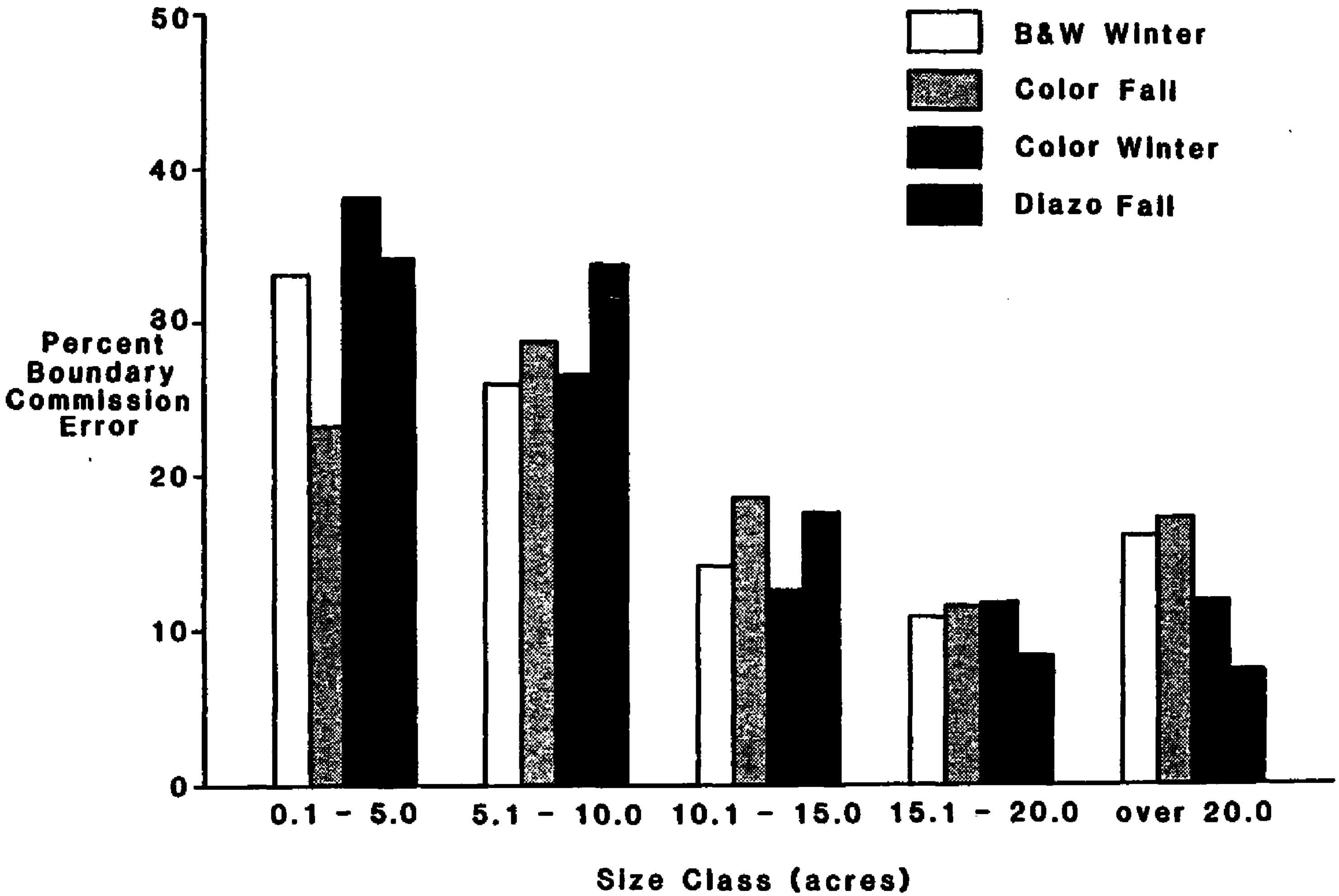

Figure 16. Distribution of boundary commission error by size class (acres) and type of Landsat image.

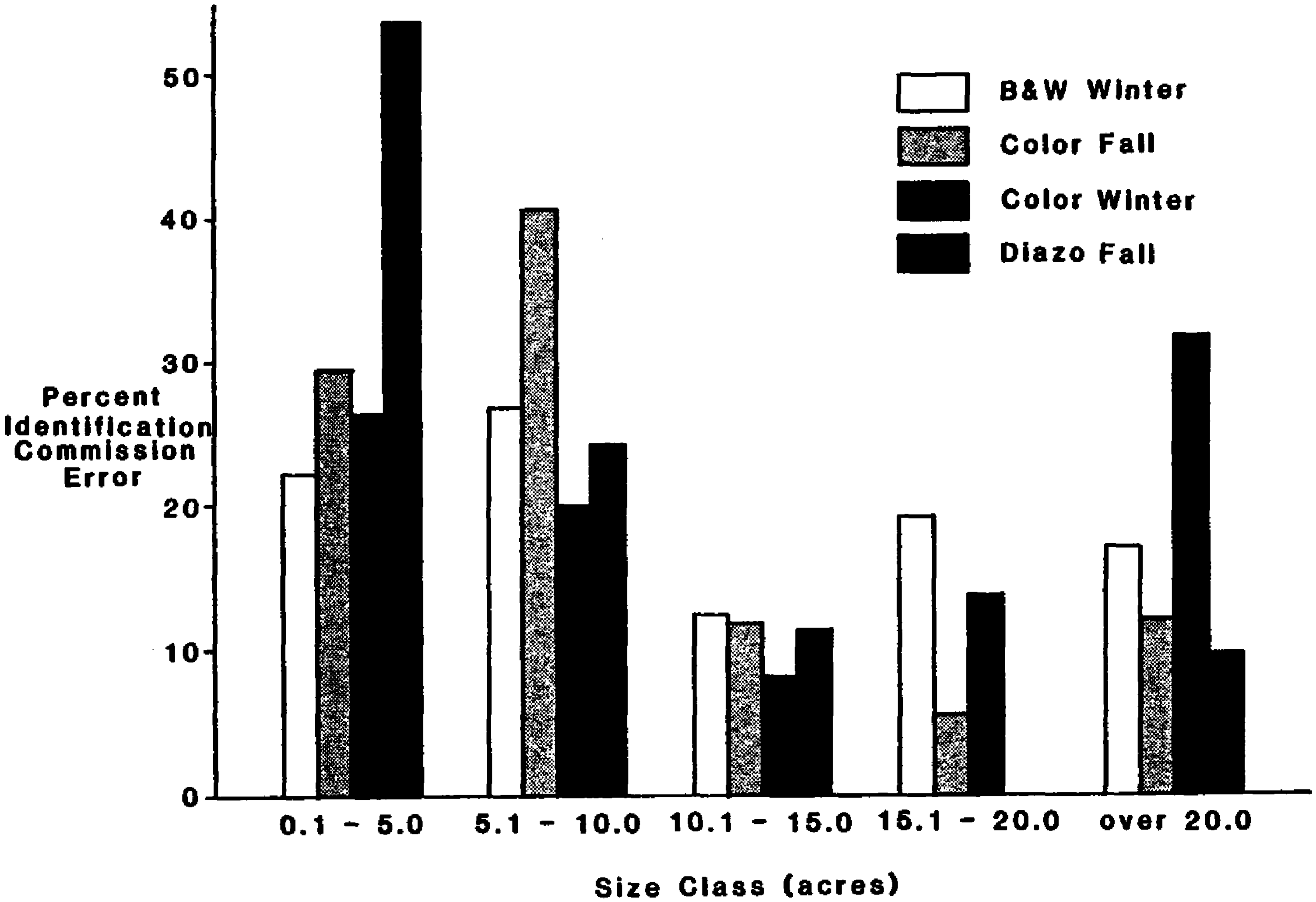

Figure 17. Distribution of identification commission error by size class (acres) and type of Landsat image.

of the error acreage in the diazo imagery was concentrated in the smaller size class, whereas in the black-and-white and fall color it was in the second class, the the last size class for the winter color. This indicates that the fall images, especially the diazo, are the best in terms of identification commission error. The same conclusion can be reached by examining the average identification error size and the respective standard deviations. However, since the percent contribution of the identification error to the overall commission error is very small compared to the corresponding contribution of the boundary error (see Table 6), the above results are negligible.

In conclusion, most of the commission errors (boundary and identification) that occurred during the interpretation of all four images had a size of less than ten acres. In three of the images (all but the fall color), the highest percentage of these errors (less than 10 acres) had an average size of less than five acres. In all images very few commission errors had a size over 20.0 acres. Only in one case (the winter color imagery) was the percent acreage of the last class (over 20.0 acres) over 30.0 percent of the total acreage of the identification error. Furthermore, comparison of the commission errors of all images indicated that the winter color was the best imagery followed by the diazo imagery.

2. Omission Errors

Total omission errors by size class are given in Table E-8. Over 55 percent of the total number of omission errors occurred in the smallest size class for all images. Over 75 percent of the total number of the omission errors in each of the winter images had a size of less than five acres. More error cases were found in the 5.1 to 10.0 acres class for the fall images than for the winter ones. However, the cumulative percentages of both classes were over 91.0 for the winter color, black-and-white and the diazo images.

In terms of acreage (Figure 18), the situation was slightly different. Approximately half of the total omission error acreage for the winter images was assigned to the smaller size class (0.1 to 5.0 acres), whereas the corresponding percentage of the fall images was less than 38.0 percent. The percentages of the error acreages assigned to the second size class (5.1 to 10.0 acres) was slightly lower for the winter images than for the fall images. Error cases and the corresponding acreage assigned to the other size classes decreased substantially for all images. For winter as opposed to fall images, fewer omission errors of a size greater than 20.0 acres occurred. In fact, omission errors of sizes over 10.0 acres were relatively few.

Within the winter images the winter color gave slightly better results than the black-and-white, whereas within the fall images the diazo improved considerably the size of the errors over the color.

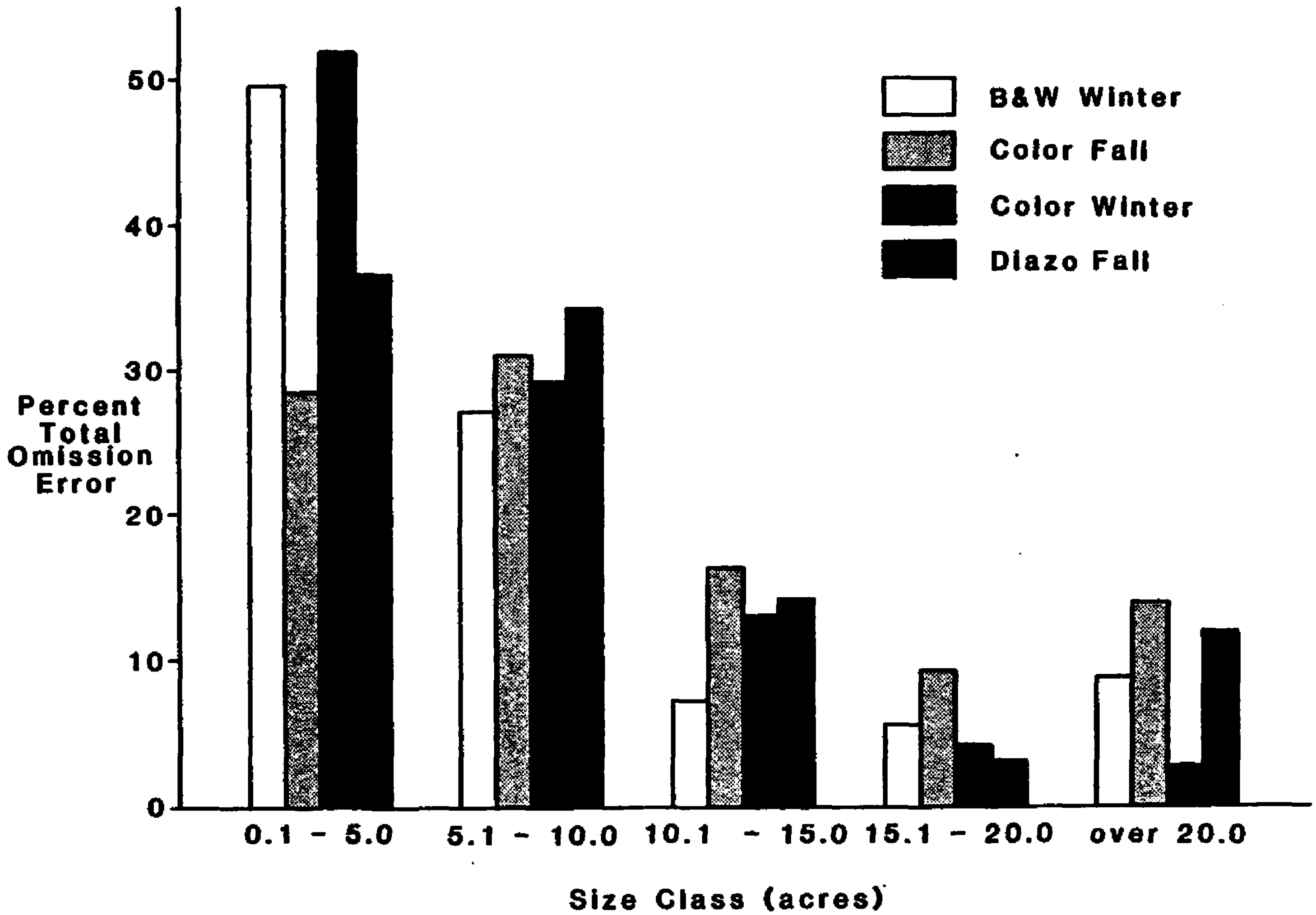

Figure 18. Distribution of total omission error by size class (acres) and type of Landsat image.

The classification of the boundary omission error by size is shown in Figure 19 (see also Table E-9). The distribution of boundary error for all images was similar to total omission error. For all images, over 65.0 percent of the boundary omission errors were less than five acres in size. The frequency of making boundary omission errors of a size of less than five acres was highest in the winter color imagery, followed by the black-and-white, diazo and fall color images.

In terms of acreage, over 80.0 percent of the total acreage in the winter images fell in the two smallest classes (Figure 19). Considering the size of the average boundary omission error the winter imagery were better than the fall ones.

The classification of the identification omission errors of every image into the size classes showed that this kind of error, as the others previously discussed, formed the same type of distribution (Table E-10, Figure 20). The majority of the errors (over 90.0 percent in all images) were classified in the two smaller size classes. Two-thirds of them, for all images, were grouped into the smallest size class. Over 75.0 percent of the total acreage of the identification error of all images fell into the two smallest size classes. The average size of the total identification error was the same for both the winter images. However, the winter color imagery had no error larger than 20.0 acres in size and the black-and-white imagery had no errors of

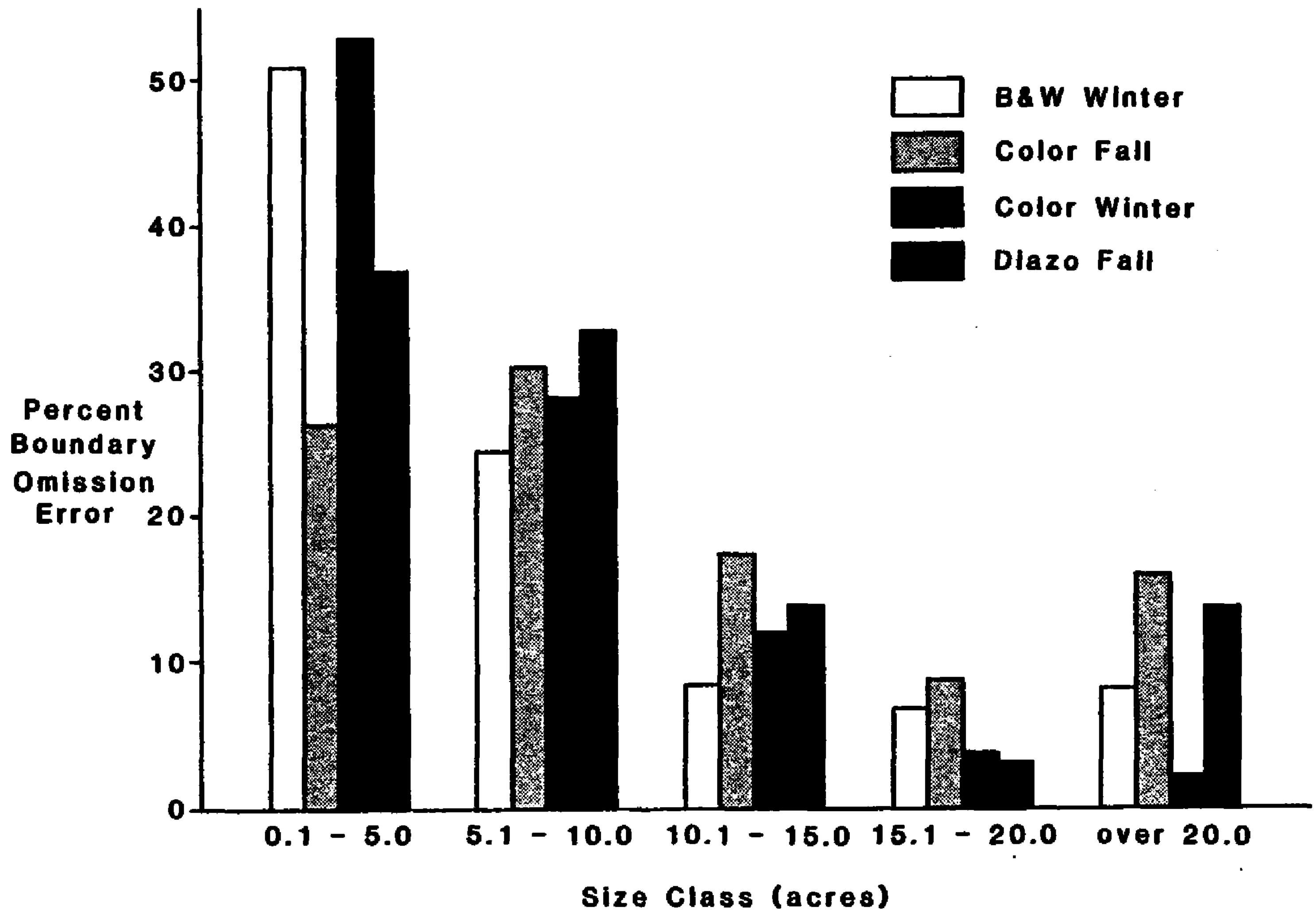

Figure 19. Distribution of boundary omission error by size class (acres) and type of Landsat image.

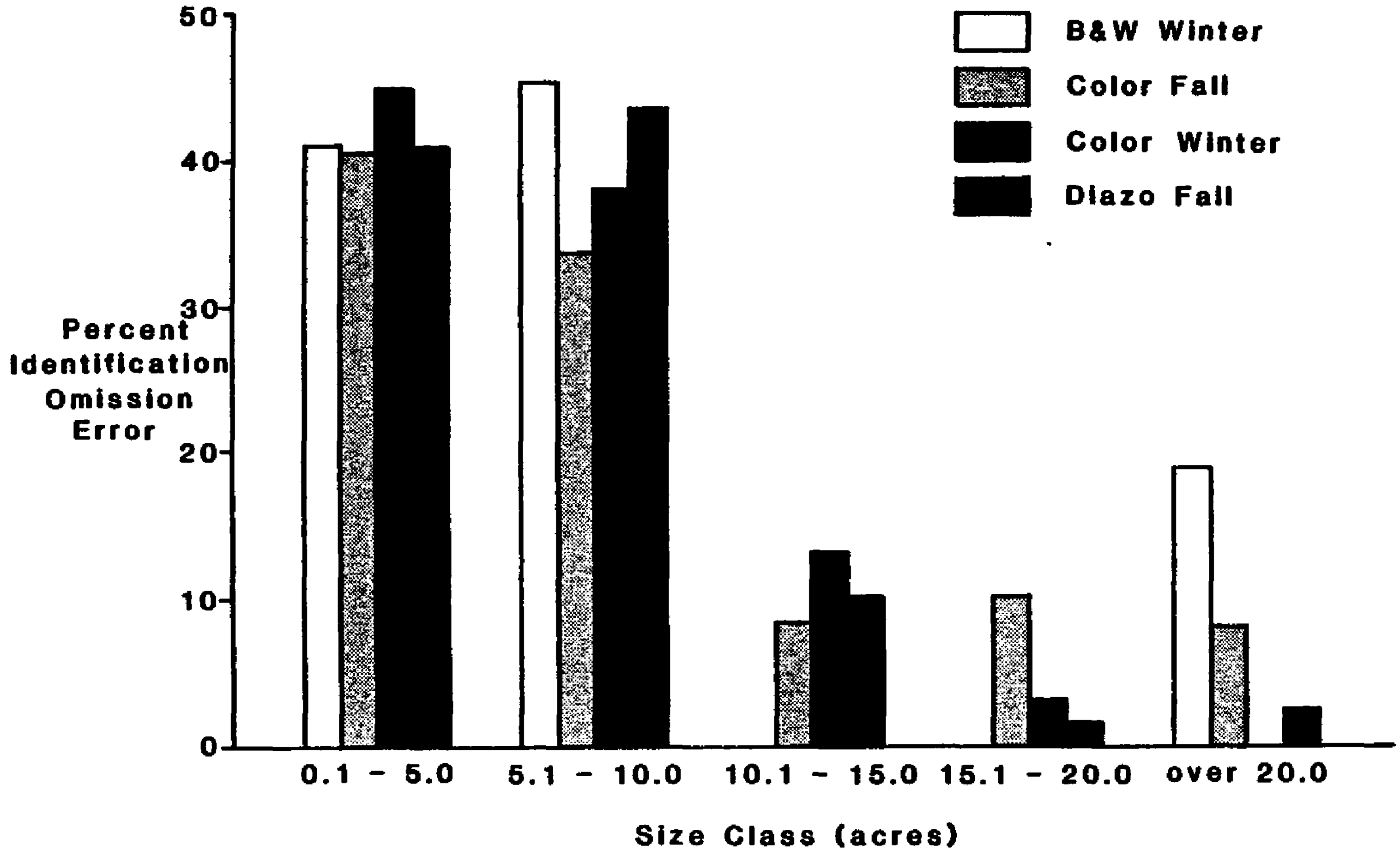

Figure 20. Distribution of identification omission error by size class (acres) and type of Landsat image.

10.1 to 20.0 acres.

To summarize, the classification of all error types by size formed distributions skewed toward the smaller size classes. The majority of both the number of error cases and the respective acreages were classified in the two smaller size classes (0.1 to 5.0 and 5.1 to 10.0 acres). The smallest class (0.1 to 5.0 acres) had the highest frequency of errors. A very small percentage of the errors were over 20.0 acres. The winter color imagery had the highest frequency of errors in the smallest size class. In terms of commission errors, the diazo imagery gave the smallest size identification error of all the images. In the case of the omission errors, the second best imagery was the black-and-white. The poorest results in both types of errors were given by the fall color imagery. Consequently, winter color imagery is recommended as the best data source. The diazo is recommended as the best alternative.

D. Land Cover/Use Categorization of the Interpretation Errors

All the errors committed during the interpretation of the Landsat images were assigned to predefined non-forest land cover/use categories or subcategories (commission error) or to forest cover type categories (omission error). It is usually desirable to have some idea of the relative importance of the various land cover/use types on the interpretation of the forest resources and their contribution to the various interpretation errors. It is also beneficial to know which forest types and silvicultural conditions are more frequently subjected to interpretation errors.

1. Commission Errors

The classification of the commission errors into the various land cover/use categories or subcategories is shown in Table E-11. Examination of the percentages of the number of cases indicated that most of the commission errors of all images were due to the misinterpretation of Agriculture fields as forests. The contribution of the Agriculture category to the total number of error cases was lower in the winter images than in the fall ones. The winter color image had the lowest total followed by the black-and-white and diazo images. The fall color had the highest total. The high contrast of the forestlands with the snow-covered agricultural fields in the winter images reduced, substantially, the number of errors (predominately boundary errors) assigned to this class. The high percentages of commission errors for all images were due, mainly, to the long boundaries typically found between forests and agricultural fields, as most of the land in the study area is in agricultural use.

The second highest percentage level of the commission error cases were assigned to the Treed Bog category. The winter images had the highest values and the fall the lowest; however, these values are not significantly different. The high level of error for this category was probably due to the spectral similarities between forests and treed bogs due to the dense brush and occasional trees growing in bogs. Another contributing factor was the abundance of this land cover/use category in the study area. The slight improvement of the percentages in the fall images could be attributed to the presence of water in conjunction with the dense vegetation. This gave a characteristic spectral tone to the treed bog areas which facilitated, to a certain degree, their separation from the forest areas.

The contribution of the other land cover/use categories and subcategories to the overall commission error cases of each imagery was less than 8.0 percent in most of the cases. The exceptions were the Urban with Trees and Scattered Trees categories with 15.6 and 10.7 percent, respectively, in the winter color imagery and 8.0 percent for both in the black-and-white imagery. Although the absolute acreage of areas classified as Urban with Trees (e.g., cottages beside lakes) is not very large in the study area, the percent of misclassification was fairly high for the winter images. This was probably due to the similar spectral and spatial appearance of this category and the forests in the winter images. The relatively high percent error of the Scattered Tree category can be attributed to the fact that a few large trees can change the spectral values of pixels so that these pixels are considered forests. Because of the low contribution of the other land cover/use categories and subcategories to the overall commission error cases, they will not be discussed in detail. However, the considerable effect which the combined Brushland subcategories had on the overall commission error cases should be pointed out. After grouping the Brushland subcategories together, the corresponding error values were 20.3 percent for the black-and-white, 16.6 percent for the fall color, 15.5 percent for the winter color and 18.1 percent for the diazo images. Again, misclassification was due to the spectral and spatial similarities of the brushlands and the forests. These errors were primarily boundary errors because when these two categories were adjacent, the determination of the exact location of the forest boundaries was a very difficult task.

So far it was found that the number of commission errors assigned to the Agriculture category was the highest for all images. The winter color imagery had the lowest error of all the others. Thus, in areas where agriculture is the predominant category, the winter color imagery is best. For the Treed Bog category, no significant differences were found among the images, whereas the misclassification of the Urban with Trees was high in the winter color imagery. The Brushland category was misclassified least in the winter color imagery and this imagery, therefore, is recommended in areas where brushland is abundant.

The distribution of the acreage of the commission errors classified by land cover/use categories or subcategories shows that the Agriculture category contributed the most to the overall commission error acreage (Figure 21). Over 45 percent of the commission errors of the fall images were assigned to the Agriculture category. For the winter color

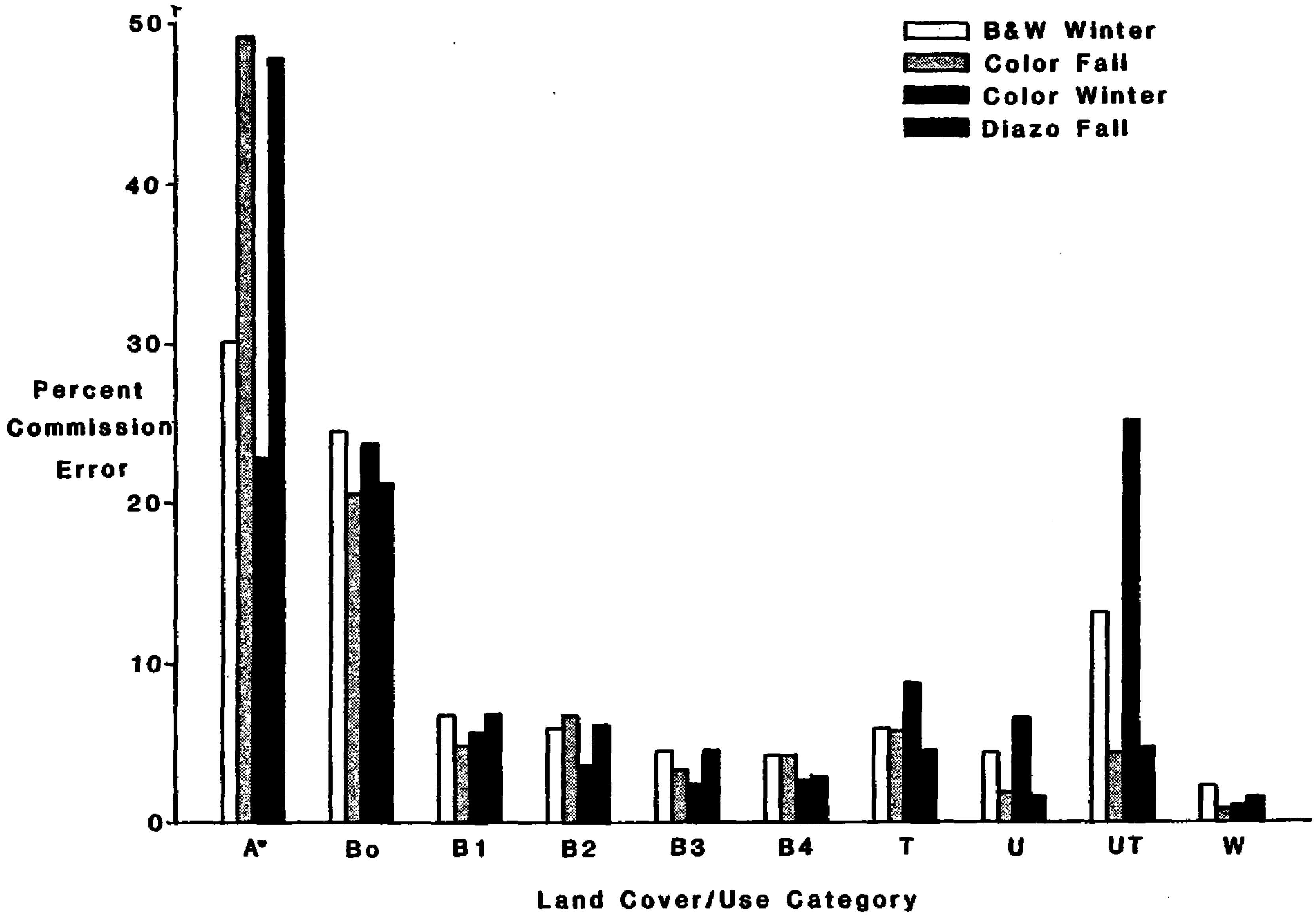

Figure 21. Commission error acreage by land cover/use category or subcategory and type of Landsat image.

*A = Agriculture, B_0 = Treed Bog, B_1-B_4 = Upland, Lowland Brush of different maturity levels, T = Scattered Trees, U = Urban, UT = Urban-Trees, W = Water-Marsh.

image, the highest percentage (24.9) was that of the Urban with Trees category. For all images the Treed Bog category gave the next highest percent contribution to the overall commission error (20.0 percent). There was no difference in the percent contribution of the Treed Bog category within the images of the same season and only a slight improvement in the fall images. The other categories had a very small contribution (less than 8.0 percent) to the overall commission error acreage for all images except the Urban with Trees in the black-and-white imagery (13.0 percent). When all the brushland subcategories were combined, they formed a major error group which was significantly different between the winter images. The Brushland category contributed 7.1 percent more to the corresponding error acreage of the black-and-white imagery than to the winter color.

Summarizing the distribution of the commission error by land cover/use category and subcategory, the Agriculture category contributed the highest percentages to the overall number of error cases and error acreage for all images. The main reason for this was the extensiveness of this category in the study area. The Treed Bog category was the next most important; the percent contribution of the rest of the categories or subcategories was low with very few exceptions. When the Brushland subcategories were grouped into one category, the respective percentages increased substantially for all images making this category an important source of error. Regarding the average error size, the Urban with Trees and the Urban categories and the Brushland--B_2 subcategories had the largest average error size in the fall color image and the smallest in the winter color.

Thus, for the lands having physiographic and vegetational components similar to those in the study area, Agriculture will be the most significant land cover/use category in terms of interpretation commission error, followed by the Treed Bog and brushland categories. The smallest contribution to these categories to the total commission error of each image was found for the winter color.

2. Omission Errors

Following the same procedure as before, the various omission errors were grouped according to the developed forest classification scheme (Tables 2 and 3). The results are shown in Table E-12.

The Lowland Hardwoods category had the highest percent frequency of error in the black-and-white, the fall color and the diazo images, while Mixed Hardwoods contributed the most for the winter color imagery. The second most important percent frequency category was the Mixed Hardwoods for the black-and-white, the fall color, and the diazo images, and the Lowland Hardwoods for the winter color. The third most important forest type was Oak-Hickory. Together these three cover types contributed more than 72.0 percent to the overall omission error cases of each imagery. The probable reason for the high percentages of error cases is that these cover types occupy over 74 percent of the forests in the study area. However, although the Oak-Hickory had the largest acreage in the county, its associated frequency error percent was relatively low. This may be because the type consists of good quality, fully-stocked, well-defined stands. The high frequency of the errors categorized as Lowland Hardwoods probably occurred because of the high acreage of the stands, and also because of their poor quality and their association with wet, low-quality soils. Because of this, the location and delineation of the boundaries was difficult and caused classification errors. For the omission error cases classified as Mixed Hardwoods, probable sources of error could be low-quality and low-stocking stands and poorly defined boundaries.

The Northern Hardwoods consistently contributed less than the previous categories to the overall omission error cases (approximately 13.0 percent). As in the case of the previous forest categories, there was no significant difference due to type of imagery. For the Pine cover type, all values were less than 8.0 percent. The rest of the categories -- Aspen, Conifer Swamps, Spruce-Fir, and Locust -- contributed insignificantly to the omission error cases. The Spruce-Fir in the black-and-white and diazo images had zero omission errors due to the very small occurrence of this type in the county (only 70 acres).

Comparing the values of the average error size of each category within all four Landsat images, it was found that for seven forest categories the winter images improved the average error size (acres) over the fall ones (Figure 22). For the remaining categories, Pine and Locust, no one set of images was superior over the other. The black-and-white imagery was the best of all the other images in most forest categories, while the diazo was the best fall image. In the winter images, the Mixed Hardwoods category contributed the most to the total omission error acreage (29.0 percent), followed by Lowland Hardwoods (27.0 percent). In the fall images the Lowland Hardwoods was the most important category (29.0 percent) and the Mixed Hardwoods were second (23.0 percent). Oak-Hickory was the third ranking category for all images with approximately 19.0 percent contribution. The rest of the categories, with very few exceptions, contributed less than 10 percent to the corresponding error acreage.

In summary, the frequency and acreage of misinterpretation of the various forest categories for each image was proportional to their frequency of occurrence in the study area. The only exception was for the Oak-Hickory category. Also, for most forest categories there were no substantial differences in the omission errors among the images. The slight improvement of the interpretation performance of the Lowland Hardwood category in the winter color imagery was noted. However, no one image was substantially better than the others.

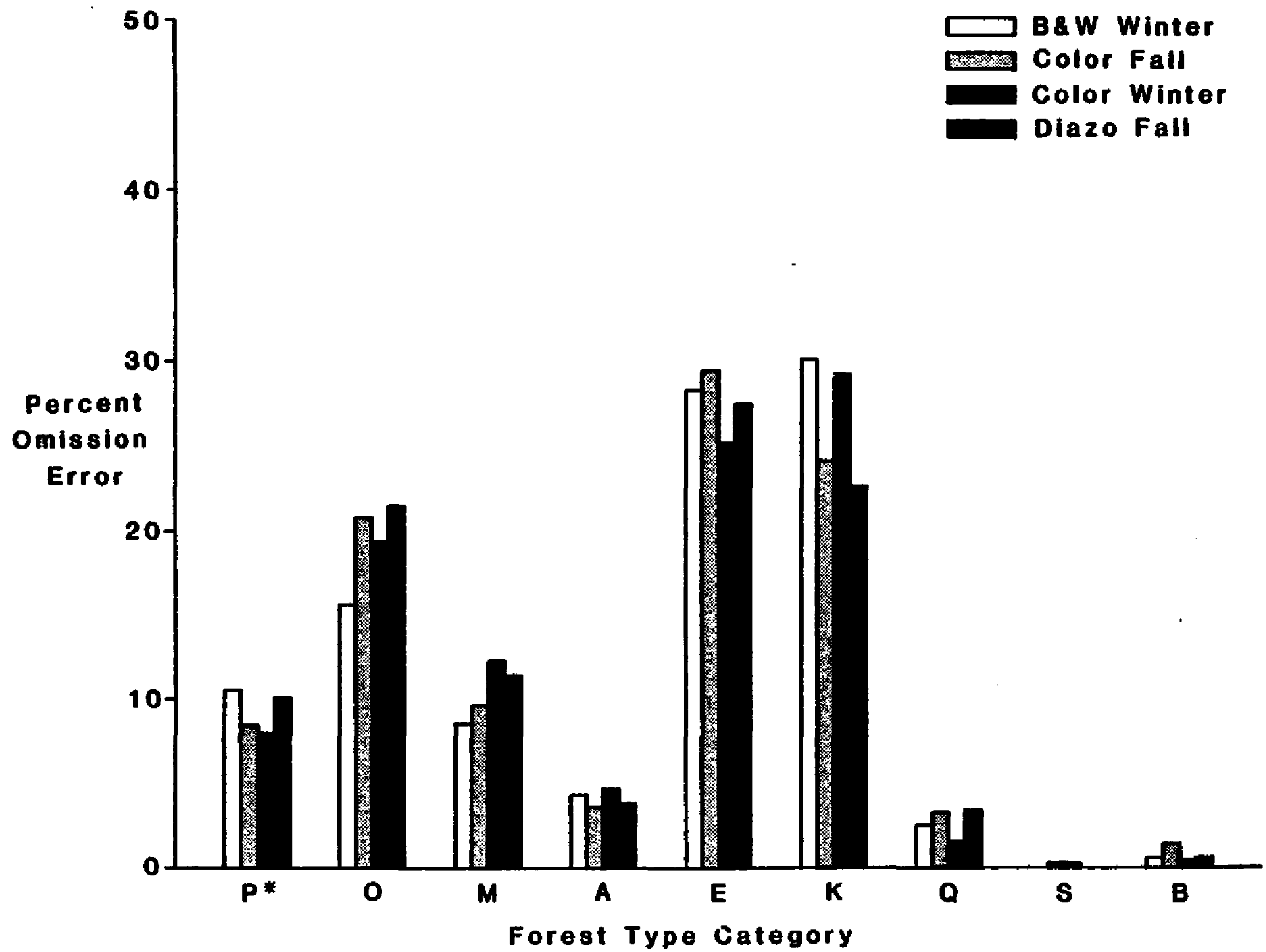

Figure 22. Acreage percent omission error (acres) by forest cover type category and Landsat image.

*P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir, B = Locust.

3. Effects of Silvicultural Condition on Omission Errors

So far the discussion has dealt with the contribution of the forest cover types to the total omission error of every image. However, during the evaluation of the interpretation maps, the various omission errors were also further classified according to the silvicultural condition of the stands (Table 3). The availability of these data permitted an analysis of the relations between the commitment of omission errors and the conditions of the forest stands.

The omission errors were classified in two ways: by forest cover type and stocking level of the stands; and by forest cover type and size of the stands. Table E-14 summarizes the classification of the errors by forest cover type and stocking level of the stands. All the errors assigned to a specific forest type were classified into three stocking level classes -- Low (L), Medium (M), and High (H) (see Table E-13 for explanation of codes). Each percent value in Table E-14 indicates the acreage of a specific stocking level-forest cover type combination missed during the interpretation process as a percent of the actual acreage in the study area.

Stocking conditions definitely affected the interpretation for all types of Landsat imagery. The poorly stocked stands were misinterpreted to a greater extent than the medium stocked ones and, in turn, these stands were misinterpreted to a greater extent than the well stocked stands. In fact, over one-third of the poorly stocked pine stands (mostly regeneration) in the study area were missed. The season of imagery also affected the interpretation. The winter images gave better results than the fall images and, within seasons, the black-and-white and diazo images improved the interpretation over the winter color and fall color images. Thus, the user should be aware that a large percentage of poorly stocked stands of all forest cover types may be lost during the visual interpretation of Landsat imagery. In order to improve the situation the use of black-and-white imagery is recommended with the diazo the best alternative.

The next categorization of the omission errors was done based on the stand size (Table E-15). As in the previous case (stocking level), three classes of stand size were defined for each forest cover type: regeneration-sapling class, poletimber and sawtimber. The code letters used to define the above classes were R, P and S, respectively (see Table E-13 for explanation of codes). The percentages of the actual acreage of the forest cover type-stand size combinations missed during the interpretation process were also calculated and included in the table.

The misinterpretation of the regeneration-sapling class was the highest for most forest cover types on all images. However, the differences of the percent values between this class and the poletimber and sawtimber classes were not as large as in the previous classification. The pine category had the highest error percentages of the regeneration-sapling class. Error percentages for poletimber were larger than those for sawtimber in most forest cover types. As in the previous classification, the error percentages of most of the forest cover type-stand size combinations were larger in the fall than in the winter images. Among the fall images, the diazo improved the interpretation over the fall color in most combinations and, among the winter images, the black-and-white was an improvement over the winter color.

Generally, it was found that both stocking level and stand size affected the interpretability of all the forest cover types for all types of Landsat images. For both characteristics the lower the stocking level or the smaller the stand size, the larger the amount of omission error. However, the percent omission values of the low stocking classes of almost all forest cover types were higher than the corresponding values of the regeneration-sapling classes. This implied that the low stocking level stands were more sensitive to misinterpretation errors than the regeneration-sapling stands. Also, the interpretation performance was better for the winter images than for the fall ones.

E. Additional Results

1. Threshold Size

The reference interpretation images were also used to determine the smallest size forest area depicted and mapped on the various types of Landsat images. This information defined the capability of visually depicting small size forest tracts on the satellite data. Such information is extremely important in planning resource analysis.

The results for each Landsat image are shown in Figure 23. The smallest size forest tract interpreted on the images was approximately 2.5 acres. The differences among the images were not significant. Comparison of the threshold value and the spatial resolution of the system (1.1 acres) indicates that the improved quality of the images produced by the EDIPS system affected substantially the interpretability of the forest resources. It should be emphasized that the small size of these forest tracts does not imply that all the larger forest tracts were identified during the interpretation process. The interpretability of a forest tract, besides its absolute areal extent and the overall quality, is affected by other factors such as season or date of the year, haze conditions, topography, spectral contrast with the background and forest cover type and condition.

2. Costs

According to the examined literature, Landsat technology has decreased the time and cost required to inventory natural resources. During periods of budget constraints reducing the cost of data collection is especially desirable and satellite technology may be an alternative which offers great potential and promise. For this reason, the cost of purchasing or producing (i.e., diazo) the Landsat images and the time spent on the various interpretation steps conducted in this study were recorded. However, the time spent on estimating the acreages of the mapped forest

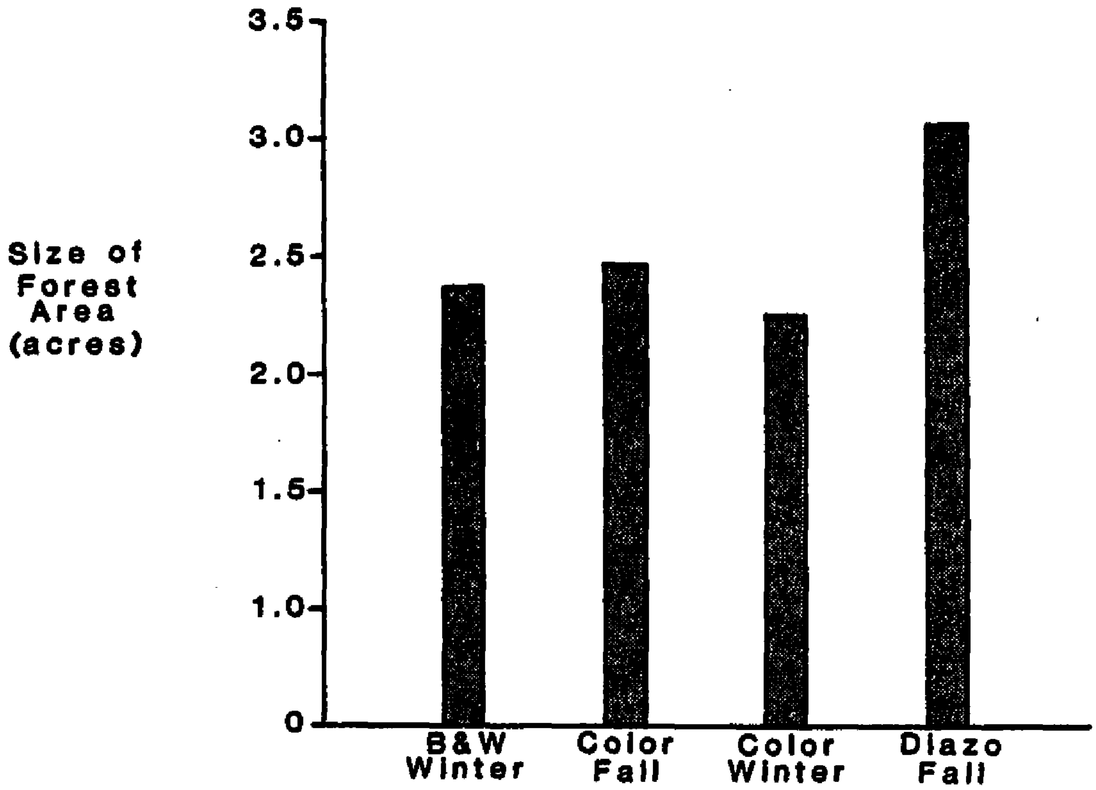

Figure 23. Smallest size forest tracts visually depicted on the various types of Landsat images.

resources was not tabulated because the procedure does not have any operational value. A summary of the time data is shown in Table 8.

The lowest cost per image was for the black-and-white imagery ($10.00). Second was the diazo whose cost included the charge of buying three Landsat black-and-white images ($10.00 x 3), plus the cost of the diazo films ($2.00), assuming diazo equipment is available. The cost of the other two standard color composites was the same -- $65.00. This amount includes the $50.00 cost for the production of the color master, which is paid by the first user who orders the color image. Other expenses (administration, travel, cartographic and report writing) were assumed to be the same for all Landsat images. In this study the cost differences between the utilized images may not be considered as substantial. However, if the study area is much larger, more images would be required and the cost difference would increase proportionally. Furthermore, as this study was a research project, the expenses of the experimentation on the diazo process were not included in the final cost.

The total time spent on the interpretation of each image consisted of three periods: 1) the initial registration of the overlay and base map showing township boundaries with the projected Landsat image of the study area; 2) the interpreter's training; and 3) the actual interpretation of the forest resources.

The time spent on registration was less for the winter

Table 8. Time spent on visual interpretation operations by Landsat image.

Landsat Image	TIME OF VISUAL OPERATION			
	Registration	Training	Interpretation	Total
Black-and-White Winter	45min	2h 15min	13h 18min	16h 18min
Color Fall	1h 21min	1h 55min	17h 42min	20h 58min
Color Winter	1h 00min	2h 01min	9h 42min	12h 43min
Diazo Fall	1h 51min	1h 45min	10h 06min	13h 42min

images than for the fall ones because the road pattern, which was used in registration, was better defined on the winter images. Among the winter images the difference of the 15 minutes was mainly due to unexpected delays. Among the fall images, the difference of 30 minutes was due to the deterioration of the contrast of the roads with their background on the diazo color composite. Generally the registration procedure was an easy task because of the existing road patterns of the study area.

The second phase of the interpretation process was the interpreter's training. As mentioned before, the interpreter trained himself before the actual interpretation of each image. Contrary to what happened during the registration of the images, the time spent on training was longer for the winter than for the fall images. During the training on the black-and-white imagery the interpreter tried to improve his knowledge about the gray tone appearance of the leafless hardwood and coniferous stands and to associate the gray tones with stocking level and size classes. The time was also extended because of the interpreter's desire to better clarify the tonal appearance of urban and water areas and the various subcategories of brushlands. Shorter training times were spent on the winter color imagery and the fall color imagery. In the case of the winter color imagery, the training procedure was similar to that of the black-and-white, however, the color factor speeded up the process. Also, for the winter color imagery the training on the appearance of the coniferous stands was straightforward for all stocking levels and stand sizes except for areas of regeneration. The training time on the fall color was mainly spent in locating forest areas of variable stocking and size classes, associating them with the color appearance on the imagery and developing visually established differences between the forest and non-forest land cover/use classes. The time spent for training on the diazo imagery was less than in the fall color because of the special appearance (enhancement) of the forest resources on the diazo.

The time spent to interpret the Landsat images, the third period, varied substantially. The shortest time spent interpreting the forest resources was on the winter color image (9 hours and 42 minutes), because of the high contrast of the forestlands with the background and the color of the images. The contrast which was obtained through the diazo process was the primary factor in reducing the interpretation time of the diazo imagery (10 hours and 6 minutes) in comparison with the fall color image. On this imagery most of the forest areas were identified and located easily and quickly but their delineation took more time because of diffused boundaries. The interpretation time of the black-and-white imagery was 13 hours and 18 minutes. The time difference between the interpretation of the black-and-white and the winter color images was due, primarily, to the absence of the color tone on the former. This decreased the separability of the forestlands from other land cover/use classes. The longest time for interpretation occurred with the fall color imagery -- 17 hours and 42 minutes. The overall low contrast of the image was the main factor for the slow performance. Because of the poor contrast the location and mapping of the forest areas was a slow process and required considerable thought with respect to forest boundaries.

The total time spent for the overall visual interpretation process was dominated in all cases by the time spent for the actual interpretation. The total interpretation time by image was: 12 hours and 43 minutes for the winter color; 13 hours and 42 minutes for the diazo; 16 hours and 18 minutes for the black-and-white; and 20 hours and 58 minutes for the fall color. It is worth noticing: 1) the 8 hours and 15 minutes difference between the winter color and the fall color images; 2) the improvement of the diazo over the fall color by 7 hours and 16 minutes; and 3) the closeness of the winter color and diazo (59 minutes).

In summary, the cost of purchasing black-and-white imagery is slightly lower than the cost of the other images. On the other hand, the time required for visual interpretation was lowest for winter color imagery, followed by diazo imagery. For very small areas (such as the study area) these differences are negligible. However, for projects of larger scale, the cost of the visual operations would be substantially higher than the cost of purchasing the images. Thus, the cost effectiveness of using winter color imagery or diazo fall imagery as an alternative would be greater.

3. Forest Tracts Mapped Only From Landsat Images

It was mentioned before that several forest tracts which were not identified on the forest cover type maps were correctly interpreted and mapped from the Landsat images. The identification was done by comparing the interpretation maps with the aerial photographs. The recorded number and acreage of these forest tracts were not used in any of the various calculations. They were included in the study solely to show that, in some cases, visual interpretation of Landsat images may be more accurate than aerial photographs and that it can improve and up-date existing inventory data. Table 9 summarizes the number and acreage of these forestlands.

Table 9. Forestlands mapped from Landsat images but not included in the reference data.

	Type of Landsat Image			
Forests	Black-and-White	Color Fall	Color Winter	Diazo
Number	171	105	169	68
Acreage	1,076.9	721.1	981.8	639.4

Evidently, more such individual forestlands were identified on the winter images than on the fall images. The acreage figures indicate that many more small tracts were interpreted from the winter images than from the fall ones. On both winter images nearly the same number of tracts were interpreted (171 on the black-and-white, 169 on the color winter). The acreage between them differed by only 95.1 acres (38.0 hectares). The high gray tone contrast of the black-and-white imagery and the color rendition of the color winter were the major factors contributing to the correct interpretation of the above tracts. Among the fall images there was a substantial difference in the number of tracts interpreted, however, the difference of the corresponding acreages was not high. The above differences between fall color and diazo images implied that, during the diazo process, several forest tracts, predominately those of small acreage, were overexposed ("burned out").

4. Availability of Landsat Imagery and Cloud Cover Restrictions

The percent of cloud cover on Landsat images is a very important factor affecting the usefulness of the images, as some projects require imagery taken in specific season(s) or year(s). Occasionally, researchers have had to change study areas because of clouds on available images. A table summarizing cloud cover and, perhaps, the radiometric quality of the available Landsat images by season and year would be very informative. It would familiarize users with the distribution of the images based on the above characteristics, facilitate them in finding images which fit specific temporal and cloud cover requirements of a study, and indicate the probability of acquiring future images of a certain quality over a given area. Such a table was constructed for the nominal center (path 23, row 30) which includes the study area. The available Landsat images between 1972 and 1980 were classified according to percent cloud cover estimated by the Earth Resources Observation Systems (EROS) Program, and by the season they were taken. Eight cloud cover classes were created. The first six classes have a ten percent interval, whereas the last two are twenty percent. The results of the classification are summarized in Table 10. According to this table, a total of 186 Landsat images have been taken of the study area since the launch of the first Landsat satellite in July, 1972. Of these, only 13 images (7.0 percent) have no cloud cover. Twenty-eight images (15.1 percent) were estimated as having 10.0 percent cloud cover, 12 images (6.5 percent) as having 20.0 percent, and 12 images as having 30.0 percent. The rest (64.0 percent) of the images had a cloud cover of more than 40.0 percent, which substantially lowers their usefulness. Of course, images with 20.0 or 30.0 percent cloud cover may be considered unuseable depending upon the location and distribution of the clouds in the scene.

The distribution of the winter images, similar to those used in this study, was as follows: one image with zero clouds, five with 10.0 percent, three with 20.0 percent and three with 30.0 percent. Thus, after nine years of operation of the Landsat system, only 12 images (6.5 percent of the total) taken during the winter period have a cloud cover of less than 30.0 percent. This implies that the

Table 10. Available Landsat images of Barry County, Michigan (path 23 and row 30) by percent cloud cover and season.

CLOUD COVER

Year	0%				10%				20%				30%				40%				50%				60-70%				80-90%				Total
	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	W	Sp	Su	F	
1972															1						1							1	1		1	4	9
1973			1		1					1		1			1					2		1				1	1		4	2	2	2	20
1974		1		1			1				1		1												2	2		2	2	2	3	2	19
1975		1		1			2		1		1				1	1		2		1			2	1	3	2	1		2	1	1	3	27
1976		1	1			1	5	1		1	2		1				1		1	1			1				1		6	4	1	2	31
1977			2		1	3	2		1						1	1	1											1	3	3	3	3	25
1978		1		1	1	1	2	1	1		1	1			2		2		3	2									1	4		3	27
1979	1	1			1	1	1	1					1		1		1	1	1		1		1		2	1			2	1		4	23
1980					1	1																							2	1			5
Total	1	5	4	3	5	7	13	3	3	2	5	2	3	0	7	2	5	3	5	6	2	1	4	1	6	6	3	4	23	18	11	23	186
%	7.0				15.1				6.5				6.5				7.7				4.3				9.7				40.3				

W = Winter: December, January, February; Sp = Spring: March, April, May; Su = Summer: June, July, August; F = Fall: September, October, November.

availability of such images will be low in the future. On the other hand, 29 images (15.6 percent) taken during the summer have an estimated cloud cover of less than 30.0 percent. Of course, the number of images with characteristics similar to those of the fall image is much larger as the growing season lasts more than three summer months. Thus, the availability of images taken during the growing season with a cloud cover of less than 30.0 percent will be higher than that of the winter ones.

The above discussion indicates that, so far, the availability of unclouded winter images is much lower than the availability of clear fall images or images taken during the growing season. This implies that, in the future, the probability of acquiring useable winter images is lower than fall images.

Throughout this study it was found that the winter color imagery was the best of all the other images. The diazo imagery, in most cases, was found to be the best alternative. However, the superiority of the winter color imagery is restricted substantially by the low availability of relatively cloud-free images. Thus, a diazo composite of a summer-early fall image is recommended as a second choice if an acceptable winter scene is not available.

CHAPTER VII

SUMMARY AND CONCLUSIONS

This study has evaluated the use of Landsat images for mapping small scattered forestlands. Four Landsat images, two from late winter and two from early fall, were tested. Three of these images, the winter black-and-white band 5, the winter color, and the fall color, were employed as purchased from the EROS Data Center without modification. The fourth image was a diazo color composite of the fall scene produced by manipulating the black-and-white transparency of each Landsat band to enhance the appearance of the forest resources.

The interpretation of forestlands from each Landsat data source was compared with a detailed forest type map that was previously prepared by another investigator using color infrared photography and extensive ground truth information. Comparison of the Landsat maps with this source identified errors which were categorized as those of commission and omission. These errors were further classified into boundary or identification errors. The level of the interpretation performance was expressed through classification, interpretation and mapping agreements or accuracies.

The major findings of the study can be summarized as follows:

1. Classification accuracy was better on the winter color images (over 93.0 percent) than on the fall color images (lower than 90.0 percent). The winter black-and-white imagery gave the best results, whereas the fall diazo imagery improved the classification accuracy over the fall color.
2. The interpretation accuracy was higher than the classification accuracy for all images except the winter black-and-white imagery. The diazo and the winter color images gave almost the same accuracy (98.0 percent). However, only for the winter color imagery was the total acreage of the forest resources underestimated.
3. The mapping accuracy (which has the greatest validity) of the winter color imagery was the highest (88.0 percent), whereas the fall diazo imagery improved the mapping accuracy over the fall color imagery.
4. Consideration of all accuracy types indicated that the winter color imagery is the best for mapping forest resources.
5. The smallest size forest area correctly mapped was about 2.5 acres for all types of images.
6. The smallest commission errors in terms of absolute frequency and acreage were achieved during

the interpretation of the winter color imagery. The diazo imagery had the next smallest values. The smallest omission errors (both absolute frequency and acreage) were achieved with the winter black-and-white imagery. The winter color imagery had the next smallest value for both frequency and acreage. Generally, commission errors were higher than omission errors for all images except the winter color imagery.

7. Most of the commission and omission errors were classified as boundary errors.
8. The classification of the frequency and acreage of all types (total, boundary and identification) of errors, commission and omission, by acreage size class showed that the majority of errors occurred in the smaller size classes. For all types of images and errors the largest percent frequencies were assigned to the smallest size class (0.1 to 5.0 acres). However, in terms of acreage, there were some deviations from the above finding. For the black-and-white and fall color images and for some types of error, the 5.1 to 10 acre size class had the highest frequency. The highest percentage of the error acreage of almost all types of error assigned to the smallest size class were achieved for the winter color imagery. Furthermore, the frequency of errors of size over 20.0

acres was very small for all images, but their contribution to the overall error acreage was much higher. Overall, therefore, it was found that a fairly large percentage of the interpretation errors had a size of less than 5.0 acres and that the winter color imagery was the best. The diazo imagery was the next best image type.

9. Qualitative evaluation of the commission errors showed that a great percentage of them were characterized as Agriculture, especially for the fall images. The second most common category for all images was the Treed Bog followed by the Brushland. The winter color imagery was the best for mapping small forest tracts surrounded by agricultural fields. In terms of omission error, Lowland Hardwoods and Mixed Hardwoods were the most important forest categories for both winter and fall images. No one image was superior over the others in this case.

10. Classification of omission errors by stocking level and stand size showed that both silvicultural conditions affected the interpretation of the forest resources. However, stocking level was the more significant variable.

11. Time spent to complete the various steps of the visual operation was lower for the winter color imagery followed by the diazo imagery. Also,

because the cost of performing the visual operations, especially for larger scale projects, increases much faster than the cost of purchasing the images, the winter color imagery is favored. The diazo image would be the next choice.

12. Examination of the available Landsat images of the same nominal center, in terms of season and percent of clouds, showed that the availability of relatively clear (i.e., less than 30 percent cloud cover) winter images is much lower than the availability of clear fall images.

Based on the above findings the general conclusion is that winter color imagery is the most appropriate type of Landsat imagery for accurate mapping of small forest tracts. It is recommended for areas having characteristics similar to the study area. However, there is a high probability that this type of imagery will not be available for the specific project area. In that case, the best alternative is the fall diazo imagery.

Future research should investigate the potential and the cost required to map small scattered forestlands using computer-assisted analysis of Landsat CCT data and compare the results with the manual interpretation.

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APPENDICES

APPENDIX A

LANDSAT PARAMETERS AND CHARACTERISTICS

Landsat-2 and -3 satellites are currently in operational orbit around the earth. Although both have some technical problems, they continue sending information about the earth's surface features and their condition.

A. Orbit Characteristics

Each satellite circles the earth every 103 minutes, or 14 times a day, from an altitude of about 570 miles (920 kilometers). The orbit is sun synchronous with an inclination of 99° measured clockwise from the equator (Landsat Data Users Handbook, 1979). The orbital characteristics insure that the satellites pass over the same area at about the same local time (e.g., 9:42 a.m. at the equator) each day. This insures that the images taken of the same area, during the same period of the year, have similar illumination and shadow conditions. This is important as it facilitates the study of earth features over time. Such changes facilitate identifying and differentiating specific natural features on the ground by taking advantage of their phenological differences. The orbital characteristics and image processing system results in various sidelap percentages of the adjacent images depending upon the latitude of the imaged area. The greater the latitude, the greater the sidelap; at the equator the sidelap is 14 percent, whereas at a latitude of 80° it is 85 percent. For images of Michigan, sidelap varies from about 36 to 43 percent. On the other hand, the overlap between consecutive scenes is about 10 percent. The scenes have a parallelogram shape because of the earth's rotation and the scanning characteristics of the MSS system.

The state of Michigan is covered by 23 Landsat scenes (Figure 2) whose nominal centers fall on the intersections of the 21 to 27 paths and 26 to 31 rows of the Worldwide Reference System.

B. Payload Systems

The satellites have two primary remote sensing systems on board: the Multispectral Scanning System (MSS) and the Return Beam Vidicon (RBV) system. Only the MSS system will be described because RBV imagery was not used in this study.

The MSS system is a line scanning device which uses an oscillating mirror to scan the earth perpendicular to the satellite's path with six sets of four detectors each. The detectors record the incoming reflected radiation from ground resolution cells of approximately 79m on a side (area of 0.452 hectares or 1.118 acres). Each frame consists of 7.8 million pixels (<u>pic</u>ture <u>el</u>ements) and covers a ground area of 115 x 115 miles (185 x 185 kilometers).

The four detectors are sensitive to the following spectral wavelengths: band 4 to 0.5-0.6 μm (green portion of the spectrum), band 5 to 0.6-0.7 μm (red portion), band 6 to 0.7-0.8 μm (reflected infrared portion), and band 7 to

0.8-1.1 μm (reflected infrared portion). Landsat-3 has a thermal band which is sensitive to 10.4 to 12.6 μm (emitted infrared radiation). Only a few thermal images are available since the system failed shortly after launch.

C. Landsat Products

Three ground receiving stations operate in the United States. The received data is converted into a usable form made available through the EROS Data Center in South Dakota. Available standard image products include: black-and-white 70mm (scale 1:3,369,000) and 225 x 225mm (scale 1:1,000,000) positive and negative transparencies of all four bands, and black-and-white and false color composites of 225 x 225mm (9 x 9 inches) in transparency or paper print form. There are also black-and-white and color paper prints at larger sizes and scales. EROS also distributes computer compatible tapes (CCT's) of each scene for computer-assisted analysis of digital data.

Radiometric corrections are applied to the raw data to compensate for errors due to improperly functioning detectors and to atmospheric scattering of the light. In the first case (detector misfunction) a procedure called "destriping" is performed to match the defective response of a detector with the overall scene. The corrected values in this destriping process are not truly values, but the result of various combinations of the surrounding spectral values. However, the resulting image is an improved, more pleasing to the eye, product.

The second procedure (haze removal) reduces the atmospheric effect on the quality of the data. Two techniques are usually employed to reduce the problem and improve the interpretability of the data (increase the contrast). Both techniques are based on the fact that the data of band 7 are free of haze (Sabins, 1978).

Landsat data are also geometrically corrected. Geometric distortions are present due to variations in satellite altitude, velocity and other orbital attitudes like yaw, pitch and/or roll, the earth's rotation, and the scanner's velocity and sampling rate. Several resampling techniques using either a large number of distinct ground control points and/or mathematical formulae are employed to correct or compensate for the distortions. The corrected data meet the National Map Accuracy Standards for about 1:700,000 scale maps.

Since the beginning of 1979 all the above corrections have been performed operationally and as a standard procedure to all image and digital (CCT's) Landsat data.

After the employment of the foregoing corrections to the data, some additional techniques called "enhancement techniques" are employed to improve the appearance of the imaged data. These techniques are applied to each band separately. The most important and commonly used ones are the following:

1. Contrast enhancement--Landsat detectors have been designed to record pixel brightness values within

a specific range, without being saturated. For most terrain scenes the values occupy a relatively small portion of the entire range. As a result, a small number of gray tones are recorded on the images creating a low contrast display. To correct this situation, several optical and digital contrast enhancement (stretching) techniques can be applied to the Landsat data. The digital ones are more commonly used because they are more flexible, easier to apply, more precise and in a greater variety. These techniques are normally optional and are applied after the completion of the other procedures.

2. Edge enhancement--in almost all applications of Landsat data sharp definition of feature edges is desirable. Sharper boundaries improve the overall appearance of the image, enhance the various features, increase the efficiency of interpretation, reduce subjective decisions regarding the location and delineations of the boundaries, and, thus, improve accuracy. An edge enhancement technique has been applied as a standard procedure since the implementation of the EDIPS (EROS Digital Image Processing System) in February, 1979.

APPENDIX B

ADDITIONAL STUDIES OF LANDSAT USES IN FORESTRY

Many other studies have been conducted to monitor and map forest changes over time (Aldrich, 1975; Santos, et al., 1977; Klankamsorn, et al., 1978; Malila, 1980), to map burned forest areas (Hitchcock and Hoffer, 1974; Boissonneau, 1975), to map forest fuel (Pala, 1980; Kourtz, 1977) and estimate its moisture content (Waters, 1975) for fire control, to map and assess insect damage (Beaubien and Jobin, 1974; Rohde and Moore, 1974; Williams, 1975; Rodriguez-Bejarano, 1978), to assess spraying projects to control insect infestation (Ashley and Morin, 1977), to estimate timber volume (Nichols, et al., 1974; Titus, et al., 1975; Jano, 1975; Peterson and Card, 1978; Strahler, et al., 1979), or species condition (Heath and Parker, 1973), to map species distribution (Kan and Dillman, 1975; Williams and Harrer, 1975; Beaubien, 1979a, 1979b).

Other studies have been conducted to assess the accuracy of Landsat data for mapping forest resources on a local basis (Heath and Parker, 1973; Mroczynski, 1978), on a regional basis (Chaudhury, et al., 1978) or on a national basis (Lachowski, et al., 1978). Furthermore, other studies have investigated the usefulness of Landsat data to forest inventories by using various computer classification methods (Lee, 1977; Rubec and Wickware, 1978) or different computer processing systems and algorithms (Goodenough and Shlien, 1974; Mead and Meyer, 1977).

Subsequent studies tried to improve the classification accuracy by incorporating digital topographic data into the classification process (Hoffer, et al., 1974; Strahler, et al., 1978; Rohde, et al., 1979; Logan and Strahler, 1980) or by using multiseasonal data (Kalensky, 1974).

Multistage and multiphase sampling schemes and, to a lesser degree, other sampling techniques have also been used which incorporated Landsat and aerial photographic data to optimize the integration of remote sensing information to forest inventory (Titus, et al., 1975; Wensel, et al., 1976; Mroczynski, 1978; Hegyi, 1980).

APPENDIX C

DIAZO PROCESSING AND METHODOLOGY

Diazo* film consists of a photosensitive diazo emulsion on an acetate or polyester base. It is produced by a number of companies. The film is available in a wide variety of colors including blue, green, red (additive primaries) and yellow, magenta and cyan (subtractive primaries).# It is also available in various sizes, the common ones being 8.5 x 11 inches (21.6 x 27.9 cm) and 10 x 10 inches (25.4 x 25.4 cm). Any diazo film which is at least 20 cm on a side is suitable for making Landsat color composites of 1:1,000,000 scale since the dimensions of a Landsat scene, between registration marks, are 18.4 cm in-track and 19.9 cm across-track. For critical applications, polyester base diazo film is preferred over acetate base because it provides greater dimensional stability and is more resistant to scratches from drum-type developers. The unexposed film is primarily sensitive to ultraviolet radiation. The affect of other light sources is negligible at least for short periods of

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* Diazo is a chemical term referring to a compound "containing the group nitrogen (N_2) composed of two nitrogen atoms united to a single carbon atom of an organic radical" (Webster's, 1979).

Yellow, magenta and cyan are called subtractive primaries because filters of various densities of these colors subtract portions or all of the blue, green and red radiation of a single white light source, respectively.

time. At room temperature the shelf-life of diazo film is about six months, but storage of up to one year is possible at temperatures below 10° C (50° F) (Whitebay, 1978). Exposed diazo film should be kept in darkness to avoid discoloration and fading.

In diazo processing it is necessary, initially, to use a densitometer to determine the density values of the target of interest on the black-and-white spectral Landsat images. Film density refers to the opacity of imaged features. The only variable in diazo processing that affects the density of the film is the duration of film exposure to ultraviolet light. The longer the exposure time, the lighter the overall density of the diazo copy. The best diazo color composite for a specific task is the one which displays most clearly the elements of interest and facilitates their detection and identification. This can be achieved by trial-and-error analysis of various combinations of diazo film types, Landsat spectral bands and length of exposures. However, this is a costly and time-consuming analysis.

To avoid this, an approach similar to that developed at Cornell University (Skaley, et al., 1974) was followed. Characteristic density (sensitometric) curves were generated for a specific brand of diazo film and exposure times. An example is shown in Figure C-1 for yellow diazo film. Similar curves would be developed for any other diazo product used. The curves are generated in a procedure devised by Lusch (1979).

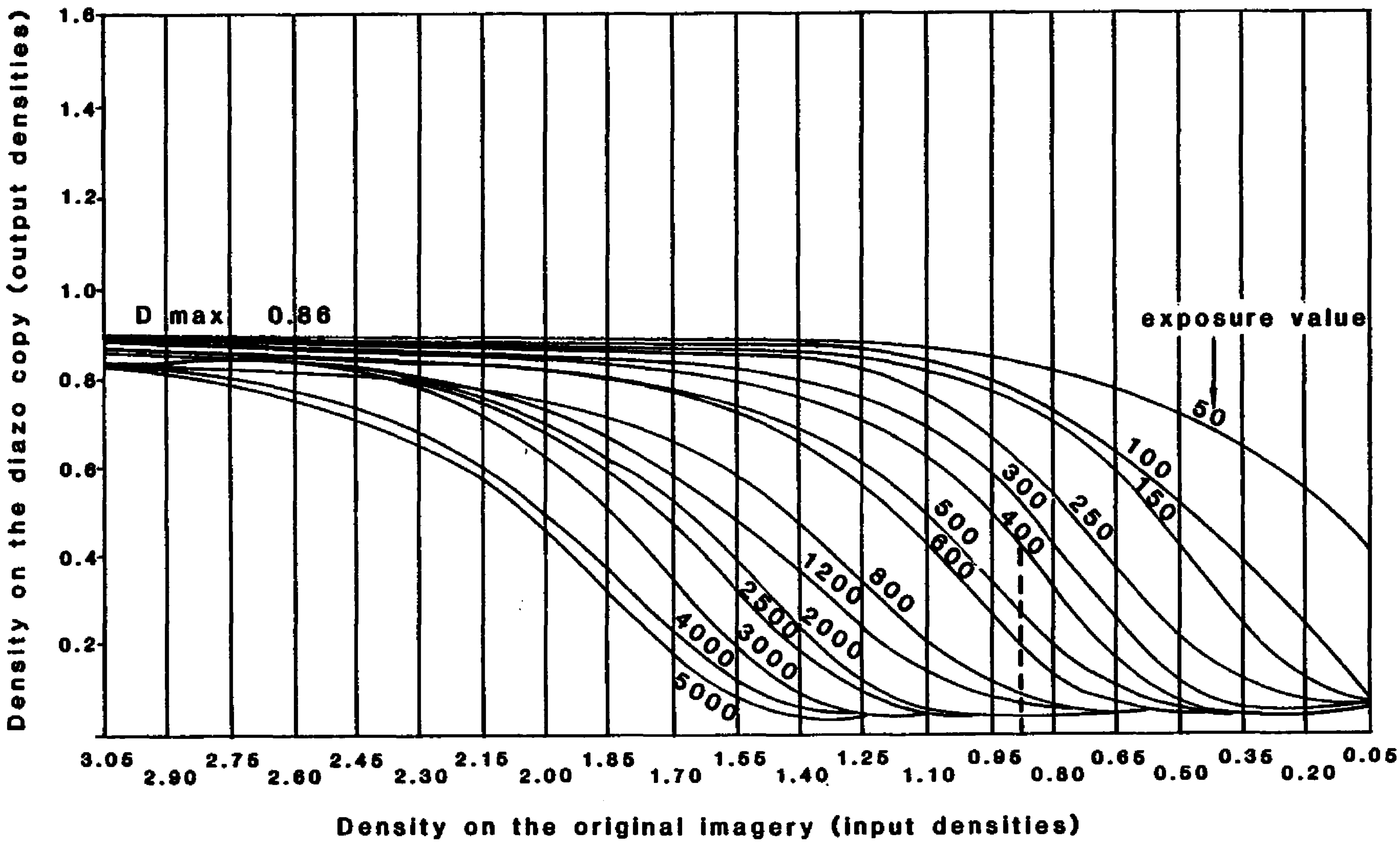

Figure C-1. Characteristic curves of a yellow diazo film at various exposure values. As an example, an average density value of 0.87 measured from forested areas on the band 4 image would require approximately 400 light units for proper exposure (see dash curve).

An important parameter which can be extracted from these curves is the gamma (γ) value, a measure of film contrast. Diazo films with a gamma value greater than 1.0 are considered to have high contrast. Diazo films with a gamma value smaller than 1.0 are considered as low contrast media.

Diazo films having large gamma values are normally used to copy black-and-white Landsat scenes because they provide better contrast between various scene elements. In the original Landsat scene from EROS, the tonal differentiation between the various scene elements is not always optimum. The density range of the scene elements is small because only a portion of the recording capability of the film is used. A copy of the scene on a high contrast diazo film stretches this density range and the corresponding values are further separated. As a result, subtle tonal differences existing in the original imagery are enhanced and more easily interpreted on the diazo copy.

The affect of the gamma or contrast value of a diazo copy film on the stretching or compressing of the density values of scene elements is shown in Figure C-2. A density range of value a of the scene elements in a Landsat image can be stretched to a value of c on a high contrast diazo copy. The same initial density range a is compressed to a value b, however, when reproduced on a low-contrast diazo film. Which portion of the total density range of the original scene will be stretched or compressed can be controlled by varying the exposure time.

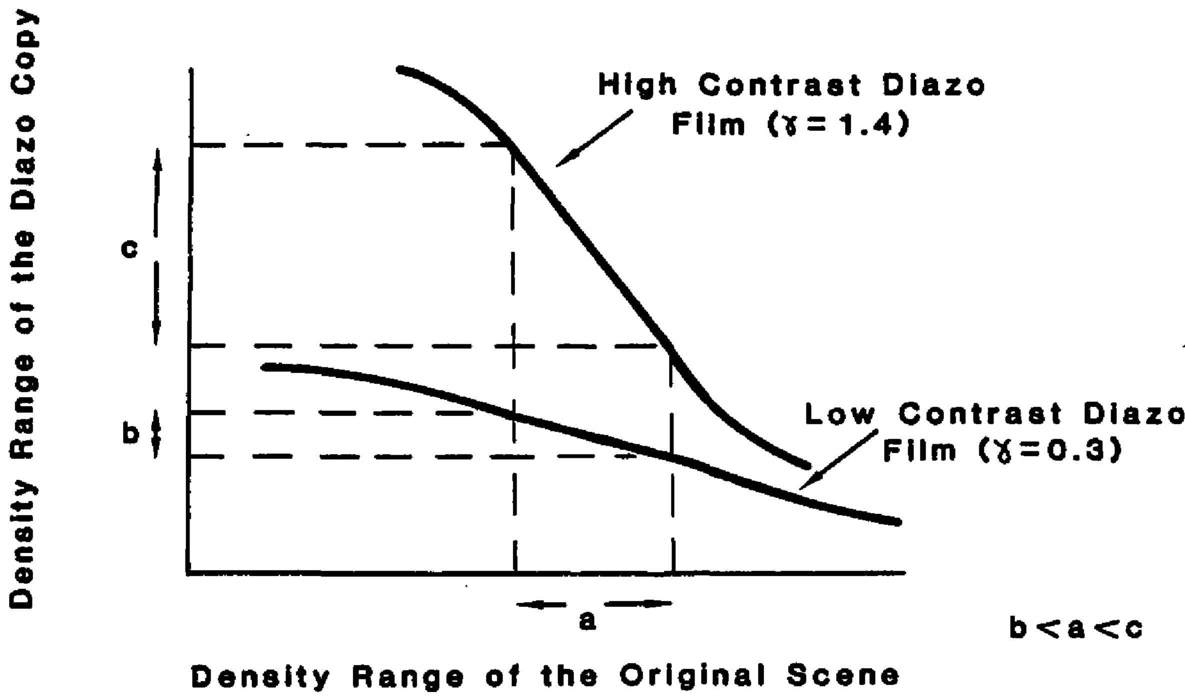

Figure C-2. Graphical presentation of a hypothetical relation between the density range of scene elements in a Landsat image and the corresponding stretched or compressed density range on a high contrast and low contrast diazo copy of the image, respectively.

A minimum of five random density measurements on the target in each spectral image are recommended to calculate the mean density value. Fewer measurements may give unrepresentative results. This process also checks the validity of the conducted density measurements, especially in the case of small targets where the possibility of making measurements outside the target areas is high.

The next step in the process is to select the combinations of diazo films (colors) and Landsat spectral images desired for image enhancement. Each combination (e.g., yellow for band 4 and magenta for band 5) is then used to select the proper set of characteristic curves and to determine the appropriate exposure time required in order to maximize the interpretability of the diazo films. That is, the selected spectral image (band) contains the density value of the target to be used, whereas the chosen diazo film determines the use of the appropriate set of characteristic curves. The determination of the exposure time is done as follows: the density value of the target of interest is located on the x-axis of the graph of the sensitometric (characteristic) curves (Figure C-1). The exposure time is then determined by identifying which straight line of a particular characteristic curve is intercepted in the middle by a line drawn parallel to the y-axis from the located density value. The associated exposure value for that particular curve is then used. To help illustrate the step, Figure C-1 shows an example for the yellow diazo film to determine exposure time to enhance forested lands.

The specified exposure time allows the density of the target of interest to fall in the middle of the density range of the diazo copy. The other tones are spread further apart (in the case of high-contrast diazo films) than in the original image, improving the interpretability of the target of interest on the diazo copy.

After selection of exposure time, the diazo film is put in the exposure equipment, emulsion side up. The black-and-white Landsat image is laid on the diazo film, emulsion side down. For close contact of the film and the imagery, a vacuum frame is recommended. The specified exposure time is set on the light integrator and the exposure takes place. The complete development of the latent diazo image is carried out by passing the exposed diazo film through ammonia gases four or five times.

The same procedure is followed for the exposure and development of the other diazo films (colors) which are used to construct a color composite. Subtractive primary colors are preferable to the additive primaries because the diazo color composite is a transparency viewed with transmitted light and the three combined additive primaries result in a neutral gray color (Seitz, 1976). To produce a false-color composite, usually band 4 is exposed in yellow, band 5 in magenta and band 6 or 7 in cyan. A color composite with vegetation in green and water in blue is created by exposing band 4 or 5 in green and band 6 or 7 in blue. Other combinations of the various bands and diazo films are possible.

The developed diazo films are super-imposed and securely registered or aligned to compose the color composite. This is done by using a light table and a magnifier to obtain maximum alignment accuracy. The sequency order of the diazo copy of each band of a composite does not affect image quality or color rendition.

Diazo processing equipment used in this study included a diazo exposure vacuum frame with an ultraviolet light source and a microfiche drum developer containing ammonia vapor.

For reference, the companies which produce diazo materials with .003' thickness and polyester base are the following:

1. Chromatic diazo film: GAF Corporation
140 West 51 Street
New York, New York 10020
(212) 621-5000

2. Chromtex film: Teledyne Post
P. O. Box 803
Chicago, Illinois 60690
(312) 299-1111

3. Diazochrome film: James River Graphic
South Hadley, Massachusetts 01075
(413) 536-7800

4. Escochrome diazo film: Arkwright Incorporated
Fiskeville, Rhode Island 02823
(401) 821-1000

APPENDIX D

INTERPRETATION EQUIPMENT

The main instrument used for the interpretation was the Transyscōp LZK-100 S,* a back-lighted projector. Four removable projection heads constitute the projection system. Projection heads with 355mm or 180mm lenses are used for overhead projection, with magnification capabilities ranging from 2X to 5X and 4X to 11X, respectively. Projection heads with 60mm or 25mm lenses are utilized for direct projection of transparencies with magnification power ranging from 13X to 32X and 34.5X to 82X, respectively. The projection head with the 60mm lens was used during the interpretation analysis because it allowed the Landsat images to be enlarged to the final scale of the map (1:50,000).

The delineation of the boundaries of various features or conditions on projections at larger scales is not easy. For example, magnification of the 1:1,000,000 Landsat imagery 32 times (the maximum of the 60mm lens) results in an image scale of 1:31,250. At that scale the boundaries of the various surface phenomena are fuzzy and a high degree of subjective decisions are required to determine their exact location. Therefore, enlarging Landsat images beyond a 1:50,000 scale is not recommended.

*Trademarks or names do not imply any endorsement by the author and Michigan State University.

A Zoom 240 Stereocope on a Richards light table was used in conjunction with the Transyscōp. Employment of this instrument facilitated the interpretation of the imagery on the Transyscōp through optically viewing other copies of Landsat imagery or other Landsat bands. The stereoscope has a continuous variable magnification range from 3 to 30 times.

APPENDIX E

TABULATION OF THE RESULTS

Table E-1. Interpretation errors of Barry County by township for black-and-white image of the winter scene (February 26, 1979).

INTERPRETATION ERROR

	COMMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	101	663.8	92.7	10	52.6	7.3	111	716.4	7.7
Carlton	78	339.4	80.5	12	82.5	19.5	90	421.9	4.5
Woodland	35	238.1	52.2	17	217.5	47.8	52	455.6	4.9
Rutland	140	984.3	90.0	14	118.8	10.0	154	1103.1	11.9
Hastings	85	588.1	94.0	5	40.6	6.0	90	628.7	6.8
Castleton	67	309.4	62.2	20	188.1	37.8	87	497.5	5.4
Orangeville	77	688.2	93.6	5	47.5	6.4	82	735.7	7.9
Hope	114	879.4	89.3	10	102.5	10.7	124	981.9	10.6
Baltimore	110	720.0	90.3	10	83.8	9.7	120	803.8	8.7
Maple Grove	79	333.7	87.7	11	46.9	12.3	90	380.6	4.1
Prarieville	59	414.4	78.6	13	112.5	21.4	72	526.9	5.7
Barry	75	614.4	87.0	13	96.8	13.0	88	711.2	7.7
Johnstown	101	621.4	88.3	15	81.8	11.7	116	703.7	7.6
Assyria	134	615.1	96.5	3	21.7	3.4	137	636.8	6.8
Total	1255	8009.7	86.1	158	1294.1	13.9	1413	9303.8	100.0

Table E-1. (cont'd.)

	INTERPRETATION ERROR								
	OMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	47	167.6	92.1	3	13.4	7.9	50	181.0	6.0
Carlton	29	82.5	76.3	7	25.6	23.7	36	108.1	3.6
Woodland	29	116.2	87.0	3	16.9	13.0	32	133.1	4.4
Rutland	50	300.6	94.0	3	19.4	6.0	53	320.0	10.7
Hastings	35	145.0	58.1	12	100.0	41.9	47	245.0	8.2
Castleton	36	110.0	90.0	2	10.6	10.0	38	120.6	4.3
Orangeville	14	68.2	100.0	0	0	0	14	68.2	2.3
Hope	71	332.2	92.4	7	28.7	7.6	78	360.9	12.0
Baltimore	59	268.1	91.1	5	26.1	8.1	64	294.3	9.8
Maple Grove	51	147.5	96.6	1	5.6	3.4	52	153.1	5.1
Prarieville	19	222.7	97.0	1	7.5	3.0	20	230.2	7.7
Barry	33	180.2	85.0	7	31.8	15.0	40	212.0	7.1
Johnstown	53	244.4	89.1	6	30.0	10.9	59	274.4	9.1
Assyria	65	285.6	96.4	3	10.6	3.6	68	296.2	9.9
Total	591	2670.8	89.1	60	326.2	10.1	651	2997.0	100.0

Table E-2. Interpretation errors of Barry County by township for false color composite of the fall scene (September 12, 1979).

	INTERPRETATION ERROR								
	COMMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	129	1011.8	96.7	7	34.4	3.3	136	1046.2	10.7
Carlton	152	1208.9	94.5	10	71.2	5.6	162	1279.9	13.1
Woodland	63	418.7	88.7	7	53.2	11.2	70	471.8	4.8
Rutland	123	858.1	91.8	5	76.9	8.2	128	935.1	9.6
Hastings	79	687.5	84.6	9	43.8	15.4	88	731.3	7.5
Castleton	108	951.4	97.6	4	23.8	2.4	112	975.2	10.0
Orangeville	52	631.7	91.3	7	60.3	8.7	59	692.0	7.1
Hope	105	916.3	97.7	4	20.6	2.2	109	936.9	9.1
Baltimore	83	602.5	91.5	8	56.8	8.7	91	659.3	6.8
Maple Grove	76	479.4	93.0	9	36.2	7.0	85	515.6	5.3
Prarieville	32	267.5	81.8	7	59.3	18.2	39	326.8	3.3
Barry	46	290.0	92.8	5	23.1	7.2	51	313.1	3.2
Johnstown	66	326.9	95.7	4	14.4	4.3	70	341.3	3.5
Assyria	82	513.2	88.9	9	64.4	11.1	91	577.6	5.9
Total	1196	9163.9	93.5	95	638.6	6.5	1291	9802.5	100.0

Table E-2. (cont'd.)

	INTERPRETATION ERROR								
	OMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	83	585.5	90.6	8	60.4	9.4	91	645.9	7.7
Carlton	83	377.5	87.3	9	55.1	12.7	92	432.6	5.2
Woodland	47	235.9	69.0	15	105.7	31.0	62	341.6	4.1
Rutland	90	682.8	87.6	14	96.2	12.3	104	779.0	9.3
Hastings	79	403.7	84.7	11	73.1	15.3	90	476.8	5.7
Castleton	65	463.8	92.3	8	38.3	7.7	73	502.1	6.0
Orangeville	48	515.6	95.7	5	23.1	4.3	53	538.7	6.4
Hope	61	372.7	87.3	9	53.1	12.7	70	425.8	5.1
Baltimore	72	527.1	86.8	18	83.1	13.2	90	610.2	7.3
Maple Grove	76	479.6	87.2	10	70.8	12.8	86	550.4	6.6
Prarieville	49	553.0	84.4	13	102.6	15.6	62	655.6	7.8
Barry	61	492.5	84.1	18	93.1	15.9	79	585.6	7.0
Johnstown	92	629.3	87.9	15	86.3	12.1	107	715.6	8.6
Assyria	111	975.4	88.4	19	127.5	11.6	130	1102.9	13.2
Total	1017	7294.4	87.2	172	1068.4	12.8	1189	8362.8	100.0

Table E-3. Interpretation errors of Barry County by township for false color composite of the winter scene (February 26, 1979).

	INTERPRETATION ERROR								
	COMMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	45	190.2	85.2	8	33.1	14.8	53	223.3	7.2
Carlton	23	120.6	81.1	5	28.1	18.9	28	148.7	4.8
Woodland	14	143.7	60.0	7	96.3	40.0	21	240.0	7.8
Rutland	62	256.2	81.5	2	58.1	18.5	64	314.3	10.1
Hastings	14	69.4	88.8	3	8.7	11.2	17	78.1	2.5
Castleton	24	154.5	70.8	7	58.1	29.1	31	212.6	6.5
Orangeville	34	331.9	91.0	4	33.2	9.0	38	365.1	11.7
Hope	47	303.7	91.5	3	27.5	8.5	50	331.2	10.7
Baltimore	41	181.2	91.9	4	15.6	8.1	45	196.8	6.3
Maple Grove	26	77.5	92.6	2	5.6	7.4	28	83.1	2.5
Prarieville	14	127.5	63.4	6	73.8	36.6	20	201.3	6.5
Barry	27	165.1	88.6	5	21.3	11.4	32	186.4	6.0
Johnstown	53	220.2	86.0	9	36.9	14.0	62	257.1	8.3
Assyria	58	261.3	97.2	3	7.5	2.8	61	268.8	8.6
Total	482	2603.0	83.8	68	503.8	16.2	550	3106.8	100.0

Table E-3. (cont'd.)

	INTERPRETATION ERROR								
	OMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	89	374.5	96.0	3	15.6	4.0	92	390.1	9.2
Carlton	80	314.8	89.5	9	36.8	10.5	89	351.6	8.3
Woodland	41	185.1	96.7	1	6.3	3.3	42	191.4	4.5
Rutland	94	452.7	91.5	5	41.9	8.5	99	494.6	11.6
Hastings	83	356.6	77.6	18	102.5	22.4	101	459.1	10.8
Castleton	42	167.5	82.9	6	34.5	17.1	48	202.0	4.7
Orangeville	24	119.0	100.0	0	0	0	24	119.0	2.8
Hope	59	283.8	85.6	10	47.5	14.4	69	329.3	7.7
Baltimore	83	297.9	88.5	8	38.7	11.5	91	336.6	7.9
Maple Grove	69	261.0	90.8	4	26.9	9.2	73	287.2	6.7
Prarieville	21	246.5	93.3	3	17.5	6.7	24	264.0	6.2
Barry	61	283.9	91.0	6	28.1	9.0	67	312.0	7.3
Johnstown	71	252.8	89.2	5	30.6	10.8	76	283.4	6.6
Assyria	61	202.7	83.8	8	39.3	16.2	69	242.0	5.7
Total	878	3796.8	89.1	86	465.5	10.9	964	4262.3	100.0

Table E-4. Interpretation errors of Barry County by township for diazo color composite of the fall scene (September 12, 1979).

	INTERPRETATION ERROR								
	COMMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	131	881.9	98.1	5	18.1	1.9	136	900.0	12.5
Carlton	92	594.8	100.0	0	0	0	92	594.8	8.3
Woodland	70	446.1	97.8	3	10.6	2.2	73	456.7	6.4
Rutland	103	723.6	93.9	11	46.9	6.1	114	770.5	10.7
Hastings	68	394.9	96.2	5	18.8	3.8	73	413.7	5.8
Castleton	64	404.4	97.4	3	11.3	2.6	67	415.7	5.8
Orangeville	61	525.8	100.0	0	0	0	61	525.8	7.3
Hope	86	519.7	96.2	4	15.6	3.8	90	535.3	7.5
Baltimore	104	555.5	98.0	3	11.9	2.0	107	567.4	7.9
Maple Grove	77	308.9	94.6	2	16.9	5.4	79	325.8	4.5
Prarieville	27	203.7	97.7	1	5.0	2.3	28	208.7	2.9
Barry	62	364.3	94.0	2	24.4	6.0	64	388.7	5.4
Johnstown	90	510.0	95.6	4	23.1	4.4	94	533.1	7.4
Assyria	92	523.8	96.3	3	20.0	3.7	95	543.8	7.6
Total	1127	6957.4	96.9	46	222.6	3.1	1173	7180.0	100.0

Table E-4. (Cont'd.)

	INTERPRETATION ERROR								
	OMISSION								
	Boundary			Identification			Total		
		Acreage			Acreage			Acreage	
Township	No.	Abs.	%	No.	Abs.	%	No.	Abs.	%
Irving	79	453.2	96.3	4	17.5	3.7	83	470.5	7.4
Carlton	66	302.8	78.4	17	84.6	21.6	83	387.3	6.1
Woodland	44	201.3	70.9	12	82.4	29.1	56	283.7	4.5
Rutland	67	352.5	79.8	12	89.1	20.2	79	441.6	7.0
Hastings	63	281.4	74.5	17	96.0	25.5	80	377.4	6.0
Castleton	46	291.3	87.2	9	42.8	12.8	55	334.1	5.3
Orangeville	38	302.4	90.6	4	31.2	9.3	42	333.6	5.3
Hope	72	363.7	93.0	6	27.5	7.0	78	391.2	6.2
Baltimore	107	562.5	87.8	15	78.0	12.2	122	640.5	10.2
Maple Grove	80	417.8	90.0	9	46.3	10.0	89	464.1	7.4
Prarieville	35	596.9	96.6	4	21.2	3.4	39	618.1	9.8
Barry	62	351.9	84.8	12	63.1	15.2	74	415.0	6.6
Johnstown	77	343.7	85.7	10	57.0	14.3	87	398.7	6.3
Assyria	100	643.7	86.4	21	101.3	13.6	121	745.0	11.8
Total	936	5465.1	86.7	152	839.0	13.3	1088	6304.1	100.0

Table E-5. Total commission error by size class (in acres) and type of Landsat image.

Size Class (acres)	TYPE OF LANDSAT IMAGE: Black-and-White Winter: Frequency		Acreage		Cumulative Acreage		Color Fall: Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	893	63.2	2905.3	31.3	2905.3	31.3	673	52.1	2328.6	23.9	2328.6	23.9
5.1-10.0	316	22.4	2412.1	26.0	5317.4	57.3	364	28.2	2878.5	29.5	5207.1	53.4
10.1-15.0	101	7.1	1301.8	14.0	6619.2	71.3	137	10.6	1794.6	18.4	7001.7	71.8
15.1-20.0	54	3.8	1092.9	11.8	7712.1	83.1	59	4.6	1052.1	10.8	8053.8	82.6
> 20.0	49	3.5	1570.0	16.9	9282.5	100.0	58	4.5	1698.7	17.4	9752.5	100.0
Total	1413	100.0	9282.5	100.0			1291	100.0	9752.5	100.0		
Average (acres)	6.6						7.5					
Standard Deviation	6.2						6.2					

E-5. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	378	68.7	1134.8	36.5	1134.8	36.5	708	60.4	2492.7	34.7	2492.7	34.7
5.1-10.0	109	19.8	807.1	26.0	1941.9	62.5	317	27.1	2370.4	33.0	4863.1	67.7
10.1-15.0	28	5.1	349.3	11.2	2291.2	73.7	100	8.5	2280.7	17.8	6143.8	85.6
15.1-20.0	20	3.6	363.4	11.7	2654.6	85.4	30	2.6	537.9	7.5	6681.7	93.1
> 20.0	15	2.7	452.2	14.5	3106.8	100.0	18	1.5	498.3	6.9	7180.0	100.0
Total	550	100.0	3106.8	100.0			1173	100.0	7180.0	100.0		
Average (acres)	5.6						6.1					
Standard Deviation	5.4						4.6					

Table E-6. Boundary commission errors by size class (in acres) and type of Landsat image.

T Y P E   O F   L A N D S A T   I M A G E

Size Class (acres)	Black-and-White Winter						Color Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	811	66.2	2609.8	32.7	2609.8	32.7	620	51.8	2140.0	23.5	2140.0	23.5
5.1-10.0	270	22.0	2069.4	25.9	4679.2	58.6	333	27.8	2620.6	28.7	4760.6	52.2
10.1-15.0	88	7.2	1132.9	14.2	5812.1	72.7	130	10.9	1712.5	18.8	6473.1	71.0
15.1-20.0	45	3.7	834.7	10.4	6646.8	83.2	57	4.8	1017.1	11.1	7490.2	82.2
> 20.0	41	3.3	1349.1	16.8	7988.9	100.0	56	4.7	1623.7	17.8	9113.9	100.0
Total	1255	100.0	7988.9	100.0			1196	100.0	9113.9	100.0		
Average (acres)	6.4						7.6					
Standard Deviation	6.1						6.2					

Table E-6. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	334	69.3	998.2	38.3	998.2	38.3	672	59.6	2372.7	34.1	2372.7	34.1
5.1-10.0	96	19.9	706.3	27.1	1704.5	65.5	310	24.5	2316.3	33.3	4689.0	67.4
10.1-15.0	25	5.2	311.7	12.0	2016.2	77.4	98	8.7	1253.8	18.0	5942.8	85.4
15.1-20.0	16	3.3	292.1	11.2	2308.3	88.7	30	2.7	537.9	7.7	6480.7	93.1
> 20.0	11	2.3	294.7	11.3	2603.0	100.0	17	1.5	476.7	6.8	6957.4	100.0
Total	482	100.0	2603.0	100.0			1197	100.0	6957.4	100.0		
Average (acres)	5.4						6.2					
Standard Deviation	4.8						4.4					

Table E-7. Identification commission error by size class (in acres) and type of Landsat image.

TYPE OF LANDSAT IMAGE

Size Class (acres)	Black-and-White Winter						Color Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	82	51.9	295.5	22.8	295.5	22.8	53	55.8	188.6	29.5	188.6	29.5
5.1-10.0	46	29.1	342.7	26.5	638.2	44.3	31	32.6	257.9	40.4	446.5	69.9
10.1-15.0	13	8.2	168.9	13.1	807.1	62.4	7	7.4	82.1	12.8	528.6	82.8
15.1-20.0	9	5.7	258.2	19.9	1065.3	82.4	2	2.1	35.0	5.5	563.6	88.2
> 20.0	8	5.1	228.3	17.6	1293.6	100.0	2	2.1	75.0	11.7	638.6	100.0
Total	158	100.0	1293.6	100.0			95	100.0	638.6	100.0		
Average (acres)	8.2						6.7					
Standard Deviation	7.6						5.6					

Table E-7. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	44	64.7	136.6	27.1	136.6	27.1	36	78.3	120.0	53.9	120.0	53.9
5.1-10.0	13	19.1	100.8	20.0	237.4	47.1	7	15.2	54.1	24.3	174.1	78.2
10.1-15.0	3	4.4	37.6	7.7	275.0	54.6	2	4.3	26.9	12.1	201.0	90.3
15.1-20.0	4	5.9	71.3	14.1	346.3	68.7	0	0	0	0	201.0	90.3
> 20.0	4	5.9	157.5	31.3	503.8	100.0	1	2.2	21.6	9.7	222.6	100.0
Total	68	100.0	503.8	100.0			46	100.0	222.6	100.0		
Average (acres)	7.4						4.8					
Standard Deviation	8.9						3.6					

Table E-8. Total omission error by size class and type of Landsat image.

TYPE OF LANDSAT IMAGE

Size Class (acres)	Black-and-White Winter						Color Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	504	77.4	1496.8	49.9	1496.8	49.9	668	56.2	2399.2	28.7	2399.3	28.7
5.1-10.0	113	17.3	811.7	27.1	2308.5	77.0	334	28.1	2564.0	30.7	4963.3	59.3
10.1-15.0	17	2.6	232.3	7.7	2540.8	84.8	107	9.0	1381.5	16.5	6344.8	75.9
15.1-20.0	10	1.5	190.1	6.3	2730.9	91.1	41	3.4	760.1	9.1	7104.8	84.9
> 20.0	7	1.1	266.1	8.9	2997.0	100.0	39	3.3	1258.0	15.0	8362.9	100.0
Total	651	100.0	2997.0	100.0			1189	100.0	8362.8	100.0		
Average (acres)	4.6						7.0					
Standard Deviation	4.5						6.0					

Table E-8. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	752	77.5	2207.0	51.8	2207.0	51.8	697	64.1	2352.1	37.3	2352.1	37.3
5.1-10.0	173	17.8	1253.2	29.4	3460.2	81.2	294	27.0	2167.3	34.4	4519.4	71.7
10.1-15.0	32	3.3	534.4	12.5	3994.3	93.7	65	6.0	824.2	13.1	5343.6	84.8
15.1-20.0	9	9.3	171.1	4.0	4165.4	97.7	12	1.1	214.2	3.4	5557.8	88.2
> 20.0	4	0.4	96.6	2.3	4262.0	100.0	19	1.7	746.3	11.8	6304.1	100.0
Total	970	100.0	4262.3	100.0			1087	100.0	6304.1	100.0		
Average (acres)	4.4						5.7					
Standard Deviation	3.4						5.4					

Table E-9. Boundary omission error by size class (in acres) and type of Landsat image.

TYPE OF LANDSAT IMAGE

Size Class (acres)	Black-and-White Winter						Color Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	468	79.2	1360.8	50.9	1360.8	50.9	562	55.3	1959.4	26.9	1959.5	26.9
5.1-10.0	90	15.2	662.6	24.8	2023.4	75.8	284	27.9	2202.5	30.2	4162.0	57.1
10.1-15.0	17	2.9	232.3	8.7	2255.7	84.4	100	9.8	1297.3	17.8	5459.3	74.8
15.1-20.0	10	1.7	190.1	7.1	2445.8	91.6	35	3.4	650.7	8.9	6110.0	83.8
> 20.0	6	1.0	225.0	8.4	2670.8	100.0	36	3.5	1184.5	16.2	7294.4	100.0
Total	591	100.0	2670.8	100.0			1017	100.0	7294.4	100.0		
Acreage (acres)	4.5						7.2					
Standard Deviation	4.5						6.1					

Table E-9. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	697	78.8	1997.5	52.6	1997.5	52.6	607	64.8	2003.2	36.6	2003.2	36.6
5.1-10.0	148	16.7	1076.6	28.3	3074.1	81.0	242	25.8	1804.3	33.0	3807.5	69.7
10.1-15.0	27	3.1	471.6	12.4	3545.7	93.4	58	6.2	737.1	13.5	4544.6	83.2
15.1-20.0	8	0.9	154.5	4.1	3700.2	97.5	11	1.2	196.7	3.6	4741.3	86.8
> 20.0	4	0.5	96.6	2.5	3796.8	100.0	18	1.9	723.8	13.2	5465.1	100.0
Total	884	100.0	3796.8	100.0			936	100.0	5465.1	100.0		
Average (acres)	4.3						5.8					
Standard Deviation	3.5						5.7					

Table E-10. Identification omission error by size class (in acres) and Landsat image.

TYPE OF LANDSAT IMAGE

Size Class (acres)	Black-and-White Winter						Color Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	36	60.0	136.0	41.7	136.0	41.7	106	61.6	439.8	41.2	439.8	41.2
5.1-10.0	23	38.3	149.1	45.7	285.1	87.4	50	29.1	361.5	33.8	801.3	75.0
10.1-15.0	0	0	0	0	285.1	87.4	7	4.1	84.2	7.9	885.5	82.9
15.1-20.0	0	0	0	0	285.1	87.4	6	3.5	109.4	10.2	994.9	93.1
> 20.0	1	1.7	41.1	12.6	326.2	100.0	3	1.7	73.5	6.9	1068.4	100.0
Total	60	100.0	326.2	100.0			172	100.0	1068.4	100.0		
Average (acres)	5.4						6.2					
Standard Deviation	4.9						3.9					

Table E-10. (cont'd.)

TYPE OF LANDSAT IMAGE

Size Class (acres)	Color Winter						Diazo Fall					
	Frequency		Acreage		Cumulative Acreage		Frequency		Acreage		Cumulative Acreage	
	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%	Abs.	%
0.1- 5.0	55	63.9	209.5	45.0	209.5	45.0	90	59.6	348.9	41.6	348.9	41.6
5.1-10.0	25	29.1	176.6	37.9	386.1	82.9	52	35.5	363.0	43.3	711.9	84.8
10.1-15.0	5	5.8	62.8	13.4	448.6	96.4	7	4.6	87.1	10.4	799.0	95.2
15.1-20.0	1	1.2	16.6	3.6	465.5	100.0	1	0.7	17.5	2.1	816.5	97.3
> 20.0	0	0	0	0	465.5	100.0	1	0.7	22.5	2.7	839.0	100.0
Total	86	100.0	465.5	100.0			151	100.0	839.0	100.0		
Average (acres)	5.4						5.6					
Standard Deviation	2.6						2.6					

Table E-11. Commission errors by land cover/use categories and type of Landsat image.

	TYPE OF LANDSAT IMAGE									
	Black-and-White Winter					Color Fall				
	Frequency		Acreage			Frequency		Acreage		
Category	Abs.	%	Average	Total	%	Abs.	%	Average	Total	%
A*	523	37.0	5.3	2795.4	30.0	683	52.9	7.1	4821.4	49.2
B_0	293	20.7	7.8	2273.9	24.4	232	18.0	8.6	1991.3	20.3
B_1	97	6.9	6.2	605.6	6.5	64	5.0	7.4	472.8	4.8
B_2	96	6.8	5.7	549.7	5.9	68	5.3	9.4	638.7	6.5
B_3	50	3.5	7.9	395.1	4.2	40	3.1	7.5	301.6	3.1
B_4	43	3.1	8.4	360.1	3.9	41	3.2	9.3	381.5	3.9
T	113	8.0	4.7	535.1	5.8	79	6.1	6.9	545.9	5.6
U	50	3.5	7.7	384.5	4.1	21	1.6	8.3	174.5	1.8
UT	113	8.0	10.7	1208.6	13.0	50	3.8	8.1	405.3	4.1
W	35	2.5	5.6	195.8	2.1	13	1.0	5.4	69.5	0.7
Total	1413	100.0	6.6	9303.8	100.0	1291	100.0	7.6	9802.5	100.0

*A = Agriculture; B_0 = Treed Bog; B_1-B_4 = Upland, Lowland Brush of different maturity levels; T = Scattered Trees; U = Urban; UT = Urban Trees; W = Water-Marsh.

Table E-11. (cont'd.)

	TYPE OF LANDSAT IMAGE									
	Color Winter					Diazo Fall				
	Frequency		Acreage			Frequency		Acreage		
Category	Abs.	%	Average	Total	%	Abs.	%	Average	Total	%
A*	172	31.3	4.1	709.7	22.8	594	50.6	5.8	3430.3	47.8
B_0	113	20.6	6.5	736.7	23.7	228	19.4	6.7	1515.1	21.1
B_1	35	6.4	4.7	165.7	5.3	75	6.4	6.3	471.5	6.6
B_2	24	4.4	5.0	106.7	3.4	60	5.1	7.1	428.1	6.0
B_3	16	2.9	4.5	72.5	2.3	42	3.6	7.5	314.5	4.4
B_4	10	1.8	7.5	75.1	2.4	35	3.0	5.6	194.4	2.7
T	59	10.7	4.4	262.0	8.4	60	5.1	5.0	298.6	4.2
U	31	5.6	6.3	194.8	6.3	9	0.8	13.0	117.0	1.6
UT	86	15.6	9.0	774.5	24.9	48	4.1	6.6	318.8	4.4
W	4	.7	2.0	8.1	0.3	22	1.9	4.2	91.7	1.3
Total	550	100.0	5.7	3016.8	100.0	1173	100.0	6.1	7180.0	100.0

*A = Agriculture; B_0 = Treed Bog; B_1-B_4 = Upland, Lowland Brush of different maturity levels; T = Scattered Trees; U = Urban; UT = Urban Trees; W = Water-Marsh.

Table E-12. Omission errors by forest cover type and Landsat image.

	TYPE OF LANDSAT IMAGE												
	Black-and-White Winter						Color Fall						Reference Data Acreage
	Frequency		Acreage				Frequency		Acreage				
Category	Abs.	%	Average	Total	%A[1]	%B[2]	Abs.	%	Average	Total	%A	%B	
P*	35	5.4	9.0	313.3	10.5	7.7	85	7.2	8.2	699.1	8.4	17.1	4080
O	124	19.1	3.8	468.8	15.6	2.7	259	21.8	6.8	1748.7	20.9	10.0	17501
M	74	11.4	3.4	254.0	8.5	3.0	146	12.3	5.5	795.3	9.5	9.5	8391
A	27	4.2	4.6	124.4	4.2	8.1	38	3.2	8.0	302.9	3.6	19.8	1529
E	205	31.2	4.1	849.3	28.3	5.2	348	29.3	7.0	2431.6	29.1	14.9	16293
K	169	26.0	5.3	898.4	30.0	8.6	270	22.6	7.4	2009.6	24.0	19.2	10489
Q	14	2.2	5.3	74.4	2.5	5.8	29	2.4	8.8	255.6	3.1	20.1	1272
S	0	0	0	0	0	0	2	0.2	5.0	10.0	0.1	14.3	70
B	3	0.5	4.8	14.4	0.5	5.7	12	1.0	9.2	110.0	1.3	43.8	251
Total	651	100.0	4.6	2997.0	100.0	5.0	1189	100.0	7.0	8362.8	100.0	100.0	59876

*P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir, B = Locust.

[1] The omission error of each forest category as a percent of the total omission error.

[2] The omission error (acres) of each forest category as a percent of the actual acreage of this category in the county.

Table E-12. (cont'd.)

	TYPE OF LANDSAT IMAGE												
	Color Winter						Diazo Fall						Reference Data Acreage
	Frequency		Acreage				Frequency		Acreage				
Category	Abs.	%	Average	Total	%A[1]	%B[2]	Abs.	%	Average	Total	%A	%B	
P*	47	4.9	7.3	341.3	8.0	8.4	71	6.5	8.5	602.5	10.1	14.8	4080
O	213	22.1	3.9	823.8	19.3	4.7	235	21.6	5.7	1340.5	21.3	7.7	17501
M	130	13.5	4.0	516.4	12.1	6.2	151	13.9	5.0	753.1	11.3	9.0	8391
A	39	4.0	5.0	194.6	4.6	12.7	41	3.8	5.9	240.2	3.8	15.7	1529
E	256	26.2	4.2	1063.8	25.0	6.5	313	28.8	5.5	1720.0	27.3	10.6	16293
K	260	27.3	4.8	1241.8	29.1	11.8	238	21.9	6.0	1417.3	22.5	13.5	10485
Q	15	1.6	4.2	62.5	1.5	4.9	32	2.9	6.3	200.0	3.2	15.7	1272
S	1	0.1	2.5	2.5	0.1	3.6	0	0	0	0	0	0	70
B	3	0.3	5.2	15.6	0.4	6.2	7	0.6	4.4	30.5	0.5	12.2	251
Total	964	100.0	4.4	4262.3	100.0	7.1	1088	100.0	5.8	6304.1	100.0	10.5	59876

*P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir, B = Locust.

[1]The omission error of each forest category as a percent of the total omission error.

[2]The omission error (acres) of each forest category as a percent of the actual acreage of this category in the county.

Table E-13. Stand size and stocking level codes.

STAND SIZE	STOCKING LEVEL		
	Low (L)	Medium (M)	High (H)
Regeneration-Sapling (R)	0,1	2	3
Poletimber (P)	4	5	6
Sawtimber (S)	7	8	9

Table E-14. Omission errors by forest type stocking level classes and types of Landsat image.

Forest Types/ Stocking Level	TYPE OF LANDSAT IMAGE								
	Black-and-White Winter		Color Fall		Color Winter		Diazo Fall		Reference Data Acreage
	Acreage		Acreage		Acreage		Acreage		
	Abs.	%[2]	Abs.	%	Abs.	%	Abs.	%	
P_L[1]	235.7	32.2	336.9	46.1	238.6	32.6	307.2	42.0	731
P_M	22.0	2.6	130.2	15.6	36.3	4.3	49.5	5.9	835
P_H	55.6	2.2	232.0	9.2	66.4	2.6	245.6	9.8	2514
O_L	97.5	8.0	332.2	27.3	141.3	11.6	193.4	15.9	1215
O_M	112.3	3.2	455.2	13.0	211.2	6.0	270.1	7.7	3512
O_H	259.0	2.0	961.2	7.5	471.3	3.7	877.0	6.9	12774
M_L	77.6	16.9	108.7	23.7	113.3	24.7	101.1	22.1	458
M_M	53.1	4.5	146.4	12.3	60.0	5.1	84.5	7.1	1193
M_H	123.3	1.8	540.2	8.0	343.1	5.1	567.5	8.4	6740
A_L	83.2	19.3	165.2	38.2	133.2	30.8	142.7	33.0	432
A_M	16.9	3.6	56.9	12.1	33.2	7.1	20.7	4.4	469
A_H	24.3	3.9	80.9	12.9	28.2	4.5	76.8	12.2	628
E_L	254.3	10.8	511.1	21.7	241.6	10.3	320.0	13.6	2350
E_M	435.5	5.9	1251.3	16.9	480.4	6.4	860.0	11.6	7420
E_H	159.5	2.5	669.2	10.3	341.8	5.2	540.1	8.3	6523

[1] P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir and B = Locust. See Table E-13 for explanation of codes.

[2] The values in the columns under "%" indicate the percentages of the actual acreage of the classes in the study area which were omitted during the interpretation process of the Landsat images.

Table E-14. (cont'd.)

Forest Types/ Stocking Level	TYPE OF LANDSAT IMAGE: Black-and-White Winter, Acreage, Abs.	%[2]	Color Fall, Acreage, Abs.	%	Color Winter, Acreage, Abs.	%	Diazo Fall, Acreage, Abs.	%	Reference Data Acreage
K_L[1]	534.2	14.5	1043.6	28.3	677.3	18.4	639.5	17.3	3688
K_M	274.5	6.8	591.0	14.7	405.6	10.1	496.7	12.3	4031
K_H	89.7	3.2	375.0	13.5	158.9	5.7	281.6	10.2	2770
Q_L	26.9	24.5	65.0	59.0	24.4	22.2	29.4	26.7	110
Q_M	35.6	4.9	138.1	18.8	25.0	3.4	115.0	15.7	734
Q_H	11.9	2.8	52.5	12.3	13.1	3.1	55.6	13.0	428
S_L	0	0	0	0	0	0	0	0	13
S_M	0	0	10.0	41.7	0	0	0	0	24
S_H	0	0	0	0	2.5	7.6	0	0	33
B_L	0	0	0	0	0	0	0	0	0
B_M	3.1	3.5	43.7	49.1	0	0	20.5	23.0	89
B_H	11.3	7.0	66.3	40.9	15.6	9.6	10.0	6.2	169
Total	2972.0		8362.8		4262.3		6304.1		59876

[1] P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir and B = Locsut. See Table E-13 for explanation of codes.

[2] The values in the columns under "%" indicate the percentages of the actual acreage of the classes in the study area which were omitted during the interpretation process of the Landsat images.

Table E-15. Omission errors by forest type stand size classes and types of Landsat image.

TYPE OF LANDSAT IMAGE

Forest Types/ Stand Size	Black-and-White Winter		Color Fall		Color Winter		Diazo Fall		Reference Data Acreage
	Acreage		Acreage		Acreage		Acreage		
	Abs.	%[2]	Abs.	%	Abs.	%	Abs.	%	
P_R[1]	252.7	17.4	426.9	29.4	275.2	18.9	447.8	30.8	1453
P_P	59.3	2.6	266.6	11.5	66.1	2.9	152.2	6.6	2307
P_S	1.3	0.4	5.6	1.9	0	0	2.5	0.8	320
O_R	47.8	5.3	137.4	15.3	64.4	7.2	121.4	13.5	898
O_P	259.6	2.4	1217.1	11.1	548.6	5.0	921.5	8.4	11008
O_S	161.4	2.9	394.2	7.1	220.8	3.9	297.6	5.3	5595
M_R	93.2	3.7	277.1	11.0	174.7	6.9	276.4	11.1	2518
M_P	93.7	2.7	292.0	8.5	202.2	5.9	300.1	8.7	3441
M_S	67.1	2.8	226.2	9.3	139.5	5.7	176.6	7.3	2432
A_R	20.6	10.5	36.6	18.6	29.5	15.0	43.2	21.9	197
A_P	96.3	8.0	230.7	19.2	154.0	12.8	177.6	14.8	1200
A_S	7.5	5.7	35.6	27.0	11.1	8.6	19.4	14.7	132
E_R	267.3	5.7	717.6	15.4	279.0	6.0	622.4	13.3	4665
E_P	529.5	5.4	1565.7	16.1	727.8	7.5	1036.1	10.6	9741
E_S	52.5	2.8	148.3	7.9	57.0	3.0	61.5	3.3	1887

[1] P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir and B = Locust. See Table E-13 for explanation of codes.

[2] The values in the columns under "%" indicate the percentages of the actual acreage of the classes in the study area which were omitted during the interpretation process of the Landsat images.

Table E-15. (cont'd.)

Forest Types/ Stand Size	TYPE OF LANDSAT IMAGE: Black-and-White Winter, Acreage		Color Fall, Acreage		Color Winter, Acreage		Diazo Fall, Acreage		Reference Data Acreage
	Abs.	%[2]	Abs.	%	Abs.	%	Abs.	%	
K_R[1]	470.3	11.8	914.6	22.9	677.3	17.0	569.0	14.3	3984
K_P	406.2	6.9	1026.0	17.5	510.7	8.7	779.3	13.3	5853
K_S	21.9	3.4	68.6	10.5	53.8	8.3	69.5	10.7	652
Q_R	19.3	8.0	60.0	24.8	21.3	8.8	77.3	31.9	242
Q_P	46.3	4.8	186.8	19.5	41.2	4.3	113.1	11.8	959
Q_S	8.8	12.4	8.8	12.4	0	0	9.6	13.5	71
S_R	0	0	0	0	0	0	0	0	42
S_P	0	0	10.0	35.7	2.5	8.9	0	0	28
S_S	0	0	0	0	0	0	0	0	0
B_R	0	0	0	0	2.5	4.5	0	0	56
B_P	14.4	9.1	93.8	59.4	13.1	8.3	23.7	15.0	158
B_S	0	0	16.2	44.1	0	0	6.8	18.4	37
Total	2997.0		8362.8		4262.3		6304.1		59876

[1]P = Pine, O = Oak-Hickory, M = Northern Hardwoods, A = Aspen, E = Lowland Hardwoods, K = Mixed Hardwoods, Q = Conifer Swamps, S = Spruce-Fir and B = Locust. See Table E-13 for explanation of codes.

[2]The values in the columns under "%" indicate the percentages of the actual acreage of the classes in the study area which were omitted during the interpretation process of the Landsat images.