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APPLICATION OF DIGITAL ANALYSIS OF
MSS DATA TO AGRO-ENVIRONMENTAL STUDIES

Semi-Annual Progress Report

NASA Grant NSG-5080

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Columbia Univ.
Dept. of Geography
N.Y.C. 10027

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DEPARTMENT OF GEOGRAPHY

International Affairs Building
420 West 118th Street

APPLICATION OF DIGITAL ANALYSIS OF MSS DATA TO AGRO-ENVIRONMENTAL STUDIES

Semi-Annual Progress Report
NASA Grant NSG-5080
April 1, 1978

Principal Investigators

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Colin J. High
Jerry C. Coiner
Leonard Zobler

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2. Neary, Patricia J. and Jerry C. Coiner. "Monitoring Agricultural Systems," (to be presented as a Poster Session at the 12th International Symposium on Remote Sensing of the Environment, Manila, April, 1978).

3. Coiner, J. C. and R. C. Bruce. "Use of Change Detection in Assessing Development Plans: A Philippine Example," (to be included in the Proceedings of the 12th International Symposium on Remote Sensing of the Environment, Manila, April, 1978).

I. Columbia University, Geography Department, Remote Sensing Project.

Since June 1975, Columbia University, Department of Geography has been conducting research on various aspects of applying Landsat and other remote sensor data to a broad range of topics related to agriculture, agricultural development, and the environment. The research is carried out in collaboration with the NASA/Goddard Institute for Space Studies (GISS) and is in support of the Institute's program in Earth Resources.

The primary purpose of the research is to aid in developing a global agricultural monitoring system which would rely on satellite data collection systems as major data sources. This involves the study of three specific topics: 1) agricultural change, 2) traditional agricultural systems and 3) relationships between agriculture and the physical environment, i.e. the agroecosystem.

Primary data sources for these studies are simulated advanced multispectral sensors of various resolutions, 24-Channel multispectral scanner (MSS) data, Landsat data, as well as other remote sensor data made available through the offices of GISS. MSS, Landsat, Skylab and aircraft spectrometer data are analyzed by means of GISS-developed software and computing facilities.

The faculty of the Department of Geography, Columbia University works closely with GISS personnel as well as supervises the student research assistants who may undertake individual projects within the framework of this proposal.

Participating Columbia University faculty members from the Department of Geography are:

Professor Kempton E. Webb, Chairman

Professor Leonard Zobler

Professor Colin J. High

Dr. Jerry C. Coiner

In addition to the four principal investigators, the staff includes five funded graduate students, three part-time student technicians and four graduate researchers funded from other sources.

The following papers were prepared by the staff during the reporting period.

1. Neary, Patricia. "Monitoring Agricultural Transition in Southern New Jersey Using Landsat Data." M.A. Thesis, Department of Geography, Columbia University, January, 1978.

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II. Experiments in Progress

A. Support to Airborne Spectroradiometer Studies

GISS/Columbia has developed a high resolution spectroradiometer. This instrument acquires line trace spectra over a range from .43 to 1 micron for sequential areas approximately 18 meters square. To aid in interpreting these spectra and relating them to specific ground locations a 35 mm photograph is acquired with every tenth spectrum.[1]

Analysis of data acquired by this system over Imperial Valley, California has pointed to the existence of a spectral shift in the chlorophyll red absorption edge associated with the heading of wheat and grain sorghum.[2]

Preliminary results of a study being conducted with data acquired over the LACIE Intensive Test Site in Finney County, Kansas further substantiate this red-shift phenomenon. Figure 1 shows the ratios (averaged over each individual agricultural field) of data from two bands, 780-790 nm and 740-750 nm, of the GISS/Columbia spectroradiometer. Fields in the corn and grain sorghum categories were planted within the month preceding the date of data acquisition (May 21, 1975); therefore, these categories consist primarily of exposed soil surfaces. The

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[1] Chiu, Hong-Yee and William Collins, "A Spectroradiometer for Airborne Remote Sensing." Photogrammetric Engineering and Remote Sensing, Vol. 44 (4), April 1978, pp. 507-517.

[2] William Collins, "Remote Sensing of Crop Type and Maturity," Photogrammetric Engineering and Remote Sensing, Vol. 44 (1), Jan. 1978, pp. 43-55.

FIGURE 1: AIRBORNE SPECTRORADIOMETER FIELD AVERAGE RATIOS

(730-790nm)/(740-750nm)

FINNEY COUNTY, KANSAS MAY 21, 1975

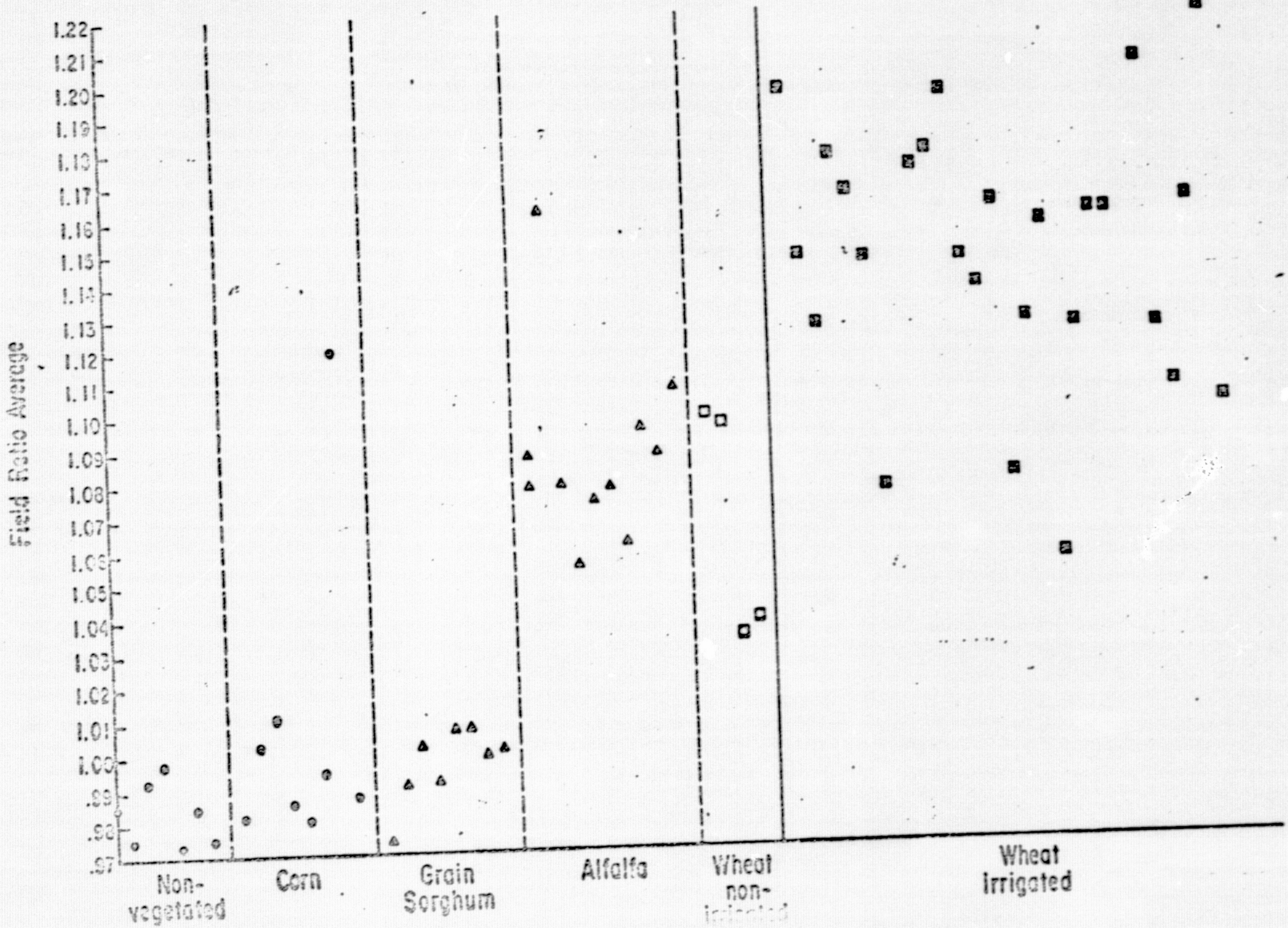
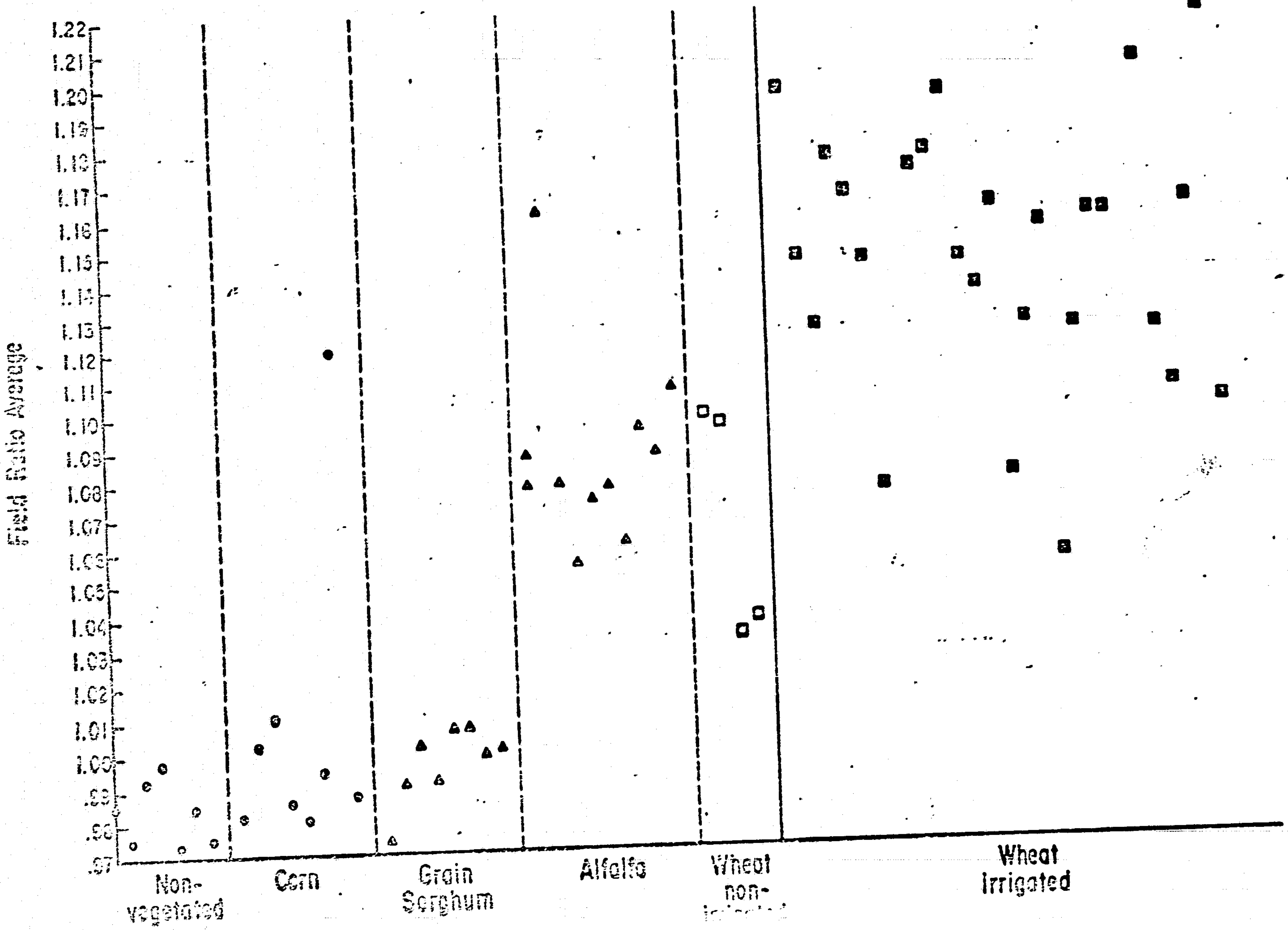


FIGURE 1: AIRBORNE SPECTRORADIOMETER FIELD AVERAGE RATIOS

(780-790nm)/(740-750nm)

FINNEY COUNTY, KANSAS MAY 21, 1975



alfalfa fields are mature with predominately full canopy cover. The winter wheat is also mature, having been planted in September and October the previous year. As Fig. 1 indicates, mature, irrigated wheat is discriminated from the other crops and field conditions by ratios greater than approximately 1.10. Some confusion occurs with 3 wheat fields below the 1.10 ratio, 1 corn field and 2 alfalfa fields above. These anomalies cannot be accounted for with the available ground truth information.

To corroborate the spectroradiometer data, JSC helicopter FSS (S-191 H) data, acquired over the Finney County Test Site on the same day (May 21, 1975), was also analyzed. The ratios of two 20-nm bands (780-800 nm, 740-760 nm) were averaged for each field flown within the site and plotted by crop type and maturity (Figure 2). As with the spectroradiometer data, mature (heading and fully headed) wheat are separable from other crops and field conditions by a band ratio value of approximately 1.124. One alfalfa and 3 wheat fields are misassigned.

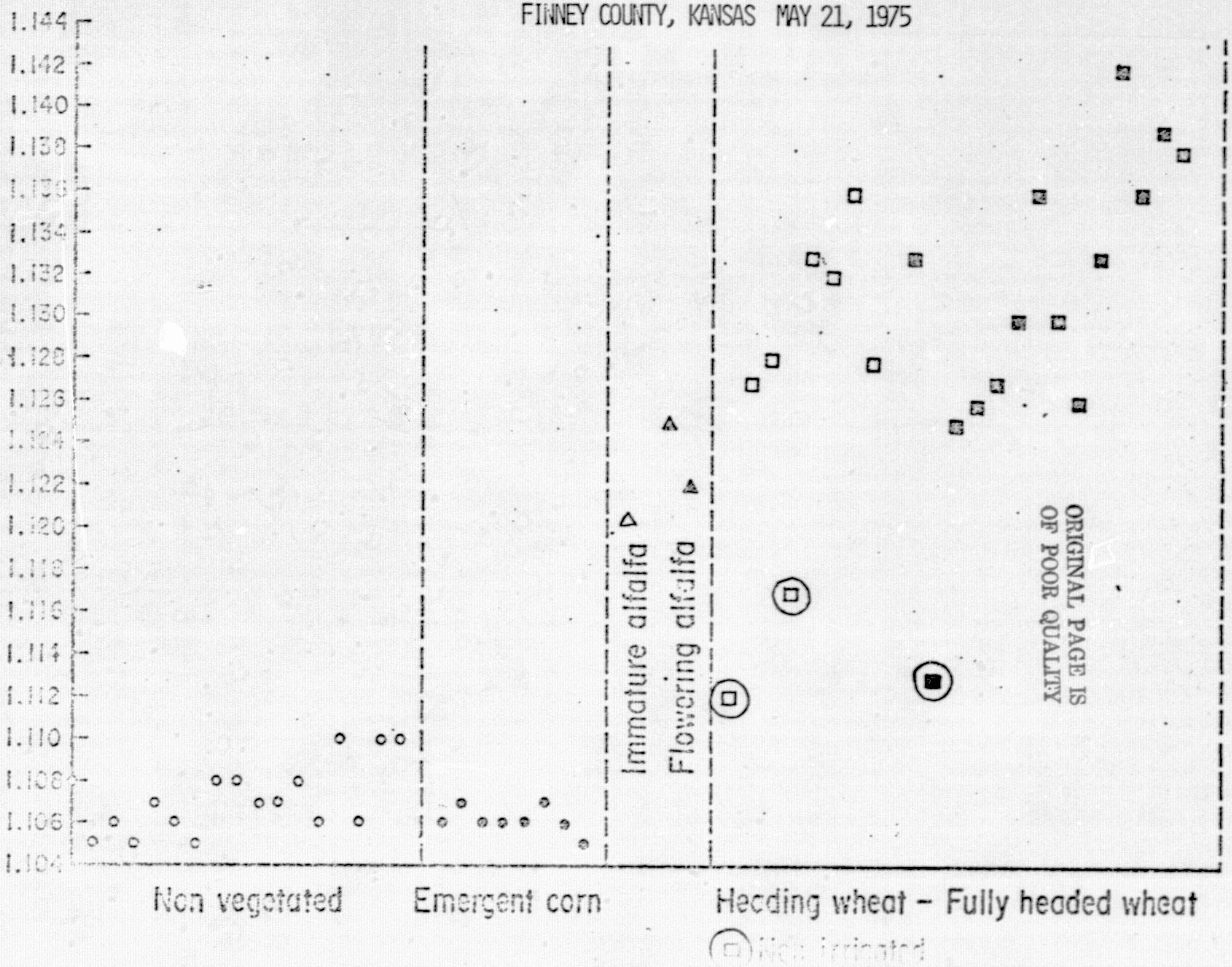
Data from both instruments confirm the existence of the widening absorption edge initially identified by Collins in the Imperial Valley. Figure 3 shows the correlation between data acquired by each instrument for fields that were jointly covered by the two missions. The r^2 value for the nine jointly covered fields is .985. These results support the findings that both instruments are detecting the same phenomenon.

Additional analysis is continuing on FSS data acquired over this site on an earlier date (May 14, 1975).

FIGURE 2: SPECTRAL BAND RATIOS FOR VARYING CROP STAGES

FSS -- (780-800NM)/(740-750NM)

FINNEY COUNTY, KANSAS MAY 21, 1975



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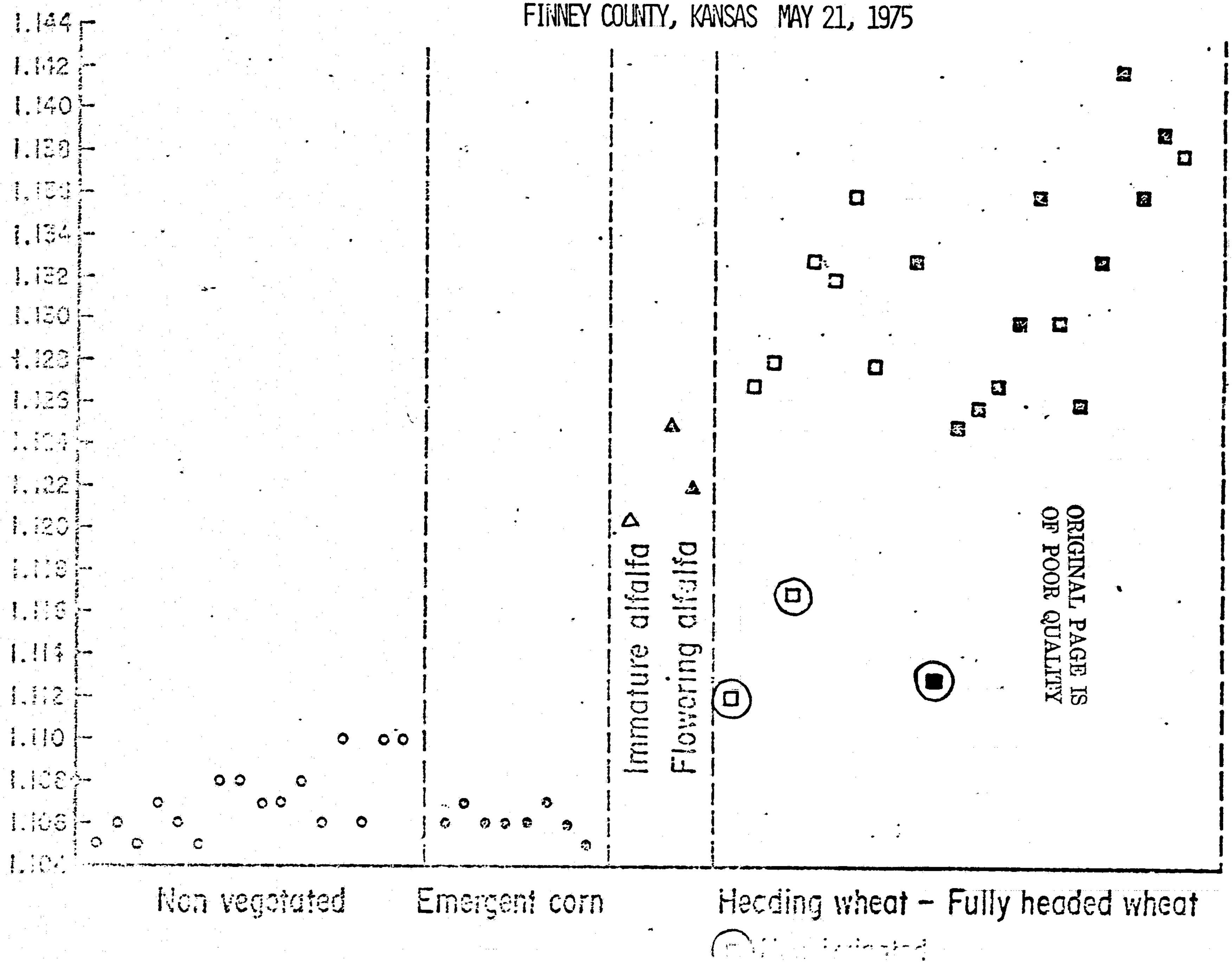


FIGURE 3: FSS vs SPECTRORADIOMETER RATIO

FINNEY COUNTY, KANSAS 5/21/75

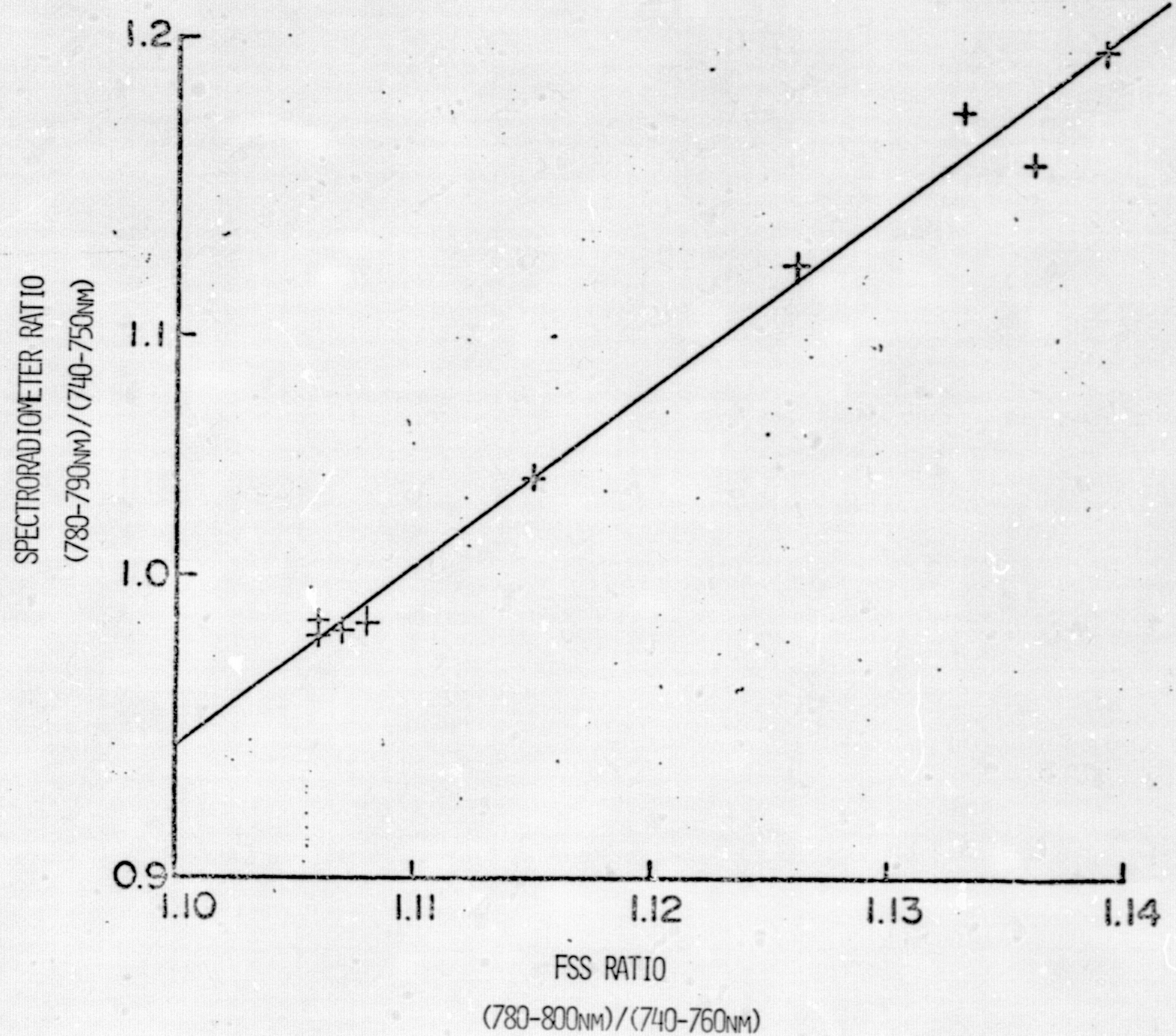
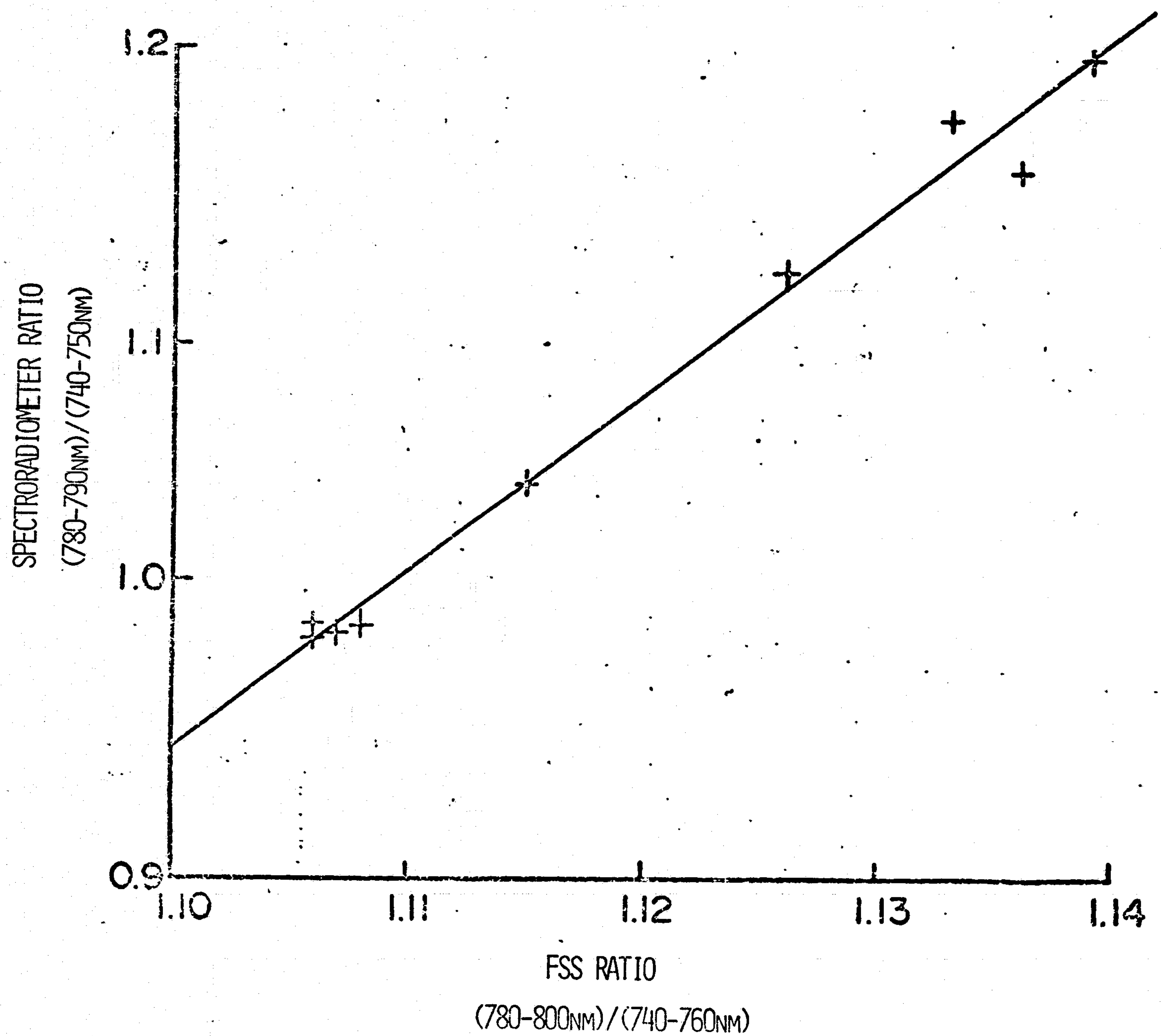


FIGURE 3: FSS vs SPECTRORADIOMETER RATIO

FINNEY COUNTY, KANSAS 5/21/75



B. Landsat Applications to Agricultural and Land Use Change Studies

1. Monitoring Agricultural Transition in Southern New Jersey

This research, part of a broader effort to explore the possibilities of monitoring agricultural change with Landsat data, is outlined below and described more fully in the Appendix to this report.

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1.1. Background

For this study a 13,675 hectare area in southern New Jersey was chosen, an area which is known to be under considerable pressure to adjust to new agricultural circumstances. The study area is located about 40 kilometers south of Philadelphia, Pennsylvania, and 15 kilometers west of Vineland, New Jersey.

Agriculture and food processing combine to form New Jersey's largest industry. Over the past few years, the state's total area in vegetables has declined whereas total area in wheat, corn, and soybeans has increased. Table 1 shows a decline in hectares harvested over the period 1971-1976 for commercial vegetables, in particular, for processing vegetables.[1]

---

[1] Significant discrepancies have been noted with respect to data in this category as reported annually in New Jersey Agricultural Statistics for the years 1971 through 1976. (Each annual report gives statistics in this category for preceding years as well as the current year.) For example the 1972 Statistics reported the total area harvested in 1971 for all commercial vegetables for processing as 17,200 hectares. The 1976 Statistics reported 17,600 hectares in this category for 1971, and in 1977 the figure given was 13,400 hectares, as shown in Table 1. According to the New Jersey Crop Reporting Service, the latest (1977) figures are the most accurate, implying that it took six years to rectify a 4,000-hectare error--an error amounting to nearly one-third the acreage in that category. It appears that LANDSAT acreage estimators would be more efficient in this regard.

TABLE 1

AREA HARVESTED IN HECTARES--ALL COMMERCIAL VEGETABLES

STATE OF NEW JERSEY

1971-1976

Year	For Fresh Market	For Processing	Total
1971	24,140	13,400	37,540
1972	24,120	12,300	36,420
1973	22,610	12,970	35,580
1974	20,850	13,800	34,650
1975	19,280	11,080	30,360
1976	19,850	5,700	25,550

SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1977.

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SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1977.

Economic pressures have forced several vegetable processing concerns in New Jersey to move their operations elsewhere. Many New Jersey farmers have thus had to find either new markets or new crops.

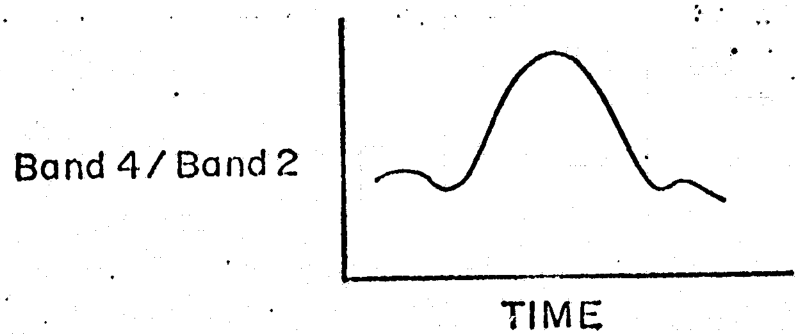
The approximately 14,000 hectares which comprise the test area for this study lie in and around the area formerly farmed by Seabrook Farms, Incorporated, which closed its fresh vegetable processing plant in Cumberland County in March 1976. This meant that 1,485 hectares farmed by Seabrook and 8,100 hectares under contract with 150 farmers would be released from their current land uses. All 1,485 hectares farmed by Seabrook are included in the test area except for a small area surrounding the town of Seabrook itself. Also included are privately owned farms, most of which operated indepently of Seabrook; these are included as a comparison to the Seabrook land which had been completely devoted to vegetables.

1.2. Experimental Design

The purpose of this study is to detect agricultural systems change by separating two agricultural systems, corporate vegetable farming and field cropping, in order that the transition from the former to the latter may be detected. This study traces land utilization over time in an area where two agricultural systems exist in close proximity, each imposing a different spatial pattern on the landscape.

With respect to "land utilization in time," crop calendars vary for each of the two types of agricultural system in this area. For example, vegetables are planted mainly during the warmer months, whereas winter grains are planted in the Fall. The period of active photosynthesis for vegetables extends later into the Fall than it does for field crops. Winter grains are seeded in October and do not make an impact on land cover until early November.

In addition to the temporal component of land utilization, the spatial component must be considered. In the agricultural area being examined here, vegetation and soil are the dominant surface features. Actively photosynthesizing plants are characterized by a relatively large amount of near infrared reflectance (bands 3 and 4 on the MSS) and a relatively small amount of red reflectance (band 2 on the MSS). Soils exhibit spectral patterns distinct from vegetation while also differing within soil categories. Generally, spectral response curves of soils are rather flat in the visible region with a decrease in reflectance in the near infrared. The reflectivity of soils in the visible is also dependent upon soil color--a lighter soil will be more reflective than a darker one. The coastal plain soils in the test area are rather bright and therefore strongly influence spectral response in the visible bands. In this study, the ratio of band 4 to band 2 is used as an indicator of vegetation density and growth stage. Plotting the ratio of band 4 to band 2 over time for a specific ground area yields a curve for each of the four years of the study, similar to the diagram below.



Although Landsat MSS measurements of reflected energy are made at approximately the same time of day, the sun elevation at a specific latitude at a given hour changes throughout the year. To account for this variation, a sun elevation correction factor was introduced which adjusts all measurements to a solar angle of 90^{0}. In addition, the use of the band 4/band 2 ratio reduces solar angle differences as well as signal fluctuations and differences attributable to changing atmospheric conditions by using a relative measure, a ratio.

The analysis employed digital Landsat data and relied upon, as support materials, Landsat imagery, aerial photography, United States Geological Survey maps, Seabrook Farms Corporation maps, and ground-collected information.

Although Landsat data are available for passes made every eighteen days from July 1972 to January 1975 and every nine days from January 1975 through most of 1976, not all of it is useable, due to excessive haze or cloud cover or to technical problems in producing computer compatible tapes of the data. Out of 119 possible coverages, 26 acquisitions (or 22 percent) were found to be useable in this study. All 26 scenes were preprocessed for geometric correction and rectification to a Universal Transverse Mercator grid.

Imagery was used initially to choose suitable passes and to geographically identify the corresponding digital data. A Landsat image, or "scene" corresponds to a block of data over a geographic area of approximately 34,225 square kilometers, and each data tape contains information from an entire scene. From each scene twenty-four smaller areas of 595 hectares, or "quads", are used as the basic unit of analysis. These areas may encompass up to 40 agricultural fields. It is felt that this unit is suitable for the long-run objective of the study--to simulate global monitoring. In addition, the unit conforms to technical constraints in the software used in support of the project. Each set of twenty-four areas is registered spatially from date to date. Therefore the study concerns the change in reflectance of twenty-four identical areas over the course of four years--1973 through 1976.

An unsupervised classification routine developed at GISS was used to obtain a nominal spectral response for each quad. Normally, this routine is used to delimit clusters of pixels which have similar response curves. In this study, however, the object was to delimit one single cluster for each quad into which approximately 95 percent of all the pixels in the quad fall. This percentage was chosen to filter out highly reflective, exotic pixels which might influence the quad's spectral response disproportionately. The classification routine was applied to twenty-four quads from each of twenty-six passes to obtain 624 characteristic 4-band spectral responses. The reflectances for bands 4 and 2 were ratioed for each of the 624 nominal spectral responses and then plotted against time for each of the 24 quads.

1.3. Results

Classification was performed on all of the 24 quads for each of the available 26 LANDSAT passes and the band 4/band 2 ratios calculated and plotted. Two sample plots are presented in Figures 4a and b for quads 2 and 23, which are representative of field crops and vegetables respectively, as determined from information collected in the field and maps from Seabrook Farms. Figure 5 is a superimposition of these two plots to facilitate comparison.

The shapes of the curves differ from year to year because of a lack of concurrence in satellite acquisition times for usable data and local atmospheric differences. The two quads can be compared to each other within each year, however. The curves diverge within the summer months when both field crops and vegetables are growing. Field crops tend to be in full canopy during July and August whereas vegetables tend to have less canopy cover with rows being separated by strips of soil. The large amount of exposed soil decreases the band 4/band 2 ratio, and this is evident in the figure. Curve separation may also be related to meteorological events which have immediately preceded data acquisition. For example, the Landsat pass during the summer of 1975 occurred ten to fifteen days after a series of severe storms destroyed crops in the southern New Jersey region. In Figure 5, this event is reflected in the similarity of the two plots of 1975 during the summer, when they would be expected to diverge.

The application of a non-parametric Mann - Whitney "U" test to the band 4/band 2 ratios of the two groups of quads (vegetable and field crops) yielded a significant difference in the means of the two groups of ratios for nine of the twenty-six acquisition dates, with a 98 percent level of confidence. Seven of these nine passes were during July and August, thus emphasizing the significance of the divergence between the two agricultural systems in the summer months.

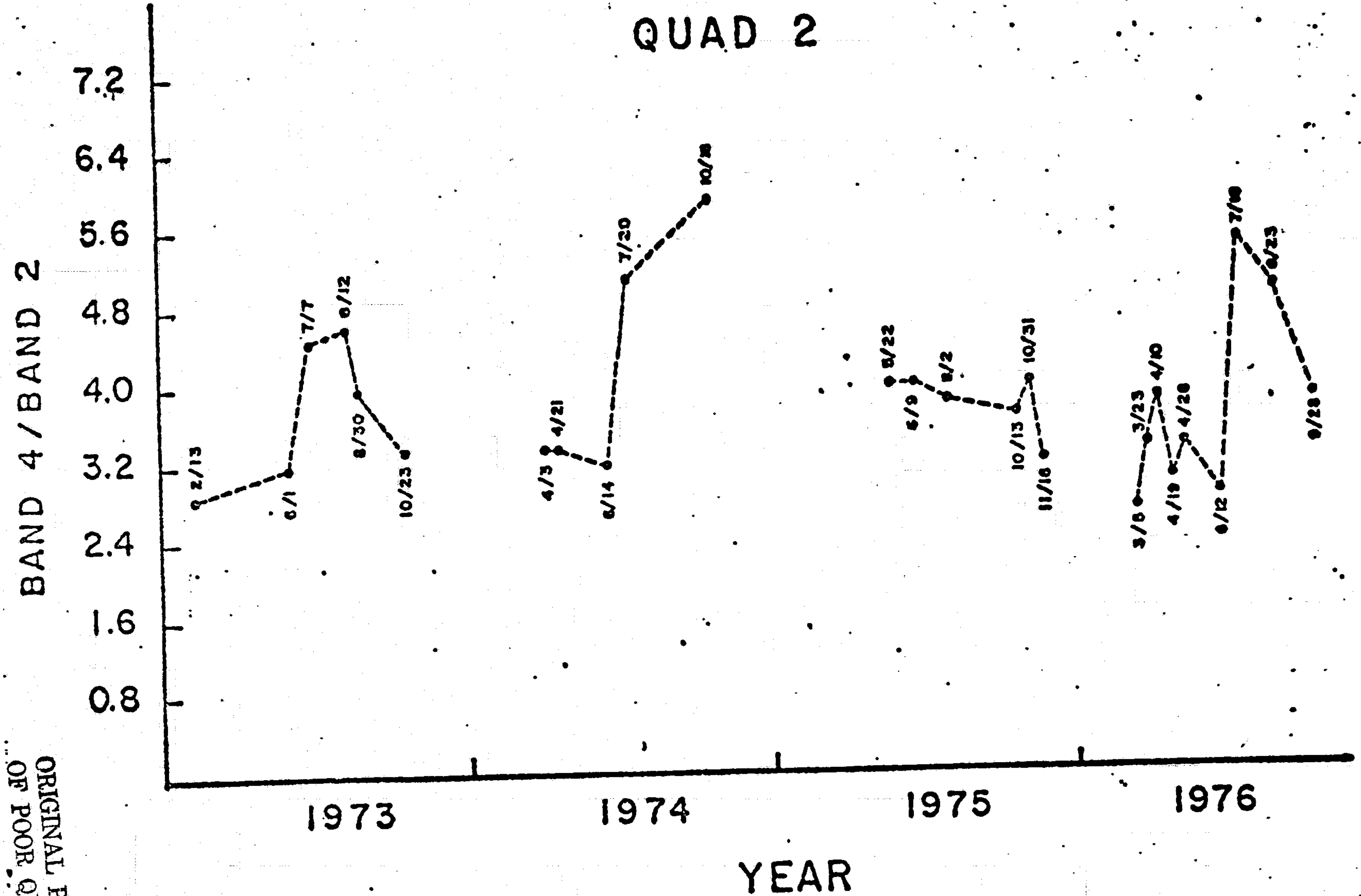


Figure 4a Quad 2. (field crops)

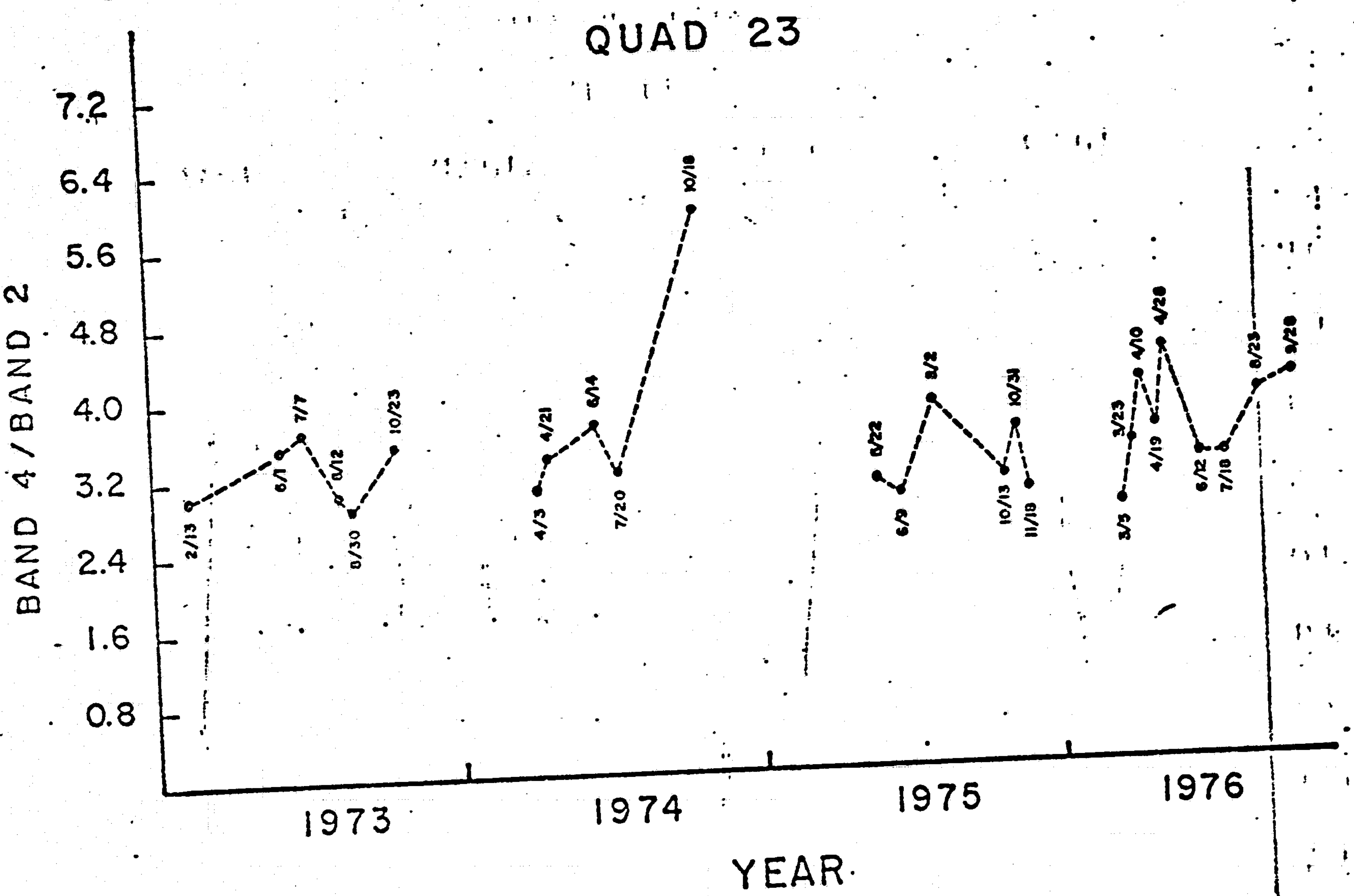
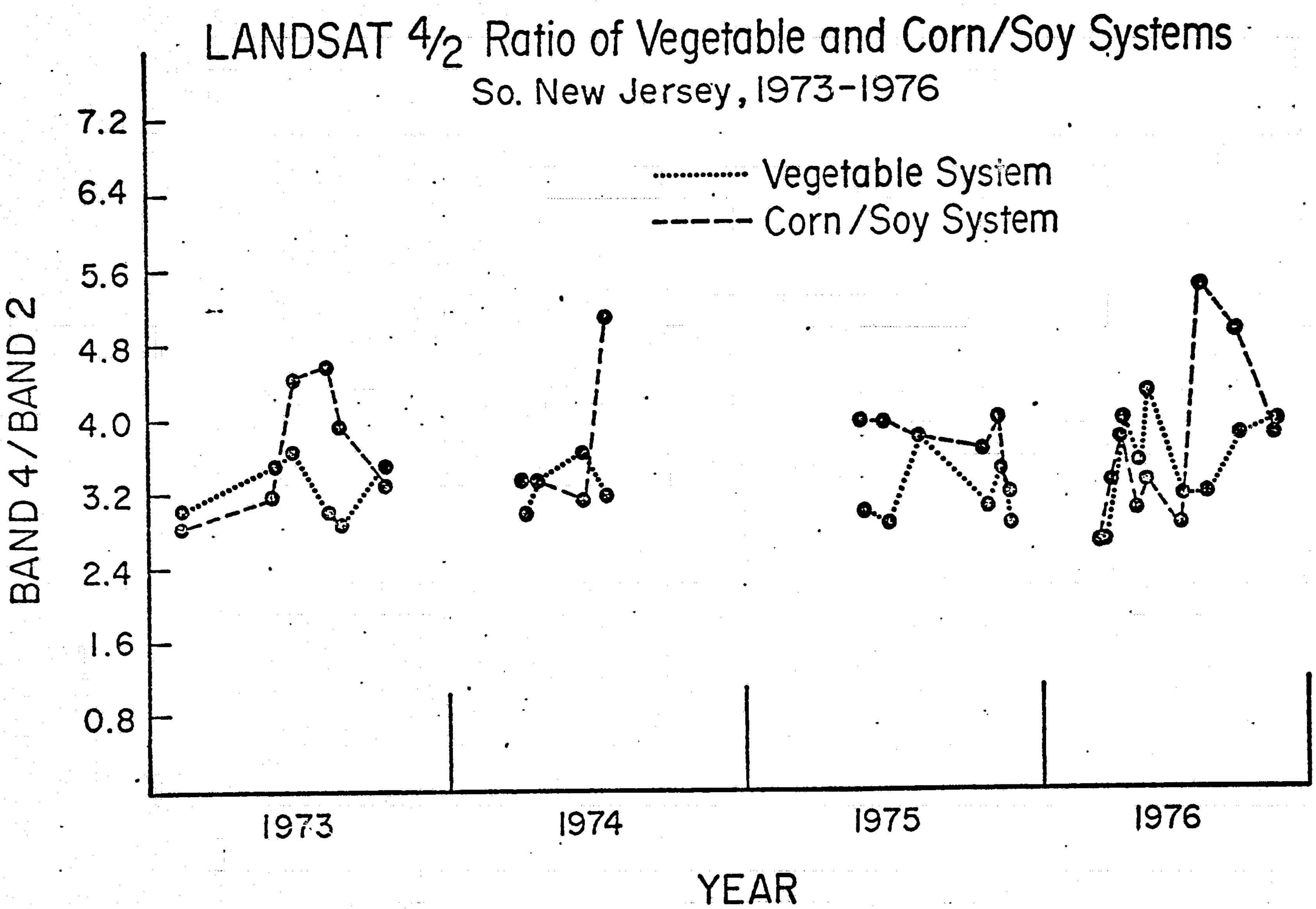


Figure 4b Quad 23. (vegetables)

FIGURE 5



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To test the separability of the two agricultural vegetation systems from the natural vegetation component of the landscape, the nonparametric Kruska - Wallis test was applied to the three sample groups. This test revealed that the three sample groups belong to different populations, at a 99 and 95 percent confidence level, respectively, for the data from June 1973 and June 1976.

As a preliminary test of an aggregated-unit approach to monitoring agricultural systems, the results are encouraging. The Landsat derived radiometric indicator, even at this level of aggregation, appears to offer a viable method of differentiating agricultural systems from each other as well as from natural vegetation elements.

2. East African Swidden Agriculture

An investigation into the feasibility of detecting shifting cultivation in East Africa has encouraging preliminary results.

The study site is in the West Pokot District of Kenya. Landsat computer-compatible tapes for three dates are available: scene 1067-07221, 9 September 1972; scene 1193-07230, 1 February 1973; and scene 2063-07111, 26 March 1975.

Supplementary data include 1956 black-and-white aerial photography and data from 1961-62 anthropological fieldwork.

Using the supplementary data in conjunction with gray scale printouts of geometrically corrected LANDSAT data, a preliminary study site of 595 hectares was selected. An approximately ten-hectare area in this study site lies in a region locally known as Asar and always contains active cultivation. This area was thus selected as the training area, from which the most frequent, or modal, response in each spectral band was determined, for each of the three available dates. These modal responses constituted the training data.

These training data, after successful application to the preliminary study site, were extended to a larger 200 by 200 pixel area (approximately 19,000 hectares).

Information about the study area and swidden agriculture as it is practiced there, in conjunction with an understanding of the characteristics of the satellite data and of the analysis procedure, provides a basis for the development of a model of expected results. The model developed here has three components: data points classified as swidden should be on east-facing slopes below 2,500 meters; one-sixth to one-fourth of the cultivable east slope area below 2,500 meters could be in cultivation at one time; a number of data points should be in swidden on all three dates, covering two and one-half years. Analysis results were evaluated in terms of these three expectations: for the three dates, 78.6 percent, 88.9 percent, and 86.5 percent of the points classified did fall on east-facing slopes below 2,500 meters; roughly one-eight of the cultivable east slope area below 2,500 meters was in cultivation on each date; 387 data points were in swidden on the first two dates, and 76 data points were in swidden on all three dates.

The high rate of correspondence between expected results and analysis results leads to the inference that swidden agriculture has been successfully identified in this area using the method described above.

3. Suburban Land Use Change and Flooding

Major flooding has occurred in the Saw Mill River watershed, Westchester County, New York, in 1975 and 1977 despite the construction of numerous flood control structures. It is believed that watershed development is a major contributing factor to the flooding, due to reductions in natural vegetation, compaction of the earth's surface, increases in impervious surface area and in smoother less frictional surfaces. The purpose of this study is to monitor changes in land use categories of hydrologic significance over a five year period (1972-1977) using Landsat data.

The areal extent of the following land use categories, each of which posesses unique runoff characteristics, will be determined for the 26-square mile watershed for both 1972 and 1977:

1) Commercial, business and industrial
2) Residential- multi-family housing
3) Residential- single family homes situated on ¼ acre lots or smaller
4) Residential- single family homes situated on lots greater than ¼ acre
5) Lawns, parks and cemetaries
6) Woodlands
7) Water

Aerial photography (1:24,000) acquired in 1970 and 1976, in addition to ground survey of the area, will be used to assist in the selection of test sites for the development of spectral signatures for the land use categories.

C. Effect of Environmental and Agro-Management Factors on Computer Classification of Crop Type

Current research in computer classification of remote sensing techniques concentrates on acreage estimation of agricultural land use. The techniques used for acreage estimation identify and then separate radiance values of the scene into categories. These values are usually considered discrete elements of the environment, and no attention is given to their composition. Another way of examining the spectral response of any landscape is to view it as a composite of management and physical environmental characteristics, which make varying contributions to the landscape's radiance. It is the purpose of this research to assemble major environmental and agro-management factors into a model measuring their relative influence on spectral signatures of an agricultural landscape. The area of study is in a LACIE intensive study site in the northern Great Plains. The remote sensor data was acquired by the Johnson Space Center 24-Channel multispectral scanner, August 15, 1975.

The computer classification method used in this digital analysis consists of two major elements: 1) the ground truth system and 2) the radiance values of the landscape. The first element divides the scene into finite geographic units of varying sizes and shapes (i.e., agricultural fields, soil boundaries), and the second element represents the spectral response of the environment. It is the function of the classification algorithm to distinguish between and assign each pixel to its respective land use/land cover category. A change in the ground truth system results in classification of the same landscape into different categories. This may reveal a greater degree of homogeneity within a category, resulting in higher classification accuracies and a more thorough understanding of the spectral reflectances.

In agricultural studies, two categories of environmental parameters are identified: management and physical environment. Management consists of such farming factors as tillage direction, fertilization, planting date, and irrigation. The physical environment category includes elements such as soil type, soil color, and terrain slope. The relative influence of a set of parameters on land use classification is unique for each landscape.

The study region for this investigation is a 5 x 7.5 kilometer area of Williams County, North Dakota, where severe winters and dry summers predominate. Spring wheat is the major crop in a landscape intermixed with summer fallow and pasture fields. Summer fallow is practiced almost exclusively as an anti-wind erosion measure in strip cropping patterns. Pasture includes harvested and non-harvested oats and other natural grasses which may or may not be grazed. The agricultural practices are influenced to some extent by remnant glacial features, such as potholes and till knobs. Potholes create areas of poor drainage which become marshy during stages of evaporation after the rainy season. Sections of patchy bare soil (till knobs) produce a mottled effect in the appearance of the landscape.

The management practices and physical environmental factors of this area comprise a landscape system of varying spectral responses. Explanation of the spectral variability will be attempted through the testing initially of three environmental/management parameters as separate ground truth systems: tillage direction, planting date, and soil type.

To date, the three ground truth files have been constructed in preparation for computer classification of the multi-spectral scanner data. The ground truth management system used in this study is a computerized geographic information system developed in cooperation with GISS.[1]

Continuing work on this experiment involves computer classification using each of the three ground truth systems in order to determine the relative influence of each environmental and agro-management parameter on classification accuracy for the land cover classification categories. The classification procedure is as follows:

1) Flight Line 1 was selected as the training area. An unsupervised classification is performed on this data in order to derive spectral signatures for each individual land cover category. The ground truth arrays are used to "mask" the data. For example, to determine the signature of the "wheat-soil type A" category, only pixels in that category, as defined by the ground truth, are used in the classification routine.

2) Once signatures are established for each combination of crop type and management or envionmental parameter value, all signatures for land cover categories in a single management or environmental parameter (e.g., soil type) are simultaneously applied to the entire training area in a supervised classification mode to determine classification decision criteria. Flight lines 2 and 3 are then classified using these signatures and their associated decision criteria as established from the training data.

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[1] See Coiner, J. C. and Ungar, S. G., "Ground Truth Management System to Support Multispectral Scanner (MSS) Digital Analysis." Proceedings of the ASP-ASCM Joint Annual Meeting, Washington, D. C., February 27 - March 5, 1977.

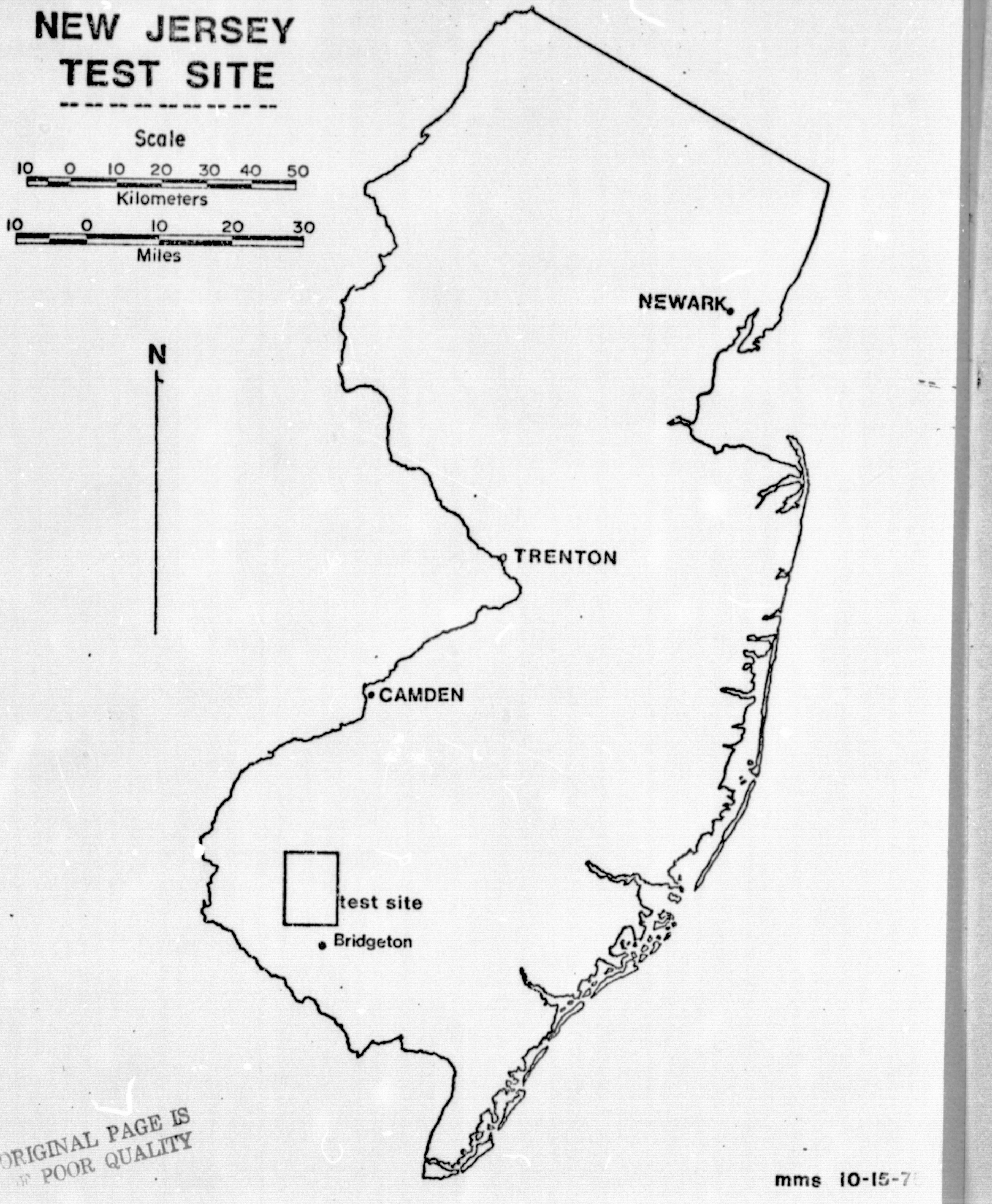
APPENDIX

MONITORING AGRICULTURAL TRANSITION IN SOUTHERN NEW JERSEY USING <u>LANDSAT</u> DATA

Patricia Jeanne Neary

Submitted in partial fulfillment of the
requirements for the degree of
Master of Arts,
in the Faculty of Political Science,
Columbia University

January 1978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Scale
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Kilometers
10 0 10 20 30
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test site
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INTRODUCTION

Purpose

Agriculture is one of this nation's most important industries. It is also one of the prime activities through which man modifies the natural ecosystems of the earth. It is therefore of tremendous importance that decision makers in business and government have an accurate picture of the state of agricultural production from season to season and of the long-range trends in different agricultural regions. This paper will explore the possibilities of monitoring agricultural systems change with LANDSAT data and will discuss the results of one attempt using data from southern New Jersey.

Why Monitor Regional Agriculture?

The ability to detect and measure agricultural change allows a geographer to assess the impact of new land uses on the social and business community and on the environment of a particular region. There are a number of reasons for investigating the type and amount of agricultural change which may be occurring. First, there are the economic con- considerations. Local agribusiness must identify regional trends in order to anticipate future demands of specialized services. A fertilizer manufacturer must know what crops are gaining in importance so that he can plan the production, distribution, and storage of his product. A dealer in farm machinery would be interested in agricultural trends to aid in planning for future machine inventory and maintenance demands. Builders of storage and marketing facilities monitor regions undergoing conversion of cropping systems to enable them to provide necessary warehousing.[1] Commodity brokers, wholesalers, and retailers have an interest in how agricultural change will affect prices. Local governments use agricultural statistics to establish assessment values and tax rates.

Secondly, environmental conditions are affected by agricultural change. Different cropping systems require different types of fertilizer, herbicide, and pesticide which affect the environment when used and, perhaps, for a long time afterward. Irrigation practices can affect groundwater supplies or alter flow in streams. In addition, certain crops can encourage or discourage organisms from entering a particular environment.

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[1] Hill-Rowley et al., in "Improved Resource Use Decisions and Actions through Remote Sensing," National Aeronautics and Space Administration Earth Resources Survey Symposium (Houston: National Aeronautics and Space Administration, June 1975), 1747-1768, note that for economic and technical effectiveness processing facilities for beans, corn and small grains should be located very close to areas of high production. Specifically their report states ". . . in the past, elevator location decisions were a 'hit-or-miss' process based mainly on subjective and unscientific procedures and criteria. Crop Reporting Service statistics regularly indicate production totals by counties. However, elevator service areas, with a radius of 13 to 16 kilometers, are areas substantially smaller than a county, and many include parts of more than one county."

LANDSAT as a Monitoring Tool

Since agriculture represents a renewable resource whose cycle of renewability can be as short as two months, monitoring the resource is an onerous and expensive task. Traditional methods of data collection such as ground surveys and aerial photographs are more appropriate for slowly changing phenomena, for example, nonrenewable resources, geologic features, or certain residential areas. "Monitoring" has been described as the process of "obtaining a new inventory periodically."[1] LANDSATs I and II, earth resources satellites maintained by the National Aeronautics and Space Administration, offer a means to collect data periodically at little expense to the user. Between 1972 and 1975, a LANDSAT satellite passed over the same locale every eighteen days and from January 1975 through most of 1976, every nine days. It is, therefore, well suited for monitoring a seasonal resource such as agriculture.

Were LANDSAT used to monitor regional agriculture, it could prove very economical for the agribusiness community. A recent study estimates that the improved information capabilities afforded by LANDSAT could benefit the United States annually a sum of $200 to $250 million for wheat, $50 to

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[1]Robert N. Colwell, "Introduction," in Manual of Remote Sensing, ed. Robert G. Reeves (Falls Church, Virginia: American Society of Photogrammetry, 1975), p. 2.

$100 million for corn, and $6 to $11 million for soybeans, "using conservative assumptions on expected LANDSAT system performance."[1]

The methodology proposed in this paper is tested on an area in southern New Jersey, where it is known that a change in land use is occurring due to the loss of a specific market. An indicator is developed which separates two agricultural systems in order that the change from one to the other may be detected. Should the monitoring of agricultural transition in New Jersey prove feasible, it may be extended to other agricultural regions which are currently undergoing rapid change.

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[1] Econ, Incorporated, Economic Benefits of Improved Information on Worldwide Crop Production (Washington, D.C.: NASA Scientific and Technical Information Facility, N77-22003, NASA-CR-152657, 1977), p. iii.

AREA OF INVESTIGATION

Location and General Characteristics

For this experiment a 13,675 hectare (approximately 34,000 acres) area in southern New Jersey was chosen, an area which is known to be under considerable pressure to adjust to new agricultural circumstances. Map 1 shows the approximate location of the study area, which is located about 40 kilometers south of Philadelphia, Pennsylvania, and 15 kilometers west of Vineland, New Jersey. Map 2 shows more specifically the area which is being analyzed.

This specific region lies in both Salem and Cumberland counties, within the Upper Pittsgrove and Alloway townships in Salem County and the Upper Deerfield Township in Cumberland County. Upper Pittsgrove and Alloway are in the central portion of Salem County. The landscape is gently rolling, underlain by geologic formations of loosely consolidated sedimentary deposits. Soils in the parts of these townships which are in our test area belong to a soil association that is silty, well-drained to poorly drained, nearly level to gently sloping.[1] In 1953 this part of Salem County

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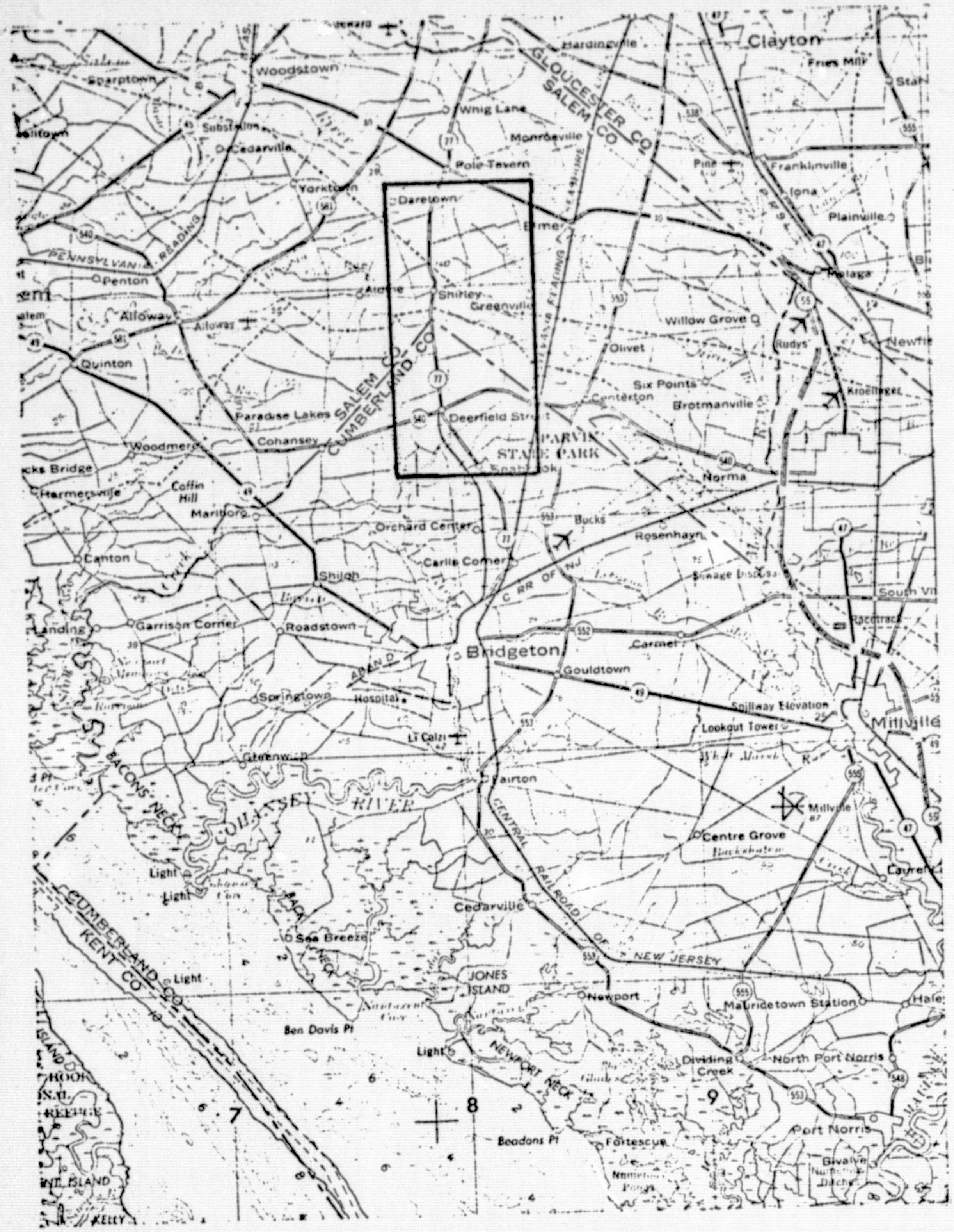
[1] U.S., Department of Agriculture, Soil Conservation Service, New Jersey Agricultural Experiment Station, Soil Survey of Salem County, New Jersey, by Van R. Powley (Washington, D.C.: Government Printing Office, 1969) p. 5.

Map 2. Location of Test Site within Cumberland and Salem counties.



SOURCE: United States Geolcgical Survey 1:250,000 map, entitled "Wilmington, Delaware; New Jersey; Penna.; Maryland."

was characterized by "dairy-cash crop and corporation vegetable farming on heavy textured soils."[1] Personal observations in 1976 reveal that the Salem County section of the test site is dominated by corn, wheat, soybeans, potatoes, orchards, pastures, and nurseries.

Upper Deerfield Township in Cumberland County is immediately south of the area just described. Its topography and soils share the same general properties. Most of that part of the township which is in the study area is very well suited for agriculture. In 1974, 5,158 hectares (12,746 acres) in the Upper Deerfield were devoted to agriculture.[2] Until 1976 vegetables dominated the agriculture in the township; beginning in 1976 corn and soybeans replaced vegetables as the dominant crop.

Recent Agricultural History

Agriculture and food processing combine to form New Jersey's largest industry.[3] The position of the state in the Boston-to-Washington urban sprawl along the east coast of the United States affects its agriculture both positively and negatively. The advantages of its position are obvious in that it lies in close proximity to urban centers which serve

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[1]Leonard Zobler, "Man-Land Relations in Salem County, New Jersey" (Ph.D. dissertation, Columbia University, 1953), p. 193.

[2]Cumberland County Planning Board, Land Use: Existing Patterns and Environmental Characteristics, Upper Deerfield Township, Cumberland County, New Jersey (Bridgeton, New Jersey: Upper Deerfield Township Planning Board, 1974), p. 35.

[3]Donald Janson, "State to Gauge Pollution in Hope of Easing Curbs," New York Times, 16 January 1976, p. 63.

as its markets for both fresh and processed foods. The state has been known for many years for its "commercial gardening and fruit culture."[1] On the other hand, the nearness to urban centers increases the problems of taxation, labor, development, and environment, many of which result from competition with urban centers for a comparable standard of living. These problems have had two effects on New Jersey agriculture: (1) the abandonment of farming and the sellout to industry and housing development, and (2) a gradual change from labor-intensive systems (for example, vegetables and fruits) to more mechanized farming (such as wheat, corn, and soybeans).

Over the past few years, the state's total area in vegetables has declined whereas total area in wheat, corn, and soybeans, has increased.[2] The area harvested in Cumberland and Salem counties for selected field crops is detailed in Table 1. These latter crops have always played a part in the New Jersey agricultural system, but their recent areal increase is indicative of a statewide trend. Table 2 shows the decline

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[1]This type of farming is described as "highly intensive cultivation . . . small land area with large yields of food . . . heavily fertilized . . . labor intensive . . . operations do not require large or numerous building" in Vernor C. Finch et al., Elements of Geography, 4th ed. (New York: McGraw Hill Book Company, 1957), p. 591.

[2]New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1977.

TABLE 1

AREA HARVESTED IN HECTARES--SELECTED FIELD CROPS

CUMBERLAND AND SALEM COUNTIES, 1971-1976[1]

County/Year	Corn	Wheat	Soybeans
Cumberland			
1971	1,290	930	1,170
1972	1,150	1,290	1,170
1973	1,320	1,620	1,340
1974	1,340	1,940	1,700
1975	1,460	2,270	1,900
1976	2,020	2,350	3,040
Salem			
1971	5,260	1,340	2,020
1972	4,130	1,660	2,430
1973	4,740	1,990	2,910
1974	5,020	3,360	3,640
1975	5,220	3,160	3,850
1976	6,480	3,320	5,950

SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1972, August 1975, August 1976, August 1977.

[1]The area harvested in hectares has been calculated by the author, using the conversion factor of 1 acre = .40468564 hectares, from information on acres harvested provided in the NJDA sources.

TABLE 2

AREA HARVESTED IN HECTARES--ALL COMMERCIAL VEGETABLES

STATE OF NEW JERSEY

1971-1976[1]

Year	For Fresh Market	For Processing	Total[2]
1971	24,140	13,400	37,540
1972	24,120	12,300	36,420
1973	22,610	12,970	35,580
1974	20,850	13,800	34,650
1975	19,280	11,080	30,360
1976	19,850	5,700	25,550

SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1977.

[1]The area harvested in hectares has been calculated by the author, using the conversion factor of 1 acre = .40468564 hectares, from information on acres harvested proved in the NJDA sources.

[2]The amount listed in the "Total" column is the sum of hectares listed in the previous two columns.

in hectares harvested for commercial vegetables, both fresh market and processing.[1] From this table it appears that the processing vegetables have undergone the more severe drop. Economic and environmental pressures have forced many members of the vegetable processing community in New Jersey to move their operations elsewhere. In recent years, the Del Monte Corporation, P. F. Ritter (Curtis-Burns Corporation), and the Seabrook Foods Corporation have ceased purchasing New Jersey-grown produce.[2] New Jersey farmers have had either to find new markets or new crops; if they choose the latter alternative, field crops are often the most suitable because (1) a farmer can easily convert to this labor-extensive system and (2) wheat, soybeans, and corn have been drawing an increasingly higher price on the market (wheat and corn dropped in 1977).

The approximately 14,000 hectares which comprise the test area for this study lie in and around the area formerly farmed by Seabrook Farms, Incorporated, which closed its

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[1]These figures were also obtained from New Jersey Agricultural Statistics (1977). It was noted that there was a significant discrepancy between data reported for the years 1971 through 1976 in each year's report. For example New Jersey Agricultural Statistics (1972) reports that acres harvested for all commericial vegetables for processing amounted to 42,420. In 1976 Statistics reports 43,420, and in 1977 it reports 33,120. That the latest figures are supposed to be the most accurate (according to the New Jersey Crop Reporting Service) implies that it took six years to find a 10,000-acre error, an error amounting to one-third the acreage in that category. It seems that LANDSAT acreage estimators would be more efficient in this regard.

[2]Donald Janson, "Seabrook Farms' Plan to End Processing of Vegetables is Termed a 'Disaster,'" New York Times, 6 January 1976, p. 67.

fresh vegetable processing plant in Cumberland County in March 1976.[1] This meant that 1,485 hectares (3,670 acres) of their own and 8,100 hectares (20,000 acres) under contract with 150 farmers would be released from their current land uses. All 1,485 hectares farmed by Seabrook are included in the test area except for a small area surrounding the town of Seabrook itself. Also included are privately owned farms, most of which operated independently of Seabrook; these are included as a comparison to the Seabrook land which had been completely devoted to vegetables.

The departure of one processor does not ordinarily signify a trend; however, in this case the reasons given for such action relate to regional and state problems and are similar in nature to those expressed by Ritter and Del Monte. The president of Seabrook Farms, James M. Seabrook, cited the following causes for the January 1976 decision:

a) The fringe benefits to labor in New Jersey are higher than in the other states where the company operates

b) The farmers' prices for the growth and delivery of vegetables are higher in New Jersey than elsewhere

c) The environmental requirements posed by state law are difficult to implement; for example, the Department of Environmental Protection refused a request to burn high-sulphur fuel oil, a measure which Seabrook and others considered necessary

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[1] A repackaging plant and warehouse are still maintained by the Seabrook Farms Division of Seabrook Foods, Atlanta, Georgia, a wholly-owned subsidiary of Springs Mills, Inc. The plant and warehouse now handle only bulk frozen produce, however, which has been grown and packed elsewhere.

economically

d) New Jersey is less pioneering in its research into vegetable problems than California and other states[1]

e) energy is less costly in other states.[2]

It appears, then, that the Seabrook action, along with those of Ritter and Del Monte before it, are part of a larger agricultural change occurring in the state. As James M. Seabrook commented on the situation in January 1976, "The future is bleak for vegetable farmers in New Jersey."[3]

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[1]This point is debatable. C. W. Thornthwaite did pioneering work in microclimatology and irrigation of vegetables in conjunction with Seabrook Farms in the 1950s. See, for example, C. W. Thornthwaite, Climate and Scientific Irrigation in New Jersey, The Johns Hopkins University Laboratory of Climatology Publications in Publications in Climatology, vol. 6, no. 1 (Seabrook, New Jersey, 1953). Also, see works by others, both in the 1950s and more recently, such as J. J. Higgins, Instructions for Making Phenological Observations of Garden Peas, The Johns Hopkins University Laboratory of Climatology Publications in Climatology, vol. 5, no. 2 (Seabrook, New Jersey, 1952); David K. Robertson, Ground Water Availability in Southern New Jersey, C. W. Thornthwaite Associates Publications in Climatology, vol. 26, no. 1 (Elmer, New Jersey, 1973); and J. R. Mather, Estimation of Areal Average Precipitation Using Different Network Densities and Averaging Techniques, C. W. Thornthwaite Associates Publications in Climatology, vol. 28, no. 2 (Elmer, New Jersey, 1975).

[2]Janson, "Disaster," p. 67.

[3]Ibid.

This being the case, it is imperative that monitoring of New Jersey agriculture be undertaken so that the social and business communities are prepared to accommodate the transition. Traditional methods must be relied upon for now; but the New Jersey example points out the potential usefulness of a fast and inexpensive method. Modern data collection tools, such as the Multispectral Scanner described below, are used in this study to develop such as the Multispectral Scanner described below, are used in this study to develop such a method.

DESCRIPTION OF THE LANDSAT SENSOR AND THE DATA IT OFFERS

LANDSAT I and II serve as platforms for a particular remote sensing device,[1] the multispectral scanner (MSS). The MSS consists of four sets of detectors which scan the earth as the satellite passes in its sun-synchronous orbit.[2] Each set of detectors is sensitive to a different portion of the solar radiation reflected from the ground object. Table 3 lists the four bands of the MSS and the portions of the electromagnetic spectrum to which each is sensitive. Recipients of energy from the sun may reflect, transmit, or absorb (and then re-emit) the sun's energy. This applies to both targets on the earth's surface and particles in the atmosphere. The MSS measures mainly the reflected energy from both these recipients.[3]

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[1]Other instruments use LANDSAT as a platform but are not discussed here.

[2]"Sun synchronous" is defined as "as an Earth satellite orbit in which the orbital plane is near polar and the altitude such that the satellite passes over all places on Earth having the same latitude twice daily at the same local sun time," in American Society of Photogrammetry, Manual of Remote Sensing, pp. 2105-2106.

[3]During daylight hours, reflected energy dominates radiation returned to space from Earth until about 3 micrometers, when emitted radiation begins to dominate, according to John Estes, "Imaging with Photographic and Nonphotographic Sensor Systems : in Remote Sensing, eds. John E. Estes and Leslie W. Senger (Santa Barbara: Hamilton Publishing Co., 1974), p. 36.

TABLE 3

THE FOUR BANDS OF THE MSS, THEIR CORRESPONDING WAVELENGTH INTERVALS IN MICROMETERS AND THEIR COMMON NAMES

MSS	Wavelength Interval	Common Name
1	0.5 - 0.6	Green
2	0.6 - 0.7	Red
3	0.7 - 0.8	First Near-Infrared
4	0.8 - 1.1	Second Near-Infrared

LANDSAT data products are of two general types, namely, imagery and digital tapes. The first, imagery, is a remote sensing term which includes both photographic and nonphotographic (but photograph-like) products of sensing instruments, from cameras to radar. In this study we use imagery only as a locating tool. LANDSAT imagery is a pictorial display much like an aerial photograph but produced from digital data acquired one scan line at a time. Data represent amount of radiation reflected from the ground, and intervals of reflectance are assigned gray tones depending on this amount. In this study, imagery is used as a device to associate portions of the digital data with known ground areas. Digital information displayed as imagery allows one to use the shape and context of certain parts of the data to ascertain the ground features with which the data are associated. For example, if one intends to analyze a ground area just east of a river, one would first examine imagery to determine the location of the river, easily discernible by the linear, dendritic pattern formed by the riverine vegetation which borders it. One would then know the approximate coordinates of the area on the digital tape. Digital tapes are our main source of data for analysis.

The word "digital" here implies numbers assigned to physical entities. In LANDSAT data the physical entity with which one works is a parcel of ground surface. The smallest ground area for which reflection is measured--that ground area to which a number is assigned--is approximately .464 hectares or 60 by 76 meters on a side. This unit of ground area is called a "pixel" ("picture element") when referring to the data. The same pixel is represented in four bands; in other words, four measurements are made for each pixel, or .464 hectares. See Figure 1 for a diagrammatic representation of this.

The spectral response of a pixel is shown in bar graph form in Figure 2. This is important because the shape of a pixel's spectral response curve may be associated with a particular type of land cover. In addition, aggregations of pixels may be spatially related to the same land cover class (for example, the numerous pixels in a large agricultural field) and thus have similar spectral response curves. Generally, digital analysis of LANDSAT data in agriculture involves clustering pixels into areal units associated with different crop types. In this experiment, however, the

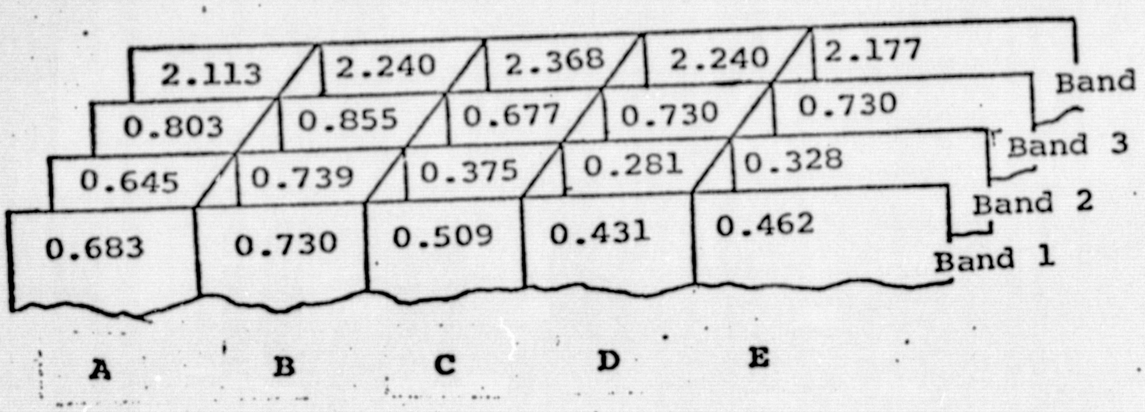


Fig. 1. Five adjacent pixels and their associated responses in units of energy (mw/cm^2/ steradian) in each of the four bands of the MSS.

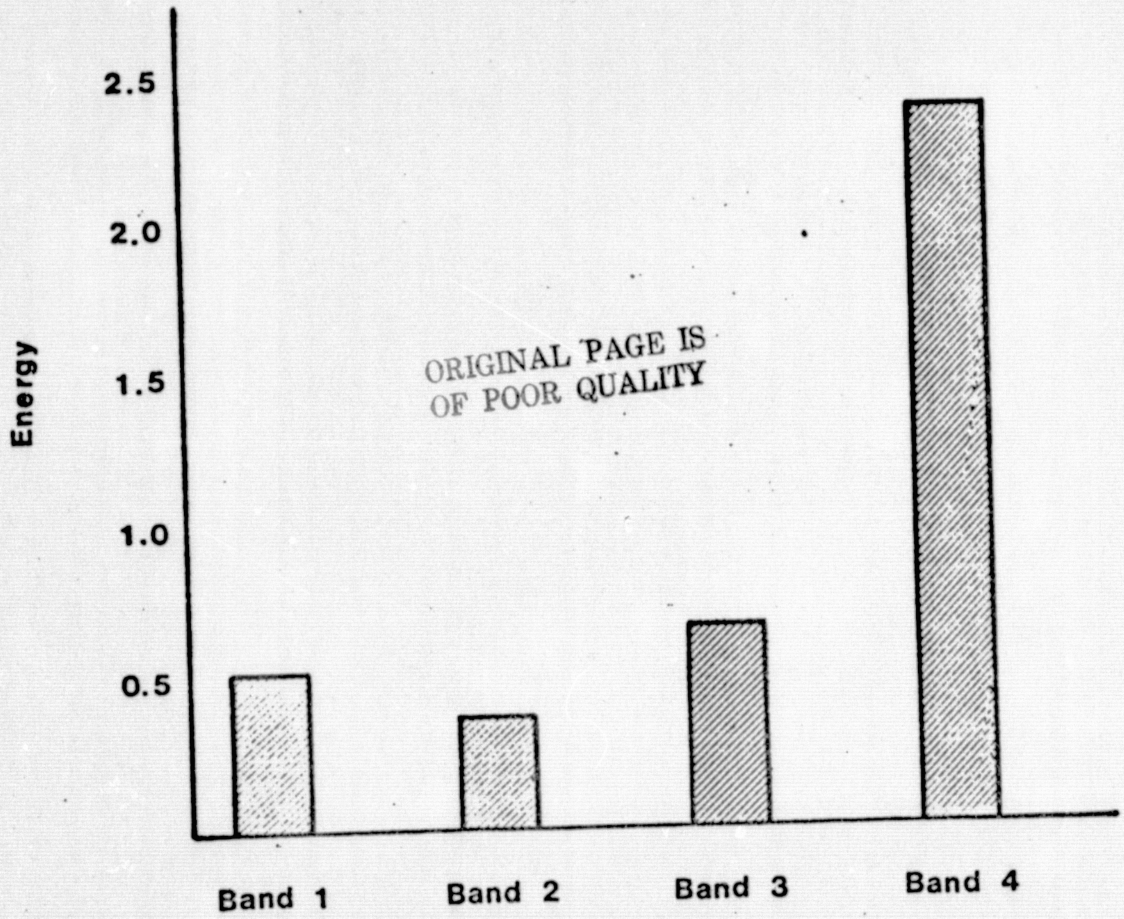
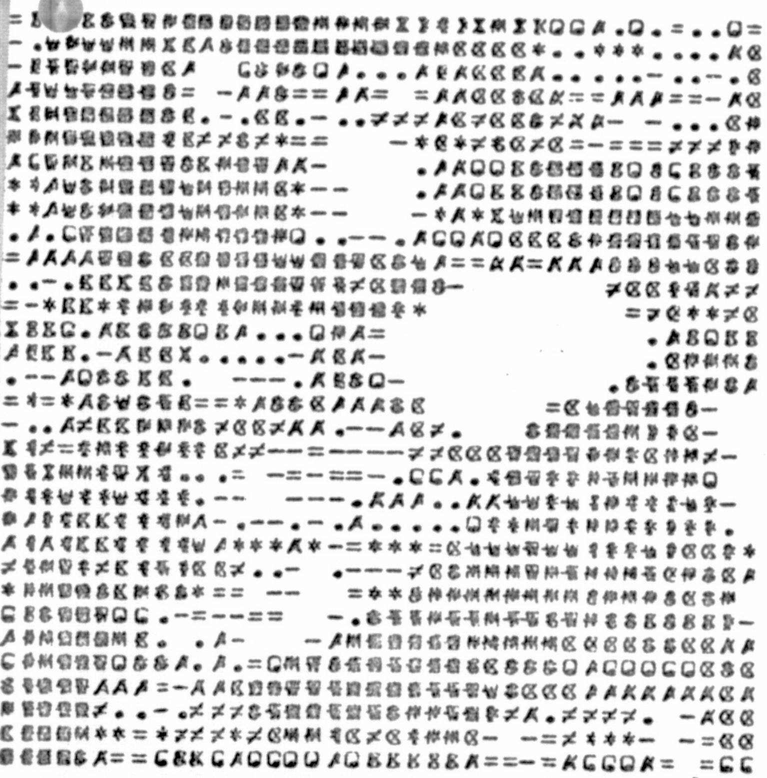


Fig. 2. Spectral response of pixel C from preceding figure.

BAND 1 (.5 - .6 micrometers)

BAND 2 (.6 - .7 micrometers)

BAND 3 (.7 - .8 micrometers)



BAND 4 (.7 to 1.1 micrometers)

Fig. 3. Gray scales of one quad in Salem County, New Jersey, shown in the four bands of the MSS.

areal unit is not one associated with a homogeneous crop class, derived from pixel similarities, but a unit of larger dimensions composed of 1280 pixels. Such an aggregation may include many agricultural fields and several crop classes. The purpose of aggregating a number of fields into one unit is to facilitate a large area monitoring operation--as for the globe--in which field-by-field analysis would be too time-consuming and expensive. The units used, here called "quads" (a software term used at the Institute for Space Studies, Earth Resources Program, to describe a 40 by 32 array of LANDSAT data), consist of 1,280 pixels or 595 hectares. Figure 3 shows four gray scales (corresponding to four bands) for one quad of 1,280 pixels in the test area. Gray scales, like imagery, are simple displays of digital data in which gray tones, achieved by character overprinting, are associated with discrete intervals of energy responses--bright with high responses, dark with low responses. For example, the printed character in the upper left hand corner of each gray scale represent the radiance/response for the same ground parcel in each band. The gray scales are shown here to give a visual impression of the data and the quad size.

EXPERIMENTAL DESIGN

Theory

The purpose of the work described herein is to detect agricultural systems change by separating two agricultural systems, corporate vegetable farming and field cropping, in order that the transition from the former to the latter may be detected. DeSchlippe describes "agricultural systems" in terms of four characteristics, two of which serve as the basis for this study, namely:

(1) land utilization in space (pattern of field types on their respective ecological background)
(2) land utilization in time (pseudorotations)[1]

(The other two characteristics involve labor and nutrition, which are not appropriate in a remote sensing context.) This experiment traces land utilization over time in area where two agricultural systems exist in close proximity, each imposing a different pattern on the soil background.

With respect to "land utilization in time," crop calendars vary for each type of agricultural system. For example, vegetables are planted mainly during the warmer months, whereas winter grains are planted in the Fall.

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[1]Pierre DeSchlippe, Shifting Cultivation in Africa (London: Routledge and Kegan Paul, 1956), p. 238.

Figures 4 and 5 show the planting and harvesting dates for both field crops and vegetables respectively. Table 4 shows the approximate periods of peak growth for a variety of crops, calculated from Figure 4 for field crops and from a list of planting and harvesting dates used at Seabrook Farms.[1] It appears from this list that the actively photosynthesizing period for vegetables extends later into the Fall than it does for field crops. Winter grains are seeded in October and do not make an impact on land cover until early November. Vegetables and field crops have somewhat different cyclical patterns, and this method attempts to trace these cycles over time.

With respect to "land utilization in space," field crops and vegetables impose different percentages of canopy cover on the land. The influence of exposed soil on a spectral response is discussed below.

Surface features influence the amount of solar energy reflected into space from the earth to an earth-oriented sensor. Vegetation, soil, exposed rock, and water reflect energy differently in each spectral band. In the agricultural area under examination in this paper, vegetation and soil are the most dominant surface features. Although vegetation types differ in their spectral response curves, they do exhibit general characteristics distinct from other types of land cover.

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[1] Information received from Mr. Val Perri, Seabrook Farms, Inc., August 4, 1977.

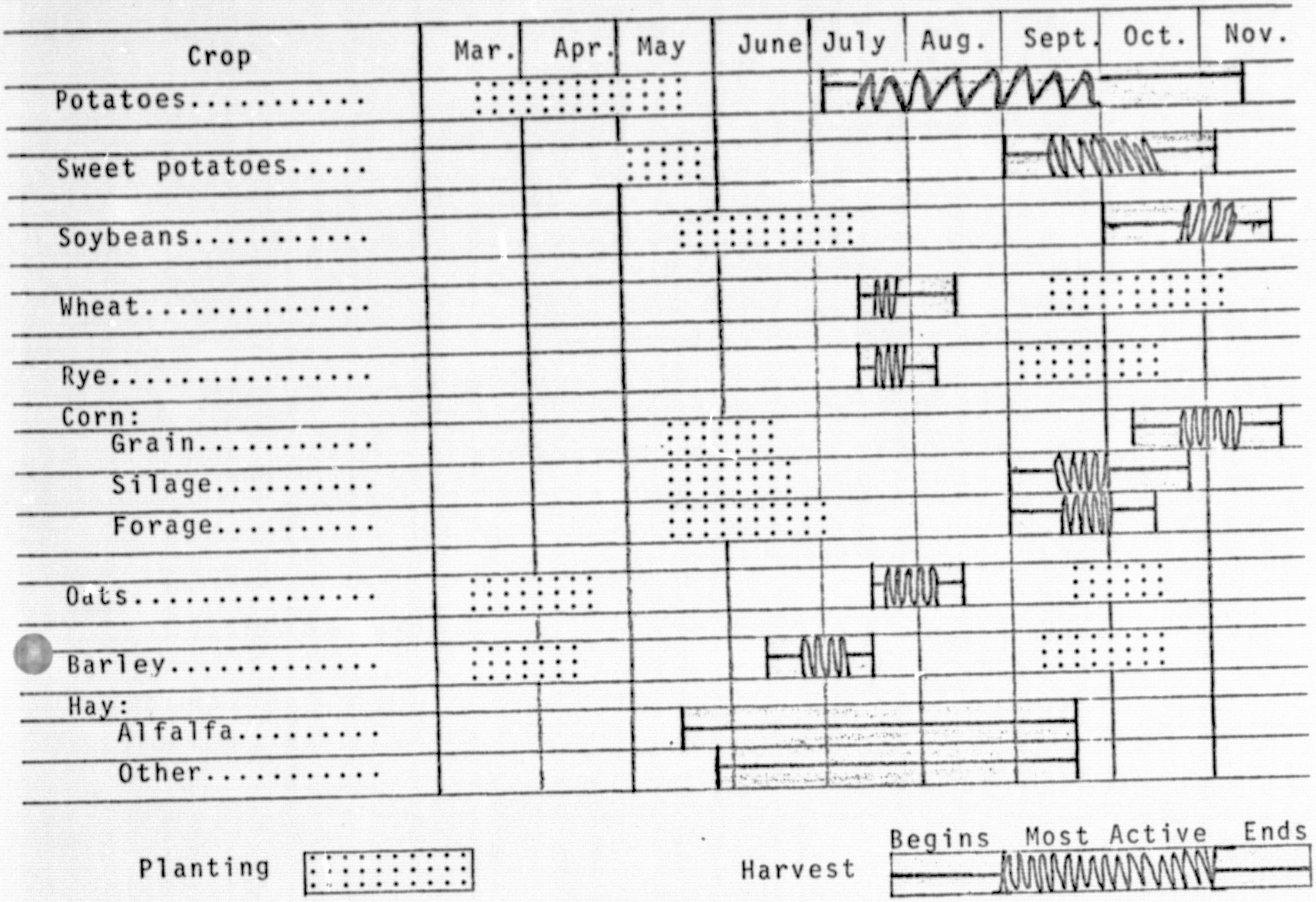

Figure 4. New Jersey: Field Crops, Usual Planting and Harvesting Dates.

SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1976.

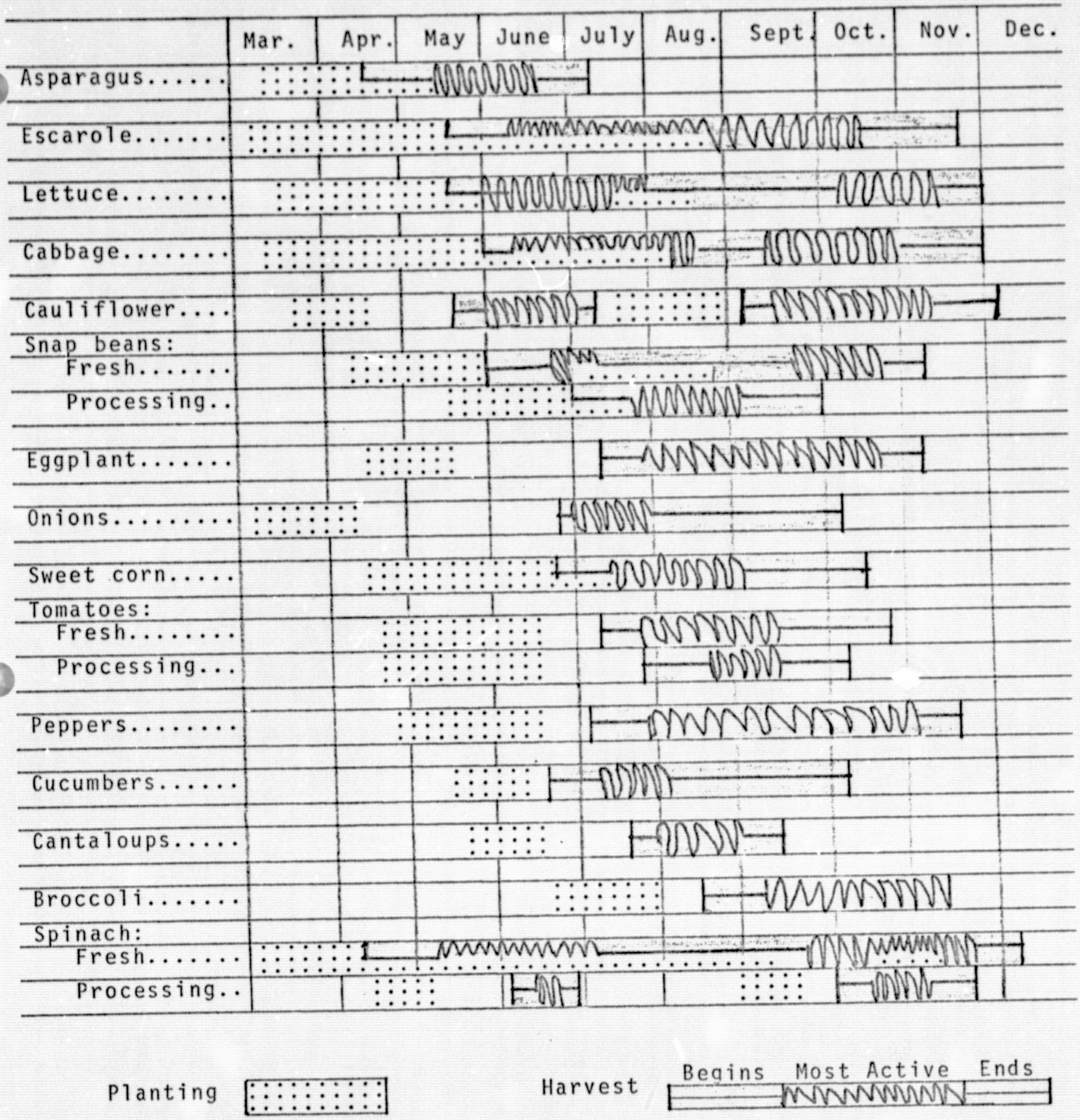

Figure 5. New Jersey: Vegetables, Usual Planting and Harvesting Dates.

SOURCE: New Jersey, Department of Agriculture, New Jersey Crop Reporting Service, New Jersey Agricultural Statistics, August 1976.

TABLE 4. PEAK GROWTH PERIODS OF FIELD CROPS AND VEGETABLES

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Field Crops									
Wheat		X	X						X
Rye		X	X	X					X
Oats			X	X					X
Barley			X						
Soybeans					X	X			
Corn					X	X			
Hay-Alfalfa				X	X	X			
Vegetables									
Cauliflower						X	X		
Carrots				X	X	X	X	X	
Broccoli						X	X		
Spinach--Fall									
Spinach--Spring	X	X	X						
Squash					X	X	X	X	
Kale--Fall							X		
Kale--Spring			X					X	
Baby Limas					X	X	X		
Green Beans				X	X	X	X		

Actively photosynthesizing plants are characterized by a relatively large amount of near infrared reflectance (Bands 3 and 4 on the MSS) and a relatively small amount of red reflectance (Band 2 on the MSS). Soils exhibit spectral patterns distinct from vegetation although they also differ among themselves. Generally spectral response curves of soils are rather flat in the visible region with a decrease in reflectance in the near infrared. The reflectivity of soils in the visible is also dependent upon soil color--a lighter soil will be more reflective than a darker one.[1] The coastal plain soils in the test area are rather bright and will therefore be very influential on the visible bands' spectral responses.

The increase in near infrared reflectance which occurs as green plants develop is associated with the maturation of the plant leaf. Simply described, the structure of a plant leaf, from upper to lower layer, consists of cuticle, upper epidermis, mesophyll (palisade parenchyma, then spongy parenchyma), lower epidermis, and cuticle. The maturation of plant leaves is accompanied by an increase in the number of intercellular air spaces in the spongy mesophyll layer. The cell

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[1]S. J. Kristof and M. F. Baumgardner, "Change of Multispectral Soil Patterns with Increasing Crop Canopy," LARS Information Note 102372, (West Lafayette, Indiana: The Laboratory for Applications of Remote Sensing, Purdue University, 1972), p. 16.

walls of the spongy parenchyma act as multiple reflectors of near infrared radiation. As Gates describes it,

> A small amount of light is reflected from the leaf cuticle; much is transmitted into the spongy mesophyll, where the rays have frequent encounters with the cell walls . . . The multiple reflection is essentially a "random walk" as the rays frequently change direction within the leaf.[1]

The reduced amount of reflected radiation in the red band is due to the absorption of light in the .6 to .7 micrometer region by chlorophyll-a, the major pigment involved in photosynthesis. Five photoreceptive structures are found in plants as follows: grana-containing chloroplasts, grana-free chloroplasts, chromatoplasm, chromatophores, and free grana.[2] The grana-containing chloroplasts are most common in higher plants and are commonly found in the palisade layer. (In plants where the mesophyll is undifferentiated, such as in corn and other grasses, cells containing chloroplasts are found in herbaceous stems, twigs, and unripe fruits.[3]) Light enters the leaf and certain portions of its spectrum are

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[1]David M. Gates, "Physical and Physiological Properties of Plants," in Remote Sensing (Washington, D.C.: National Academy, 1970), pp. 226-227.

[2]J. B. Thomas, Primary Photoprocesses in Biology, (Amsterdam: North Holland Publishing Co., 1965), pp. 127-135.

[3]Carl L. Wilson and Walter E. Loomis, Botany, 4th ed. (New York: Holt, Rinehart and Winston, 1967), p. 86.

absorbed as light reaches the palisade layer. Green light is absorbed as well as red but in lesser amounts; for example, Wilson and Loomis report the average leaf absorption of light in the green-yellow region (.5 to .6 micrometers) is 68 percent while that in the orange-red (.6 to .7 micrometers) is 78 percent.[1] Thus, in the MSS data, a decrease in reflection will occur in Band 2 with respect to Bands 1, 3, and 4 in pixels dominated by actively photosynthesizing vegetation. As a plant approaches senescence, the chlorophyll-a deteriorates and absorption decreases.[2]

Because leaves reflect increasing amounts of near-infrared light as they mature and because the pigmented parts of the mesophyll reflect decreasing amounts of visible light as chlorophyll increases, the amount of reflectance in Bands 2 and 4 would be a good indicator of vigorous vegetative cover. In this study, the ratio of Band 4 (second near-infrared) over Band 2 (red) is used as an indicator. Since an increase in Band 4 is associated with a decrease in Band 2, a ratio of the two bands is more sensitive to vegetation changes than, for example, one band alone. Similar ratios

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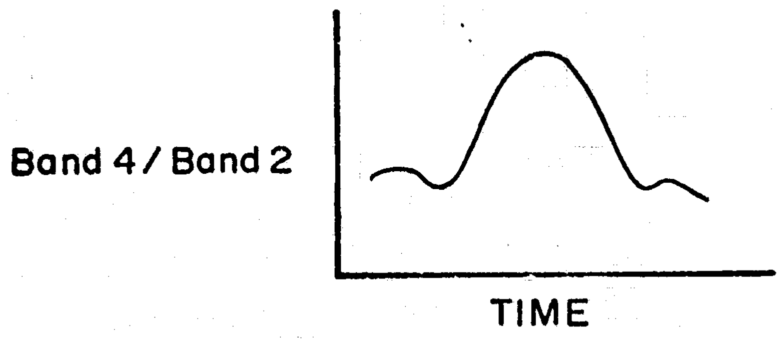
[1]Wilson and Loomis, Botany, p. 93.

[2]For examples of reflectance spectra of plants in vivo at all stages of growth see S. G. Ungar, W. Collins, J. Coiner, et al., preparers, Atlas of Selected Crop Spectra, Imperial Valley, California (New York: NASA Institute for Space Studies, 1977).

have been used previously in remote sensing work.[1]

Plotting the ratio of Band 4 to Band 2 on the y-axis against time on the x-axis for a specific 595-hectare ground area, the quad, yields a curve for each of the four years of the study, similar to the diagram below.



It is hypothesized that a change in the shape of a plot, such as a shift in the peaks, from one year to the next represents a change in agricultural system because of the different temporal growth patterns of vegetable and field crops. The year 1976 is particulary important in the Seabrook area because of the land use change described earlier; a sharp departure from the curves of the three previous years would indicate a rapid adjustment to the Seabrook Farms' decision to cease farming and processing.

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[1]See, again, Kristof and Baumgardner, "Multispectral Soil Patterns," and also Eugene L. Maxwell, "Multivariate System Analysis of Multispectral Imagery," Photogrammetric Engineering and Remote Sensing 42 (September 1976): 1173-1186.

Although measurements of reflected energy are made at approximately the same time of day, the sun elevation at a specific latitude at a given hour changes throughout the year. To account for this variation, a sun elevation correction factor was introduced which adjusts all measurements to a solar angle of 90° through the equation

$$\text{sun elevation correction factor} = \frac{1}{\sin\,(\text{sun elevation})}$$

In addition, the use of the Band 4/Band 2 ratio reduces solar angle differences as well as signal fluctuations and differences attributable to changing atmospheric conditions by using a relative measure, a ratio.

Description of Method

The analysis employs digital LANDSAT data and relies upon, as support materials, LANDSAT imagery, aerial photography, United States Geological Survey maps, Seabrook Farms Corporation maps, and ground-collected information.

Although LANDSAT data are available for passes made every eighteen days from July 1972 to January 1975 and every nine days from January 1975 through most of 1976, not all of it is useable. Weather conditions such as thick haze or cloud cover over the study area make certain passes unuseable for analysis. Other technical problems occasionally preclude the transformation of data from certain passes into computer compatible tapes. Out of 119 possible coverages, 26 acquisitions (or 22 percent) were found to be useable in this study. All 26 scenes are preprocessed for geometric correction and rectification to a Universal Transverse Mercator grid.[1]

Imagery is used initially to choose suitable passes and to geographically identify the corresponding digital data. A block of data over a geographic area of approximately 34,225 square kilometers (13,225 square miles) is called a "scene," and each data tape contains information from an entire scene.[2] From each scene twenty-four smaller areas of 595 hectares (1400 acres) are used as the basic unit of analysis. It was felt that this unit was suitable for the long-run objective of the study--to simulate global monitoring. As well, the unit conformed to certain technical restraints in the computer programs which are used in support of the project. Each set of twenty-four areas, called "quads," is registered spatially from date to date. Therefore the study concerns the change in reflectance of twenty-four identical areas over the course of four years--1973 through 1976. Map 3 shows the spatial distribution of the twenty-four quads in the study.

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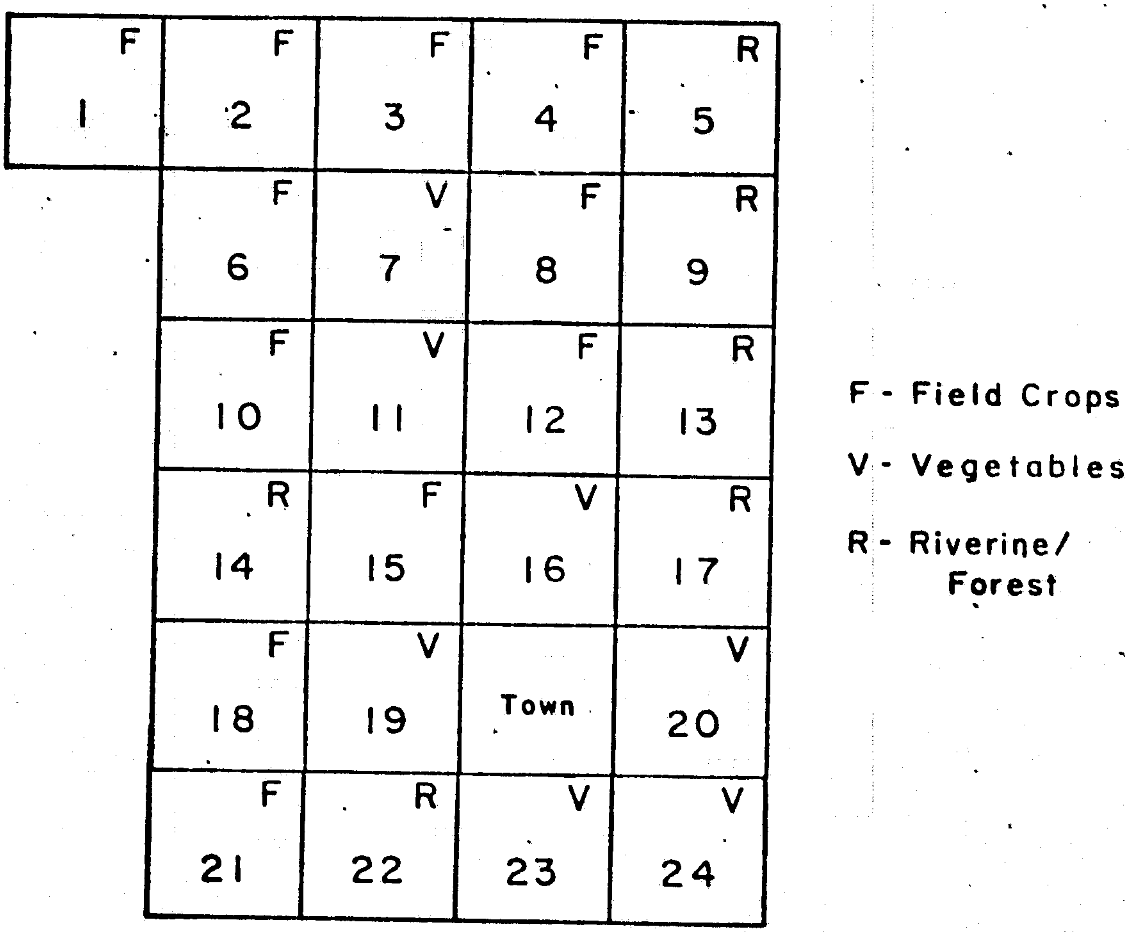
[1]For a description of geometric correction and rectification, see Ralph Bernstein and Dallam G. Ferneyhough, Jr., "Digital Image Processing," Photogrammetric Engineering and Remote Sensing 41 (December 1975):1465-1476.

[2]For a list of LANDSAT tapes used in this study, see Table 6 in the Appendix.



Map 3. Distribution and Land Use Designation of the Twenty-four Quads Used in the Study.

A classification routine developed at the Institute for Space Studies was used to obtain a nominal spectral response for each quad.[1] Normally, this routine is used to delimit clusters of pixels which have similar response curves. In this study, however, the object was to delimit one single cluster for each quad into which approximately 95 percent of the pixels fall, regardless of similarities. This percentage was chosen to filter out highly reflective, exotic pixels which might influence the quad's spectral response disproportionately. The classification routine is applied to twenty-four quads from each of twenty-six passes to obtain 624 characteristic spectral responses in four bands.

For each pass over each quad, the reflectance measured in Bands 4 and 2 is ratioed, and this ratio is then plotted against time on the y-axis, with time on the x-axis.

[1]Both the classification routine and the method of establishing the nominal values for each cluster are described in Stephen G. Ungar, "A Color Vector Classification Algorithm," (in preparation). Dr. Ungar is Director, Earth Resources Program, NASA Institute for Space Studies, New York, New York 10025.

RESULTS

The results of this study are shown graphically in Figures 6a through 6x, which display the Band 4/Band 2 ratios over four years for each quad. The exact date of the LANDSAT pass whose data was used to determine each ratio is found either above or below the point corresponding to its ratio . The Band 4/ Band 2 ratio performs as was expected in that the results show that in all quads there is a general correspondence between the variation in the ratio with time and the variation in the ground truth and reference data. There is a depression in the ratio in the late Fall and late Winter-early Spring months and during the major planting, early growth, and harvesting periods due to lack of vigorous plant cover. The timing of these periods is documented by personal observations during the season of 1976, discussions with farmers, a four-year file of general cropping conditions in New Jersey compiled from the Weekly Weather and Crop Bulletin,[1] the crop cycle calendars shown in Figures 4 and 5, and information obtained from Seabrook Farms. In addition, the two agricultural systems under study, vegetables and field crops, performed differently in their ratio plots. The twenty-four graphs follow, after which the results are described more fully.

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[1]U.S., Department of Commerce, environmental Data Service, and Department of Agriculture, Statistical Reporting Service, Weekly Weather and Crop Bulletin (Washington, D.C.: 1973 through 1976).

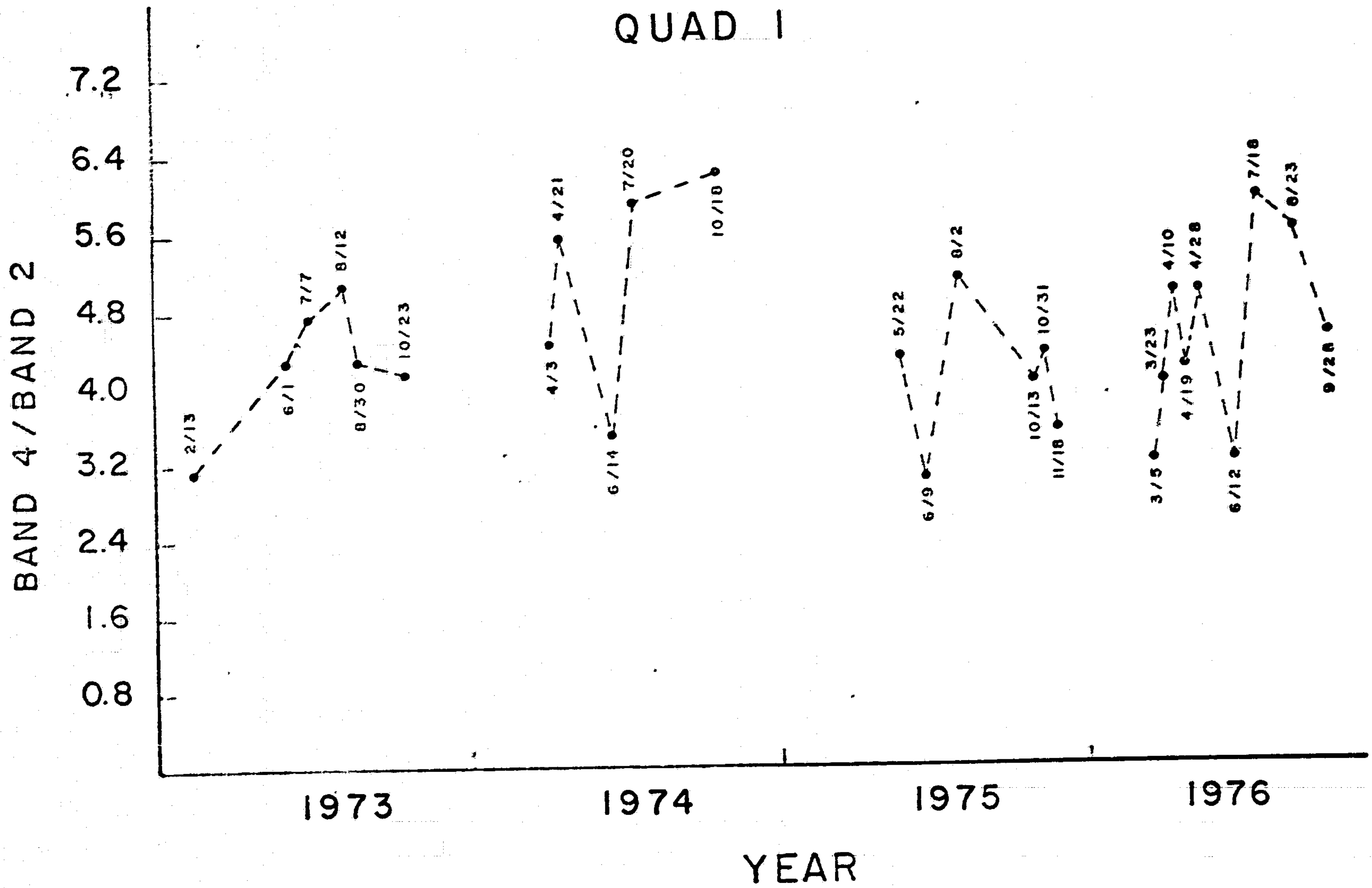

Figure 6a through 6x. Ratio of Band 4 over Band 2 for twenty-six dates, 1973 through 1976. Figure 6a. Quad 1.

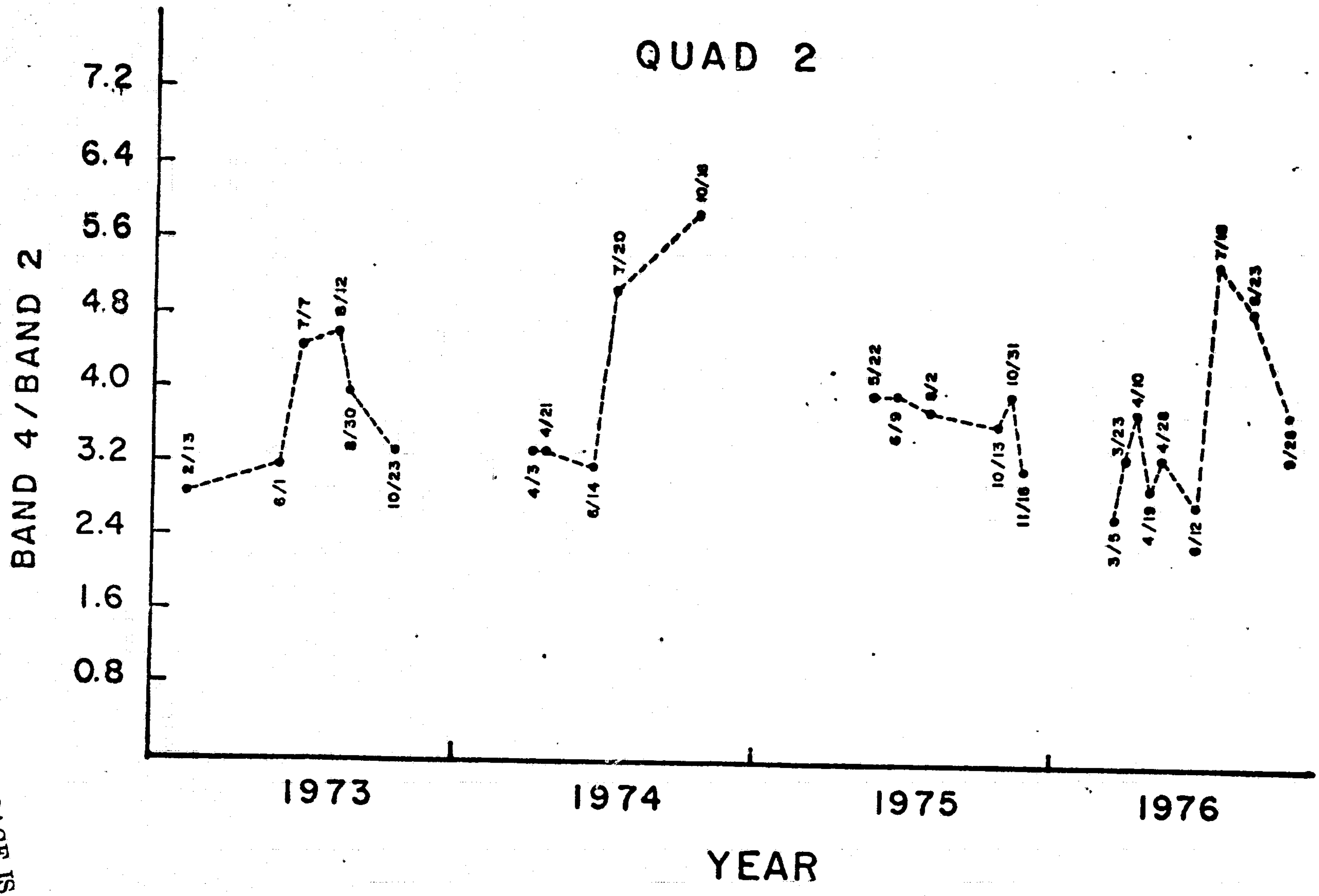

Figure 6b. Quad 2.

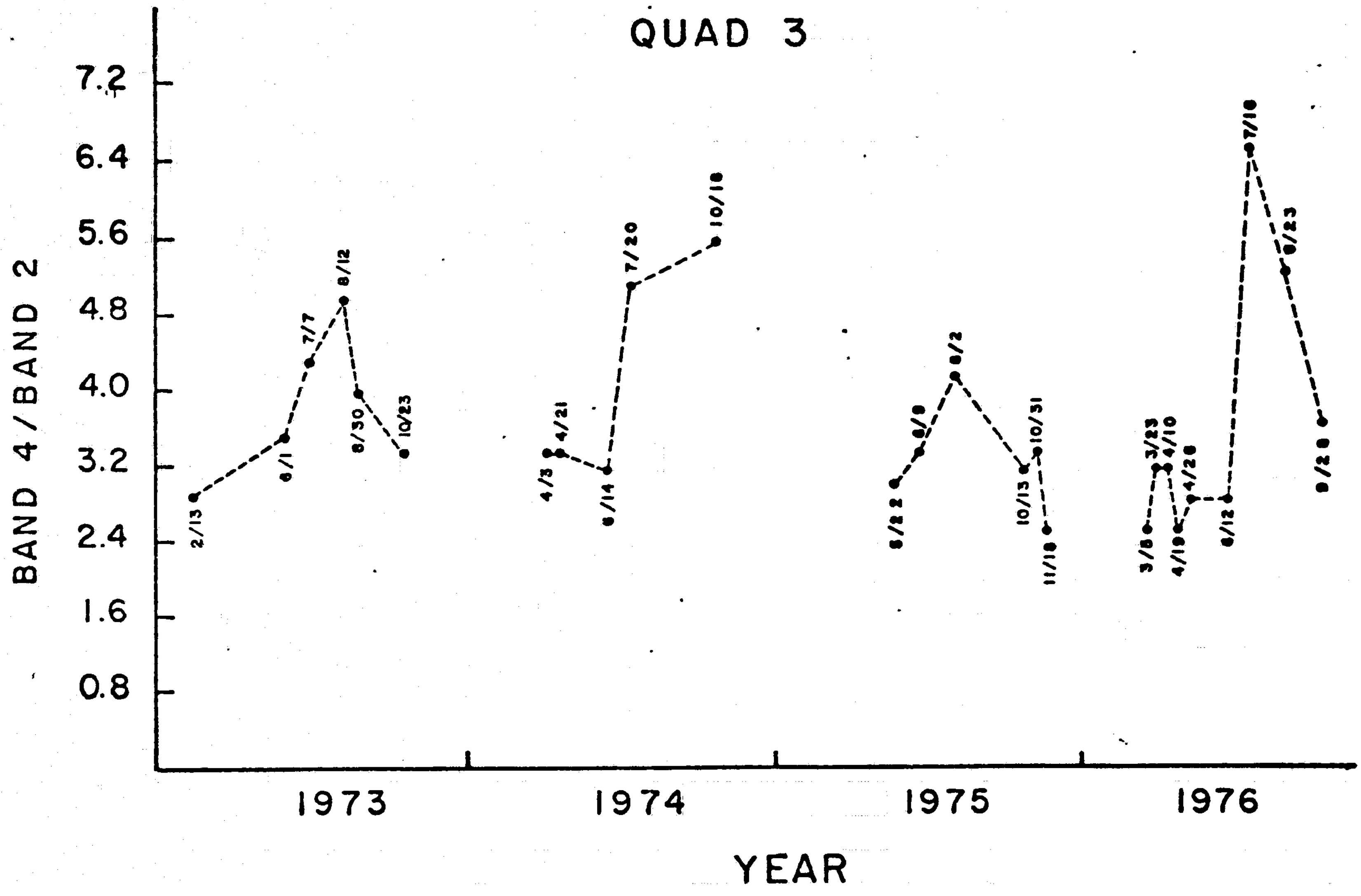

Figure 6c. Quad 3.

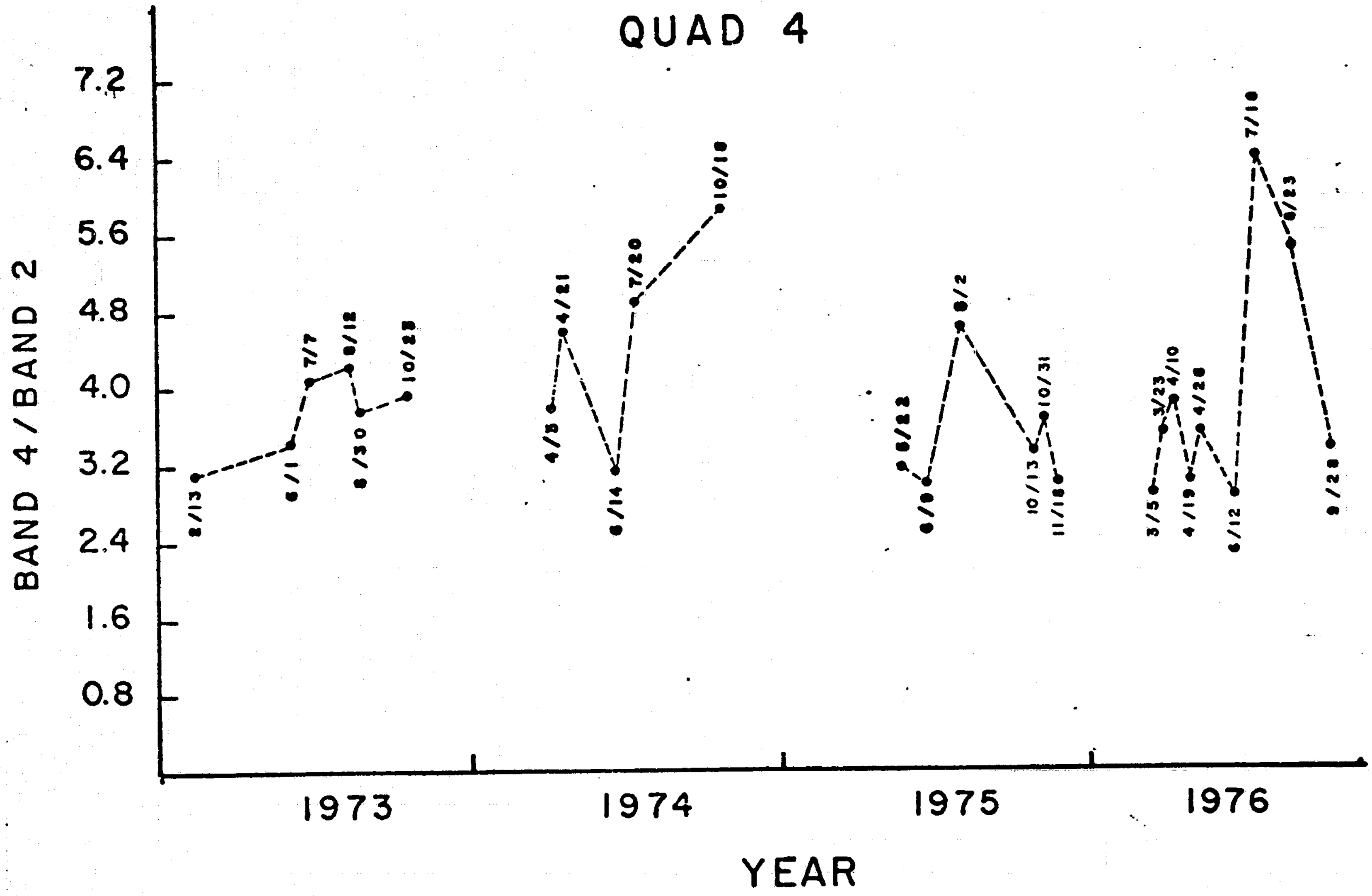

Figure 6d. Quad 4.

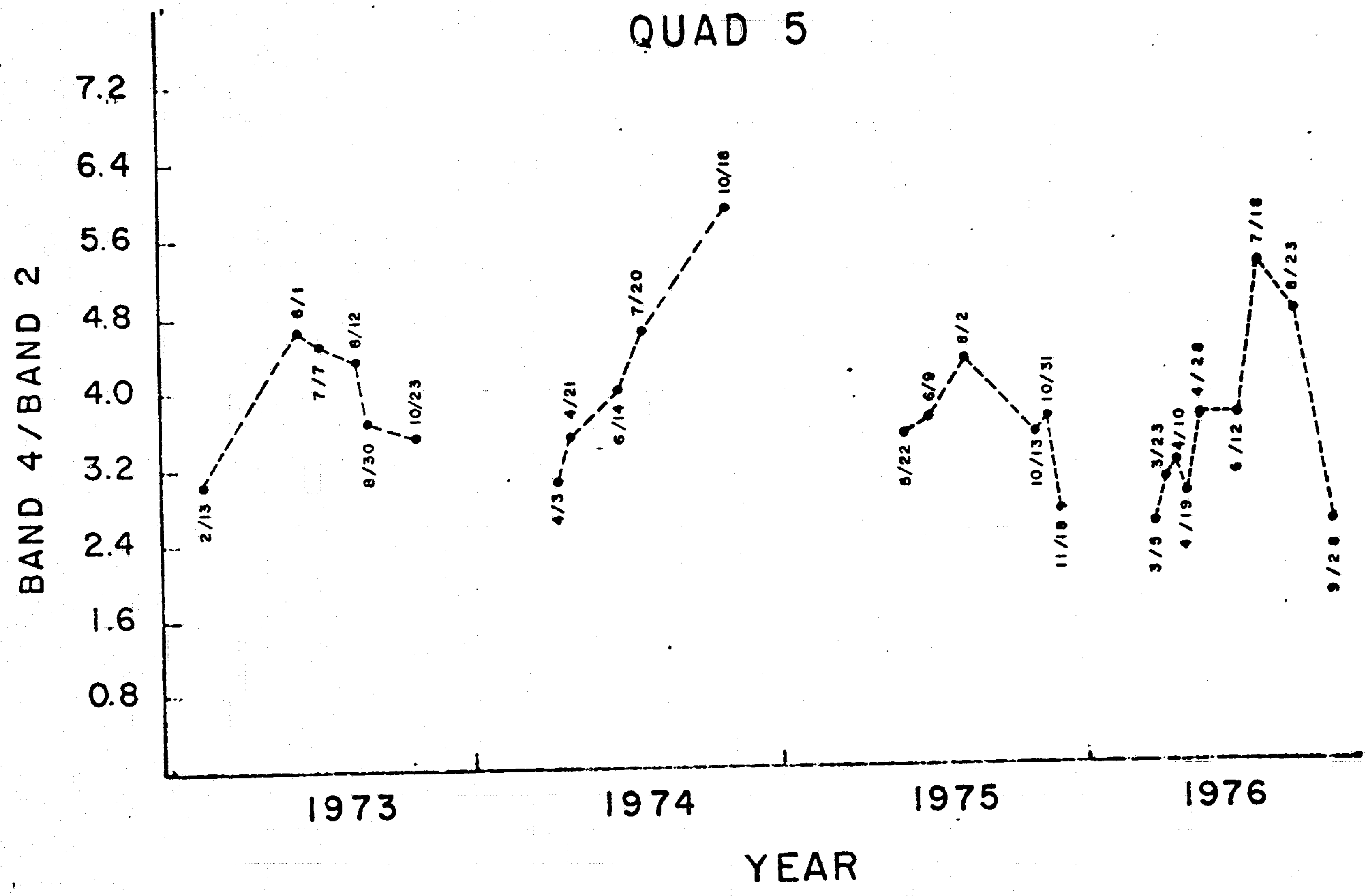

Figure 6e. Quad 5.

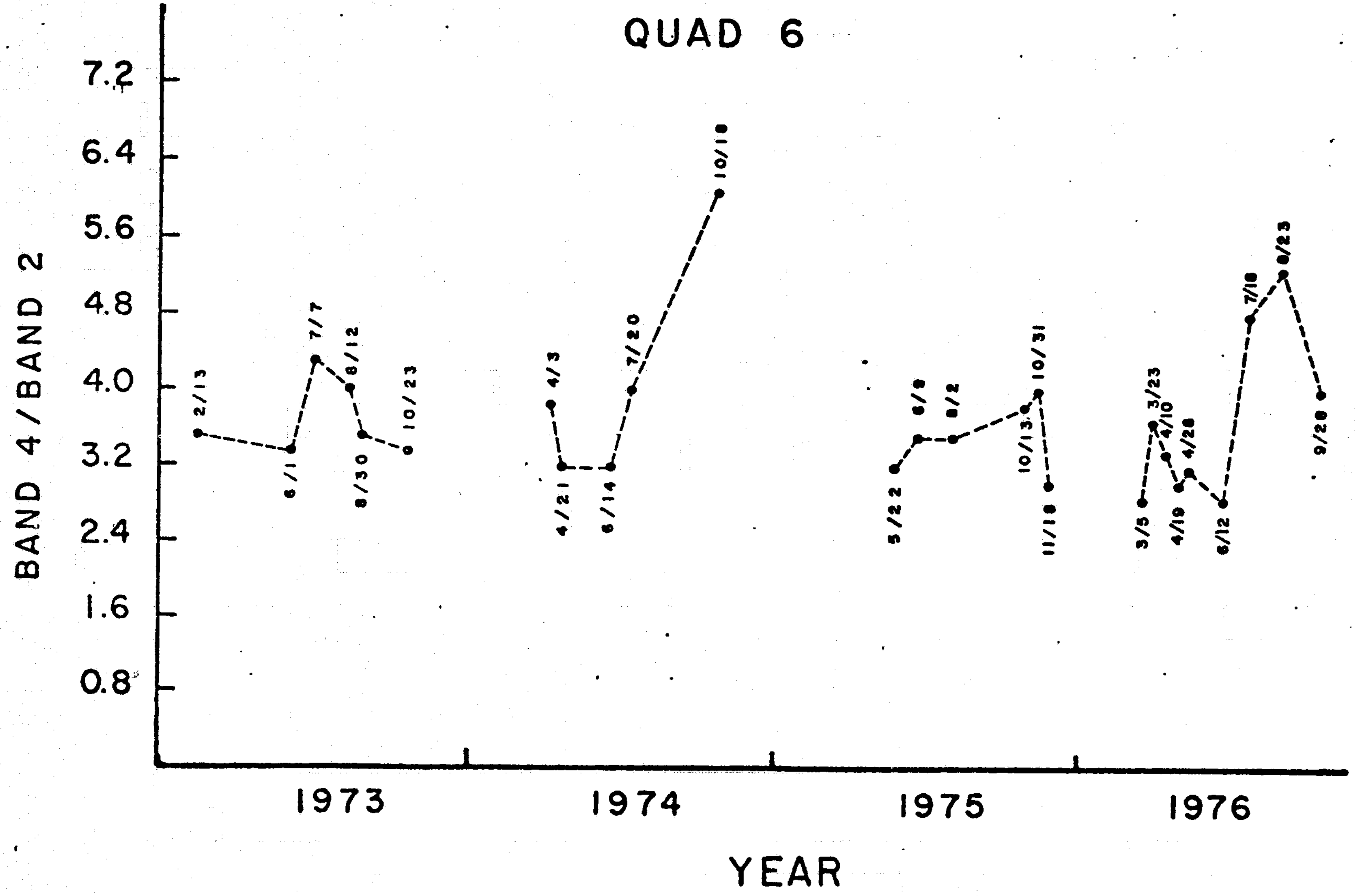

Figure 6f. Quad 6.

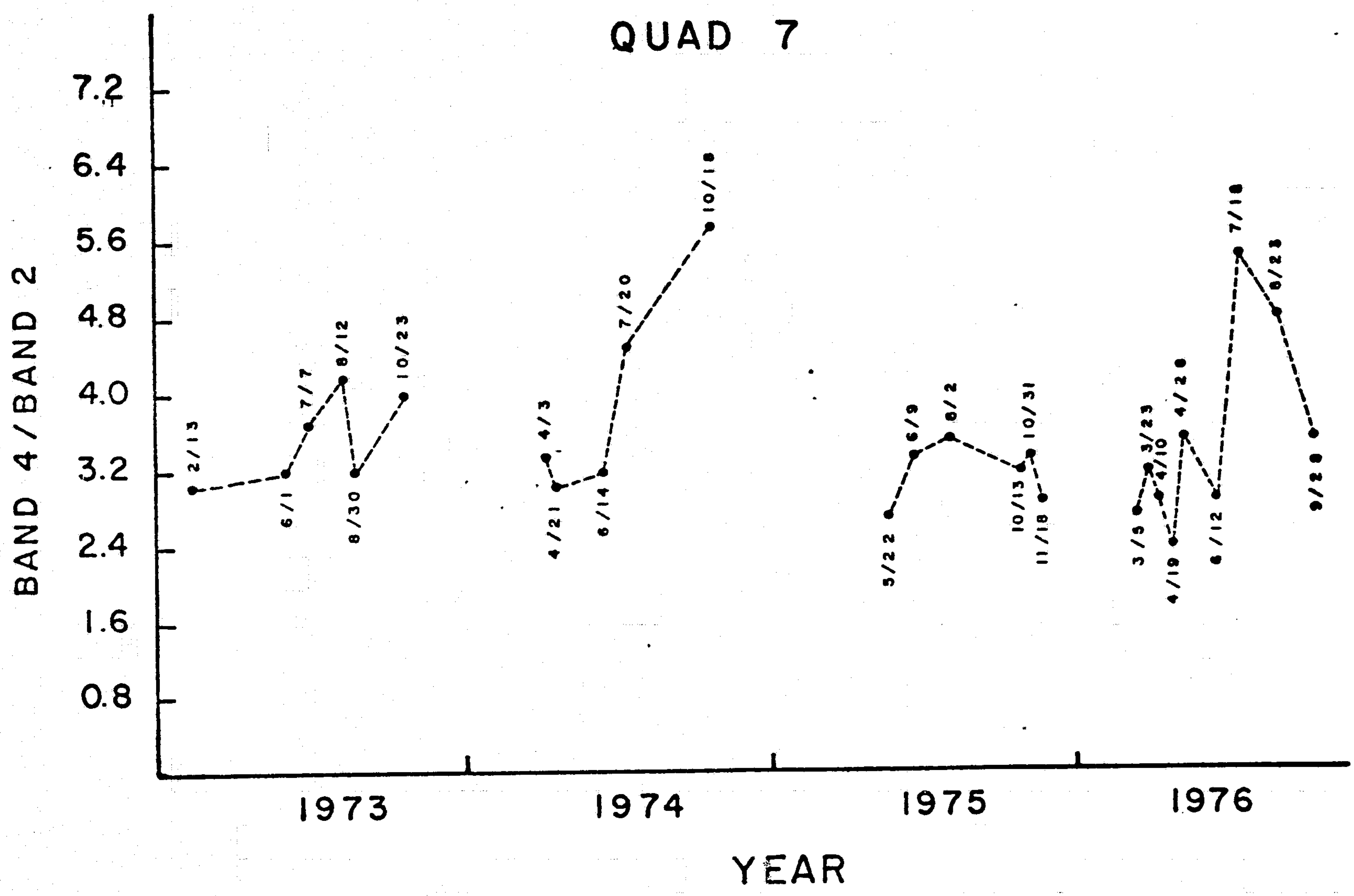

Figure 6g. Quad 7.

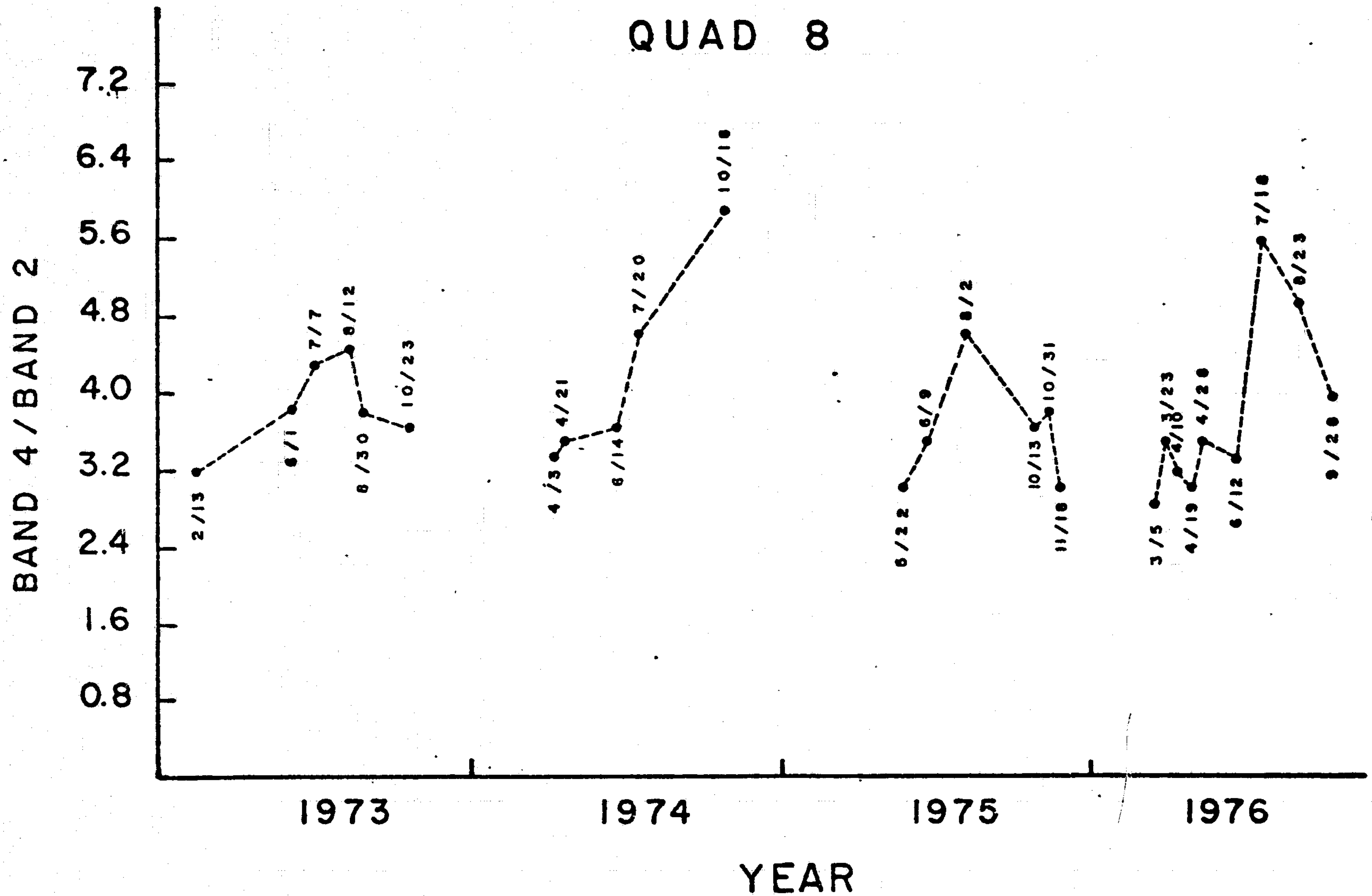

Figure 6h. Quad 8.

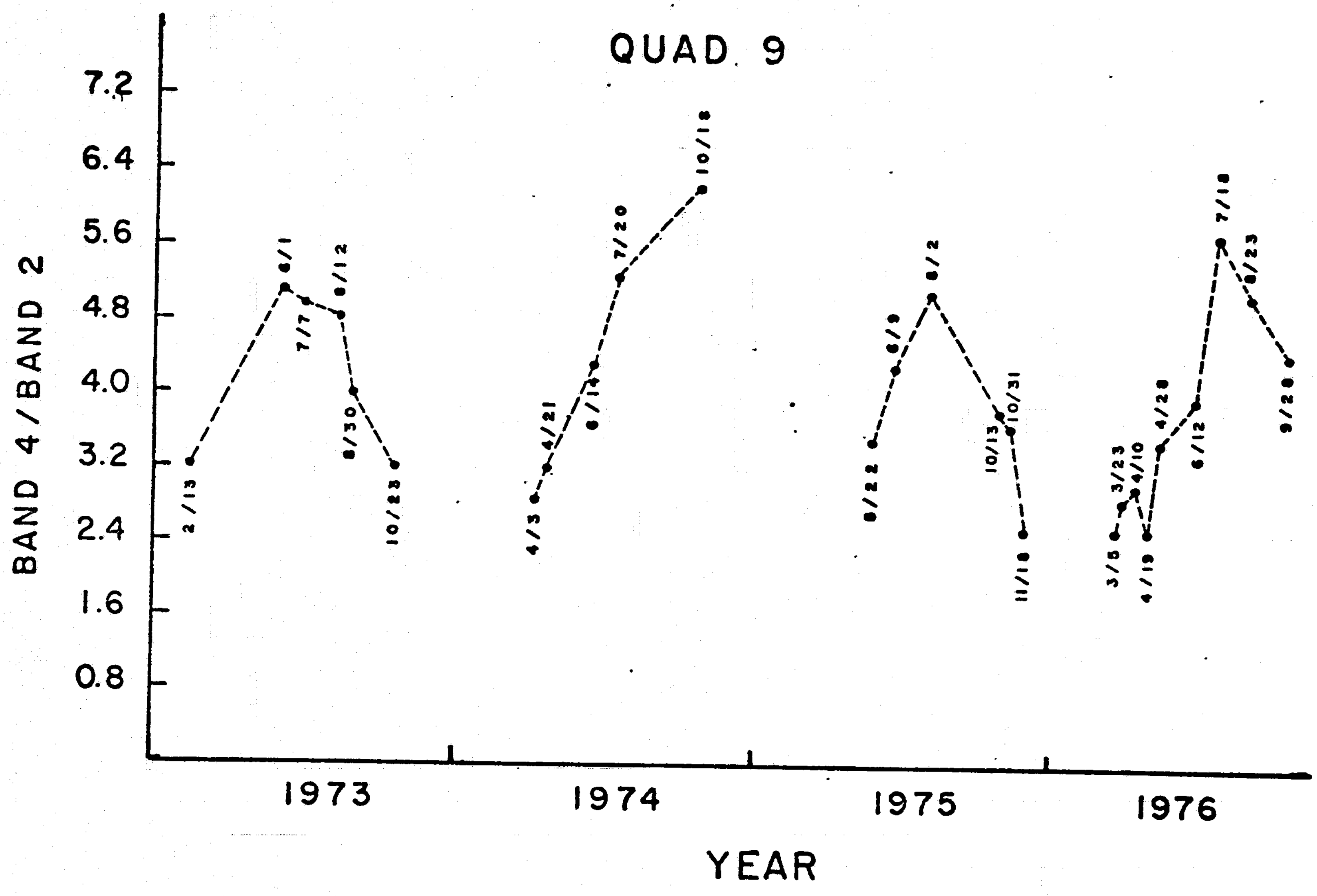

Figure 6i. Quad 9.

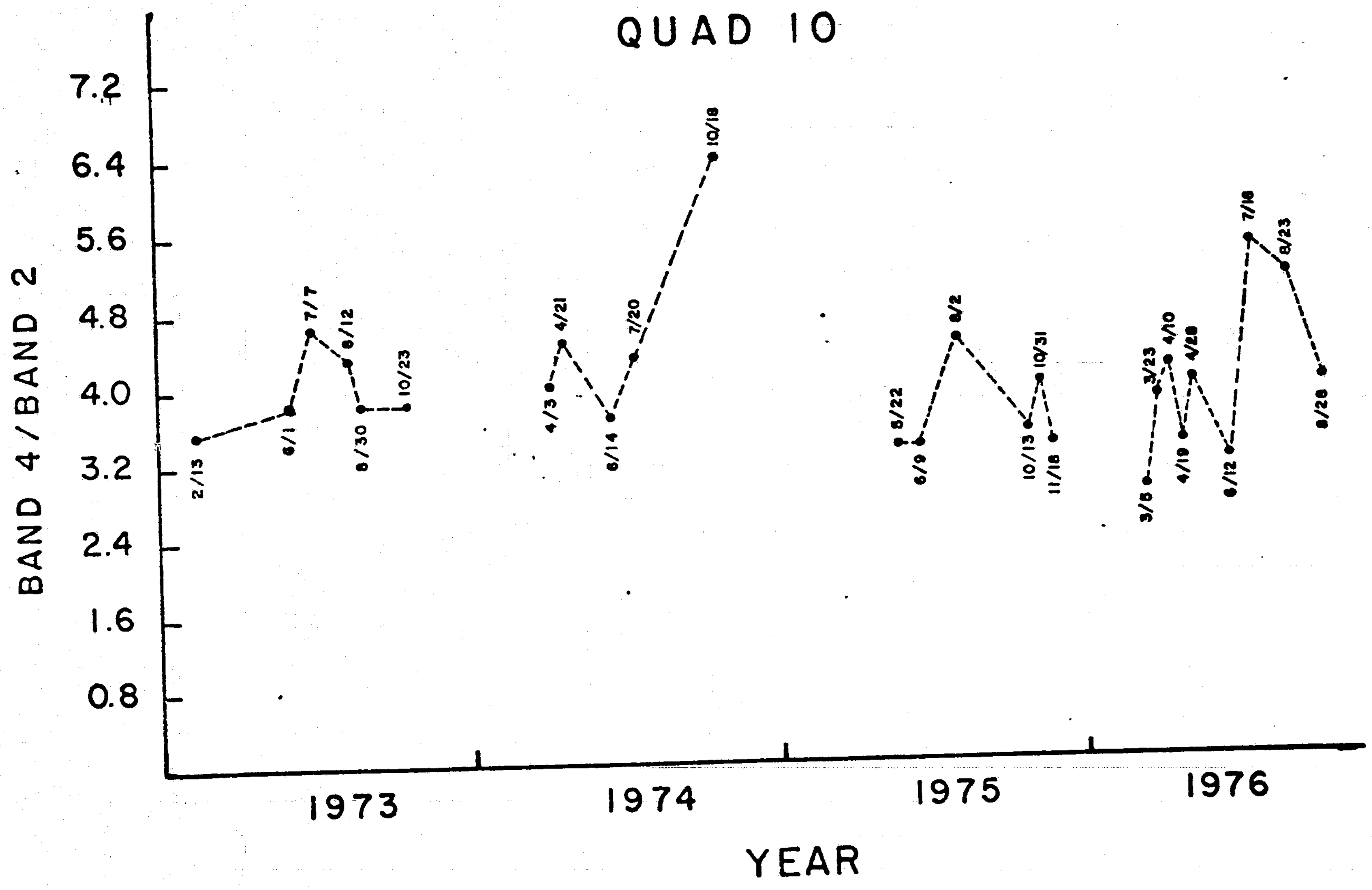

Figure 6j. Quad 10.

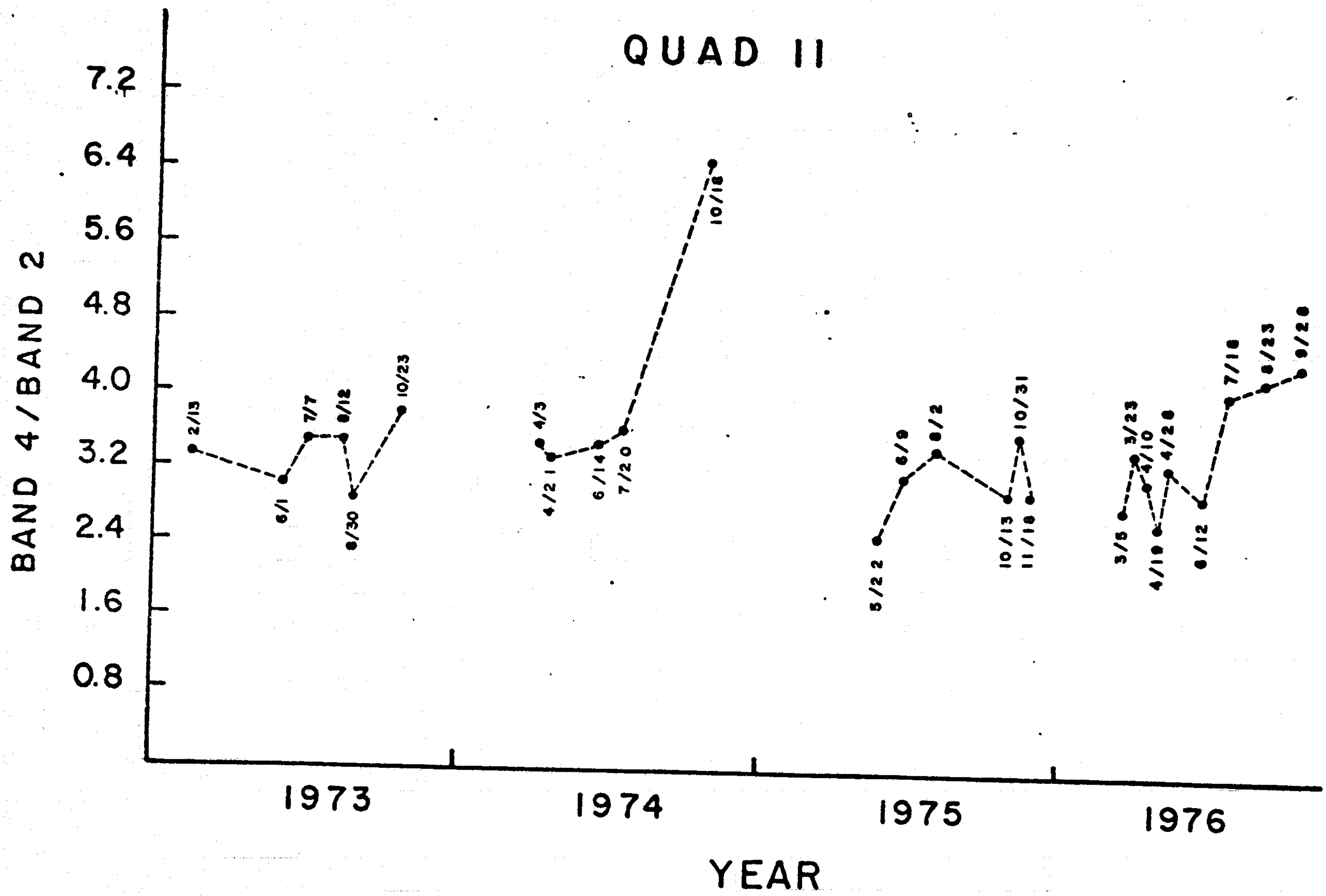

Figure 6k. Quad 11.

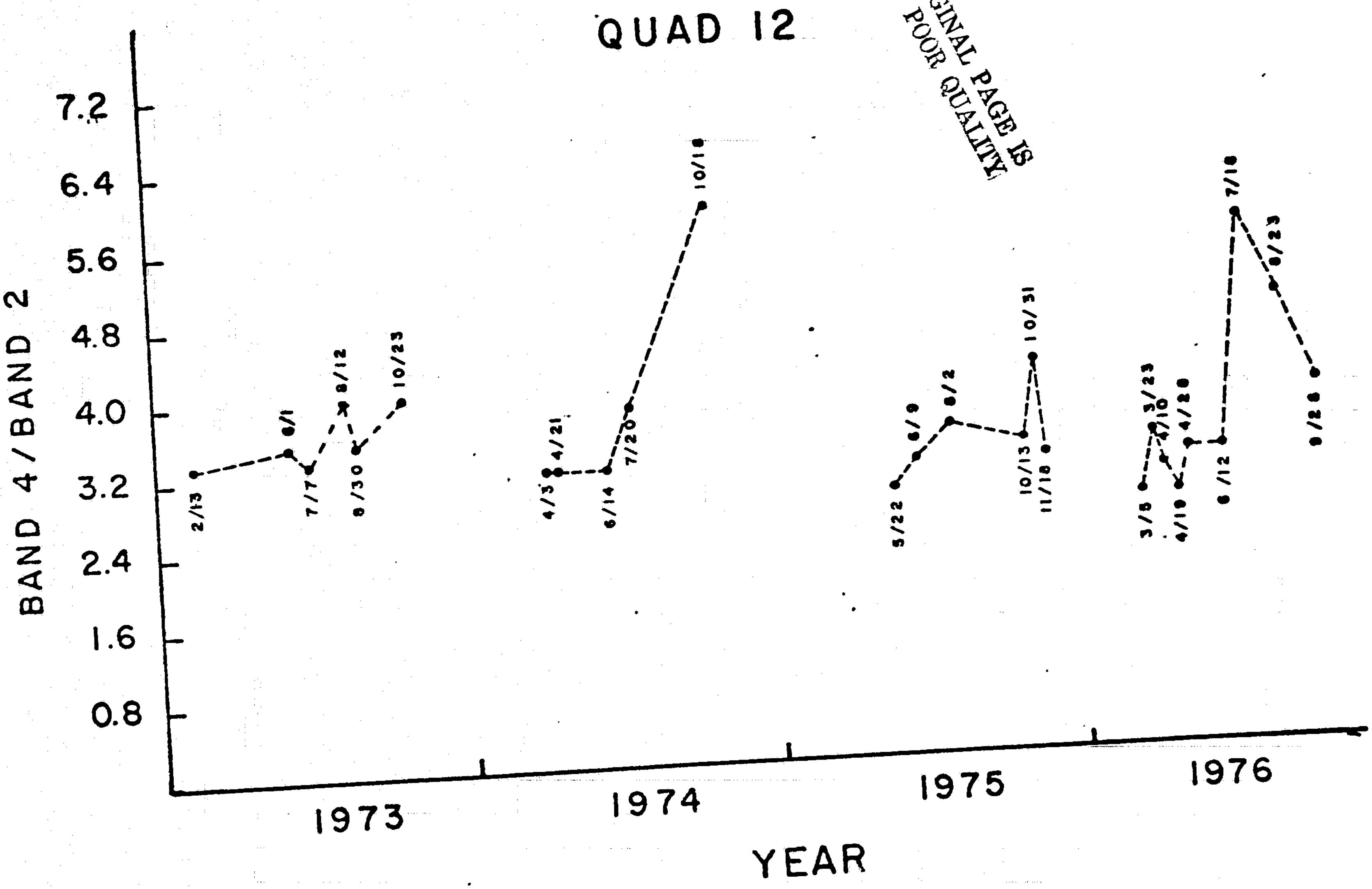

Figure 61. Quad 12.

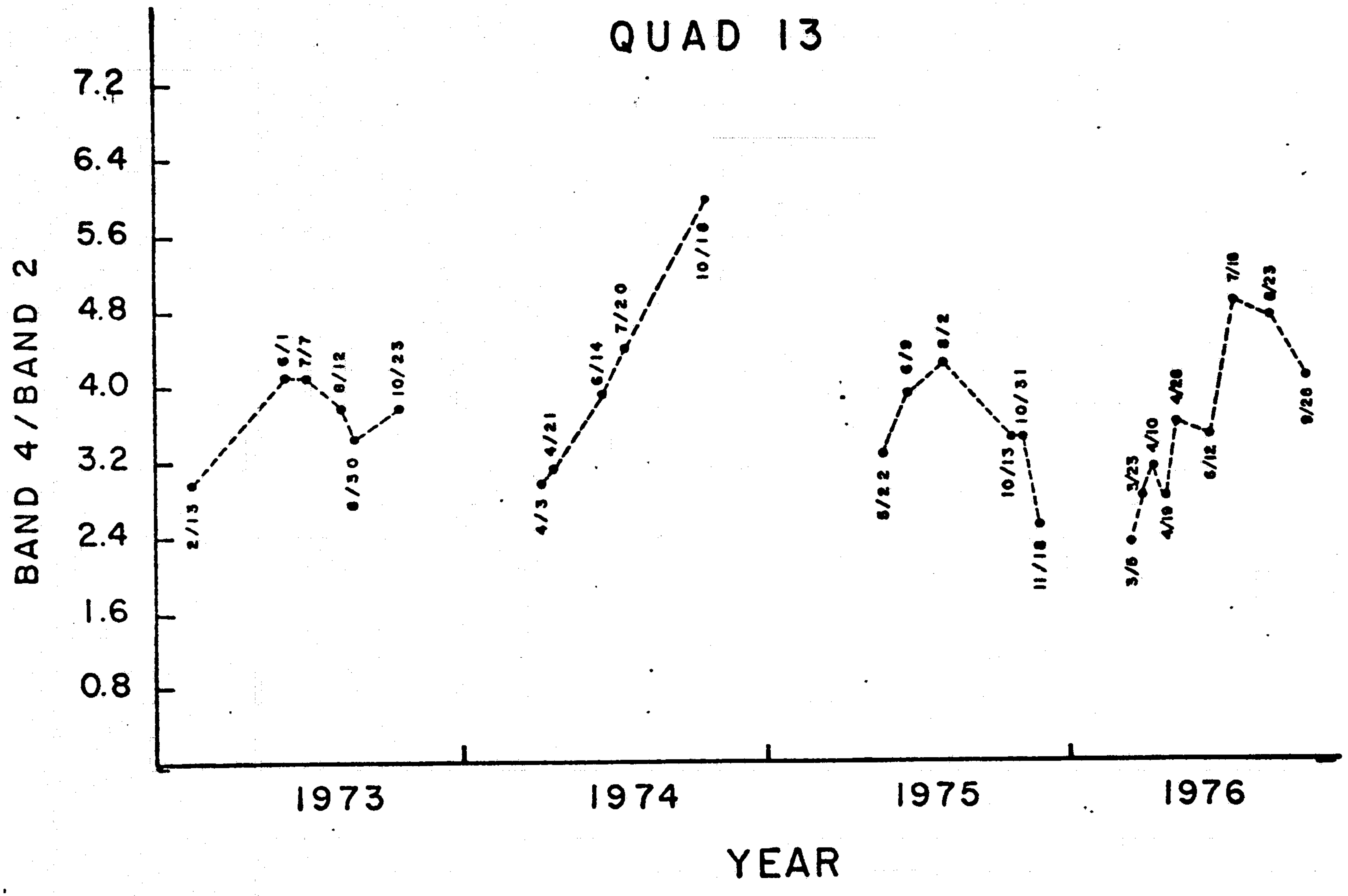

Figure 6m. Quad 13.

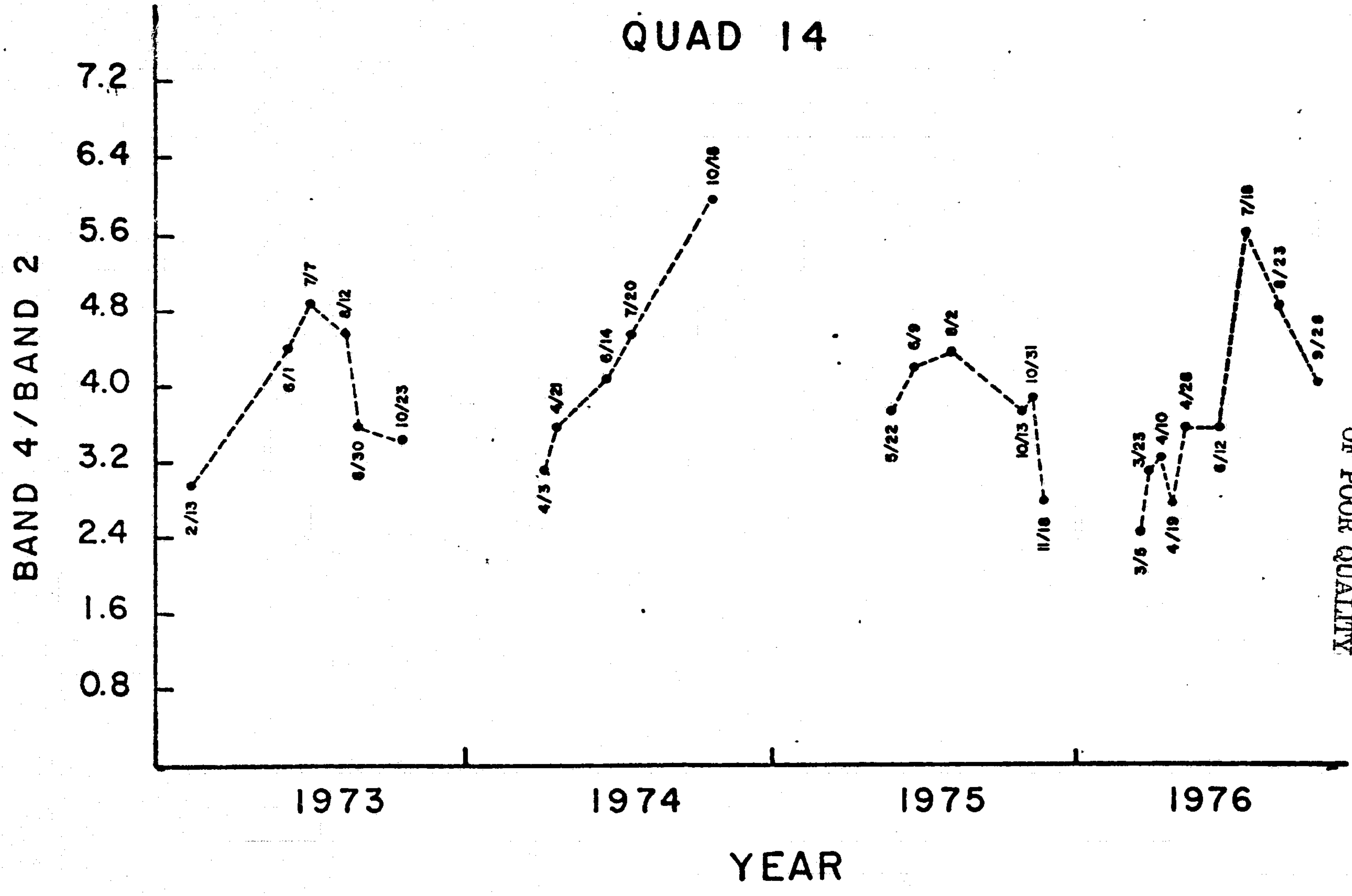

Figure 6n. Quad 14.

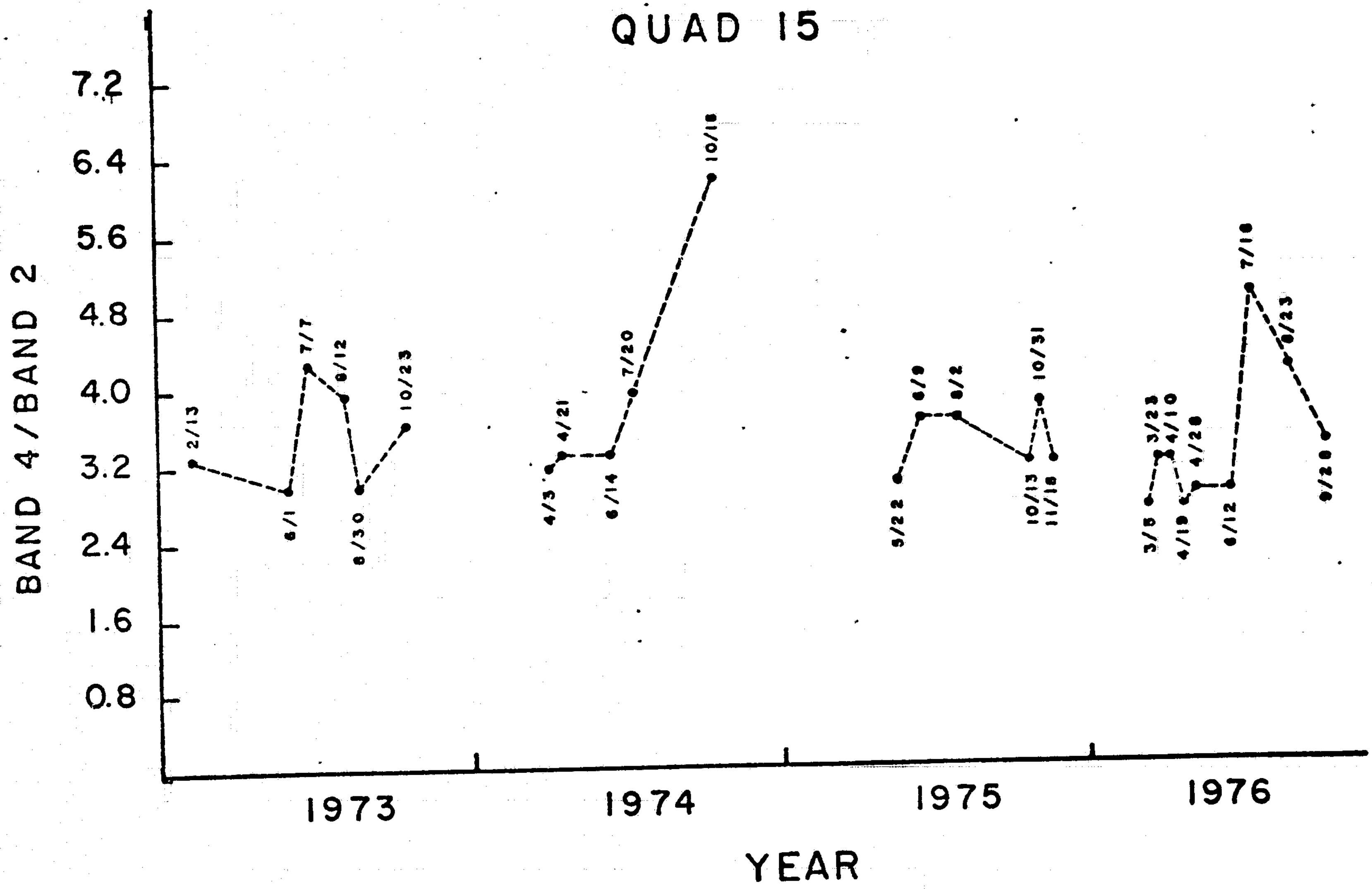

Figure 6o. Quad 15.

ORIGINAL PAGE IS OF POOR QUALITY

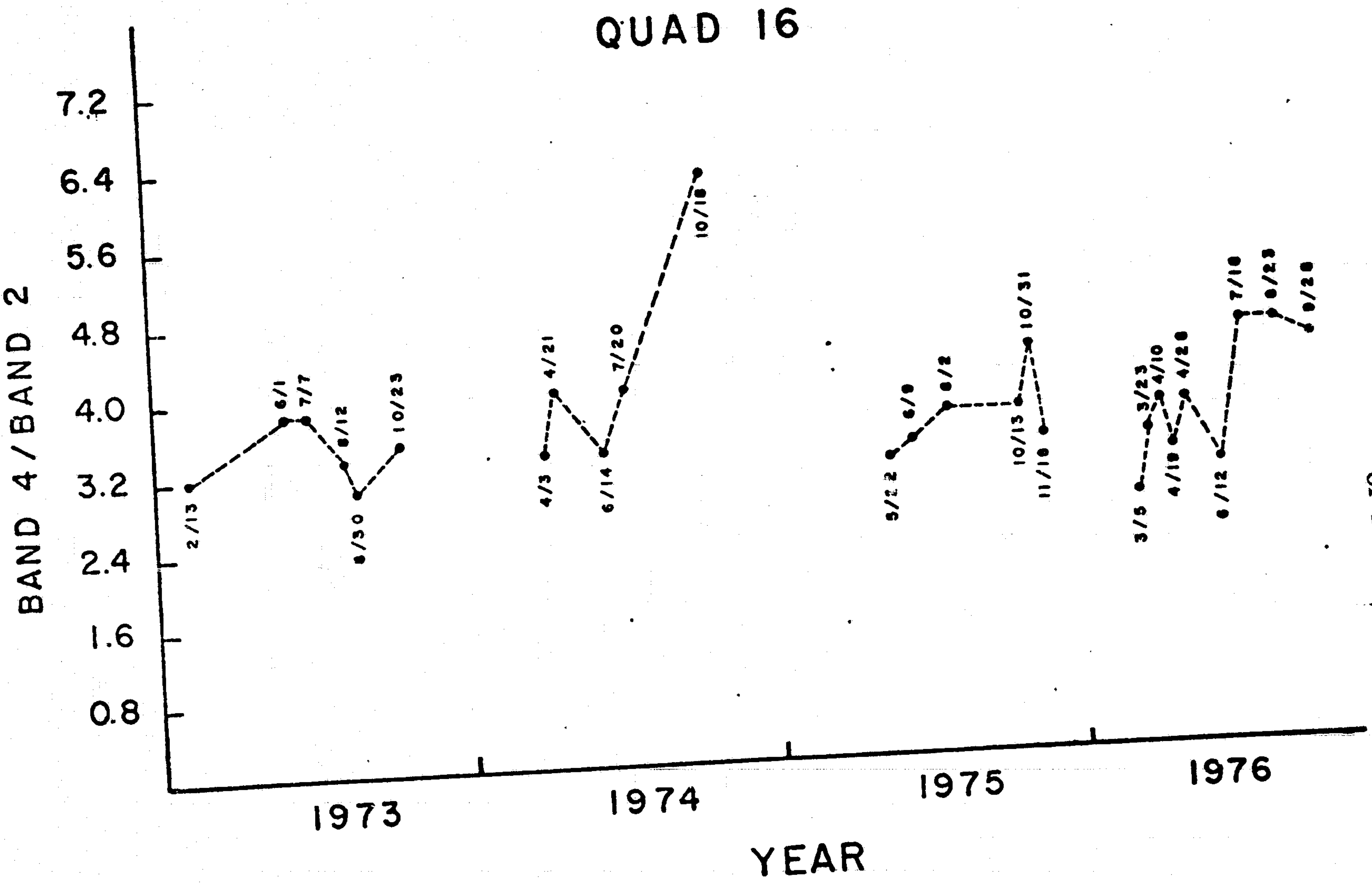

Figure 16. Quad 16.

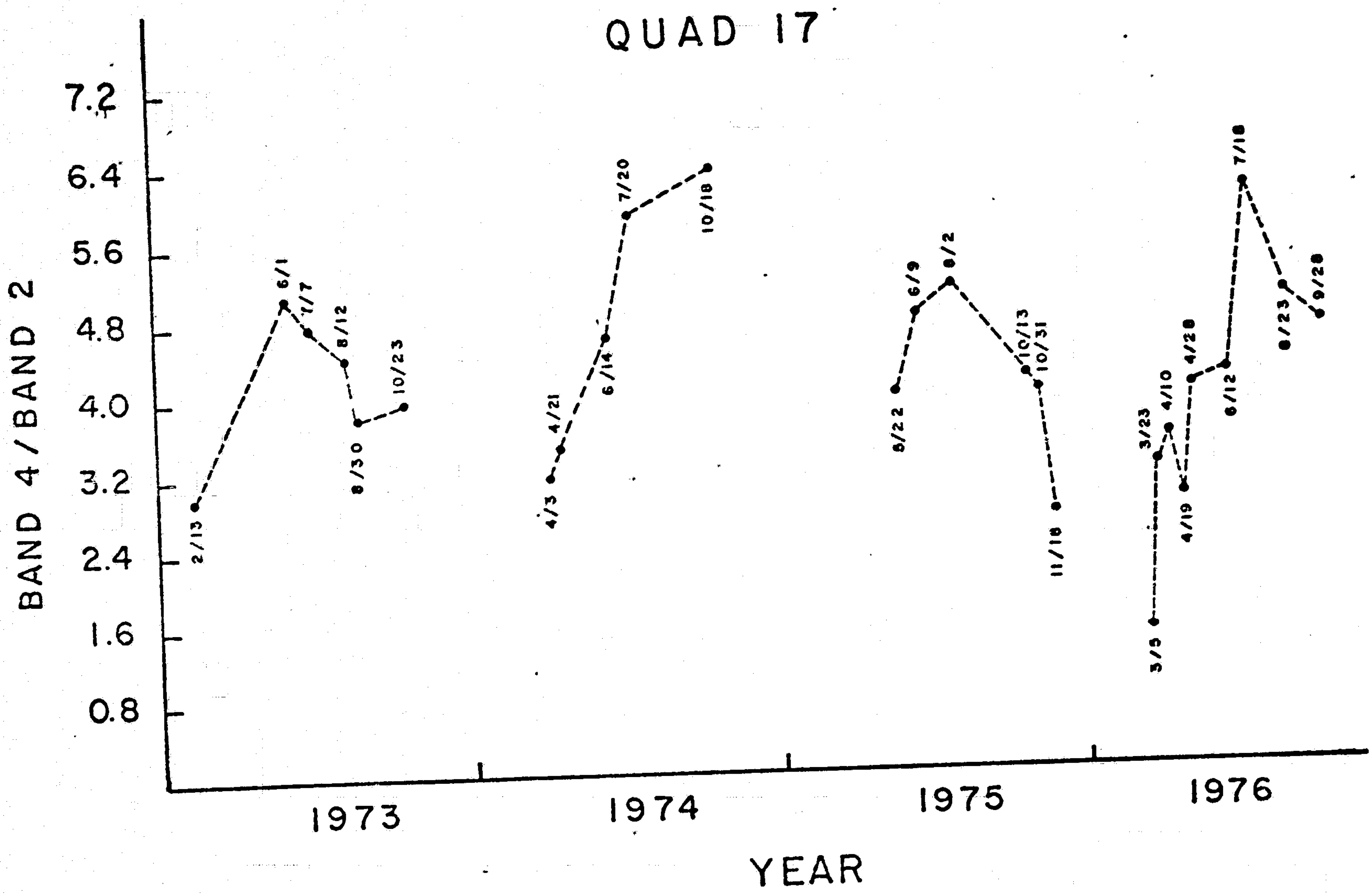

Figure 6q. Quad 17.

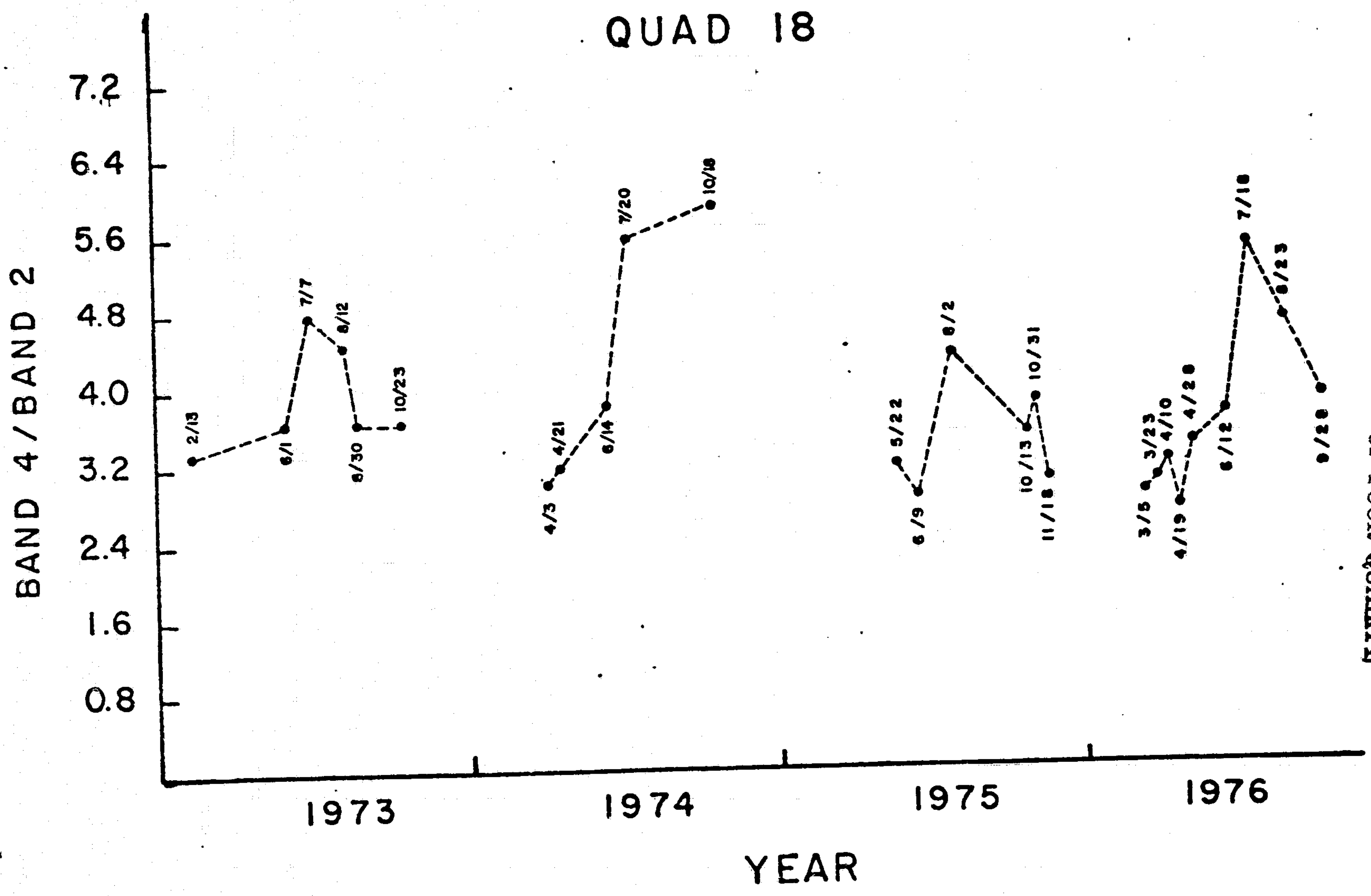

Figure 6r. Quad 18.

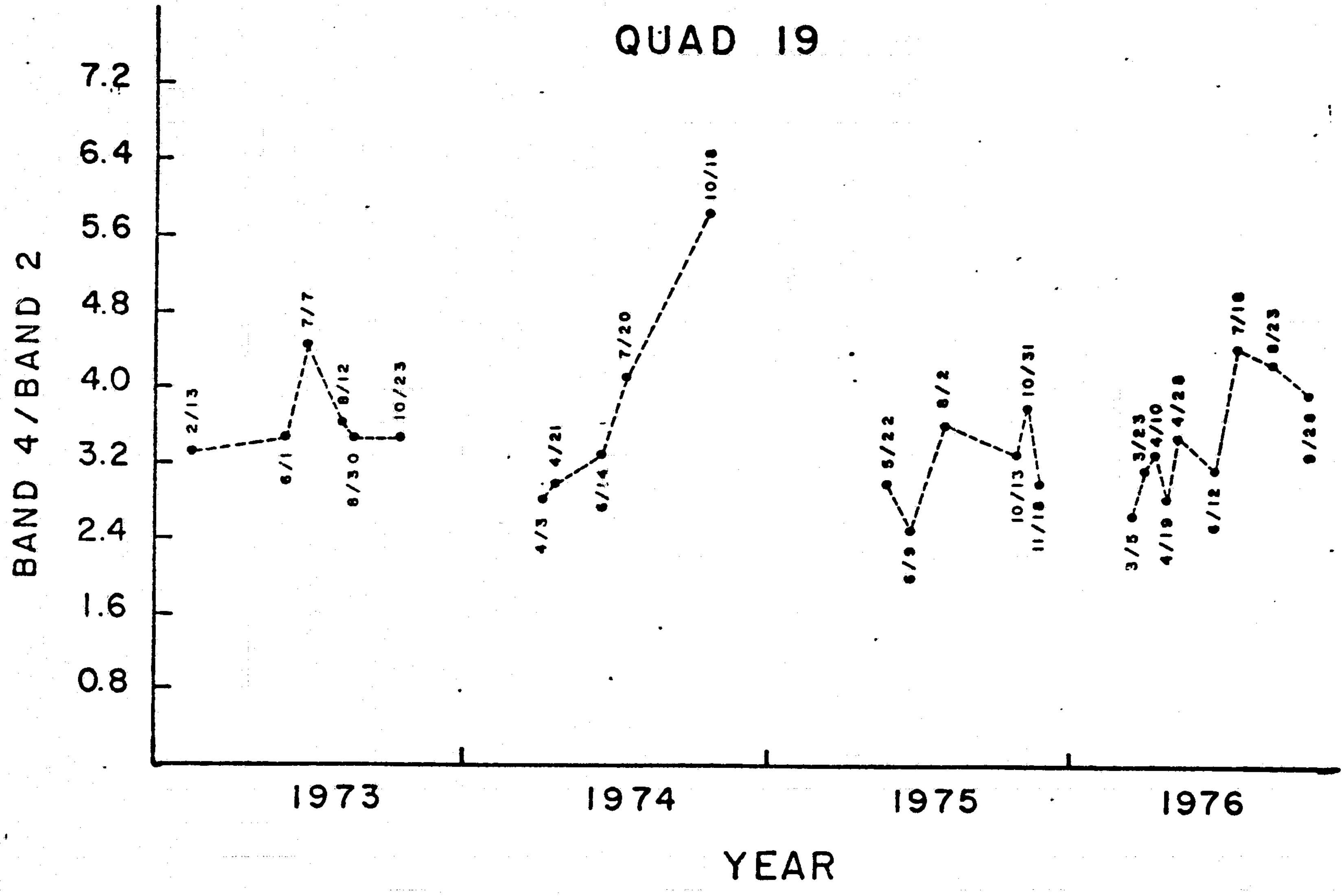

Figure 6s. Quad 19.

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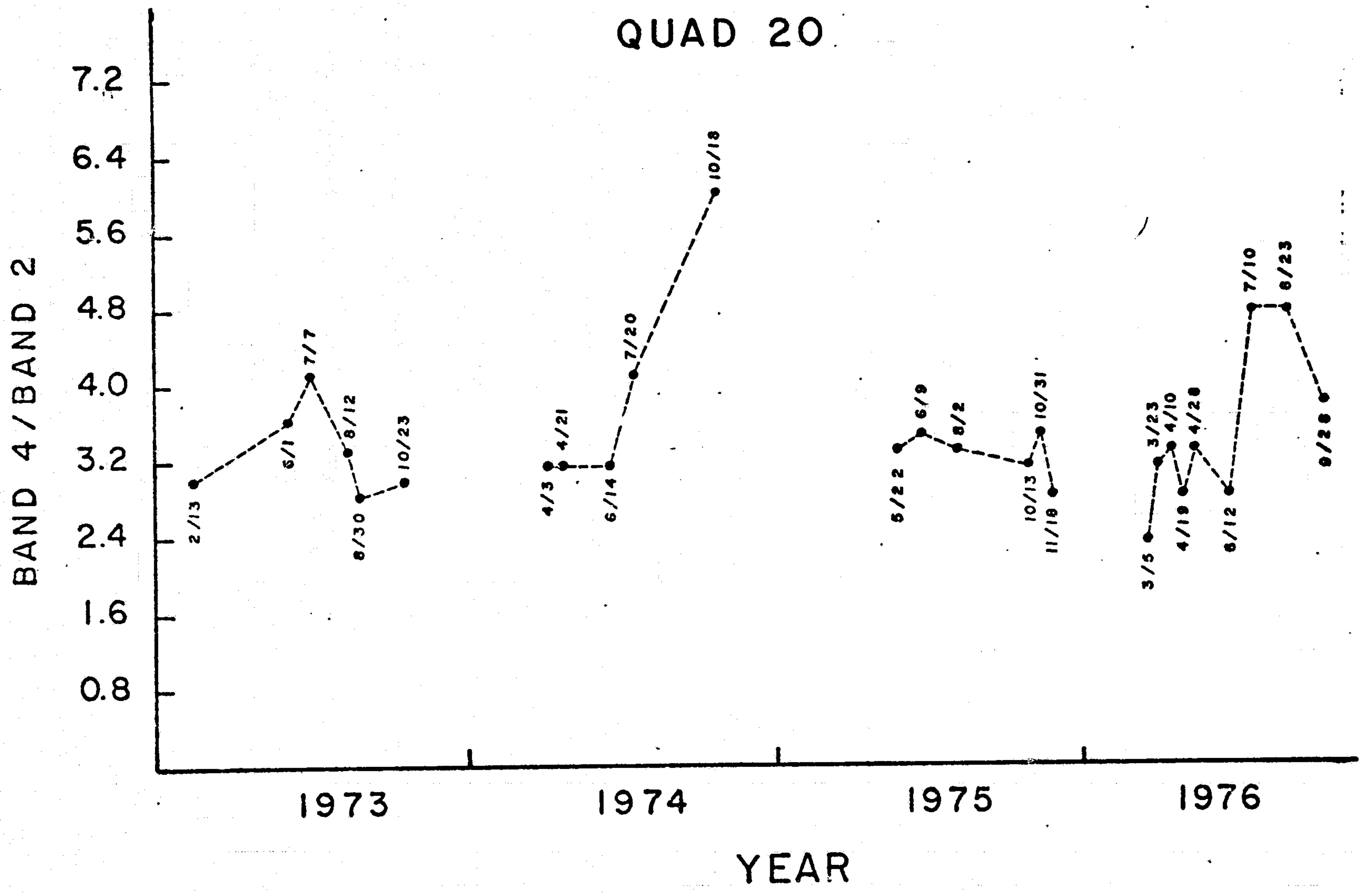

Figure 6t. Quad 20.

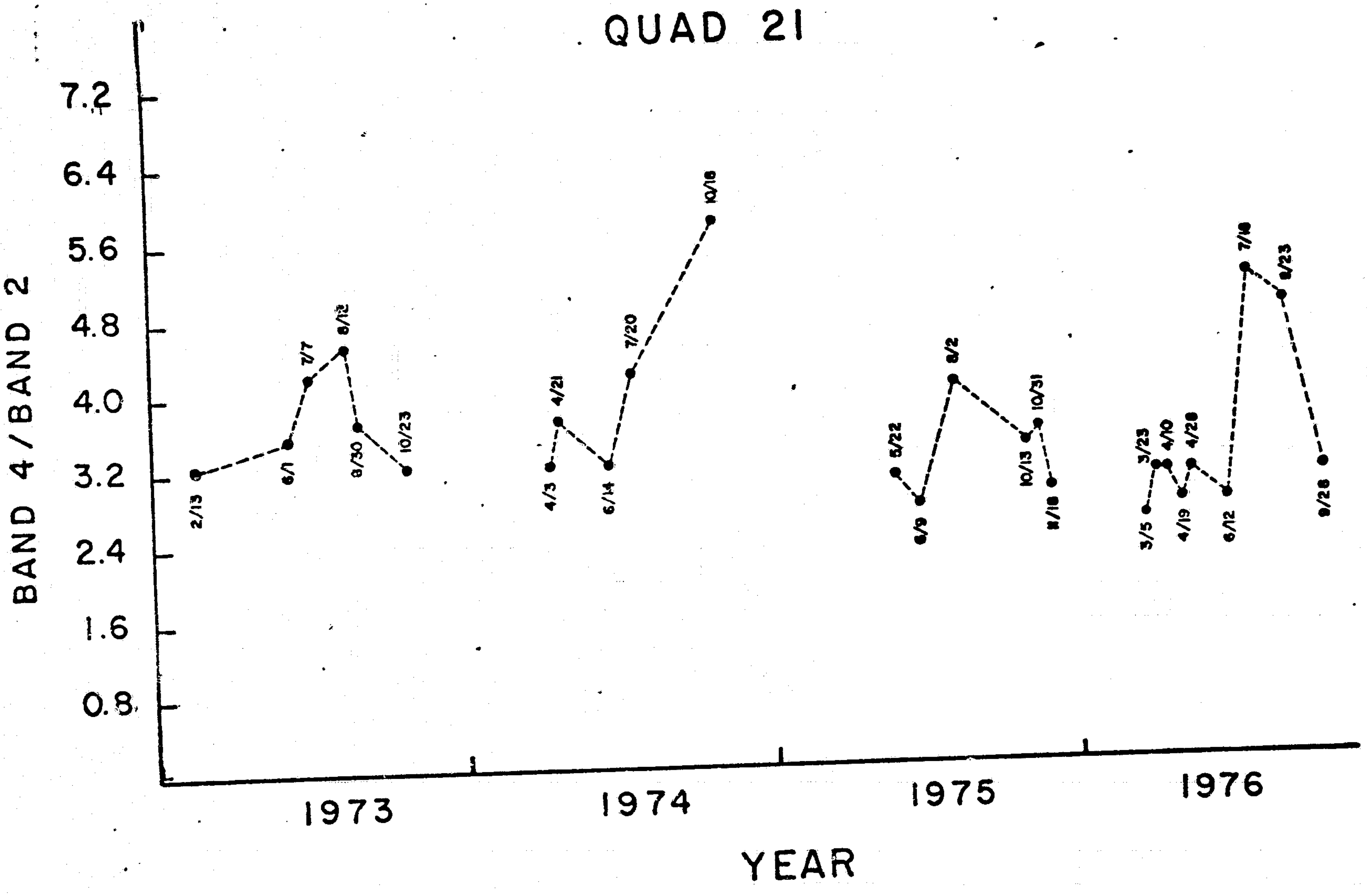

Figure 6u. Quad 21.

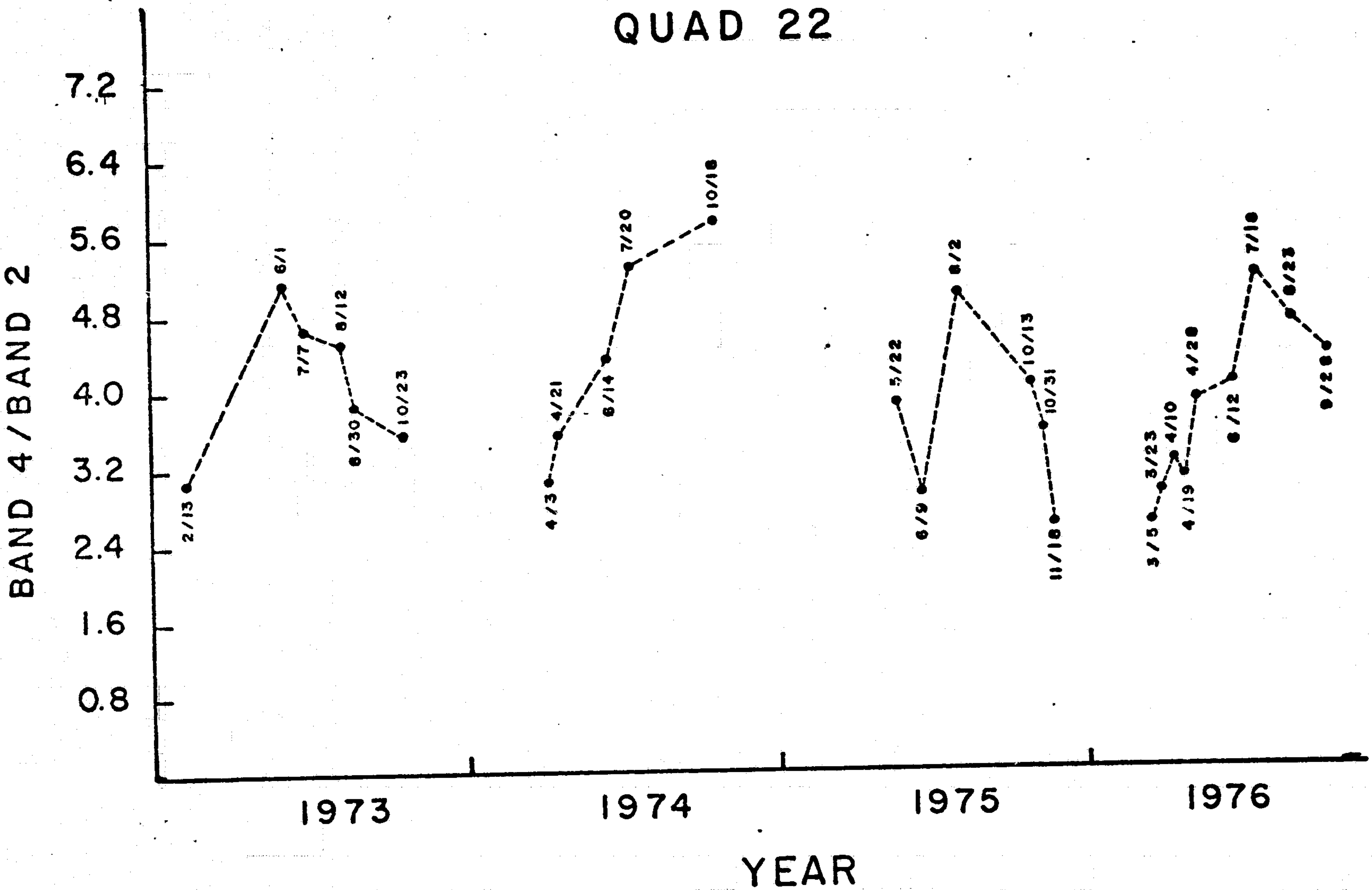

Figure 6v. Quad 22.

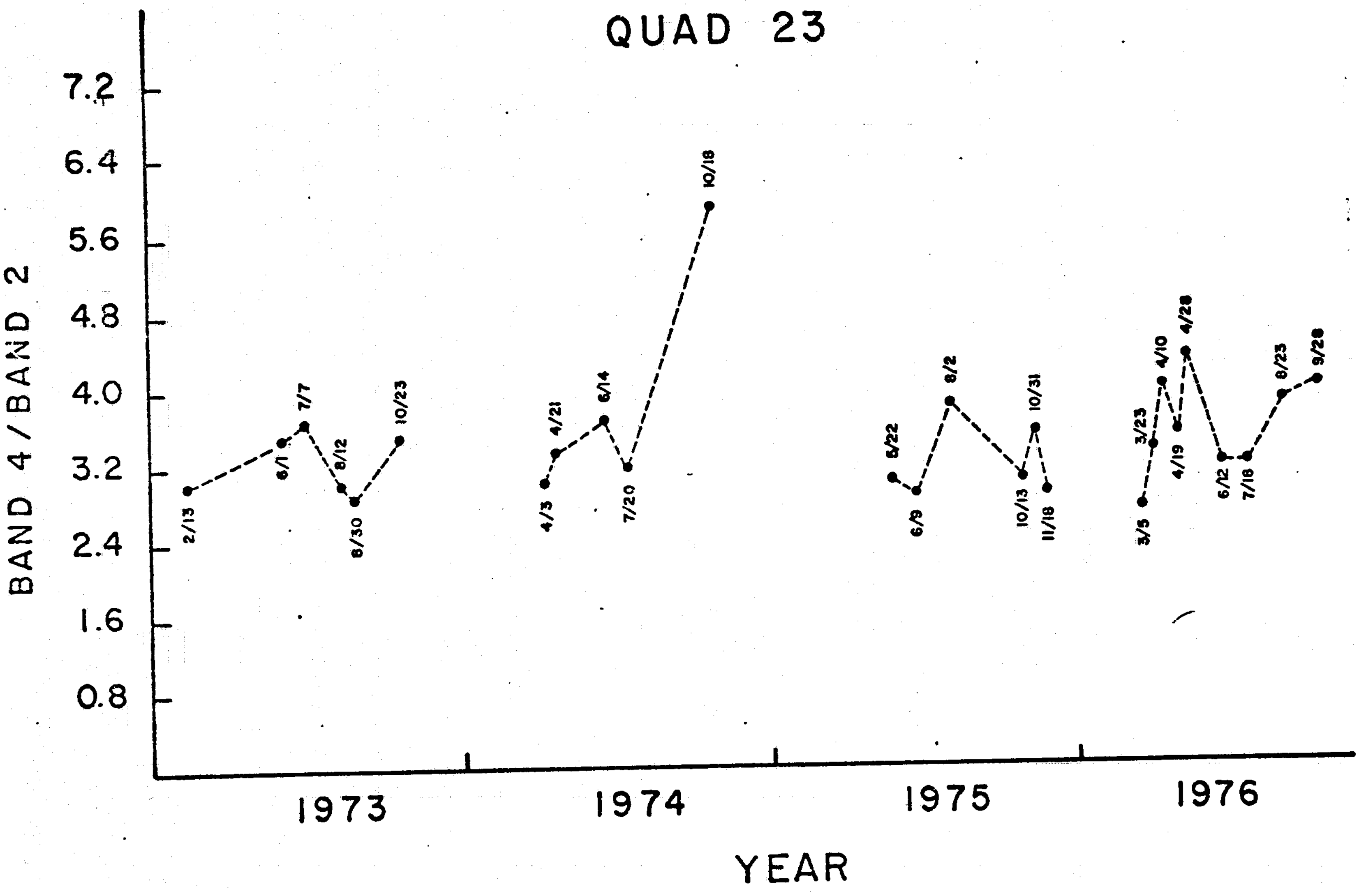

Figure 6w. Quad 23.

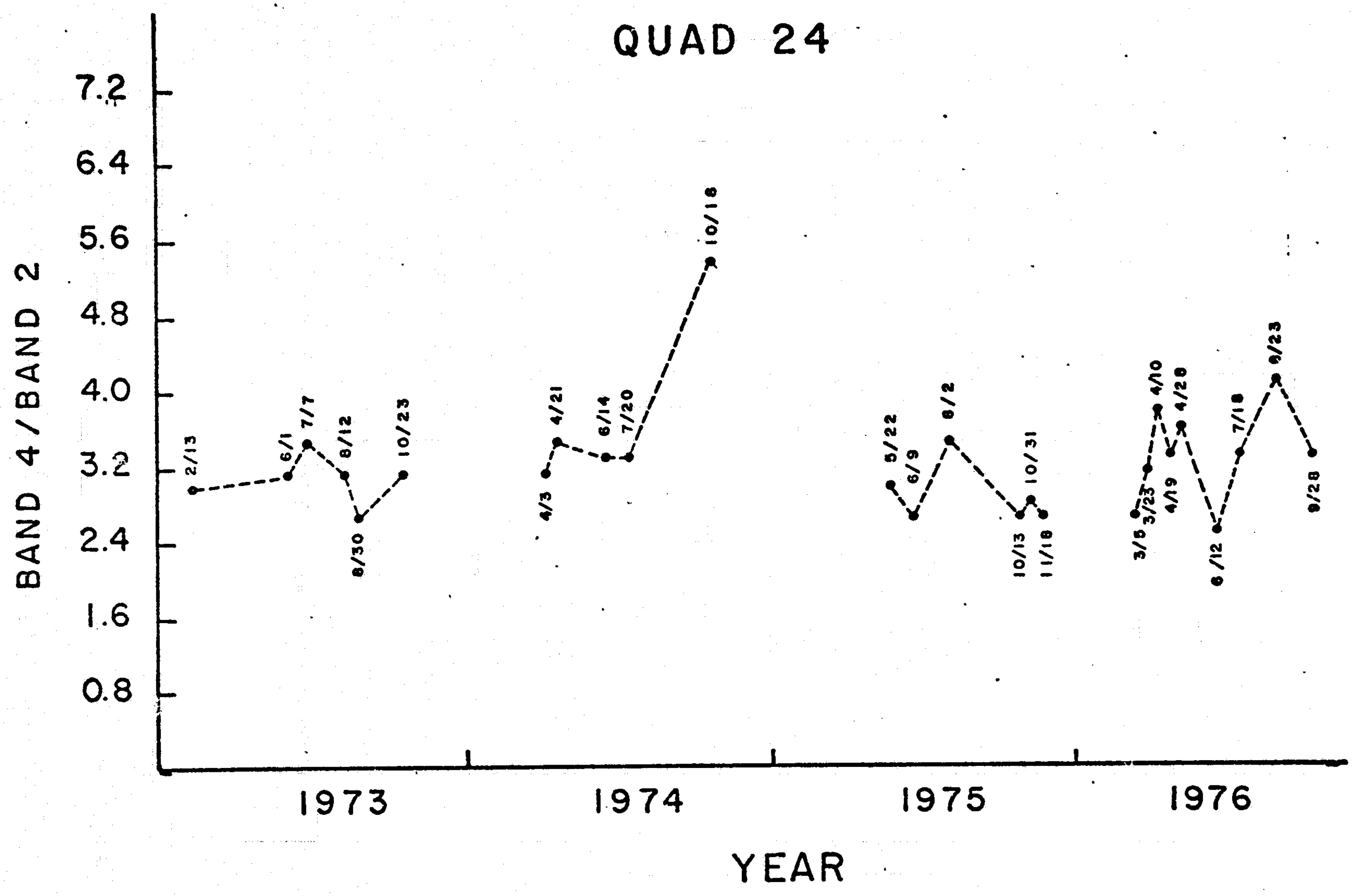

Figure 6x. Quad 24.

Comparison of Quads to Each Other

Though the discrepancy in the dates of data acquisition from year to year makes statistical comparisons of the four curves of a quad with each other difficult, it is possible to compare statistically the curves of "vegetable" quads with those of "field crop" quads. Two such quads are shown in Figure 7. These quads, numbers 2 and 23, were chosen to represent field crops and vegetables, respectively, from personally collected ground truth information and maps from Seabrook Farms. Figure 7 overlays the two types of systems so that their differences are readily observable. Table 7 in the Appendix lists the exact differences between the ratios; generally, they are most distinct in July and August, with an occasional distinction in April, May, and June.

The calculation of the Band 4/Band 2 ratio was extended to eighteen other quads labelled either vegetable or field crop based on the information at hand. Using the nonparametric Mann-Whitney "U" test, the two groups were tested for differences.[1] The means of the two groups were significantly different on data from nine of the twenty-six acquisitions, with at least a 95 percent level of confidence. Seven of these nine passes were during July and August. Again the summer months show a significant divergence between agricultural systems. The "U" scores for each date are listed in the Appendix in Table 8.

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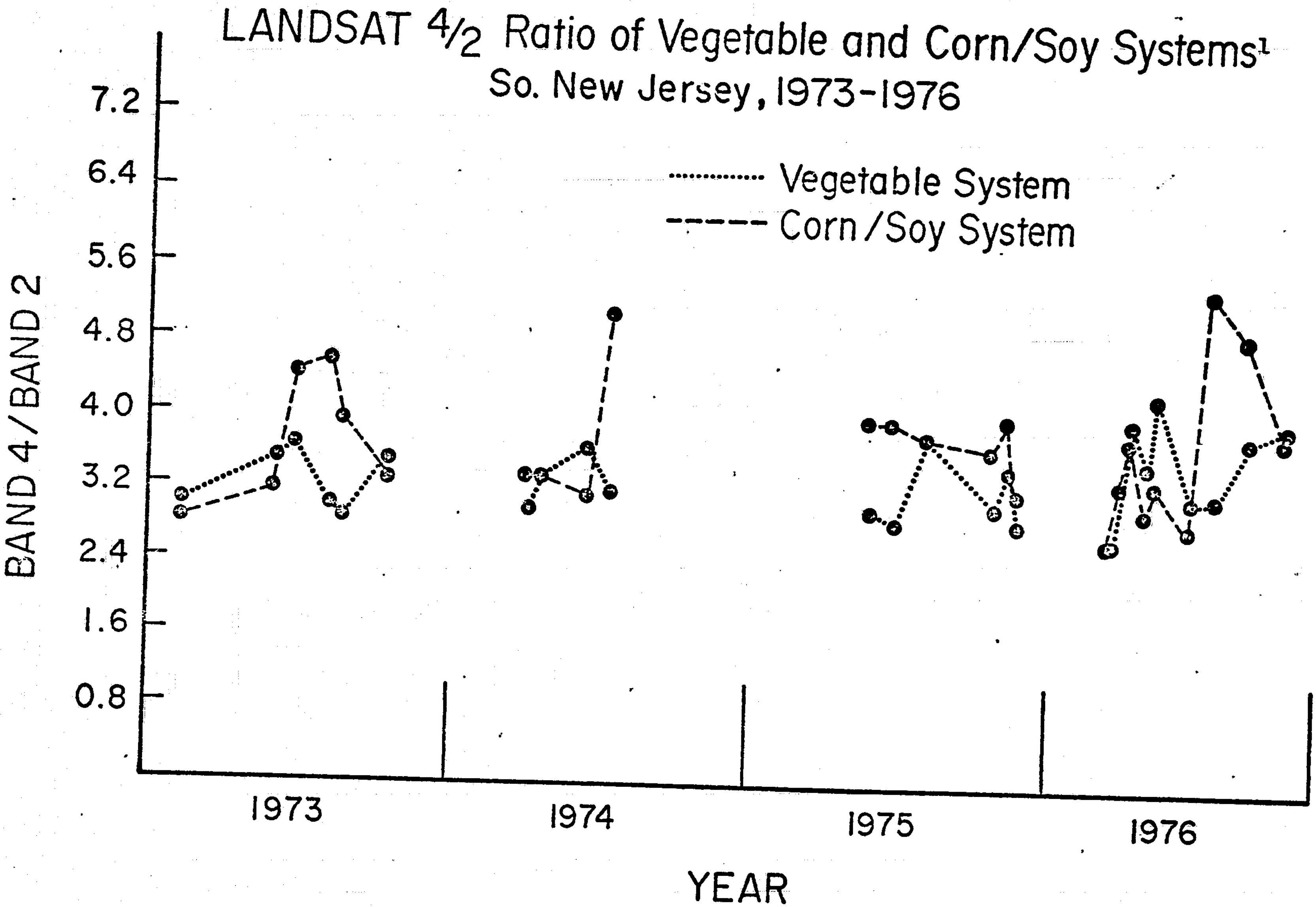
[1]Sidney Siegel, Nonparametric Statistics (New York: McGraw-Hill Book Company, 1956), pp. 116-127.

Figure 7



[1]The exact differences between the vegetable and corn/soy ratios are listed in the Appendix in Table A2.

Although the ratios tend to show differences at a specific time of year, the reason proposed for these differences has more to do with land utilization practices in space rather than in time. The curves diverge within the summer months when both field crops and vegetables are at a maximum, perhaps the very time when convergence would be expected if one considered crop cycles alone. Field crops tend to be in full canopy during July and August whereas vegetables tend to have less canopy cover with rows being separated by strips of soil. The large amount of exposed soil decreases the Band 4/Band 2 ratio, and this is evident in the figure.

Curve separations or similarities may also be related to meteorological events which immediately precede data acquisition. For example, the LANDSAT pass during the Summer of 1975 (August 2) occurred ten to fifteen days after a series of severe storms destroyed crops in the southern New Jersey region. On Figure 7, this event is reflected in the similarity of the two plots of 1975 during the Summer, when they would be expected to diverge.

The ratios for the year 1976 do not behave differently from those of the preceding years. Two explanations are possible, namely (1) the transition from vegetables to corn and soybeans, complete in 1977, may not have been far enough advanced in 1976 to be detected; or (2) residual factors of vegetable farming practices may still be impacting former Seabrook Farms land in 1976 to some extent. Supporting this second possibility, the former Seabrook Farms' Farm Manager, Mr. Val Perri, is of the opinion that the strips formerly used in rotation of vegetable farming will be evident in the field cropping system for a few years to come.[1]

To test the separability of a co-existing natural vegetation component in the landscape, an analysis of variance was performed using the nonparametric Kruskal-Wallis test on three types of vegetative systems--vegetable, field crop, and riverine/forest.[2] Quads containing riverine and forest vegetation also contained agricultural land, but they appeared to group together in the data. Observe the shapes of riverine/forest quads 5, 9, 13, 14, 17, and 22; these quads have the widest range of ratio values and form simple plots with few oscillations. The Kruskal-Wallis statistic revealed that the three sample groups were most probably (99 percent confidence for June 1973 and 95 percent for June 1976) taken from different populations.

Two-Year Cycle

A two-year cycle is evident in some quads. In twelve quads, the plots for 1974 and 1976 were similar.[3] Table 7

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[1]Val Perri, Seabrook Foods, Incorporated, Warehouse Manager, personal communication, August 4, 1977.

[2]Siegel, pp. 184-193.

[3]The similarity of the plots was determined by the agreement of two persons who visually compared each of the years within a quad to each other. When both persons felt that the plots of two years were alike, they were designated "similar" and entered as such in Table 7.

TABLE 5

PAIRS OF YEARS IN EACH QUAD WHICH HAVE SIMILAR PLOTS[1]

Quad	73-74	73-75	73-76	74-75	74-76	75-76
1		X		X	X	X
2	X		X			
3		X			X	
4				X	X	
5				X	X	X
6					X	X
7	X					
8		X			X	X
9				X	X	X
10		X		X		
11		X				
12						
13					X	
14						
15			X			
16					X	
17					X	X
18			X			
19						
20						
21						
22					X	
23	X					
24						

[1]The "similarity" of the plots was determined by the agreement of two persons based on visual inspection.

lists all quads and their year-to-year similarities. This pattern may be explained by the wheat-soybean cropping system which many farmers practice. In this system, wheat is planted in the Autumn and harvested in late June or July. A late crop of soybeans is then planted and harvested in late October. By this time the growing season is too short to drill in a new crop of winter wheat and the land remains clean-tilled. The following Spring an early crop of soybeans is planted, and this is harvested in time for a fall planting of winter wheat, two years after the first winter wheat crop. Not all wheat-soybean fields in a quad will be in the same stage of the cycle at any one time, but the effect is still present unless exactly half of those fields are in one stage and half in the other. Theoretically, a half-and-half situation would cancel the effects of both stages of the cycle and the cycle would not be evident. However, it is unlikely that this is the case, and thus the two-year cycle is exhibited.

DISCUSSION

The method used in this experiment to monitor agricultural change and its approximate location is based on a sound principle; that is, the identification of agricultural systems by tracing the periods of peak living biomass in a fixed area over the course of a year. Some problems exist with the method as it was used in this experiment which prevented optimal results and which should be noted when extending the method to other areas. Some of these problems relate to lack of ducumentation on certain cropping practices when the method was devised; and others are instrument-dependent, relating to the temporal resolution of the satellite, the impenetrability of cloud cover, and the occasional failures of telemetry and data processing.

During the winter months the Seabrook land was planted to a cover crop of rye or wheat, which was cut before the crop reached maturity. Then the land was turned and vegetables were planted. Data collected in short time intervals--nine days should be sufficient--would exhibit the abrupt shift from fairly thick green vegetation to bare soil. But if the data collection platform missed the cutting and cultivating period (because of atmospheric or mechanical problems), the results could be misleading to the analyst.

If winter months are used in the separation of agricultural systems, cover crops may be easily confused with winter grains. In addition, there is some fall planting of vegetables which might be confused in the October reading with cover crops and winter grains if the grains were planted early.

The growth patterns of corn and soybeans are similar and are here considered to be part of the same agricultural system. Their growth patterns are distinct from other crops: planting in May and June; three to five leaves showing through late June; luxuriant green growth in July and early August; yellowing through September and October. A late crop of soybeans planted after wheat might confuse the signal in terms of timing although not in terms of sequence. In September and October, however, it should be fairly easy to watch the ripening of corn and soybeans with this technique. At that time, either fall vegetables (for example, fall mustard and turnip greens, squash, and fall spinach) or cover crops will be well along and would not be confused with the corn and soybeans.

Orchards are a source of confusion since between each row of trees are about twenty feet of nonorchard growth, usually soybeans or hay. If the interarbor spaces are planted with soybeans, they will contribute to the assumption that a quad is predominantly devoted to field crops, while the fact that orchards make up a large part of the quad will go undetected.

That a two-year cycle of wheat and soybeans is practiced in many fields means that the analyst must construct his models of cropping around a biennial rather than an annual sequence of changes in the ratio. It is not known how widely this practice is used and so its effect cannot be estimated.

C-2

Even discounting the biennial pattern effect, it is possible that the wheat/soybean curve would be significantly different from the vegetable curve under optimal conditions of data acquisition.

In reality, the temporal resolution of the LANDSAT data available at the user end of the system turns out to be too coarse for this type of analysis. Because not all LANDSAT passes are useable due to weather or mechanical difficulties, there are wide time gaps between measurements in some years and a lack of concurrence between years. For instance, except for early/mid June, there is no time period which is represented in all four years.

If one were to extend this method to other areas of the world where different types of agricultural systems existed, certain adjustments should be made. Smaller or larger field sizes than those in southern New Jersey might justify an increase or decrease in the size of the areal unit used. A higher degree of crop mixing might mean a broader definition of "agricultural system" would be in order. Cyclical characteristics of the crops grown merit attention. Finally, when two agricultural systems are being compared, the seasonal aspects of the systems must be considered to determine if nonoverlapping periods exist.

CONCLUSIONS

A change in agricultural practices in an area of southern New Jersey has offered the opportunity to experiment with agricultural systems identification methods using LANDSAT. The method described in this paper is a promising tool because it differentiates the vegetable and field crop systems and because the shape of the curves over time generally corresponds to growth patterns. Summarized, the experiment revealed the following conclusions:

1) The Band 4/Band 2 ratio, when calculated for a 595-hectare area, differentiates vegetable from field cropping systems most effectively in the months of July and August.

2) Areal units of the size used in the experiment are also sufficient to identify regions where riverine/forest vegetation predominates.

3) A biennial cycle, where it exists, must be incorporated into the analyst's hypothesis.

4) In the agricultural systems investigated, patterns of land utilization in space rather than in time have the most impact on the behavior of the ratio.

With better processing technology or microwave sensing, it may be possible to eliminate large gaps in the series of data acquisitions. Microwave sensing eliminates the problems imposed by cloud cover; however, different indicators sensitive to vegetation must of course be developed in the microwave portion of the electromagnetic spectrum.

A LANDSAT pass every nine days would be sufficient for this type of experiment, were each pass useable. A more frequent data collection system would increase the probability of passing over a given area on a cloud-free day. Improved similarity between the dates of acquisition in each year would increase the ability to detect a change in the shape of a curve from one year to the next, and it may also permit the use of more formal analysis to quantify this difference.

The results from the study are encouraging enough to suggest that the method employed would be sensitive to a change from one agricultural system to another. The methodology may be useful in other areas of the world undergoing agricultural transition with field sizes and a degree of crop mixing similar to that of southern New Jersey. Alternatively, the method is adaptable to the agricultural systems which are being monitored.

APPENDIX

TABLE 6. LANDSAT DATA USED IN THIS STUDY

	DATE	SCENE IDENTIFICATION NUMBER
1973	February 13	1205-15141
	June 1	1313-15141
	July 7	1349-15134
	August 12	1385-15131
	August 30	1403-15125
	October 23	1457-15113
1974	April 3	1619-15083
	April 21	1637-15080
	June 14	1691-15063
	July 20	1727-15052
	October 18	1817-15023
1975	May 22	5033-14530
	June 9	5051-14520
	August 2	5105-14485
	October 13	5177-14443
	November 18	5213-14422
1976	March 5	5321-14352
	March 23	5339-14341
	April 10	5357-14330
	April 19	2453-14571
	April 28	5375-14314
	June 12	2507-14553
	July 18	2543-14545
	August 23	2579-14535
	September 28	2615-14525

TABLE 7

THE RATIOS OF QUAD 2 (FIELD CROPS) MINUS THE RATIOS OF QUAD 23 (VEGETABLES)

	DATE	DIFFERENCE
1973	February 13	-0.10
	June 1	-0.29
	July 7	0.88
	August 12	1.70
	August 30	1.23
	October 23	-0.24
1974	April 3	0.33
	April 21	-0.01
	June 14	-0.58
	July 20	1.94
	October 18	omitted
1975	May 22	0.99
	June 9	1.27
	August 2	0.11
	October 13	0.70
	October 31	0.53
	November 18	0.36
1976	March 5	-0.03
	March 23	0.08
	April 10	-0.18
	April 19	-0.54
	April 28	-1.00
	June 12	-0.27
	July 18	2.32
	August 23	1.13
	September 28	-0.26

TABLE 8

TESTING THE DIFFERENCE BETWEEN THE MEANS OF THE VEGETABLE AND FIELD CROP QUADS USING THE MANN-WHITNEY "U" TEST

DATE		"U" STATISTIC	SIGNIFICANCE[a]
1973	February 13	27	
	June	30	
	July 7	15	.05
	August 12	3	.002
	August 30	3	.002
	October 23	28	
1974	April 3	25.5	
	April 21	24	
	June 14	37.5	
	July 20	16	.10
	October 18	mitted	
1975	May 22	18	
	June 9	27.5	
	August 2	8	.02
	October 13	14	.05
	October 31	21	
	November 18	26.5	
1976	March 5	22	
	March 23	27.5	
	Paril 10	34.5	
	April 19	34	
	April 28	21	
	June 12	29.5	
	July 18	5.5	.002
	August 23	8	.02
	September 28	28.5	

[a]For a two-tailed test.

SOURCES CONSULTED

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MONITORING AGRICULTURAL SYSTEMS*

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To a large extent, remote sensing of agricultural phenomena has concentrated on analysis of agriculture at the field level. Concern has been to identify crop status, crop condition, and crop distribution, all of which are spatially analyzed on a field-by-field basis. This is not the only geographical scale at which agricultural activity can be analyzed. A more general level of abstraction is the agricultural system, or the complex of crops and other land cover that differentiate various agricultural economies. This paper reports on a methodology to assist in analysis of the landscape elements of agricultural systems with LANDSAT digital data. These methods may be particularly useful in the context of the developing nations to monitor agricultural change associated with economic development.

The site used to develop and test this method is part of Cumberland and Salem counties, New Jersey, in the northeastern United States, where change from a traditional commercial vegetable system to a corn-soybean-wheat field crop system is taking place. During the period of transition, both systems exist in close proximity, as farmers make individual decisions about what crops to grow. The method to differentiate these two systems relies upon an indicator which measures vegetative cover on a given ground unit during the course of four years. The unit employed is approximately 595

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hectares and may encompass up to 40 fields. Units representing vegetable cropping were chosen from corporate farm land specializing in vegetables, while units representing field crops were chosen from private landholdings planted to corn, soybeans, and wheat nearby.

The method of analysis tested in this experiment is based on the theory that, since agricultural systems differ in their crop calendars and cropping practices, the amount of vegetative cover in a given area over the course of a year will depend on the cropping system employed. The method involves tracing the periods of photosynthetic activity in a fixed area during a four-year period to determine if land devoted to field crops can be differentiated from that planted to vegetables at the 595-hectare level of aggregation employed here.

The measure used to determine the presence of green vegetation on an unit of land is a ratio of LANDSAT Band 4 to Band 2 (Band 4 ranging from .8 to 1.1 micrometers, Band 2 from .6 to .7 micrometers) in terms of milliwatts per steradian-centimeter^2. This ratio is particularly sensitive to pre-senescent vegetation since Band 4 reflectance increases with the development of the spongy mesophyll section of leaves while Band 2 reflectance is decreased due to chlorophyll absorption. The plotting of this ratio over time yields curves similar to Figure 1.

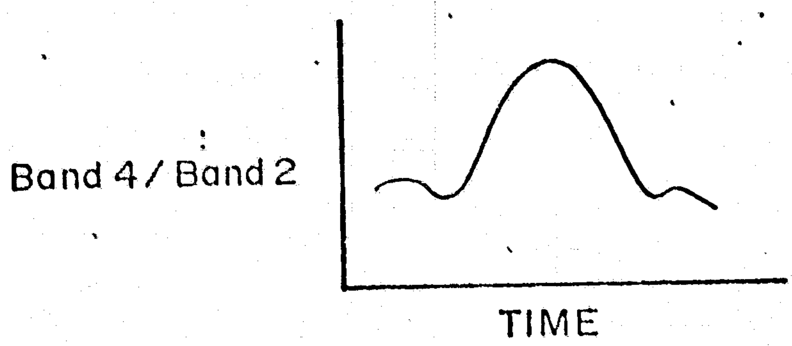


Figure 1. Example of the change in the Band 4/Band 2 ratio over time.

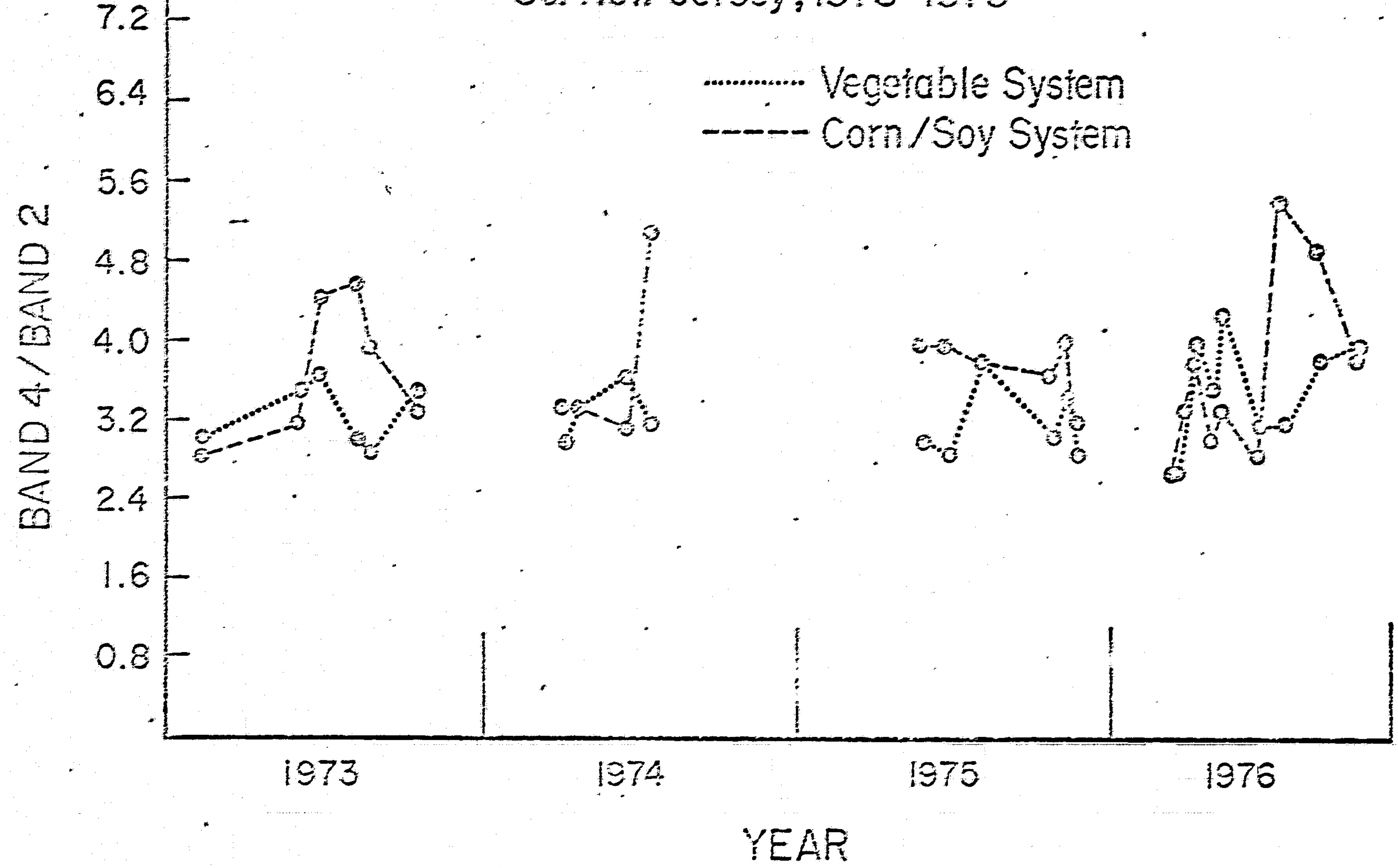
The results from two units, one predominantly vegetables, the other field crops, are shown in Figure 2. The shapes of the curves differ from year to year because of a lack of concurrence in satellite acquisition times for usable data. The areal units can be compared to each other within each year, however. The curves diverge within the summer months when both field crops and vegetables are growing. Field crops tend to be in full canopy during July and August whereas vegetables tend to have less canopy cover with rows being separated by strips of soil. The large amount of exposed soil decreases the Band 4/Band 2 ratio, and this is evident in the figure. Curve separation may also be related to meteorological events which have immediately preceded data acquisition. For example, the LANDSAT pass during the summer of 1975 occurred ten to fifteen days after a series of severe storms destroyed crops in the southern New Jersey region. On Figure 2, this event is reflected in the similarity of the two plots of 1975 during the summer, when they would be expected to diverge.

The calculation of the Band 4/Band 2 ratio was extended to twenty-two other 595-hectare units. Each unit was assigned to a vegetable or field crop category. Using the nonparametric Mann-Whitney "U" test, the means of the two groups were significantly different on data from nine of the twenty-five acquisitions, with a 98 percent level of confidence. Seven of these nine passes were during July and August. Again the summer months show a significant divergence between agricultural systems.

To test the separability of a co-occurring natural vegetation component in the landscape, an analysis of variance was performed using the nonparametric Kruskal-Wallis test on three types of vegetative systems--vegetable, field crop, and riverine/forest. In both June 1973 and June 1976, the χ^2

LANDSAT 4/2 Ratio of Vegetable and Corn/Soy Systems

So. New Jersey, 1973-1976



statistic revealed that the three sample groups were most probably (99 percent confidence for June 1973 and 95 percent for June 1976) taken from different populations.

As a preliminary test of an aggregated-unit approach to monitoring agricultural system, the results are encouraging. The LANDSAT-derived radiometric indicator, even at this level of aggregation, appears to afford a significant means to differentiate agricultural systems from each other as well as from natural vegetation elements. Future experiments will be performed using sites in both temperate and tropical regions, to extend the utility of the indicator in monitoring agricultural systems.

USE OF CHANGE DETECTION IN ASSESSING DEVELOPMENT PLANS: A PHILIPPINE EXAMPLE

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ABSTRACT

Given a need to collect serial data for regional planning, the purpose of this paper is to describe a method which uses both remote sensing and information systems for collection, spatial analysis, and display of periodic data. Findings presented here are from an aircraft/Landsat based change detection study conducted for the period 1948-1972 on Marinduque Province, Republic of the Philippines. The experimental information system for the Island allows collection and maintenance of spatial relationships inherent in the landscape through generalization of a preselected number of data elements into a uniform grid cell (twenty-five hectares). Storage is achieved by arraying the data elements as records, based on the grid cell's location within the predefined Universal Transverse Mercator (UTM) geographic reference system. Either aggregated data, categorized and combined into tables, or spatially displayed data in the form of computer maps, can be recalled for analysis and planning support. Programming allows presentation of discrete symbology or choropleth categories in computer generated maps.

Each of the 4,008 twenty-five hectare cells representing Marinduque were studied for changes in and between various development variables. These changes were measured and tested using nonparametric statistics to determine the effect of specific land cover changes on other infrastructure components and proximate land use. Since the grid was spatially registered through time, change occurring within the cell could be positionally related, allowing assessment of the change's impact.

Techniques have been developed for more continuous updating of the Marinduque data base with Landsat data. The primary effort has been to extract for each twenty-five hectare cell an indicator of change as derived from UTM geometrically corrected and aggregated Landsat data. Anomalous or unique changes over time can thus be detected and corroborated either with ground reconnaissance or high resolution aircraft imagery.

The experimental system used here demonstrates that it is possible to retain in one information system historical and current physical aspects of developing regions. In support of the planner's requirement for periodic observation, the study reveals both trends and seasonal and other periodic cycles in regional, settlement, and environmental patterns which, if unaccounted for by planners, would impact negatively on development projects. If properly used, these data provide better regional models than static base line approaches, thus markedly improving present development planning capabilities.

1. INTRODUCTION

Throughout the developing world, environmental and sociometric data series are short, of unknown reliability or nonexistent (Data for Development, 1971; United Nations, 1975). The data problem is compounded by a lack of timely collection and analysis mechanisms which make much of the data useless for other than historic purposes (Coiner, 1977). Although data deficiencies are only one aspect of the problems faced by development planners, there is little doubt that they can contribute substantially to the failures of development schemes (Johnson, 1970, pp. 346-50; Paddock and Paddock, 1973). This lack of data also inhibits application of more sophisticated environmental planning approaches, such as those advocated by Dasmann, et al. (1973), because such ecological models require environmental measurements that are unavailable without a well-established and effective applied environmental science, something that is uncommon even in developed countries. One possible solution to the problem of adequate planning data is the use of remote sensing sources to augment and possibly replace traditional data in development projects (NAS, 1977, pp. 24-36). Using remote sensing, this paper presents an experimental geographic information system which supports the various aspects of the planning process.

Before considering the experimental system, one of the implicit assumptions about data from remote sensing, now widely held by advocates of remote sensing geographic information systems, needs to be challenged (Landini and Paul, 1974; Landini and Paul, 1975; Bryant, 1976). The assumption is that remote sensing data acquired at a single time and used to form multiple data elements in a spatially contiguous, but static, data base can be employed effectively in regional planning and infrastructure implementation. The assumption is subtly misleading, and it reinforces the common view of underdeveloped areas as places where no change occurs. Both the static data base and the view it supports fail to account for the continuous change that occurs in any region because of ecological cycles and physical forces within the environment as well as of interactions between the natural environment and its human occupants. Both give rise to the idea that planning will bring change, in the form of development, to a region that has been in a fixed state. However, even the most casual time series observation should lead the planner to the conclusion that development is best understood as modification and direction of continuous change. This understanding of what development planning is about leads to different data requirements than those contained in static data bases and master plans. Thus, from the standpoint of critical planning data, the emphasis should shift from spatially extensive, multiple data elements, which others assume to be sufficient, to the identification of key indicators that reflect cyclic and noncyclic changes, and what those changes mean in terms of regional development. In the remote sensing/geographic information system context, the emphasis should shift from data basing to change detection and monitoring.

To test the utility of remote sensing and a geographic information system in a development context, a study site was chosen in the Philippines. The site Marinduque Island, Marinduque Province (see Figures 1 and 2) is a typical underdeveloped area prevalent in the tropical world. It displays the statistical symptoms of underdevelopment from the structure of its population--predominantly rural--the uses of its resources--generally extractive and unrenewable--and the basis of its economic activity--largely subsistence agriculture and lacking alternatives (Coiner, 1975).

2. INFORMATION SYSTEM

The number of features that can be interpreted from aerial photographs or extracted from Landsat data or digitized from more conventional data sources (maps and census series) require design of an information system to manage the large and complex data sources. Information systems delimit an organized approach to the specification, collection, storage, analysis, and display of data. When spatial referencing is contained within the data file structure, the system is known as a geographic information system (Tomlinson, 1972; Steiner, 1974). Such a system has been designed to support this research. It allows the collection and maintenance of spatial relationships inherent in the landscape through generalization of a preselected number of data elements into a uniform size cell (25 ha). Storage is achieved by arraying the data elements as records based on the grid cell's location within a Universal Transverse Mercator (UTM) georeferencing system. Either aggregated data, based on categorization and combination of the data fields, or spatially displayed data, in the form of computer maps, can be recalled for analysis (Figure 2).

Computer cartography for this system is based on the use of an IBM 370/145 and a CALCOMP drum-type plotter. Programming allows presentation of discrete symbology or choropleth categories, and display of either symbols or patterns can be accomplished in multiple colors.

The data base was constructed using a 500m x 500m grid as the basic unit of data collection and storage. For each of the grid cells, data were interpreted from medium scale aerial photography on a cell by cell basis using the format in Table I.

Marinduque computer files are different from traditional base line data in that they consist of three aerial photographic coverages (1948, 1967, 1972) which form a time series. Each of the three data sets were divided into two parts, 1) a land cover classification, and 2) specific data related to development, particularly human settlement infrastructure. Data elements were assigned to three categories by spatial type, point (e.g., house), line (e.g., road), or area (e.g., mangrove swamp).

Land cover categories interpreted from aerial photographs of Marinduque Island were originally developed as part of an effort to support agrarian reform throughout the Philippines, particularly Central Luzon (Veracion and Bruce, 1966; Veracion and Bruce, 1967). Because of its original purpose, the classification required slight modification and supplementary land cover categories to describe the Marinduque site. Twenty-one land cover categories were identified as area extensive on Marinduque (Table II) and were assigned a numeric code to aid in creating computer compatible files. The classification logic used in the three-digit computer code was as follows: hundredths digit--general land cover type; tenths and lower digits--specific land cover. This allowed a limited hierarchical classification structure. To mark areas that had similar land covers, a photo symbol code was applied to the photographs, a necessary step when data takeoff was a separate operation from photo interpretation. Each of the 4,008 twenty-five hectare cells, which in combination represented a virtual map of Marinduque Island in the data base, then could be subjected to analysis in a number of ways. Since the grid was spatially registered through time, change occurring within the cell could be positionally related and evaluated.

The UTM file structure of the data elements interpreted from the aerial photography provided the framework for incorporating Landsat data into the information system. Conceptually, concatination of Landsat data into an aerial photographic data base is accomplished by identifying an array of pixels within the Landsat data which represents the same ground area (here, 25 ha cell) in both sources. However, the Landsat data first must be reprojected into the UTM map referencing system. For this study, the reprojection was accomplished by geometrically correcting the digital data during preprocessing (Bernstein and Ferneyhough, 1975, pp. 1465-76). Using the Institute for Space Studies facilities, a maximum of 63 geometrically corrected pixels (7 x 9 pixel matrix) comprised a 25 ha cell, if partial pixels were included, and if they were excluded, a minimum of 48 pixels (6 x 8 pixel matrix). Figure 3 is a graphic representation of the congruencing process. The air photo on the left in the figure was overlayed with a 500m UTM grid taken from a 1:50,000 base map. On the right, the Landsat MSS band 7 (geometrically corrected) CRT image also was overlayed with the same 500m reference grid. The land cover attributes of each cell in the photograph were extracted by qualitative interpretation, while for the Landsat data, the same area was described numerically in terms of radiance.

For the purposes of continuing studies, Landsat is intended to be the major source of data for changes in land cover. To date, Landsat data from one acquisition (E-1081-01462) was filtered into a single change indicator for each of the 4,008 25 ha cells. Since locational accuracy in transferring from aerial photographic and map sources to Landsat was maintained at ± 1 pixel (76.20m x 60.96m), change due to locational error was minimized. Also, the selection of a 5 x 7 pixel matrix within each 25 ha unit minimized certain types of boundary effects. Although choice of a Landsat radiance descriptor as a change indicator for each cell remains a matter for continuing research, the data in each MSS band were described by three statistical properties: the mean, standard deviation, and percent standard deviation. Other properties of the matrix may be equally or more appropriate.

Since the airphoto file and the Landsat file were linked by locational properties, they could be used to support each other. For instance, the 1972 aerial photographic data base could be used to identify cells within the Landsat file which had a homogeneous land cover (e.g., paddy rice, coconut orchard, *cogon*--Imperata sp./*parang*--forest regrowth). These cells then could be used to establish spectral properties of various land covers. Cells which had different secondary and tertiary land covers could be included to study the spectral radiances of 25 ha areas with mixed land covers. Further, line and point data elements carried independently in the file could be investigated for land cover attributes at the subpixel level (e.g., dwelling units) through their aggregate statistical impact on a 25 ha area.

In short, these types of analyses permit use of two data sources in concert, increasing the utility of both. Aerial photography provides historic site information while Landsat provides data to study short-term environmental cycles and timely data on land cover changes which may relate to developmental activities.

3. ANALYSIS OF LAND COVER CHANGE FROM AERIAL PHOTOGRAPHS (1948-1972)

Land cover change can be cyclic, e.g., the encroachment of *parang* vegetation on coconut orchards, the subsequent removal of the *parang* and its replacement with new coconut plantings, or noncyclic, e.g., introduction of an innovation, such as a development project, which manifests itself as a new land cover. In the case of cyclic change, the periodic expansion and contraction is tied to competition between land covers, generated by either environmental or human activities. In the case of developmental change, the impact of innovation on a landscape results in the expansion of a new land cover at the expense of the old.

Since both cyclic and developmental (noncyclic) land cover change may take place at the same time, their combination in a specific place requires some form of time series analysis to measure the impact of the two land cover changes. Although time series analyses have not been used widely to study land cover change, the techniques should be applicable. The innovative component of land cover change would be measured by the linear trend in the data, while the cyclic would be represented by the periodicity of the regression error.

A third type of change within the land cover which may reflect development activity is land cover fragmentation. As land covers are added to a small fixed areal unit, such as the 25 ha cell in these files, it is recorded as an increase in the number of land cover types occurring in a given cell, and fragmentation results from such increases. For example, in a three category system, each cell could contain up to three cover types with a maximum of six (3!) possible land cover combinations. When just one new land cover is introduced by a development project, the number of possible combinations increases to twenty-four (4!). This leads to the hypothesis, testable with files used in this study, that development projects will cause land cover fragmentation by the introduction of new cover types into the landscape.

Between 1948 and 1972, the number of land cover types on Marinduque increased from 15 to 23, an increase of 8 new land covers during the twenty-four year period. The greatest increase in land cover categories was in the areally secondary class, where the number changed from 13 types in 1948 to 22 in 1972. The areally dominant class changed least, with only 6 new cover types added (Table III). Land cover types which were identified as new in 1967 and 1972 are indicative of the physical development that had occurred. These include new transport modes (airports), new agricultural activities (fish ponds and sugar cane) and new industrial and mining activities (strip mining, industrial sites).

A land cover map (Figure 4) of Marinduque provides an assessment of the spatial distributions of dominant land covers by 25 ha cell for 1972. In addition to static land cover distributions, land cover change can be measured in terms of the number of cells dominated by a given land cover and the variations in this dominance from one time to another (Table IV). A significant difference was found in the dominant land cover distribution for the 1948 to 1972 period. This difference was also evident in the north central-northeastern portion of the Island for the 1948-1972 period, although the Chi-square value was considerably smaller. Testing of the 1948 to 1967 dominant land cover distribution also revealed a significant difference. In the shorter 1967-1972 period, the distribution of cells dominated by a given land cover type was not significantly different.

The Chi-square test results revealed the degree to which each of the dominant land covers had undergone change. Clearly, the tests showed that the land cover was gradually changing, with predominance shifting from grass and brushland (1948) to coconut (1972).

The above analyses concentrated on the dominant land cover in each cell and disregarded secondary and tertiary land covers. However, evidence in Table III indicates that more new land cover types were introduced as secondary or tertiary land covers than as dominant ones, therefore, more change could be expected in these categories.

Changes in land cover can be determined by constructing an array of possible combinations (dominant land cover, secondary, tertiary or new) and by inspecting each cell for each time period and assigning it to a particular change state, i.e., no change, shift in predominance of existing land covers, addition of new land covers. Analysis shows that the majority (85 percent, 1948-1972) of cells underwent some type of land cover change. The most common change, which occurred in 17.3 percent of the cells, was the introduction of a new tertiary land cover. Complete change of all cover types in a specific cell was rare, occurring in only .5 percent of the cells in the 1948-1972 period. Cases where existing land covers in a cell shifted in relative importance totaled 35 percent of the cells. Spatial patterns of change shown in the map (Figure 5) reveal that areas where new land covers (referred to as "land uses" on the map) have been introduced ring the Island's seaward-facing lowlands, center on the Island's all-weather road, and include the upland area where the copper mine is located. Cells that have undergone land cover shifts from one degree of dominance to another tend to be located in the upland interior of the

Island where the human population is less dense and where swiddening is practiced. No-change cells are confined to two situations: (1) core areas of human dominance, around the *poblacions* (county seats) on the heavily settled lowlands, and (2) inaccessible areas, dominated by natural vegetation, which hinder human entry with physical barriers, e.g., steep slopes, swamps, etc.

When the three most prevalent cover types were analyzed together, a specific series of land cover combinations were formed. To study the expansion and contraction of these triformed land cover units, representing cyclic change, those occupying more than 28 cells were identified for the north central-northeastern area of the Island. In 1948, there were 11 triformed land covers. Of these 11, 6 showed a cyclic trend in the twenty-four year study period. Four additional triformed land covers expanded to occupy the minimum 28 cells by 1967. Of these, 2 displayed cyclic trends. One additional triformed unit exceeded the minimum area in 1972 and was of a cyclic nature. Thus, expansion and contraction in a cyclic pattern were clearly evident in 9 of the 16 triformed land covers.

Although the limited number of observation points (three) in this study minimizes the utility of time series analysis, a simple linear regression model and a calculation of a Pearson product-moment correlation (r^2) were applied to the data. Table V shows the results of linear regression on the 16 triformed land cover units previously discussed.

Results of the regression and correlation analyses indicate that triformed land cover units which have positive slopes (increasing area) and high r^2 usually contain at least one category of paddy and *cogon*, showing the expansion of the messicol land covers at the expense of semi-natural covers. Triformed units containing dry crop and *cogon* in combination show a negative slope (decreasing area) and/or relatively low r^2 values, expressing greater cyclic change and a total decrease in slash and burn (dryland crop) on the Island. Also, natural and semi-natural triformed land cover units tended to show negative slopes and relatively high r^2 values, emphasizing the constant decrease in area not directly affected by man.

It has been hypothesized that as development causes the introduction of new land cover categories, these new categories will cause greater fragmentation in the landscape, creating a larger number of new land cover combinations. Inspection of the Marinduque land cover files reveals this to be the case. The number of land cover combinations increased from 284 in 1948 to 373 in 1972, or 31 percent. For the entire Island, combinations including urban and mining, fish ponds, riverine, coconut, and forest exceeded the average rate of increase, while the number of land cover combinations with dryland crops actually decreased.

Increases in combinations referred to earlier may be the outcome of two land use systems (traditional and modern) coexisting on the Island. As the data illustrate, cells which have modernized land covers, particularly urban and mining, usually do not include traditional covers. Evidence to support the parallel, but separate, coexistence of the two systems includes the observation that the majority of new land covers held a tertiary position, meaning that new land covers occupied the least amount of area. A second point is that by plotting the triformed land covers as connectivity graphs (Figure 6), the land covers introduced since 1948 tended to be isolated whether or not they were subsequently of tertiary, secondary or primary spatial importance. This is illustrated in Figure 6 by the new land cover "fish ponds" (type 109), which was poorly connected to other land covers in the graphs, even though over time, fish ponds increased spatially from a tertiary to a secondary position in some of the cells.

4. CHANGE DETECTION WITH LANDSAT

Analysis of development related land cover change through use of aerial photography is dependent on irregular historic coverages, often resulting from high priority development demands which require an expensive aerial photographic mission. These constraints on the acquisition of aerial photography limit its utility as a source of data for change detection studies. For this reason, recent research has been oriented to incorporating Landsat data into a land cover change detection scheme.

Usable Landsat data were first acquired for Marinduque Island on 12 Oct 1972 (Landsat scene E-1081-01462). The Landsat acquisition was nearly simultaneous with the most recent airphoto coverage used in these studies and, thus, the logical basis for initial methodological studies to establish change indicators (see Section 2.). The first steps involved assessing the indicator's ability to discriminate tropical land cover types within the same scene (Table II). Using classes established for the photo interpretations, 25 ha cells which contained a single (dominant only, Table I) land cover were isolated in the base file. Twenty-five ha matrixes then were identified in the digital Landsat data, which corresponded positionally to the single land cover's location in the base file. Means, standard deviations, and percent standard deviations were extracted to use as pure land cover type change indicators.

Table VI presents the pure type indicators for the 12 Oct 1972 coverage. Inspection of the table reveals that the three indicators separate the land covers successfully. Studies now in progress will expand the number of land covers considered, and extend the analysis to two more Landsat scenes, E-1153-01465 and E-2418-01253.

Scene E-1153-01465, acquired 23 Dec 1972 is presently being processed to provide a similar data set to that available for the 12 Oct 1972 scene. This will permit introduction of short-term change data into the analysis, making possible study of change indicator performance on a seasonal basis. Additionally, the intention is to incorporate long-term data from Landsat 2 scene E-2418-01253 acquired 15 Mar 1976. With these three scenes, it will be possible to gain insight into both short and long-term variation in land cover reflectance.

Landsat data have been limited in this study by cloud cover over the area, reducing the number of pure cover cells available for analysis, and by the nature of foreign data acquisition, which is highly concentrated rather than spread throughout the satellite's operational life. These limitations reduce the seasonal similarity of the data and introduce variations which make year-to-year comparison difficult.

Further research, with mixed airphoto/Landsat files created for this project, will be directed at definition of a change detection system. Present work has shown that the aggregated Landsat data, structured into change indicators, can be used to distinguish major tropical land cover types. Research indicators such as these, or others under development, should allow satellite systems to play an important role in monitoring development as expressed in land cover change.

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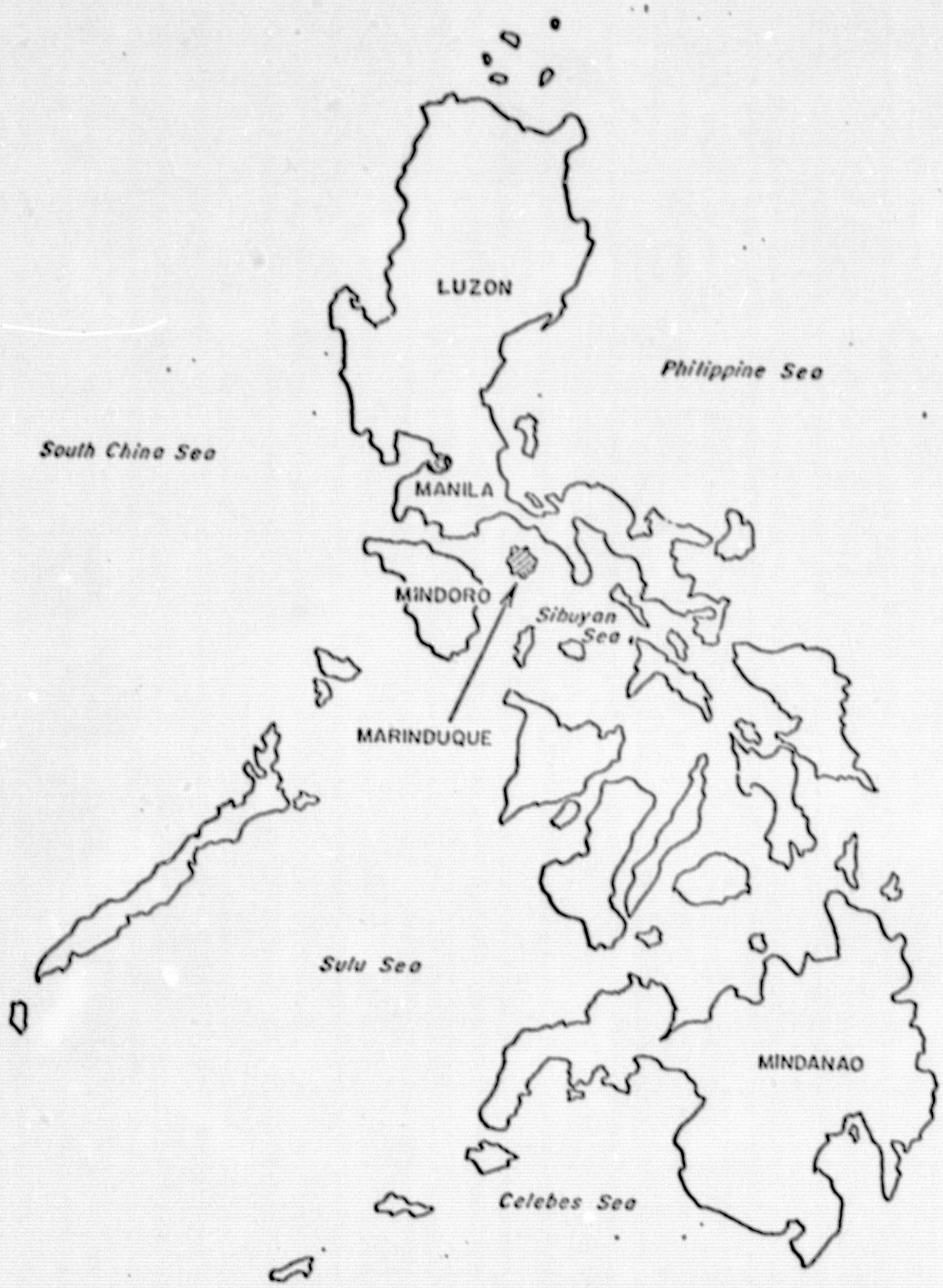

THE PHILIPPINES

Figure 1. STUDY SITE LOCATION. MARINDUQUE ISLAND, MARINDUQUE PROVINCE

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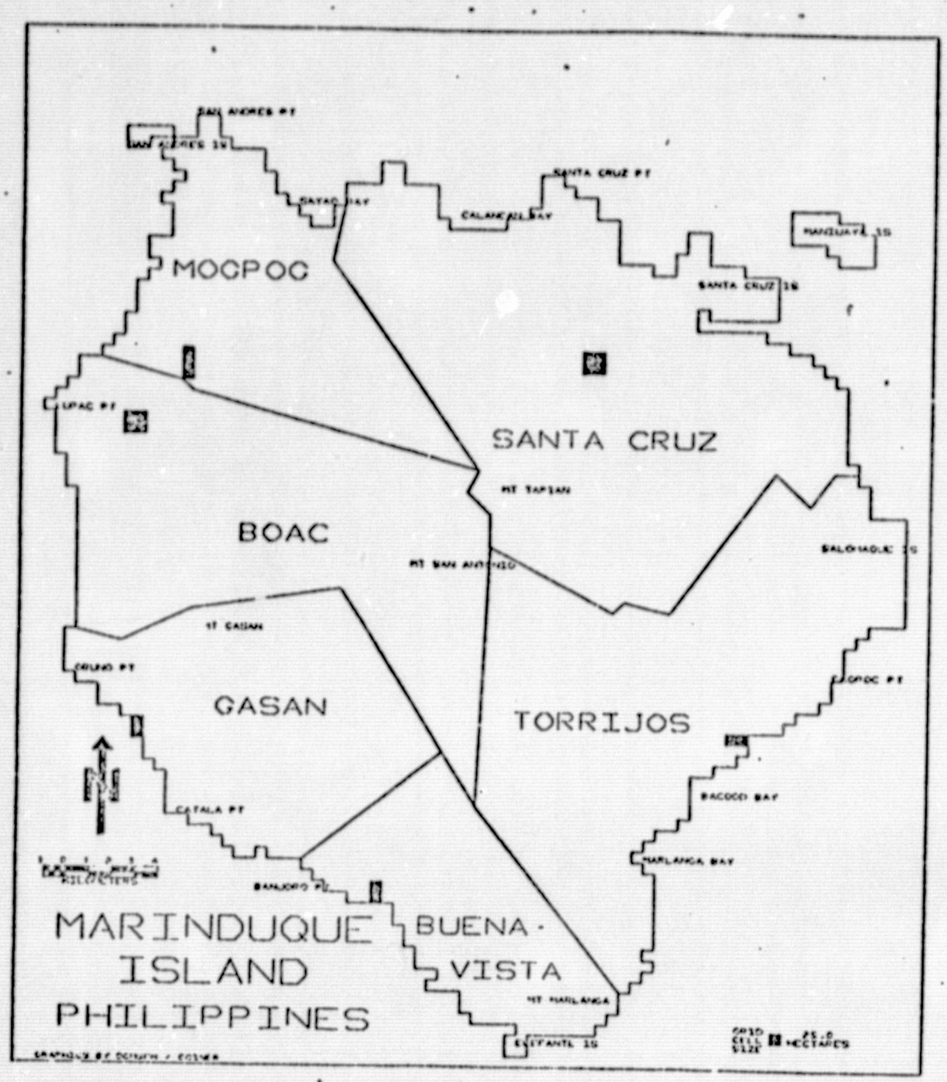


Figure 2. MARINDUQUE ISLAND, MARINDUQUE PROVINCE

(Computer base map showing municipal boundaries, place and locational names)

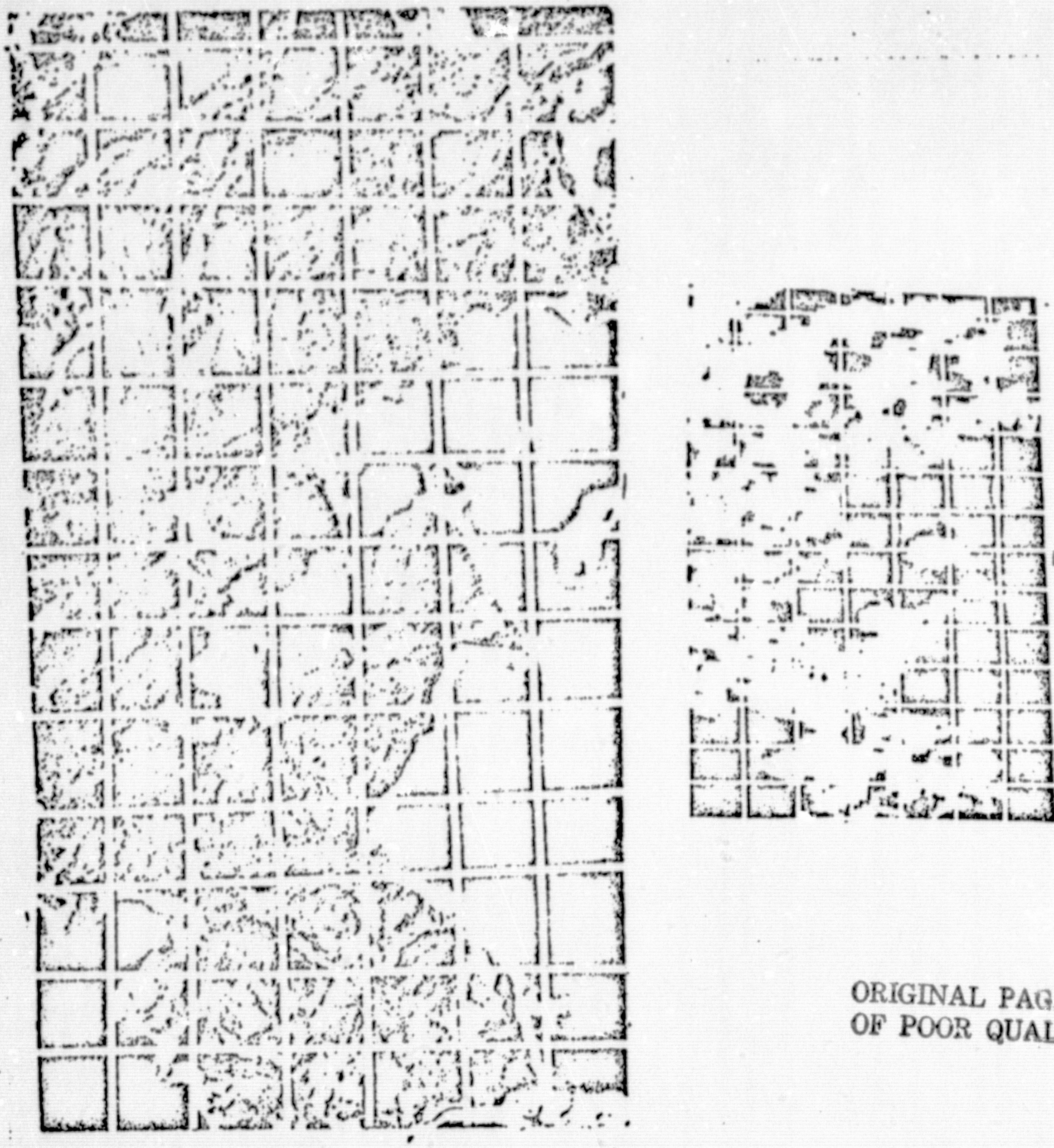
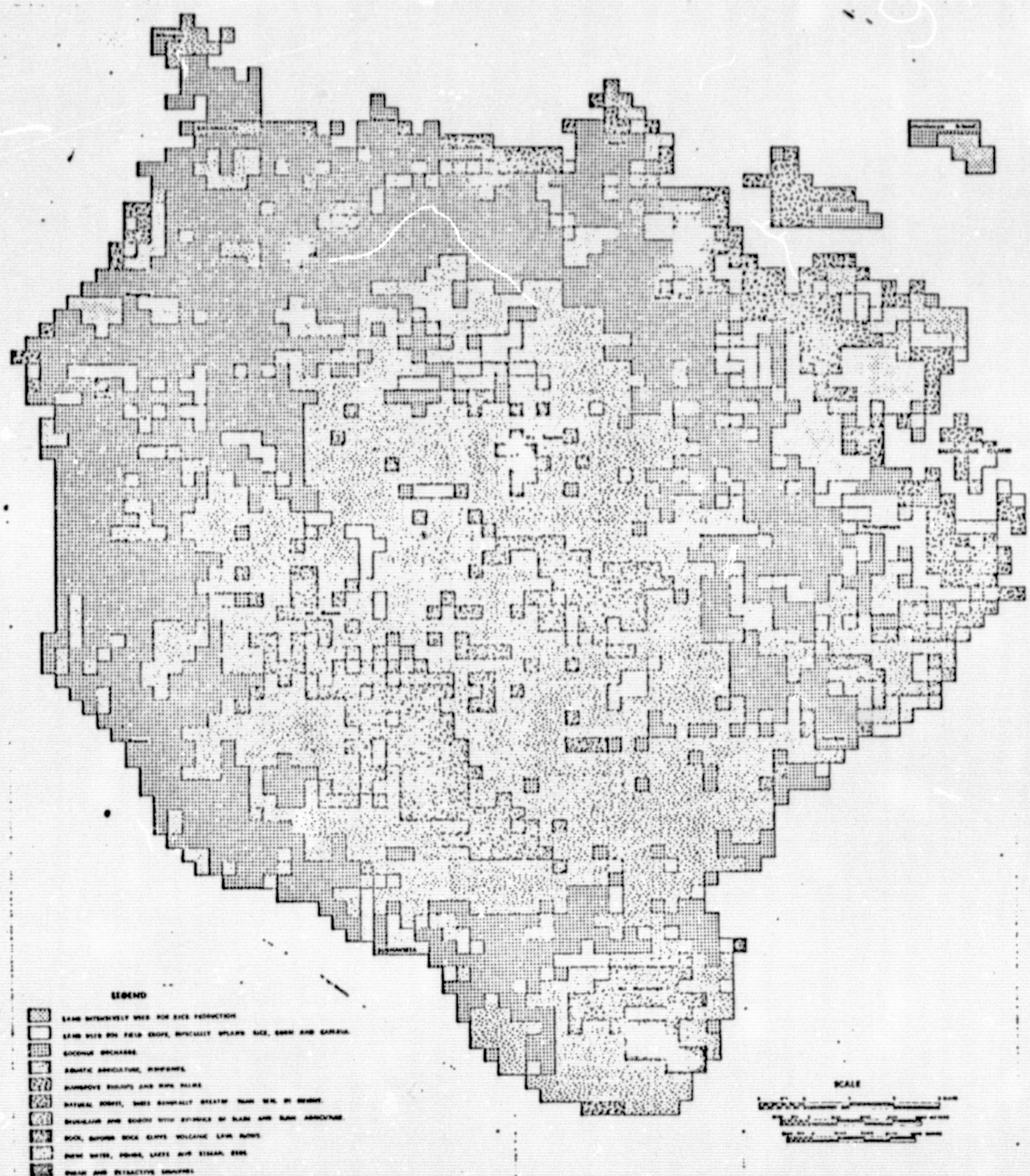


Figure 3. UTM GRID OVERLAYED ON AIRPHOTO AND LANDSAT IMAGE

(Distortion of grid due to displacement in airphoto and geometry of CRT Landsat band 7 image)

LAND COVER MARINDUQUE ISLAND

MOST COMMON COVER PER 25 HECTARE CELL



SOURCE: FIELD SURVEY AND AERIAL PHOTOGRAPHY

Figure 4.

PREPARED BY: JERRY C. COINER

FUNDING: MARCOPPER MINING CORP.

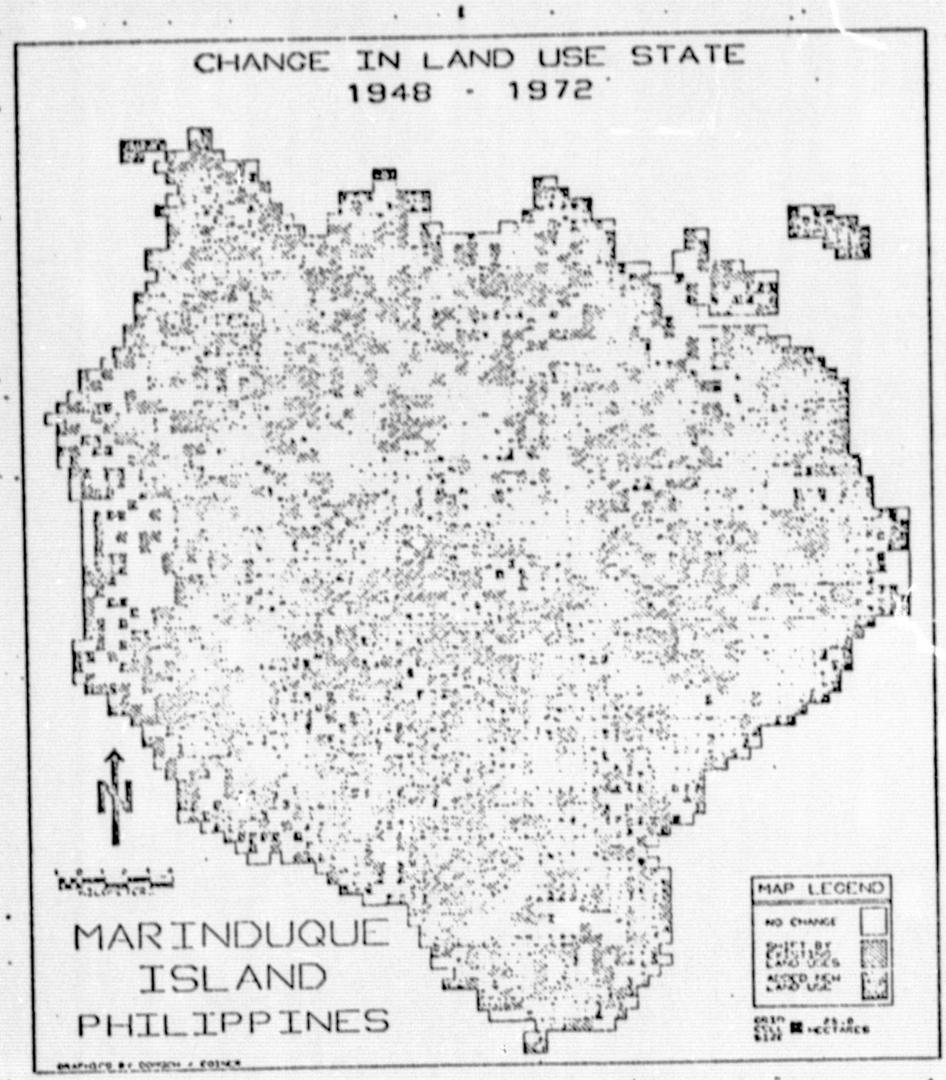


Figure 5. PATTERN OF LAND COVER CHANGE 1948 TO 1972

(Differences in land cover plotted as a three category pattern map)

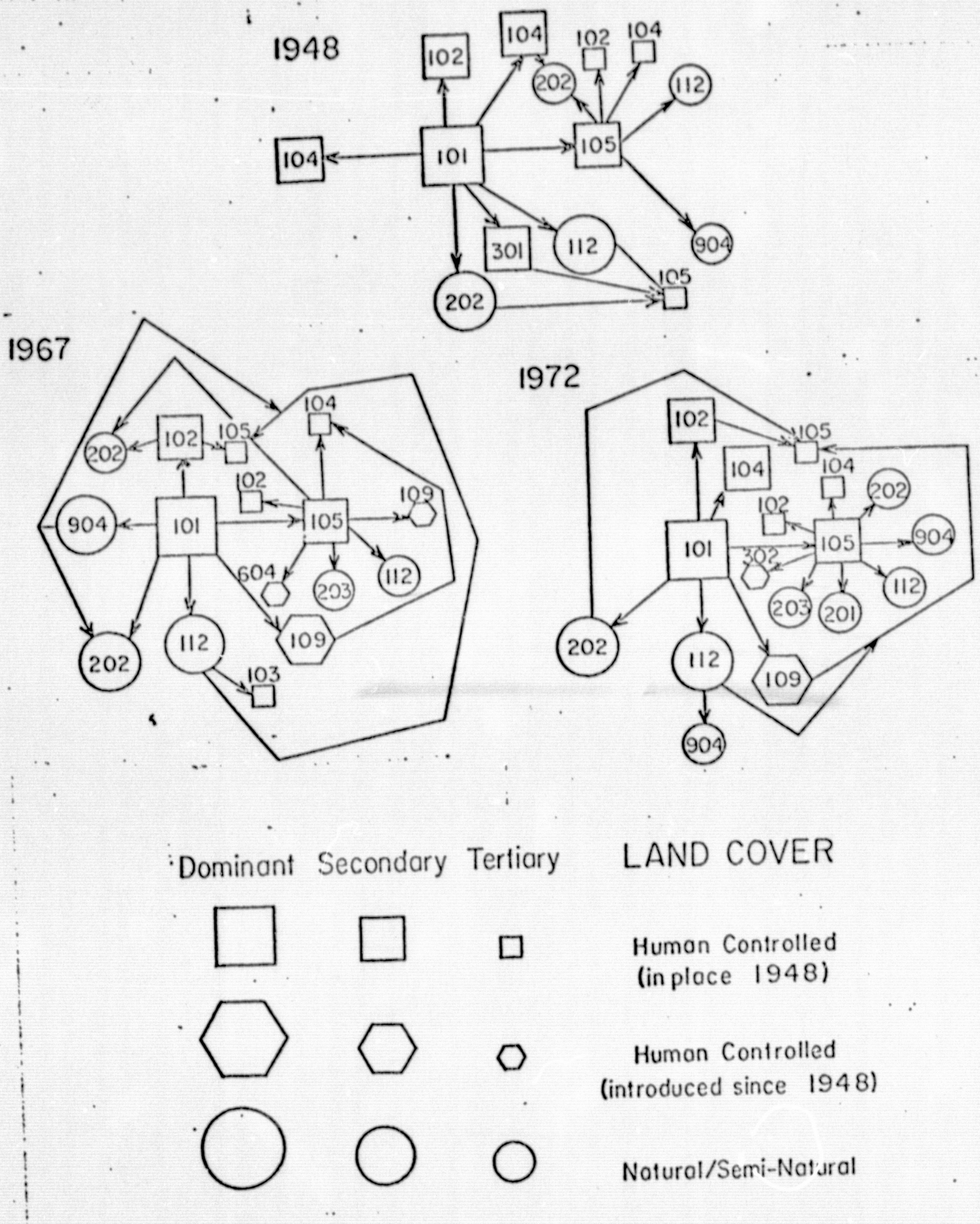


Figure 6. LAND COVER CONNECTIVITY GRAPHS

(Recently added land covers are poorly connected to traditional cover types)

TABLE I. AERIAL PHOTOGRAPHIC DATA ELEMENT FILE FORMAT

Column	Data Element
1-2	blank
3-4	year photo mission was flown
5-7	flight line of frame on which grid square being interpreted appears
8-10	frame number on which grid square being interpreted appears
11-12	blank
13-17	Universal Transverse Mercator (UTM) grid coordinate row number for the square being interpreted NOTE: This coordinate is always the coordinate of the upper left hand corner of the grid square.
18-19	blank
20-24	UTM coordinate column number for the square being interpreted
25	blank
26-28	three digit land cover for land cover occupying greatest area of grid square (see Table 2) For any grid square, there must be a land cover in this entry.
29	blank
30-32	three digit land cover code for land cover taking up second most extensive area NOTE: If the entire square is taken up by one land cover, this entry will be zero (0).
33	blank
34-36	three digit land cover code for land cover taking up third most extensive area in grid square (This may also be zero.)
37-39	number of occupied houses identifiable in the square (dwelling units)
40-41	number of schools identified in the square
42-43	number of churches identified in the square
44-45	number of other government buildings in the square
46-47	number of buildings associated with industrial activity in the square (includes oil tanks and storage areas)
48-49	type of roads/trails in square (Choose only the highest category.) 0 = no road or trail; 1 = all-weather road; 2 = usually passable to wheeled vehicles; 3 = trail not normally usable by wheeled vehicles (Choose only the
50-51	number of bridges in square
52-53	number of boats in square
54-55	number of piers or boat landing points in the square
56-57	number of concrete drying platforms or basketball courts in square
58-59	number of fish ponds in the square
60-61	number of fish traps in the square
62-63	number of marketplaces in the square
64-65	number of commercial buildings in the square, including sari-sari store front houses where identifiable

TABLE II. LAND COVER CLASSIFICATION FOR MARINDUQUE ISLAND, PHILIPPINES

Computer Coding No.	Photo Symbol	Land Cover
101[a]	Ar	Land intensively used for rice
102	Ac	Corn, beans, forage crops, upland croplands
104	Aom	Mixed orchard (dooryard orchards)
105	Aoc	Coconut orchard
108	Ai	Fallow lands
109	Aq	Aquatic lands (commercial fish ponds, salt beds, moss production, oyster beds)
112[b]	Am	Mangrove swamps (including nipa palm areas)
201[c]	Fr	Natural forest stands
202	Fb	Forest brushland (go-back, *parang*) and grassland (*cogon*)
203[b]	Fg	Natural bamboo (including all riverine tree vegetation)
301[d]	Rh	High density greater than 10 houses per centimeter on 1:15,000 air photo
302	Rm	Medium density 5 to 10 houses per centimeter on 1:15,000 air photo
303[b]	Rc	Road strip and cross road community
503[e]	Es	Strip mining
605[f]	Pm	Military base and governmental centers
706[g]	Ta	Airport
901[h]	Ns	Sand/beach
902	Nr	Rock, exposed bare earth
903	Wn	Fresh water lakes and ponds greater than 7.5 hectares
904	Wr	Permanent streams and river (including the entire width of river courses)
906[b]	Wn	Open salt water

[a]100 series, agriculture
[b]Added land cover category for Marinduque study
[c]200 series, forest land
[d]300 series, residential land cover
[e]500 series, extractive industry land cover
[f]600 series, public and semi-public land cover
[g]700 series, transportation land cover
[h]900 series, nonproductive land cover

TABLE III. CHANGES IN THE NUMBER OF LAND COVER CATEGORIES MARINDUQUE ISLAND, PHILIPPINES, 1948-1972

Year	Land Cover Categories			
	Dominant[a]	Secondary[b]	Tertiary[c]	Total
1948	9	13	14	15
1967[d]	10	14	15	18
1972	15	22	22	23

[a]Dominant land cover -- areally most extensive in a minimum of one 25 ha cell
[b]Secondary land cover -- areally second most extensive in a minimum of one 25 ha cell
[c]Tertiary land cover -- areally the third most extensive in a minimum of one 25 ha cell
[d]1967 data for only the north central-northeastern portion of the Island

TABLE IV. DOMINANT LAND COVER BY CELL (25 HA), MARINDUQUE ISLAND, PHILIPPINES, 1948-1972

Year	Paddy Rice		Dryland Crops[c]		Coconut		Fish Ponds		Mangrove		Urban		Mining		Forest		Cogon[d]		Rock/ Bare		Riverine		Salt Water	
	Cells																							
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
1948[a]	207	5.2	64	1.6	952	23.8	0	0	165	4.1	0	0	0	0	403	10.1	1,772	44.2	39	1.0	38	.9	368	9.2
1972[a]	233	5.8	57	1.4	1,323	33.0	11	.3	168	4.2	3	.1	12	.3	321	8.0	1,446	36.1	18	.4	49	1.2	367	9.2
1948[b]	46	4.1	6	.5	235	21.1	0	0	88	7.9	0	0	0	0	46	4.1	585	52.4	0	0	3	.3	107	9.6
1967[b]	64	5.7	12	1.1	314	28.1	7	.6	89	8.0	1	.1	0	0	48	4.3	481	43.1	0	0	4	.4	96	8.6
1972[b]	50	4.5	6	.5	362	32.4	8	.7	87	7.8	2	.2	9	.8	44	3.9	432	38.7	0	0	14	1.3	102	9.1

Chi-Square Results

Period	χ^2 Value	Significant Difference
1948 versus 1972[a]	114.3	Yes[e]
1948 versus 1972[b]	57.4	Yes[f]
1948 versus 1967[b]	27.2	Yes[f]
1967 versus 1972[b]	16.0	No[g]

[a]Entire Island
[b]North central-northeastern portion
[c]Includes dooryard orchards and sugar cane
[d]Includes bamboo thickets and brushland
[e]$\chi^2_{\alpha = .01[9]} = 21.666$
[f]$\chi^2_{\alpha = .01[8]} = 20.090$
[g]$\chi^2_{\alpha = .01[10]} = 23.209$

TABLE V. CYCLIC AND TREND CHANGES IN TRIFORMED LAND COVER UNITS, NORTH CENTRAL-NORTHEASTERN MARINDUQUE ISLAND, PHILIPPINES, 1948-1972

Triformed Land Cover Units			Expansion and Contraction						Linear Regression Results[a]			
Primary Land Cover	Secondary Land Cover	Tertiary Land Cover	1948 No. Cells	1948 %	1967 No. Cells	1967 %	1972 No. Cells	1972 %	a	b	r	r^2
Coconut	Paddy	None	18	1.6	14	1.3	28	2.5	.260	16.19	.436	.190
Coconut	Paddy	*Cogon*	18	3.8	34	3.1	37	3.3	.843	17.31	.998	.996
Coconut	*Cogon*	None	42	3.8	25	2.2	55	4.9	.163	38.28	.131	.017
Coconut	*Cogon*	Paddy	16	1.4	40	3.6	62	5.6	1.822	12.61	.958	.918
Coconut	*Cogon*	Dry Crop	46	4.1	57	5.1	44	3.9	.099	47.55	.171	.029
Coconut	Paddy	Dry Crop	6	.5	29	2.6	9	.8	.436	8.27	.422	.178
Cogon	Dry Crop	Forest	45	4.0	39	3.5	28	2.5	-.631	46.59	-.885	.784
Cogon	Coconut	Paddy	27	2.4	34	3.0	36	3.2	.391	26.60	.999	.999
Cogon	Coconut	Dry Crop	76	6.8	55	4.9	59	5.3	-.853	75.85	-.925	.857
Cogon	Forest	None	33	3.0	45	4.0	39	3.5	.369	33.59	.744	.554
Cogon	Forest	Dry Crop	52	4.7	46	4.1	56	5.0	.039	50.77	.093	.009
Cogon	None	None	40	3.6	23	2.1	24	2.2	-.762	40.18	-.966	.934
Cogon	Dry Crop	None	106	9.5	30	2.7	21	1.9	-3.836	108.60	-.994	.988
Cogon	Cry Crop	Coconut	48	4.3	39	3.5	22	2.0	-.962	50.45	-.882	.777
Salt Water	None	None	40	3.5	36	3.2	31	2.8	-.346	40.75	-.929	.863
Salt Water	Mangrove	None	29	2.6	25	2.2	24	2.2	-.219	29.21	-.999	.999

[a] Data fitted to linear regression model of form $Y = ax + b$.
Dependent variable (Y) = number of cells containing triformed land cover unit.
Independent variable (X) = time (year data collected) with 1948=1, 1967=19, 1972=24.

a = slope of the trend line through X dimension
b = point of intercept of trend line on Y axis
r = degree of fit of actual data to mathematically determined equation (correlation coefficient)
r^2= Correlation coefficient squared (Pearson product-moment correlation coefficient)

TABLE VI. PURE CELL (25 HA) LAND COVER INDICATORS FOR
MARINDUQUE ISLAND, PHILIPPINES
LANDSAT ACQUISITION E-1081-01462 (12 OCT 72)

Cover Type	Number Pure Cells	Change Indicator*	Band 4 .4-.5μm	Band 5 .5-.6μm	Band 6 .7-.8μm	Band 7 .8-1.1μm
Paddy Rice (101)	9	$\bar{X}$	.558	.308	.593	1.606
		σ	.030	.031	.069	.203
		%σ	5.4	10.3	12.5	13.8
Coconut (105)	19	$\bar{X}$	.515	.242	.675	2.029
		σ	.029	.026	.060	.204
		%σ	5.5	10.7	9.0	10.2
Mangrove (112)	6	$\bar{X}$	.521	.254	.612	1.744
		σ	.030	.024	.044	.134
		%σ	5.4	8.3	7.2	7.6
Cogon/Parang (202)	6	$\bar{X}$	.586	.317	.739	2.117
		σ	.030	.026	.060	.183
		%σ	4.9	8.0	8.2	8.7
Sea Water (906)	18	$\bar{X}$	.520	.229	.129	.134
		σ	.024	.017	.020	.078
		%σ	4.6	7.2	15.1	40.7

*$\bar{X}$ Mean
σ Standard Deviation
%σ Percent Standard Deviation