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THE UNIVERSITY OF ALBERTA

ANALYSIS OF THE SPECTRAL CHARACTERISTICS OF SELECTED AGROECOLOGICAL RESOURCE AREAS IN THE PROVINCE OF ALBERTA

BY

© JORGE ANIBAL IZAURRALDE

A THESIS

SUBMITED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

REMOTE SENSING

DEPARTMENT OF SOIL SCIENCE

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled ANALYSIS OF THE SPECTRAL CHARACTERISTICS OF SELECTED AGROECOLOGICAL RESOURCE AREAS IN THE PROVINCE OF ALBERTA submitted by JORGE ANIBAL IZAURRALDE in partial fulfilment of the requirements for the degree of Master of Science in Remote Sensing.

....
Supervisor

....

J. Ronald Eyton

Date: April 7, 1989.

A mis padres, H. Roberto (Q.E.P.D.) y Beba , que me dieron lo mejor.

A mi esposa, Graciela, expresión viva del amor que obra.

A mis hijas, Ana, Poli y Pía, la mejor parte de mi vida.

ABSTRACT

Remote sensing has been used for more than twenty years in natural resources mapping, land cover assessment and monitoring the effects of climatic conditions (droughts, floods). A wide range of equipment parameters affect the kind and amount of data being captured and processed by different sensors. Statistical aspects of data handling find few problems in the building of computer algorithms for classification, clustering and ratioing, however it is the responsibility of the user to interpret the "meaning" of all the information resulting from such a process. In order to apply statistical data analysis concepts to the interpretation of natural resource phenomena, it is assumed that similarities or differences in radiometric values and spectral response are highly correlated to similarities or differences respectively in the subject being sensed. It is also true that the kind and amount of variability in ground cover included in each discrete ground resolution cell could affect that correlation, especially when coarse resolution data such as that provided by NOAA-AVHRR are used.

Boundary conditions for extrapolating the results of analyses are always difficult to establish. The hypothesis tested was that physical landscape boundaries would be appropriate geographic limits rather than an image as a whole, or even mosaics of several images. This was accomplished by comparing the spectral response, as measured by NOAA-AVHRR, from selected large landscape units mapped as Agroecological Resource Areas.

On the evidence from a discriminant analysis and the calculation of vegetation indices from NOAA-AVHRR digital data, it was concluded that there were important differences between the selected Agroecological Resource Areas. Although specific crop conditions may be similar in different areas the satellite data values were the result of all the cover elements and cover types occurring in a landscape. This integration of the effects of all the elements was significant with coarse resolution NOAA-AVHRR data. It was also concluded that the global approach to the interpretation of the remotely sensed data for crop monitoring may lead to erroneous conclusions, and that there are some real advantages to conducting any analysis within the context of some pre-stratification based on landscape components.

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CHAPTER 1

INTRODUCTION

Since the early 1960's numerous weather satellites have been placed into orbit and data from these satellites have been used to provide valuable earth resource information. Weather satellites of the NOAA series, named after the National Oceanic and Atmospheric Administration in the United States, are in sun-synchronous, near polar orbits. They provide data on surface reflected energy in the visible and reflected infrared portions of the spectrum and on surface emitted energy in the thermal infrared through an advanced very high resolution radiometer (AVHRR) system. The ground resolution element for these systems is approximately 1 km x 1 km in size. Although the spatial resolution is poorer than that afforded by Landsat systems (80 m or 30 m data) or SPOT systems (20 m or 10 m data), the possibility exists for the acquisition of data twice a day compared to a 2 week cycle with the latter two.

The poor spatial resolution associated with NOAA data provides problems in image analysis in that numerical values for ground resolution cells result from a mixture of many landscape elements, all taken together as an integrated whole. As land cover complexity (mixtures of land cover types) varies across a large geographical area, the conclusions drawn from studies of the data could also vary. A potential problem to be studied, for example, could be that of the extent of drought. The conclusions drawn from studies of the satellite data in terms of the extent of severity of drought conditions would have to be tempered by the realization that the land cover in one area may be a relatively simple "crop-fallow" pattern while in another it may consist of a more complex "crop-fallow-trees-shrubland-open water" pattern. It would seem prudent to analyze NOAA satellite data in the context of some gross landscape stratification that potentially encompasses changes in land cover patterns.

Landscape Basis for Analysis

As discussed by Mabbut (1968), the advantages of high resolution sensing systems coupled with the possibility of electronic data handling, has allowed researchers to incorporate quantitative data for a wide range of physical attributes into the definition of land unit boundaries within which the results of analysis can be applied. This parametric approach reduces the difficulty in measuring variance, formulating rational sampling and expressing probability limits for the findings. The use of coarse resolution data, such as that provided by the NOAA-AVHRR, requires a more qualitative approach in the definition of the land units boundaries. Therefore, a landscape approach that uses the limits of occurrence of recognizable features, in proportionately coarser terms, is appropriate, because it not only accommodates the complexity and the gradational properties of the land, but also admits that land unit divisions are, after all, subjective rather than absolute.

Different frameworks were considered as possible bases for the stratification of NOAA satellite data prior to their analysis. The Soil Group Map of Alberta (in Atlas of Alberta, 1969) and the Agroclimatic Zones of Alberta (Bowser, 1967) were considered but rejected. Although they portray two very important differentiating criteria, soil group and agroclimate, these do not necessarily represent land cover, which is the characteristic responsible for the spectral response.

A Uniform Productivity Areas Map (Mack et al., 1986) was also considered. This map represents, at a 1:1000000 scale, areas defined by soil landscape boundaries which posses uniform spectral response related to their uniformity of agricultural productivity due to their homogeneous nature in terms of soil-climatic attributes, soil texture and cropping practices. Combining these areas with Land Use Maps further segregated permanent vegetative patterns associated with rangelands, localized trees, water bodies and other non-cultivated agricultural areas. Although this approach did take into account the land cover pattern, it was not used in this study because:

a) Polygon boundaries were based primarily on land cover units as interpreted visually from Landsat-MSS images. Therefore, the possibility exists that these units could not account for the temporal contradictions between climax status and its surrogate, projective canopy coverage (Kelly et al., 1987).

b) Although the map scale is appropriate, the minimum polygon size, as small as 5x10 km, was considered too small to be compatible with the spatial resolution of the NOAA-AVHRR data.

Finally, it was determined that the Agroecological Resource Areas framework (Pettapiece,1988, personal communication) may offer a useful approach to the stratification of NOAA satellite data prior their analysis. An Agroecological Resource Area is a natural landscape area which is more or less uniform in terms of agroclimate, landform, soils and general agricultural potential. These areas are also designed on four other assumptions that are thought to be important for this study:

a) The smallest recognized area is not less than 100.000 hectares;

b) The areas should be visually identifiable (major topo-physiographic features as limits);

c) They are defined in hierarchical structure with priority being given in decreasing order to climate, texture, soils and landform;

d) They are proposed as a framework and standard base to facilitate ecological research.

The purpose of this study was to compare selected Agroecological Resource Areas using NOAA-AVHRR data to test the hypothesis that differences between areas occur without regard to the seeded crop condition (i.e. on different dates in different years). These nine Areas were selected to represent some of the major agroclimatic, soils and landform variations in Alberta. The study was based on the assumption that the Agroecological Resource Areas represent areas of differing land cover. The study proceeded in two steps, a general spectral comparison of the selected Agroecological Resource Areas using a discriminant analysis technique and a more detailed comparison based on an analysis of the normalized vegetation index.

General Methodology

Maintaining 1 km pixels after resampling NOAA-AVHRR data

The problem:

The analysis of digital NOAA-AVHRR data was performed using a DIPIX ARIES II system with R-Stream (AIIASP V4-2) software. An initial step corrected some of the geometric distortion and registered image data from different dates, for a relatively large portion of the province of Alberta. The pixel size from the uncorrected data (approximately 1000 m pixels) was expected to be maintained to preserve the spatial context of the data and to prevent an unnecessary volume of data from being generated. Once control points had been selected and an appropriate transformation determined, a problem arose in the specification of resampled pixel size. The utilized version of the ARIES II software did not accept 1000 m as an output pixel size, the maximum being 200 m.

A solution:

Although the proper UTM Eastings and Northings for control points could not be entered and 1000 m specified as the output pixel size, an uotput pixel size of 100 m could be specified and the desired number of pixels maintained if the entered Eastings and Northings were altered in the same proportional fashion. The following general case was applied:

$$\mathbf{Ce = Cr - [(Cr - Ccp) / m]}$$

where:

Ce = Easting or Northing value entered for a control point.

Cr = actual Easting or Northing for some reference point.

Ccp = actual Easting or Northing for the control point read from a 1:250000 NTS map.

m = ratio of "desired" resampled pixel size to the resampled pixel size "selected".

In this case, the "desired" resampled pixel size was 1000 m while the "selected" resampled pixel size was 100 m.

An example:

The study area used data from the southeastern portion of Alberta, the reference Northing and Easting were 5800000 m and 400000 m respectively (Appendix I). As control points were selected, their altered Eastings and Northings were entered as shown on next page. The reference Northings and Eastings could occur anywhere but the calculations are simplified if the former are maxima for the area of interest. This technique was used only for NOAA-AVHRR data acquired when the satellite was directly over the study area, and only for relatively small numbers of lines and pixels.

CONTROL POINT	ACTUAL	ALTERED
Reference	5800000 N 400000 E	5800000 N 400000 E
#1	5601500 N 365500 E	5780150 N* 396550 E
#2	5815750 N 298000 E	5801575 N 389800 E

* = 5800000 - [(5800000 - 5601500) / 1000/100] = 5780150

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CHAPTER 2

SPECTRAL CHARACTERIZATION OF AGRO-ECOLOGICAL RESOURCE AREAS

Introduction

The recognition of the close association of soils and landforms promoted landscape mapping as a means of reconnaissance soil mapping. Research was based on the assumption that knowledge of detailed characteristics and performance for one terrain unit, could be applied to another analogous unit elsewhere (Barrett and Curtis, 1982). This concept can be even more generalized to include not only aspects of soil mapping, but also land use and land cover mapping, vegetation condition estimates, uniform productivity areas delineation, and other resources inventories.

Many factors affect the kind and the amount of data being captured and processed by different sensors as well as their meaning in the data interpretation stage. Characteristics of different sensors and data sampling systems, together with orbital path of their platforms make up a rather extensive list of types of available data in different scales, areal coverage, and resolution (spatial, spectral and temporal). There is a direct relationship, then, between the kind of data and the degree of resolution (purity) in the feature definition. The way in which the data are integrated in each discrete sample element (pixel) affects what the observer sees in each case, whether it is response patterns of individual crop fields (for example) or the generalized (integrated) response of a particular land cover/use pattern, and therefore the meaning of the derived interpretive data.

Studies related to land cover/use mapping and natural resources inventory and monitoring, rely on the availability of multidate data. This requires a data acquisition system capable of covering rather large areas with high frequency. The NOAA-AVHRR fulfills these requirements. The relatively coarse spatial resolution (1.1 km at nadir) provided by the system (NOAA Polar Orbiter Data Users Guide, 1986) produces a large area coverage with a relatively low volume of data compared to Landsat or SPOT.

Evaluations of the usefulness of the NOAA-AVHRR data have usually been done with very homogeneous test sites to reduce, as much as possible, the number of variables. Gallo and Daughtry (1987) worked with corn canopies while studying differences in vegetation indices calculated from different sensor systems data; Tucker et al. (1984) monitored vegetation dynamics in the Nile delta and correlated time trends to growing conditions and agricultural patterns.

Image processing tasks such as feature identification and classification are based on a statistical premise that site training information can be extended to the whole image or even mosaics of images covering larger areas. This premise is based on the assumption that no changes or variations occur in the spectral character of particular features, no matter where they occur in the imaged area, and that each theme or class has its own, sufficiently well defined spectral response pattern.

Broad scale data increase the probability of different "environments" being presented together in the same image. Examples would include different agro-climatic or physiographic regions. Geographic and environmental differences at this scale (in fact at any scale) may have an influence on the kind and amount of energy being reflected/emitted by different features in each scene. If this were the case, the validity of blanket within-scene statistical analysis would be suspect. This problem could be alleviated with the application of some "landscape boundaries" delineating smaller units more environmentally homogeneous than the whole scene. From the interpretive viewpoint, such "landscape boundaries" could be the geographic limits for the extrapolation of the results of any analysis. Within this framework, the assumed correlation between spectral response and subject of interest may be better explained.

For this study, the hypothesis stated was that "landscape boundaries" are more accurate geographic limits than the whole image (scene) for extrapolating the results of the analysis. To test this hypothesis, similarities or differences in NOAA-AVHRR spectral data for different landscape units were determined. The temporal nature of any similarities or differences was also considered.

Materials and methods

The study area was the southeastern portion of the province of Alberta, between 49º and 54º North Latitude, and 110º and 114º West Longitude, a dominantly agricultural-rangeland area.

Local area coverage (LAC) NOAA-AVHRR 1.1 km resolution digital data for the "visible" (0.58-.68 um) and "reflected infrared" (0.725-1.10 um) were acquired from Atmospheric Environment Services, Environment Canada, Edmonton, on several dates through the growing seasons of 1986 and 1987, and in June 1988 (Table 1).

Table 1: NOAA-AVHRR images acquired.

DATE	PASS	PLATFORM
July 16, 1986	P.M.	NOAA-9
August 20, 1986	P.M.	NOAA-9
October 22, 1986	P.M.	NOAA-9
July 14, 1987	P.M.	NOAA-9
June 15, 1988	A.M.	NOAA-10

Images selected were from satellite tracks as close as possible to the center of the study area as no correction for scan angle distortion was performed. The October 1986 image was registered to the U.T.M. grid such that the 1 km pixel size was preserved. All other images were subsequently registered to the first. All image registration was based on selected control points and resampling by cubic convolution (Bernstein and Ferneyhough, 1975). (An example of the residuals in the calculation is presented in Appendix II).

The landscape units used in this study were selected polygons from the 1:1000000 Agroecological Resource Areas map prepared by Pettapiece (1988). These were selected to represent dominant soil - climate - physiographic conditions in the study area (Figure 1). As the physical land characteristics change so do patterns of land use or cover. The latter are described in Table 2. Polygons 15 and 16 were considered together because individually they are of relatively small size, and they are similar in soil materials and differ slightly on landform.

The selected polygons were registered to the images using the digitizing facilities at the Alberta Remote Sensing Center, Edmonton. The image data were transferred to the

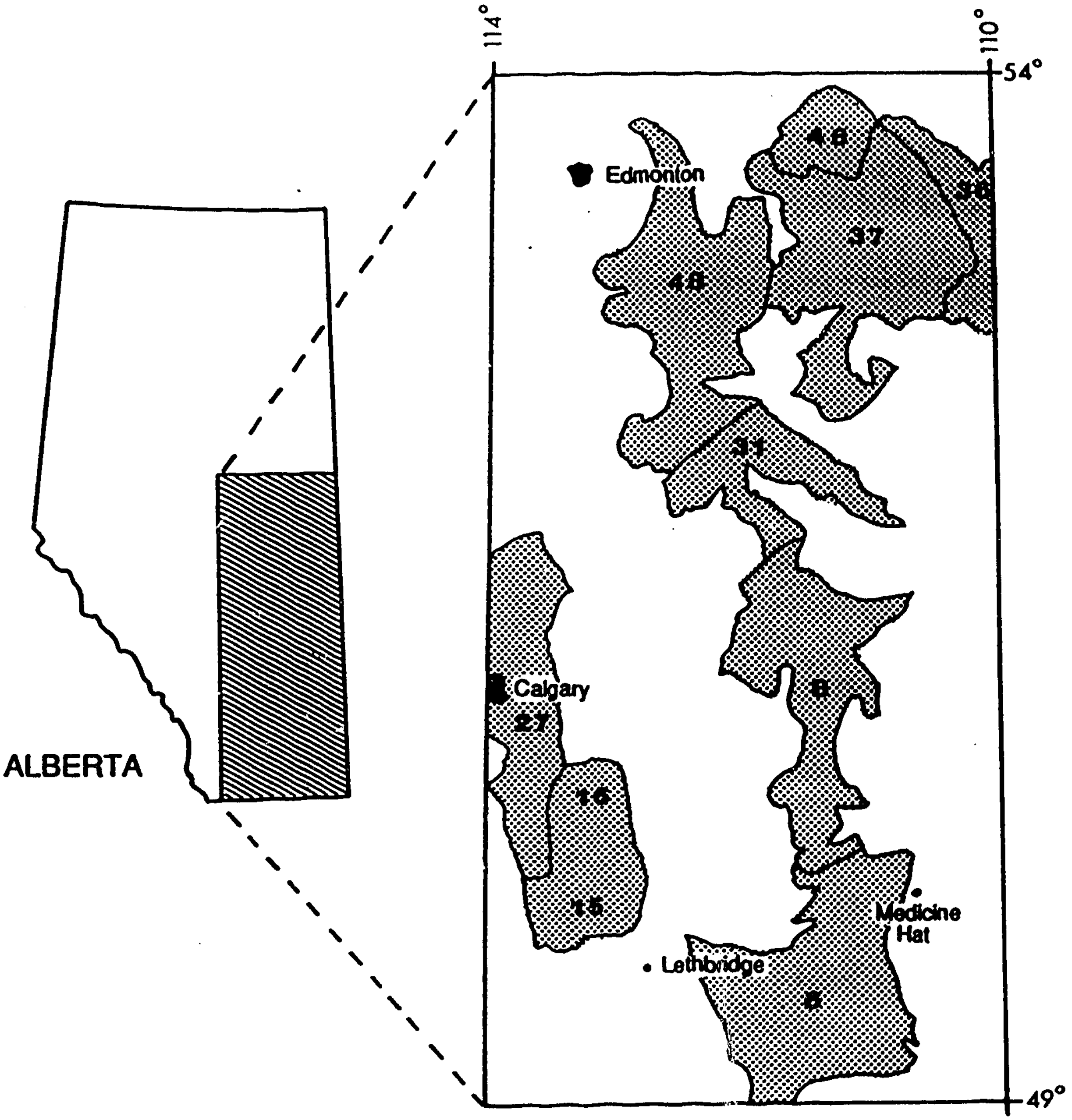

Figure 1: Agroecological Resource Areas selected for study (After Pettapiece, 1988).

Table 2 : Summary of Agroecological Resource Area (A.R.A.) characteristics. (*Physiography* after Pettapiece, 1987. *Soil texture, Soil Group, Landform and Agroclimatic Zones* after Pettapiece, 1988. *Land Cover* interpreted from Landsat-MSS imagery).

POLYGON	PHISIOGRAPHIC UNIT	LANDFORM	SOIL TEXTURE	SOIL GROUP	AGRO-CLIMATIC ZONE	LAND COVER PATTERN	AVE.FIELD SIZE (acres)	TREES (%)
6	30% M (North) 60% M-Hu (Central) 10% P (South)	P(Un)	FL	BrCh	3A	80% (C) 20% (R)	D(80%C)=40 I(20%C)=160	-
8	M	P	FL	Sn(Ch)	3A	R	640-1000	-
(15+16)	M(North) P(South)	P(Un)(North) P(South)	FL FL(CL)	DBrCh	2A	C	50-100	- -
27	P	P	FL	BkCh	2AH	C	50-100	-
31	P	P	FL	Sn(Ch)	2AH	C(R)	100-150	-
36	P	P(70%) Hu(30%)	FL	BkCh	2H	C	150	10
37	UHu	Hu(70%) P(30%)	FL CL	BkCh	2H	C	150	20
46	P	P	FL	SS-BkCh	2H	C	50-100	10
48	UHu	Hu	FL	GL(DkGL)	3H	C	100	30

<u>REFERENCES</u>: A: Aridity limitation; **BkCh**: Black Chernozems; **BrCh**: Brown Chernozems; **C**: Cropland; **Ch**: Chernozemic; **CL**: Coarse Loamy; **D**: Dryland; **DrBrCh**: Dark Brown Chernozems; **DkGL**: Dark Grey Luvisols; **FL**: Fine Loamy; **GL**: Grey Luvisols; **H**: Heat limitation; **Hu**: Hummocky; **I**: Irrigation; **M**: Morainal; **P**: Plain; **R**: Rangeland; **Sn**: *Solonetzic*; *SS: Solodized Solonetz*; *U: Uplands*; *Un: Undulating.-*

Decision Image Analysis System at the Geography Department, University of Alberta, where a data subset was created by selecting every fourth line and pixel. To prevent a biased result due to the unpredictable occurrence of clouds, data for clouds were omitted by setting a threshold value for each image. The data for each polygon were considered a "class" in the following analysis. As all the classes were previously known, a discriminant analysis was performed using the DISCRIM procedure of the SAS statistical package (SAS Inst. Inc.,1982) . The polygon identification numbers were used as the classification variable, and the digital numbers for the visible and reflected infra red channels were used as the quantitative variables. In this procedure, the pooled covariance matrix and prior probabilities of the classes were utilized to classify each of the sampled pixels into the class (polygon) that it most closely resembled. Classification procedures that use discriminating variables by themselves do not truly perform "discriminant analysis", but just merely use the theory of maximum group differences to derive classification functions (Fisher,1936 as referenced by Klecka,1987). Nonetheless, the terminology is used here in its more general sense.

Data for generalized crop condition during the imaging periods were acquired from Alberta Agriculture (P. Dzikowski, 1989).

Results and Discussion

The June 1988 image was selected as the starting point for the discriminant analysis to provide the base-line data. Seeding was delayed in the spring of 1988 because of drought conditions and thus at the image date there was not much vegetative cover in the cropland. This provided data from more stable landscape features, not confused by the temporal character of annual crops. Although there were no definitively good percentages of correct classification, the "confusion" among polygons did follow some patterns (Figure 2). In this data set there is a first group of polygons (G I) that missclassify among themselves. These were polygons numbered 6,8,(15+16), 27 and 31, and they show correct classification rates of approximately 30% (Table 3).

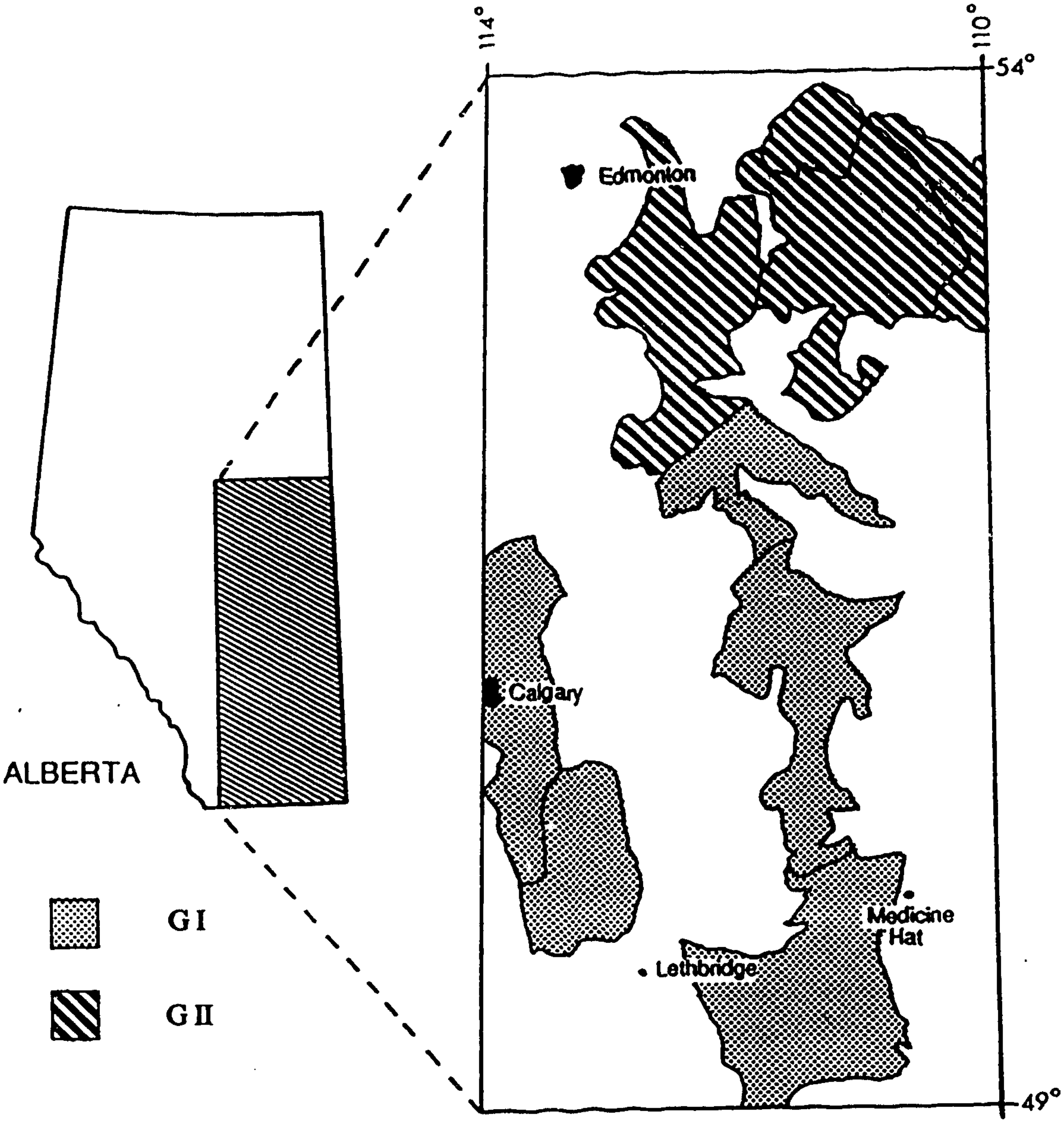

Figure 2: Groups of polygons (GI and GII) as interpreted from the results of the discriminant analysis of the images from June 1988, July 1987 and July 1986.

Table 3: **Discriminant analysis confusion matrix: percent classification summary for polygons. Groups interpreted from the matrix.**
Image date: **June 1988.**

"FROM"	"INTO" POLYGONS								
POLYGON	6	8	(15+16)	27	31	36	37	46	48
6	**12**	**25**	**31**	**14**	**14**	0	1	2	1
8	**21**	**29**	**32**	**7**	**11**	0	1	0	0
(15+16)	**11**	**6**	**64**	**15**	**3**	0	0	0	0
27	**18**	**4**	**12**	**30**	**32**	0	1	3	0
31	**9**	**7**	**7**	**14**	**53**	1	3	6	0
36	0	0	0	0	0	**34**	**24**	**11**	**31**
37	0	0	0	0	6	**16**	**38**	**18**	**21**
46	0	0	0	5	10	**9**	**20**	**40**	**17**
48	0	0	0	2	2	**29**	**13**	**10**	**46**

A second group of polygons (G II) formed by polygons 36, 37, 46 and 48, have a correct classification rate in the order of 40% (Table 3). The relative high correct classification rate of polygon (15+16) is consistent with the relatively low standard deviation, mainly in the reflected infra red channel (Appendix III-1). Although some spectral differentiation between cropland and rangeland within the same climatic region might be expected, this is not the case, as polygon 6 (cropland) and polygon 8 (rangeland) are together in Group I. Also some spectral differentiation between cropland in different agroclimatic regions might be expected, but this is not the case as cropland polygon 6 (3A), (15+16) (2A) and 27 (2AH) are together in Group I. Differences in climatic region are not expressed within the second group either, as polygons 36, 37 and 46 (2H) are included with polygon 48 (3H). In fact the highest percentage of correctly classified pixels occurs for polygon 48.

To evaluate if this pattern had any "stability" through time, the same discriminant function was performed on the "anniversary" images July 1987 and July 1986. The July 1987 data show the same general grouping with the southern polygons {6, 8, (15+16), 27 and 31} (Figure 2). Nonetheless, the northern group of polygons (Group II) is not as well defined, the result of a greatly reduced number of sample pixels for P37, P46 and P48 after the cloud removal process. Polygon 36, a definite member of the northern Group II in June 1988, was confused with P27 and P31 of the southern group in July 1987, when crops were actively growing (Table 4).

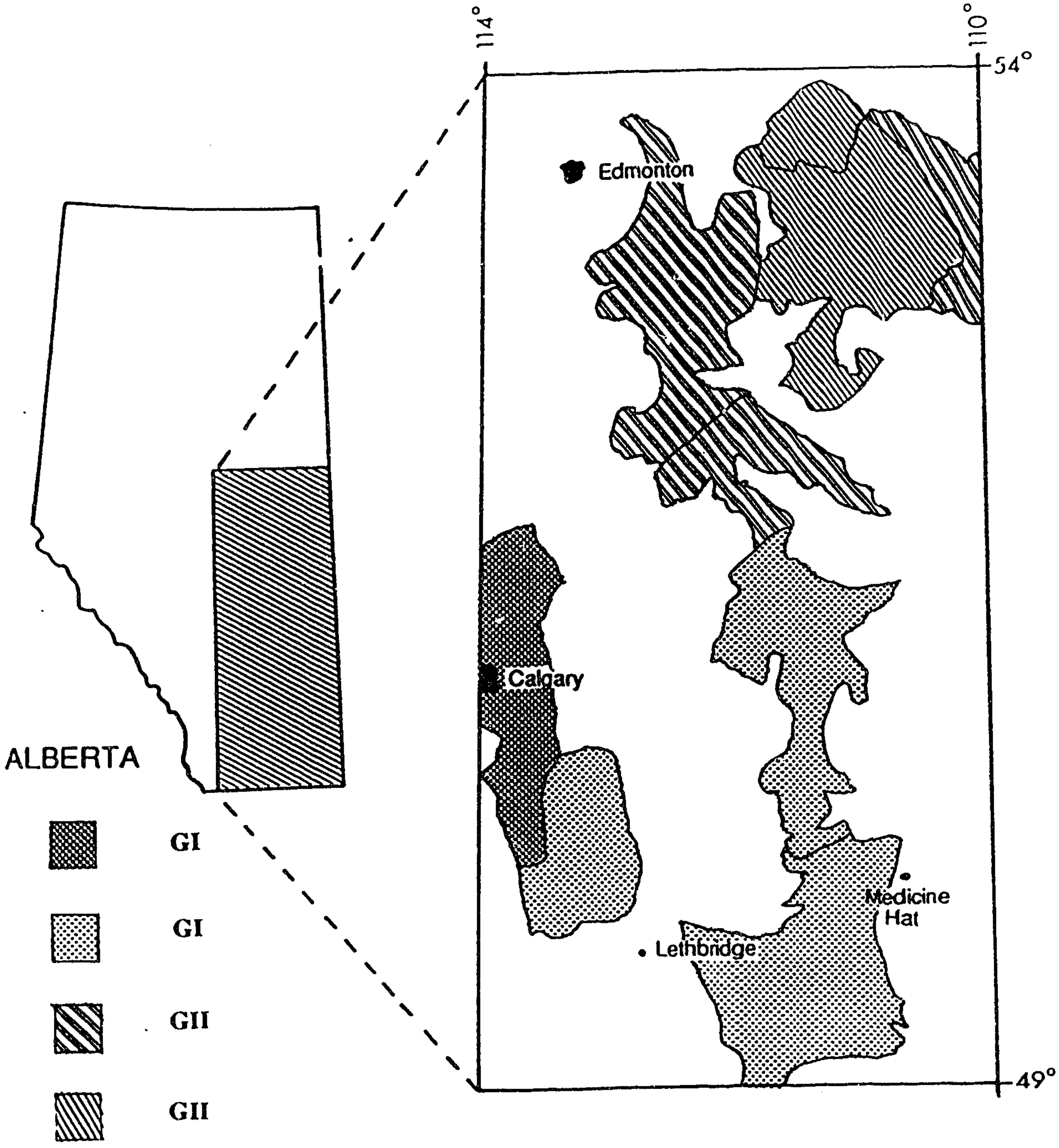

Figure 3: Groups of polygons (GI and GII) and differences between groups as interpreted from the results of the discriminant analysis of the image from August 1986.

Table 4: Discriminant analysis confusion matrix: percent classification summary for polygons. Groups as interpreted from the matrix
Image date: July 1987.

"FROM"	"INTO" POLYGONS								
POLYGON	6	8	(15+16)	27	31	36	37	46	48
6	49	28	8	11	2	1	0	2	0
8	19	46	2	0	28	1	0	1	3
(15+16)	22	9	18	12	9	3	7	10	10
27	2	2	2	64	3	7	16	3	3
31	8	15	4	2	43	1	21	2	5
36	8	0	4	29	12	8	31	4	6
37	5	1	4	19	16	7	40	4	3
46	11	1	7	27	14	5	25	7	4
48*	29	29	0	14	14	0	14	0	0

* : Reduced number of pixels after cloud removal.

For the July 1986 data the general pattern again is not as simple as that from June 1988. The pattern of confusion between polygons follows agroclimatic zonation more closely than in June 1988 where a basic north-south division was evident. Based on the July 1986 data, polygons of agroclimatic zone 3A (P6 and P8) are generally not confused with those of agroclimatic zone 2H or 3H (P27, P36, P37, P46, P48). Confusion does exist between adjunct polygons across agroclimatic zones , i.e. P8 (3H) and P31 (2AH) or P31 (2AH) and P36, P37 and P48 (2H) (Table 5).

Table 5: Discriminant analysis confusion matrix: percent classification summary for polygons. Groups as interpreted from the matrix.
Image date: July 1986.

"FROM"	"INTO" POLYGONS								
POLYGON	6	8	(15+16)	27	31	36	37	46	48
6	59	14	7	2	4	8	1	2	4
8	9	50	9	2	24	4	0	0	2
(15+16)	19	26	12	4	24	4	1	2	10
27	1	3	2	6	11	9	2	34	32
31	2	14	5	12	34	9	5	5	12
36	7	3	4	8	18	8	5	20	28
37	0	1	2	7	15	3	3	39	30
46	0	2	0	4	5	2	3	60	24
48	2	2	0	3	10	0	2	24	59

An attempt was also made to study these landscapes patterns during a growing season using data from August and October 1986. From the August 1986 image data the confusion between polygons does not follow the agroclimatic zonation as in July (Figure 3). The southern polygons 6, 8 and (15+16) are confused among themselves and a northern group of polygons 31,36 and 46 are also confused among themselves (Table 6). Polygons 27, 37 and 48 are not confused among themselves but are confused on an individual basis with 31, 36 and 46 but not with the southern polygons (Table 6).

Table 6: Discriminant analysis confusion matrix: percent classification summary for polygons. Groups as interpreted from the matrix.
Image date: August 1986.

"FROM"					"INTO" POLYGONS				
POLYGON	6	8	(15+16)	27	31	36	37	46	48
6	**69**	**22**	4	0	0	5	0	0	0
8	**15**	**60**	**22**	0	1	0	0	0	2
(15+16)	**21**	**24**	**44**	1	4	2	0	0	4
27	3	5	13	1	**19**	**14**	2	**35**	8
31	1	4	3	4	45	0	6	**28**	9
36	3	0	9	4	**16**	38	4	**21**	4
37	3	2	2	4	**28**	**21**	5	**29**	6
46	0	2	0	2	**22**	7	3	60	4
48	14	2	0	2	**30**	**14**	2	**30**	5

The spectral responses from polygons 27, 37 and 48 are less specifically defined. Their dispersion statistics are quite high for this image compared to those from June, especially for the reflected infrared channel (Appendix III-4). This accounts for the very low percentage of correctly classified pixels in these three polygons (5% or less). Perhaps the hummocky landform in the case of polygons 37 and 48 introduces a significant variability in the spectral response of the land cover. The variability in polygon 27 is such that with the exception of the hummocky landform polygons (37 and 48), it confuses with all others located in the subhumid zone. This is the time of the growing season when there are great variations in both cover composition and management practices across the study area. By the August imaging date annual crops in the south would usually be mature and in some areas harvested, while in the cooler northern areas harvesting may not be started. Added to this would be the effect of the use of different cultivars across the area in

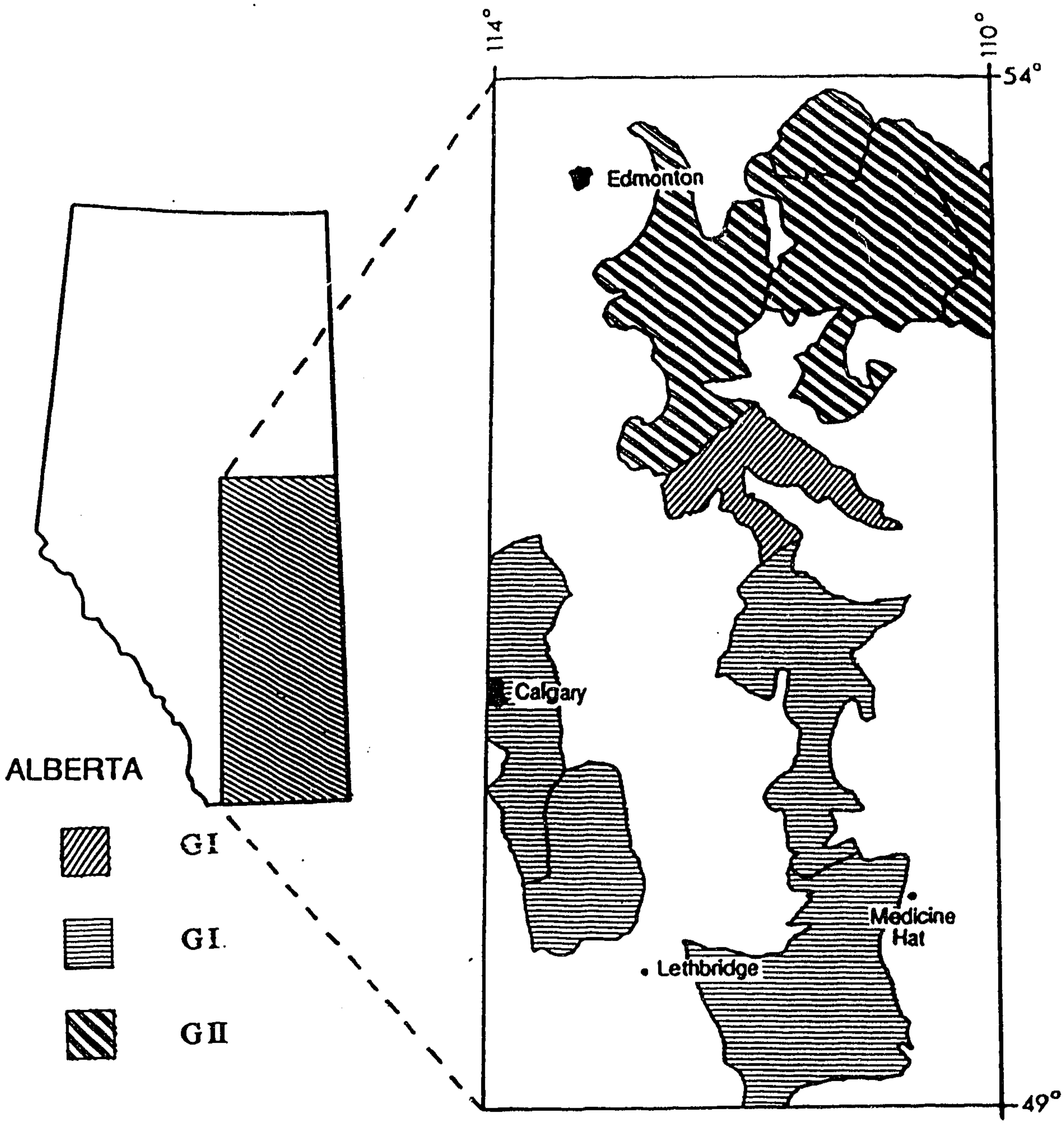

Figure 4: Groups of polygons (GI and GII) and differences between groups as interpreted from the results of the discriminant analysis of the image from October 1986.

response to potential drought conditions. This variability in the land cover plus the "integration" of the information due to the spatial "resolution" of the data, account for the complex pattern at this particular date.

In the case of the October 1986 image, the polygons' spectral responses tend to be confused in the north vs. south grouping again with polygons 6, 8, (15+16) and 27 on one hand, and 36, 37, 46 and 48 on the other (Figure 4). Polygon 31, although transitional in its response, presents a greater degree of confusion with the polygons in the south (Table 7).

Table 7: Discriminant analysis confusion matrix: percent classification summary for polygons. Groups as interpreted from the matrix.
Image date: October 1986.

"FROM"					"INTO" POLYGONS				
POLYGON	6	8	(15+16)	27	31	36	37	46	48
6*	**20**	**8**	**14**	**18**	**3**	7	0	10	21
8	**7**	**35**	**3**	**18**	**8**	15	0	10	4
(15+16)	**15**	**15**	**7**	**38**	**13**	9	0	4	0
27	**6**	**10**	**15**	**48**	**12**	1	0	6	
31	**11**	**22**	**1**	**36**	**13**	4	0	**13**	0
36	5	20	4	5	3	**19**	**0**	**18**	**26**
37	7	17	1	7	4	**18**	**0**	**20**	**25**
46	6	22	0	17	13	**5**	**0**	**23**	**15**
48	3	5	0	2	2	**0**	3	**24**	**61**

* : Reduced number of pixels after cloud removal.

A possible explanation is that polygons in the north (36, 37, 46 and 48) all have from 10-30% tree cover, and polygons in the south do not. This produces a spectral response pattern for P31 closer to that of the southern polygons. A specific mention ought to be made in reference to the response of polygon 6. At the date of the image it is almost totally covered by clouds, and the number of valid sample pixels is very low.

In summary, north vs. south grouping of the polygons is clearly evident in situations when no green annual crop is present. The June 1988 image data, a before seeding date, illustrates the base-line landscape effects of the other vegetation.

In situations when moisture is not a limitation, and blooming canola and all green (in active growth) crops are present in the landscape, the contribution of the annual crops to the spectral response pattern cannot be individualized from all the other cover pattern components. At this working scale (resolution) and in these moisture conditions, the differences among agroclimatic conditions are more evident. This is a consequence of the integration of the spectral response inherent to poor resolution data, circumstance that might be even reverse while working with higher resolution data (i.e. Landsat MSS or TM, and SPOT data).

In the August 1986 image data when crops are maturing, a situation first evident in the south and later in the north, the spectral response pattern presents a higher degree of confusion. Finally, in October 1986 when crops have been harvested and tree leaves have changed colors, the base-line differences (north vs. south) re-establish as the most evident feature.

Conclusions

Considering the map and satellite data acquired and the analysis procedures utilized, the following are concluded:

Although the situation requires further study in order to more properly define the patterns, it seems that there are some differences in the spectral response of different natural environments. This supports the idea that interpretive data (vegetation indices, crop condition assessment, yield forecast, and climatic conditions monitoring) may be improved if considered within "landscape" and "climate" boundaries, that provide a more "spectrally homogeneous" geographical context.

Although statistically satisfactory, the sampling procedure might not be the optimal. Landscape features do not follow the same "systematic" pattern as the sampling routine. What the sample data set represents depends greatly on the resolution of the data elements, the size and the shape of the landscape features under observation, and in this case also on the shape of the polygons. In this matter, a very systematic sampling routine could exclude, or on the other hand overemphasize one or more cover classes within the polygons. Besides, it could also emphasize or not consider at all very bright or very dark objects that could bias the spectral signature of the polygon (making it too narrow or too wide), leading to erroneous conclusions when used in comparisons with those from other polygons.

The scale of the Agroecological Resource Area map, with its polygons defined in a very general fashion, is compatible with the scale of the NOAA digital data. The fact that the polygons could not be unequivocally defined in spectral terms with this sampling methodology, has made it difficult to detect within-polygon variations.

The combination of digital and cartographic data, together with the analysis methodology, permits the identification of very gross differences ("north" vs. "south") for which the Agroecological Resource Areas map unit resolution is too fine. At the same time, the "within" zones (polygons) characterization presents a great confusion, making the above mentioned unit resolution too coarse in some cases. A better agreement of resolution in the information being considered may be reached either by comparing this kind of remotely sensed data to an even more generalized presentation of the agroecological regions like the Agroecological Resource Regions map (Pettapiece, 1988) for the "between" polygons analysis, or by further subdividing each Agroecological Resource Area polygon using more detailed land cover data, for the "within" polygon analysis.

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CHAPTER 3

SPECTRAL COMPARISON OF AGRO-ECOLOGICAL RESOURCE AREAS USING THE NORMALIZED VEGETATION INDEX

Introduction

The analysis performed in Chapter 2 (Discriminant Analysis) identifies that confusion exists but does not allow for an identification of its location and extent. A further spectral comparison of the selected Agroecological Resource Areas involved the calculation of a "Vegetation Index" using the NOAA data for the reflected infrared and the visible bands data. This transform provided another way to describe the effect of the land cover patterns within each polygon.

Vegetation indices are assumed to convey the spectral characteristics of image features, regardless of variations in scene illumination conditions. They compensate for the brightness variation caused by varying topography emphasizing the "spectral" content of the data. This enhanced discrimination is due to the fact that ratioed images portray the variations of the "slopes" of the spectral reflectance curves between the two bands involved, regardless of the absolute reflectance observed in the bands. Ratios only compensate for multiplicative illumination effects. Therefore, "noise" factors (i.e. atmospheric haze) that are "additive" are not affected (compensated for, or eliminated) by ratioing. Other "additive" effect are the different offsets from different sensor response curves (Rouse et al.,1973 as referenced in McGinnis et al.,1985).

Several researchers have concluded that MSS data closely relate to such vegetation indicators as biomass, leaf area, percent leaf cover and plant population, and thus a number of vegetation indices (differences and/or ratios of different spectral bands) have been developed, by empirical means, to serve as spectral indicators of vegetation conditions (Richardson and Wiegand, 1977; Banner and Lynham, 1981; Driscoll et al., 1983; Werth, 1983). The purpose has been to obtain a reliable, efficient indicator of the relative differences in digital data, to which a particular change in land cover for a specific area could be assigned (Hall et al., 1984).

Perry and Lautenschlager (1984) used cluster analysis to study the empirical relationships among a series of vegetation indices. Results of this cluster analysis made them go further and find out their "equivalence" using alarm models and graphic display techniques. The results showed that for practical purposes several of the most widely used vegetation indices are completely equivalent (i.e. all transformed vegetation indices were found to be equivalent to their corresponding band ratios). Therefore redundant information may be obtained when two or more of the vegetation indices are applied to the same data set.

The Normalized Vegetation Index is often utilized to minimize the influence of illumination and atmospheric conditions that may vary from day to day or over longer intervals (Tarpley et al., 1984). This index has been related to "greenness" or "photosynthetic activity" by numerous authors (Gallo et al.,1987; Tucker et al., 1984) and generally the greater the numerical value for the index, the more "active" the vegetation. This index has also been used as an indicator of drought conditions in the Canadian prairie region where a reduced value for the index indicates a stress condition (Prout et al., 1986).

For this study the pixel by pixel "mapping" of the land cover was used to show not only similarities and/or differences between polygons, but also the "location" and "extent" of these spectral characteristics for each polygon. Once each polygon was characterized, the effect of different environmental characteristics such as soil, climate and physiography was compared for different sets of polygons on images where there was no cloud cover.

Material and Methods

For each image date (Table 1), a Normalized Vegetation Index (N.V.I.) transform was calculated as follows:

$$\text{N.V.I.} = \quad (\text{I.R.} - \text{V.}) \; / \; \text{I.R.} + \text{V.})$$

Where IR = Infrared band reflectance value

V = Visible Band reflectance value.

The N.V.I. scores were scaled independently for each image date, using values of gain and offset to produce a mean of 128 for the 8 bit gray level value for each transform data set. Thus, data could not be quantitatively compared across dates, as each date had different scaling.

Based on the vegetation index frequency histograms which had most data between a scaled value of 60 and 200, 16 "relative" classes of N.V.I. were created by level-slicing the data within scaled values intervals (Table 8). Each of the 16 classes was identified as a theme in the Aries-II files system, and used to produce a "theme map" ("Class map"), where the location and the distribution of all 16 classes over the 9-polygon area was shown for each date. To retain the relatively low values for the N.V.I. for the October 1986 image, gain and offset values as used for the July 1986 image were applied to the former image.

The percentage of pixels within each of the 16 classes was calculated for each polygon on each date to analyze similarities and/or differences among the Agroecological Resource Areas (A.R.A.). A two-scale analysis was performed on these data. First, an overview of all 9 polygons in the study area utilized a grouping of the N.V.I. into four general categories: very low, low, high and very high represented by blue, yellow, magenta and green respectively on the accompanying Plate. This class mapping was possible only for the June 1988, July 1987, July and August 1986, when the overall cloud cover was not considered a limitation. Secondly, to analyze the sum effect of the differentiating criteria used in the definition of A.R.A. polygons (physiography, agroclimate, soil type and soil texture) on the land cover pattern between areas, comparisons using different combinations of polygons were done by plotting the percentage composition of relative N.V.I. classes for each polygon. Polygons not affected by cloud cover in different image dates are shown in Table 9. Thus, comparisons were only possible between specific polygons on specific dates.

Table 8: Class limits for the grouping of the Normalized Vegetation Index.

CLASS	SCALED SCORES LOWER LIMIT	SCALED SCORES UPPER LIMIT	GENERAL CATEGORY
1	0	59	Very Low
2	60	69	"
3	70	79	"
4	80	89	"
5	90	99	Low
6	100	109	"
7	110	119	"
8	120	129	"
9	130	139	High
10	140	149	"
11	150	159	"
12	160	169	"
13	170	179	Very High
14	180	189	"
15	190	199	"
16	200	255	"

Table 9 : Cloud-free polygons on different image dates.
Y = Cloud-free.
N = Not usable because of cloud cover.

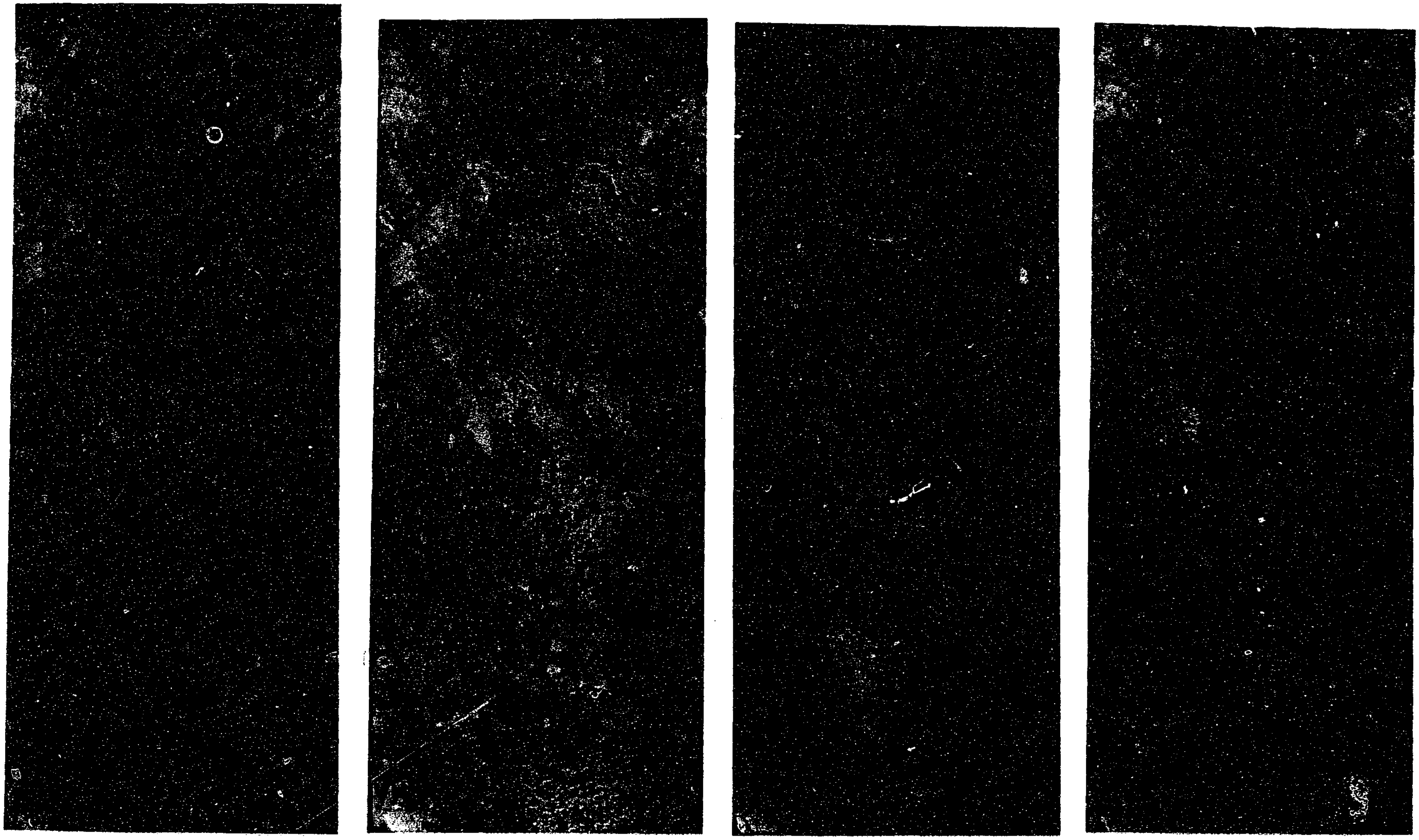
POLYGON	JULY 1986	AUG.1986	OCT.1986	JULY 1987	JUNE 1988
06	N	N	N	Y	Y
08	N	Y	N	N	Y
(15+16)	Y	Y	Y	Y	Y
27	N	Y	Y	Y	Y
31	Y	Y	Y	Y	Y
36	Y	N	Y	N	Y
37	Y	N	Y	N	Y
46	N	Y	N	N	Y
48	Y	N	Y	N	Y

Results and Discussion

a) General Comparison (Plate I):

The June 1988 image was again selected to provide base-line data. As described in Chapter 2, seeding was delayed in the spring of 1988 because of drought conditions, and not much vegetative cover was present in the fields of annual crops at this imaging date. The vegetation indices for this date confirm the discriminant analysis result of north and south groups of polygons. In general the higher the indices (green color in Plate I) belong to the northern polygons, where aspen, shrubs and hay crops were "green" by the imaging date. The indices for the southern polygons (polygons 6, 8, (15+16), 27 and 31) were relatively low with the exception of the irrigation areas to the east of Lethbridge, for which indices were also high.

In July 1987 the situation was very similar , with Polygon 27 sharing the relatively high V.I. values with the northern polygons (36, 37, 46 and 48). It is to be noticed the



JUNE 1988 JULY 1987 JULY 1986 AUGUST 1986

Plate I: General categories of normalized vegetation index (N.V.I.) for four image dates. **blue**: very low values; **yellow**: low values; **magenta**: high values; **green**: very high values.

presence in this image of a relatively large cumulus cloud over these northern polygons (specifically Polygons 37, 46 and 48).Clouds result in relatively low N.V.I. values as a result of their relatively high reflection in both the visible and the reflected infrared bands. The concentric pattern in the distribution of the V.I. values in this case could be associated with the relative water vapor concentration within the cloud (Barret and Curtis, 1982).

Data for July 1986 produced a more even distribution of the V.I. values across the study area . At this time crops in all areas were "green" and photosynthetically active. Variations in indices arise in part from the proportions of fallow and canola fields in the different areas. Fallow and canola fields in bloom would result in relatively low values for the vegetation index as the differences between infrared and visible bands reflectances are not as great for these cover types as for green vegetation. This distribution may also be the result of some cloud effect as scattered cumulus clouds occurred on the image.

In the case of the August 1986 image data, the pattern again reflects agroclimatic characteristics across the study area . By this date, annual crops are mature and mostly harvested in the south (low N.V.I. values), while in the cooler northern areas harvesting had not started or was just beginning (higher N.V.I. values), justifying then the gradient of vegetation index values from south-east to north-west.

b) Polygon-based comparison:

b-1) Prairie environment: Agroclimatic variable over Chernozemic soils (Polygons 6-(15+16)-27) (Figure 5).

The June 1988 data present a very small differentiation between polygons in the vegetation indices range distribution of all three polygons (Figure 6). The "V.I. signatures" overlap almost completely. This pattern can be explained by the no change in the cover pattern composition, and a very uniform appearance due to the absence of annual crop cover (seeding delayed because of the drought).

The same comparison was possible for the July 1987 data (Figure 6). This was a relatively moist year compared to 1988, and a more abundant crop coverage was present.

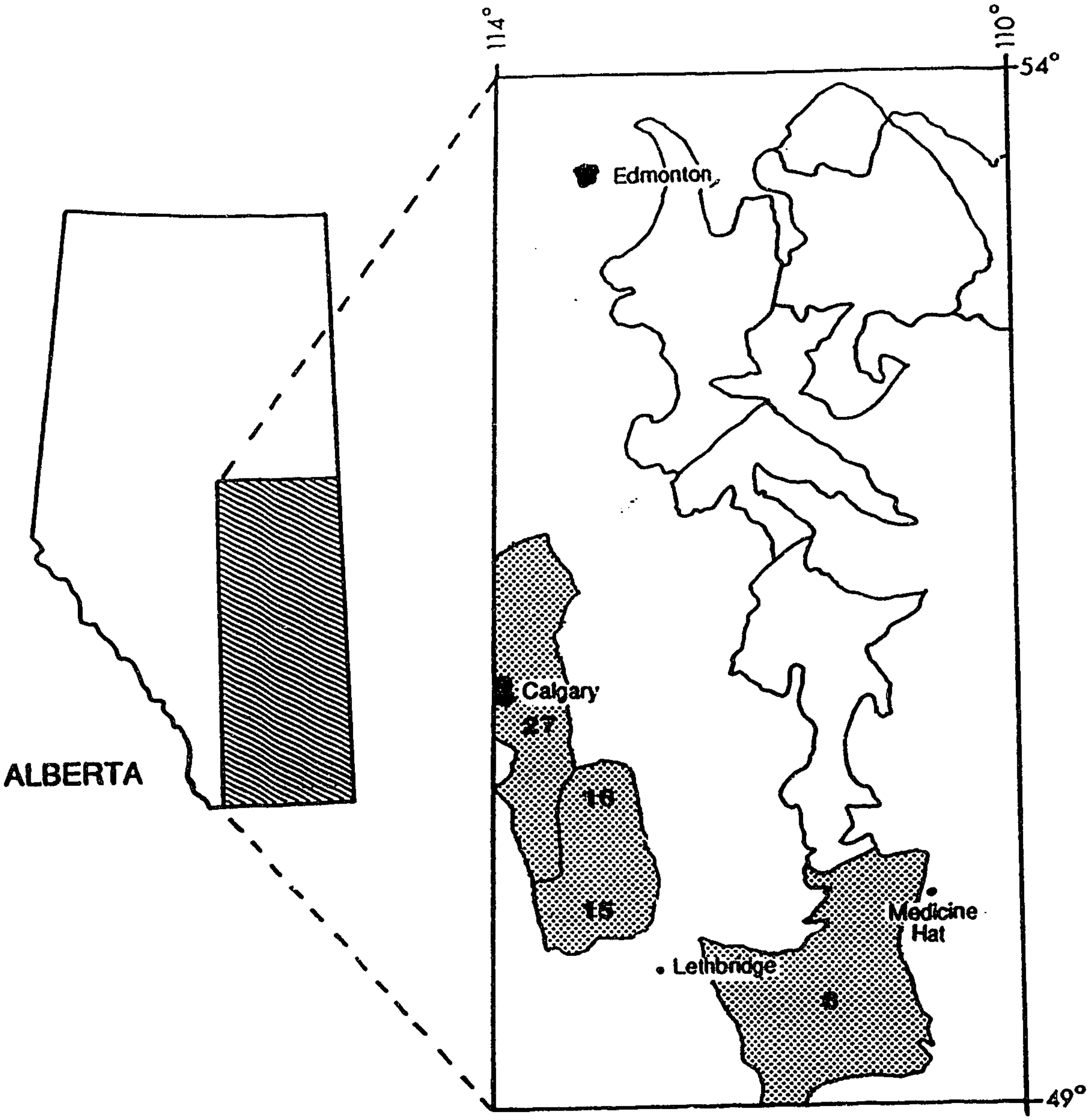
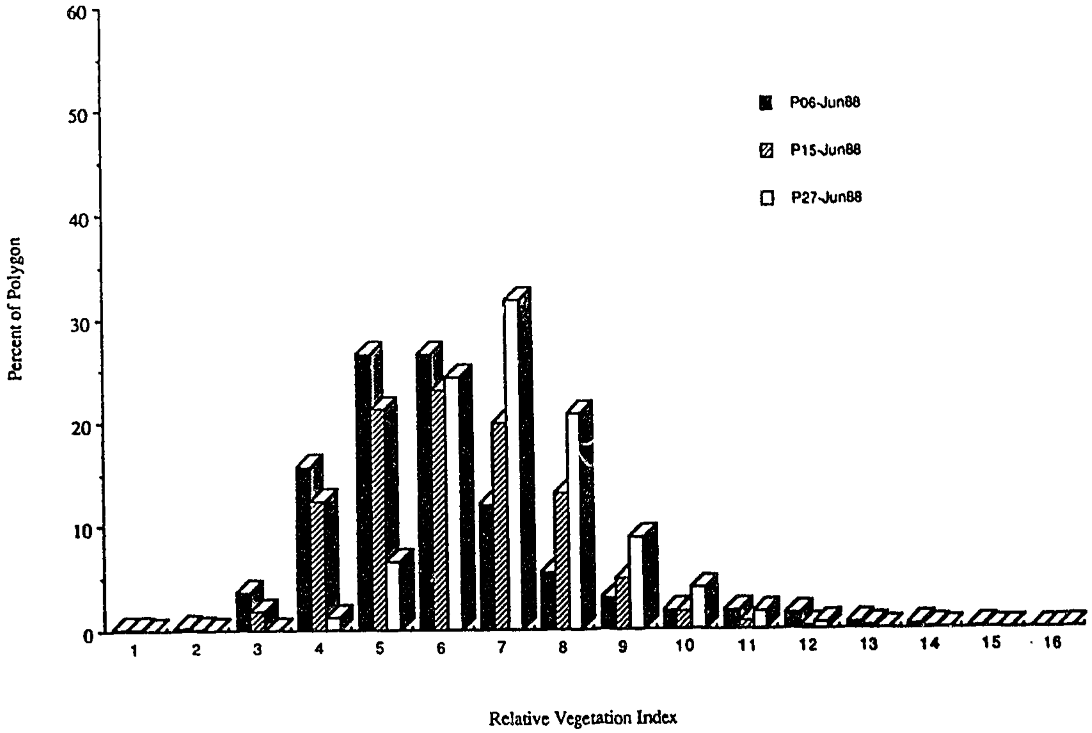


Figure 5: Polygons selected for the comparison of N.V.I. classes for prairie environment with different agroclimate and soils.



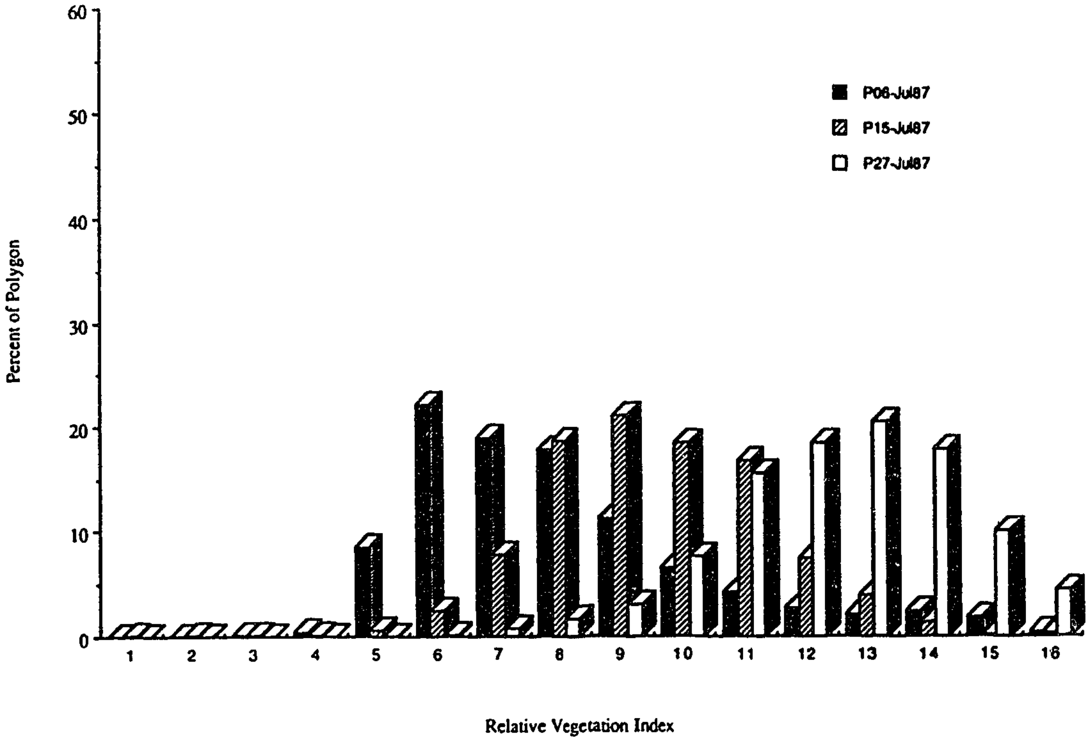


Figure 6: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 6, (15+16) and 27 (P06, P15 and P27 respectively): June 1988 above, July 1987 below.

This resulted in a greater differentiation among the signature of each polygon in this group. Polygon 27 (2AH) and (15+16) (2A) were displaced toward the higher classes of the V.I., and Polygon 6 (3A) within the lower range, following the agroclimatic zonation.

b-2) Prairie to Parkland transition environment: Agroclimatic variable over Solonetzic Soils (Polygons 8-31-46) (Figure 7):

A comparison of these polygons was also possible for the June 1988 and August 1986 data. In 1988 (Figure 8), the spectral distribution shows Polygon 46 (Parkland+cropland) in a higher response range compared to both Polygon 31 (cropland) and 8 (rangeland) which were quite similar . This provides evidence that differences in land cover pattern are dominant in the spectral response when annual crops are absent. The relatively higher response of Polygon 46 is due to the tree and shrub components of its pattern, which respond differently to the effects of the drought than the annual crops and pastures.

The situation is different for the August 1986 data (Figure 8). Despite the "integration" of the information, cropland polygons (31 and 46) differentiate quite clearly from polygon 8 (rangeland), the response from crops being higher than the one for grassland.

b-3) Prairie-Parkland environment: Land cover pattern variable over Black Chernozemic soils: (Polygons 27-36) (Figure 9):

In June 1988 (Figure 10), the spectral character of Polygons 27 and 36 resembles the situation on the same date for polygons 8 and 31 vs. polygon 46 (Figure 8). The more complex (mixed) land cover pattern of polygon 36 accounts for a relatively higher range of N.V.I. values compared to polygon 27, when annual crops are "absent". However when healthy crop vegetation is included in the cover (i.e. July 1986 data, Figure 10), it is so similar to trees as to be undifferentiated with spectral data , producing a much closer spectral identity for both agroecological areas. The situation is different in October 1986 (Figure 11). Although most crops have been harvested and green crops no longer account for the spectral response, there is no differentiation between these two polygons. This time of the year finds deciduous vegetation (aspen stands) without leaves as well, and shrubs have also changed colors. Thus, the formerly crop independent cover pattern differentiation is no longer registered by the digital data, and in general the N.V.I. ranges for both polygons (27 and 36) are considerably more compressed than those from the other dates (Figure10).

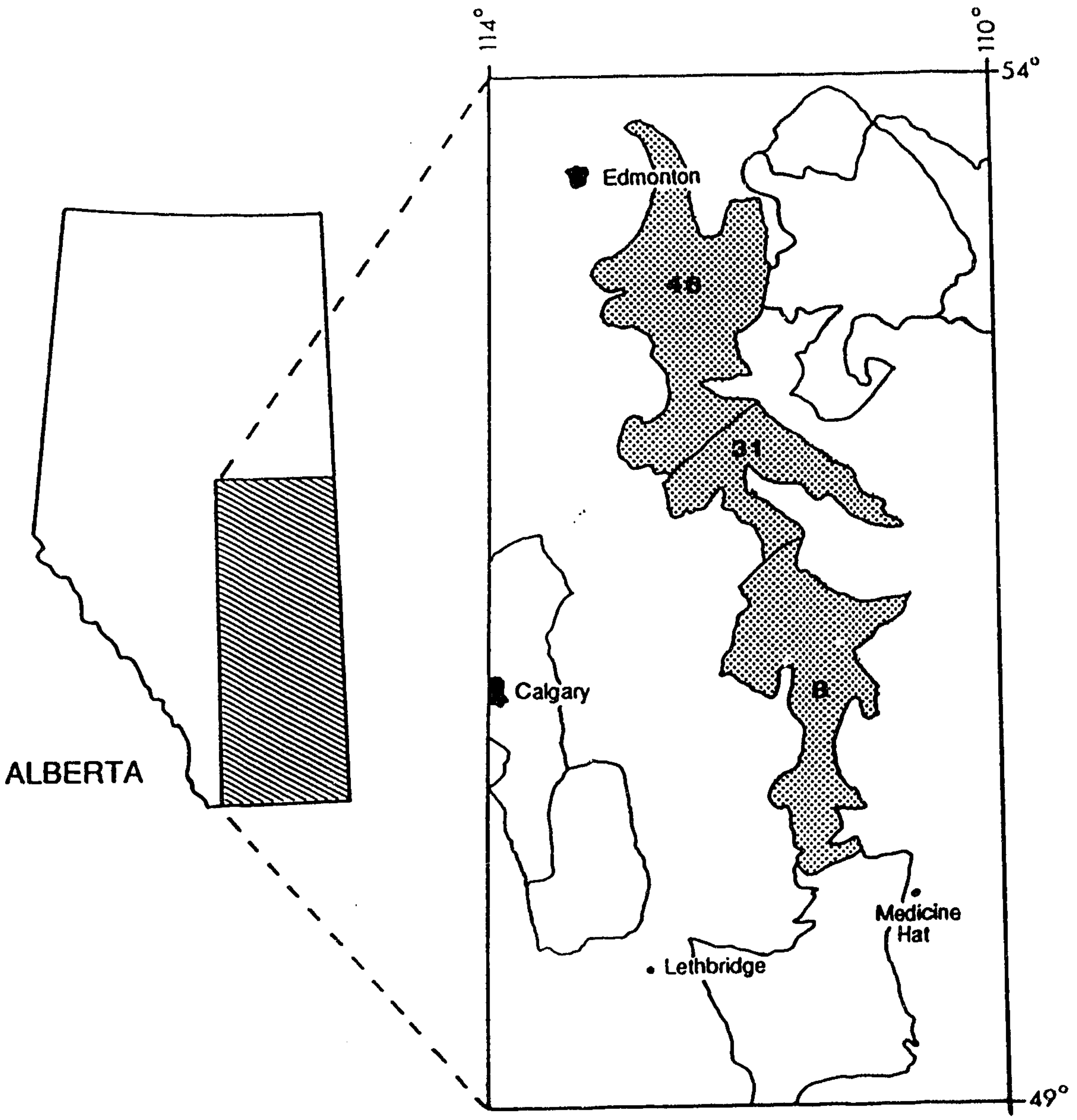


Figure 7: Polygons selected for the comparison of N.V.I. classes for prairie to parkland environment with different agroclimate and soils.

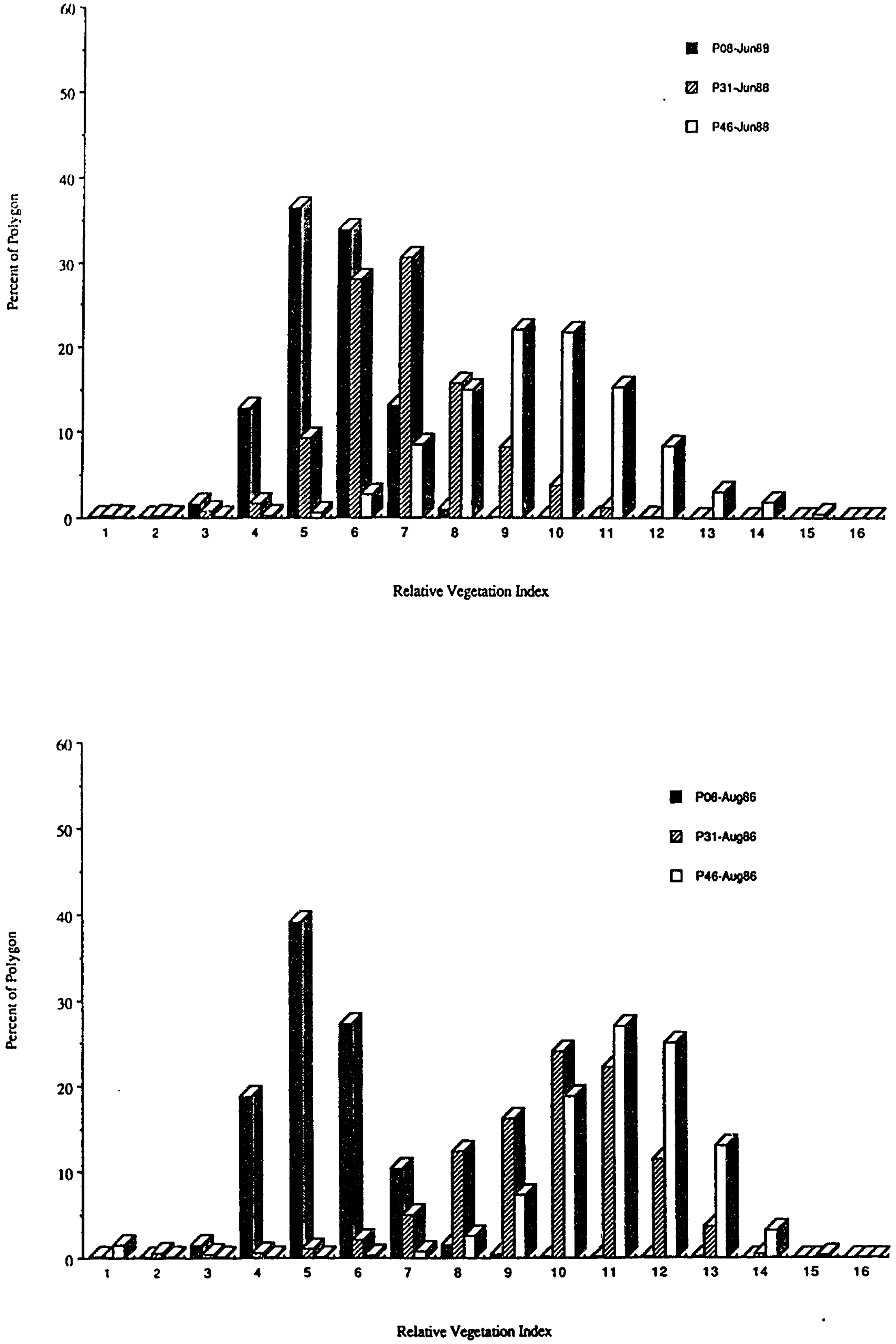


Figure 8: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 8, 31 and 46 (P08, P31 and P46 respectively): June 1988 above, August 1986 below.

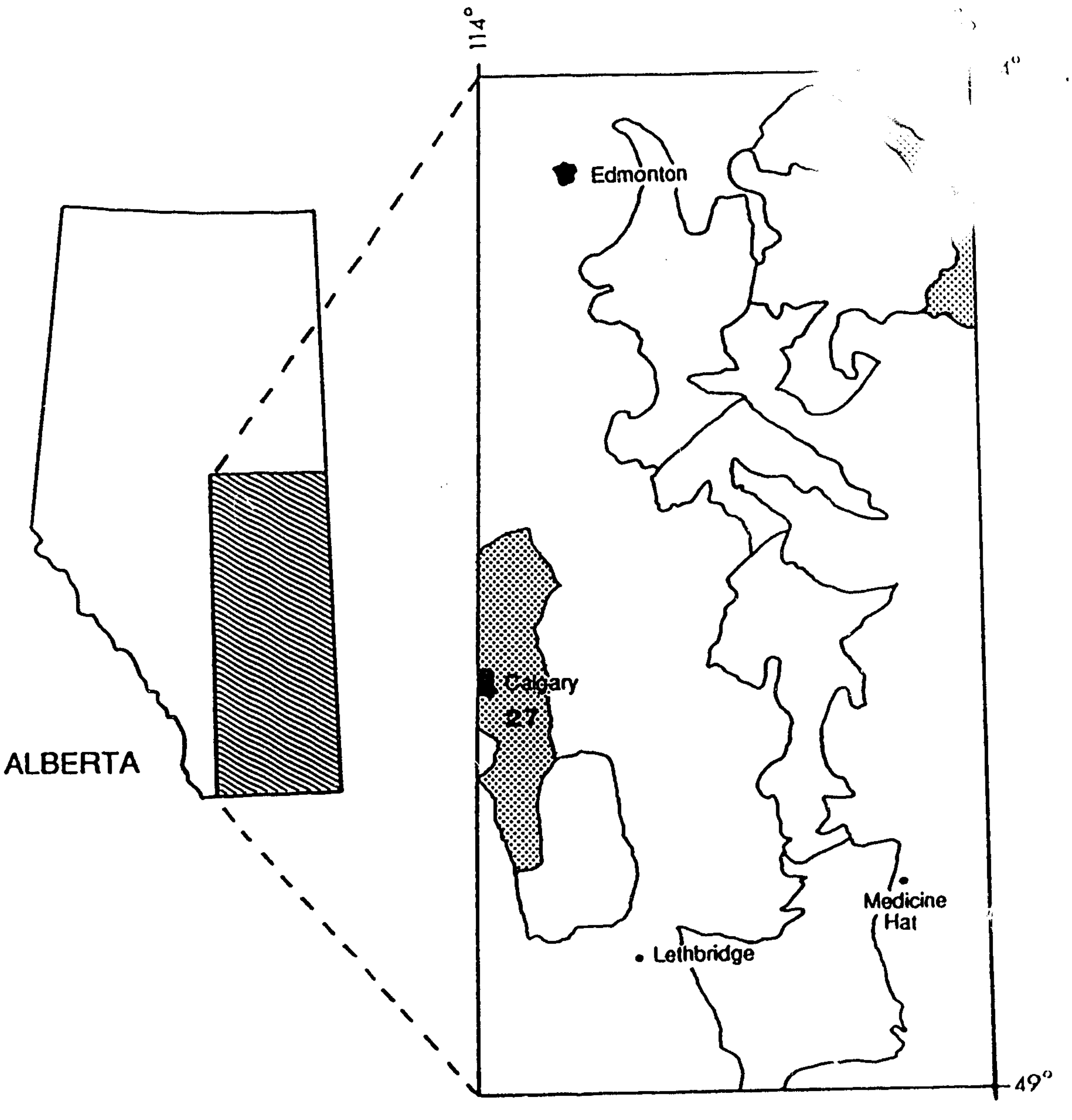


Figure 9: Polygons selected for the comparison of N.V.I. classes for prairie-parkland environment (fescue grassland versus parkland).

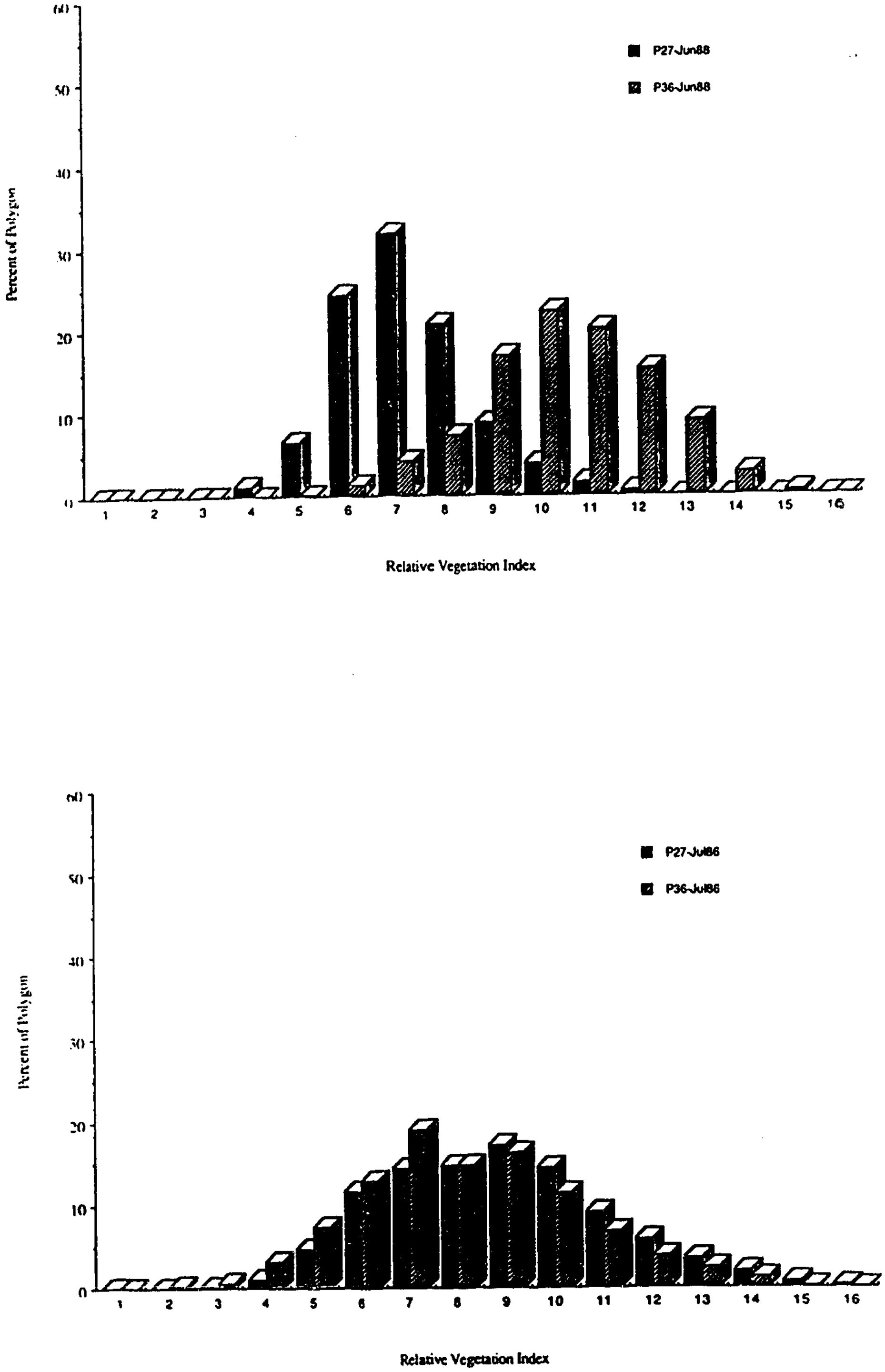


Figure 10: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 27 and 36 (P27 and P36 respectively): June 1988 above, July 1986 below.

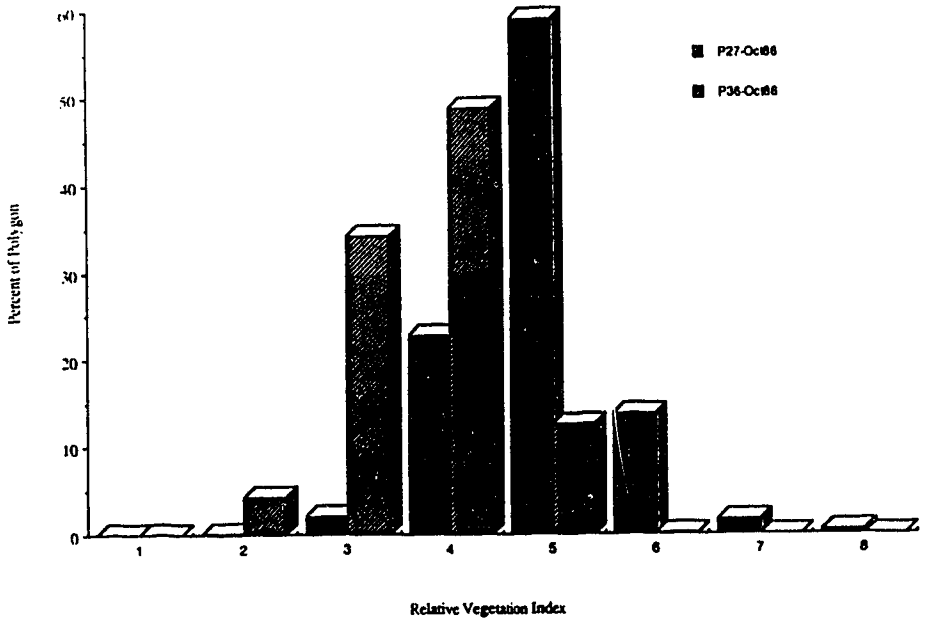


Figure 11: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 27 and 36 (P27 and P36 respectively): October 1986.

b-4) Parkland environment: Physiography effect over Chernozemic and Luvisolic soils: (Polygons 36, 37 and 48) (Figure 12):

These three polygons present a very similar land cover pattern. Thus, comparisons between polygons 36 and 37 (Figures 13 and 14) on one hand, and between polygons 37 and 48 (Figures 15 and 16) on the other for June 1988, July 1986 and October 1986, show only a very subtle relative difference in their spectral responses. The slight differences in the response among these polygons (48 relatively higher than 37 which in turn is higher than 36) may be explained by the proportion of treeland in the three polygons (approximately 30% for P48, 20% for P37 and 10% for P36). In these cases, presence or absence of annual crops in the land cover do not produce any relative spectral difference.

In summary, the "class map" supports in general the conclusions from the discriminant analysis referred to in Chapter 2. There is a base-line difference between northern and southern polygons, accounted for by the overall cover pattern. In situations where the land cover pattern does not change, aspects of crop conditions are expressed in variable degree but are still independently comparable. Where the crop response pattern is dominant in the overall signature (Polygons 6, (15+16) and 27), differences in crop conditions are quite marked, and whereas the contribution of crop to the overall response is "diluted" (integrated) with all the other cover components (Polygons 36, 37 and 48) and the differences, although noticeable, are much more subtle.

Finally, in situations where the land cover pattern does change, crop conditions cannot be assessed in a direct way, without taking into account the differences in spectral response between very "homogeneous" and more "mixed" cover patterns.

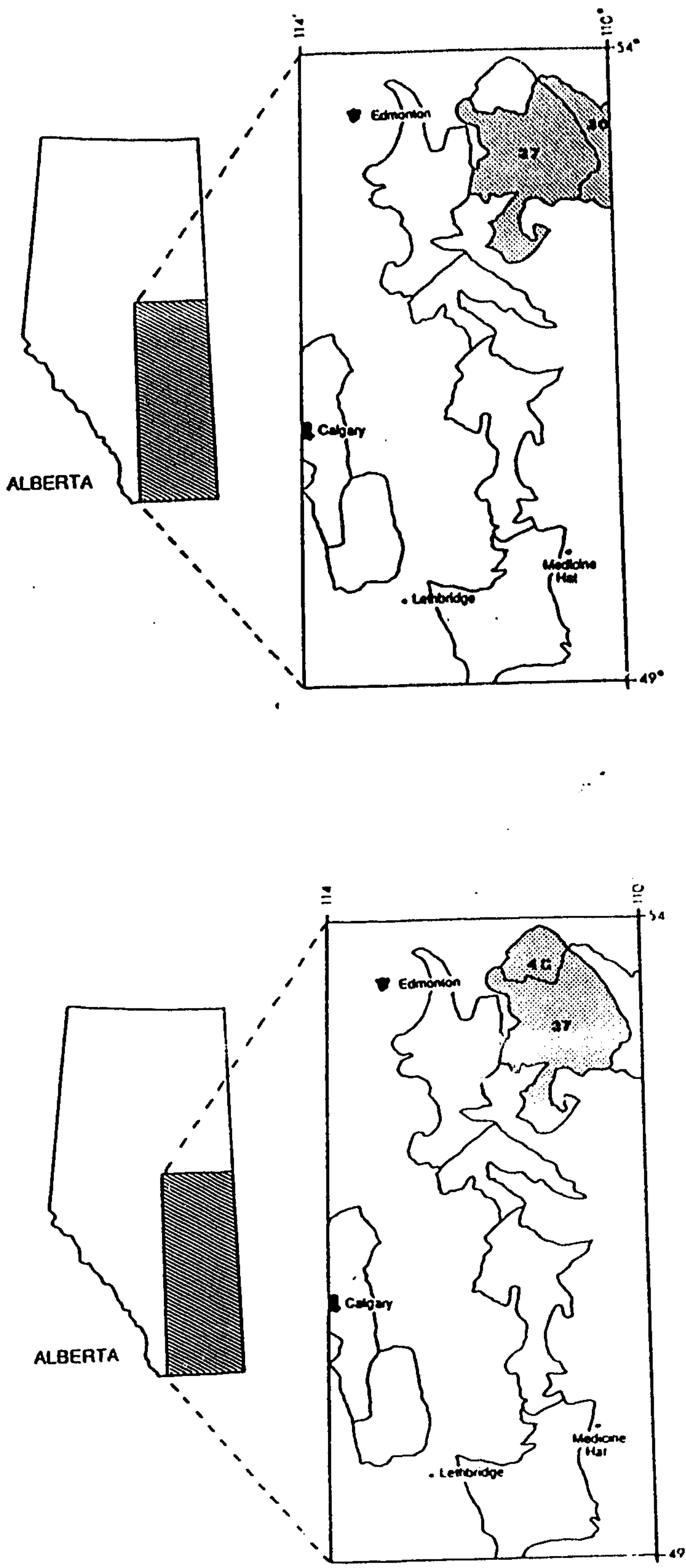


Figure 12: Polygons selected for the comparison of N.V.I. classes for different landforms and soils: different landform-same soils above, same landform-different soils below.

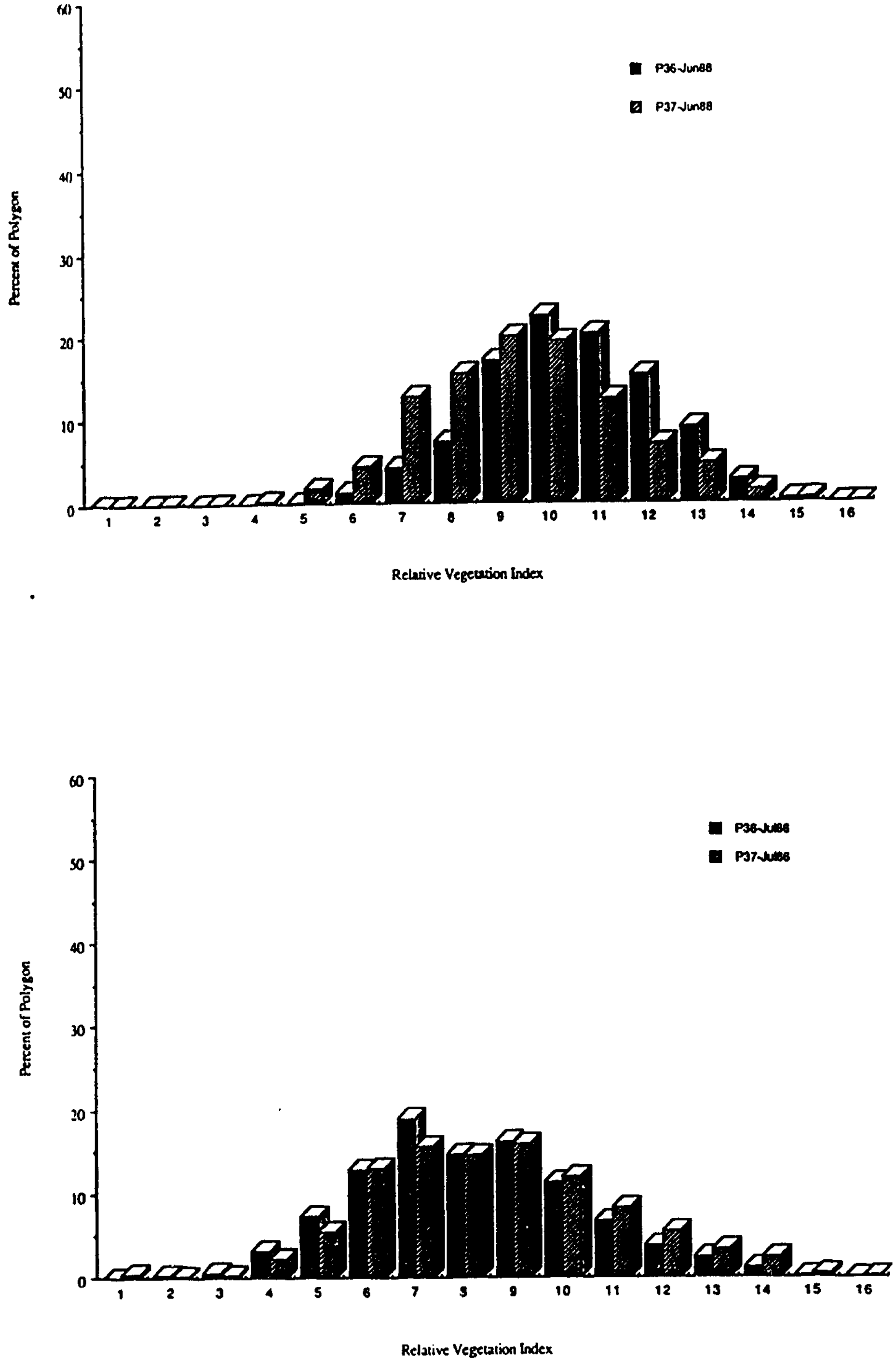


Figure 13: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 36 and 37 (P36 and P37 respectively): June 1988 above, July 1986 below.

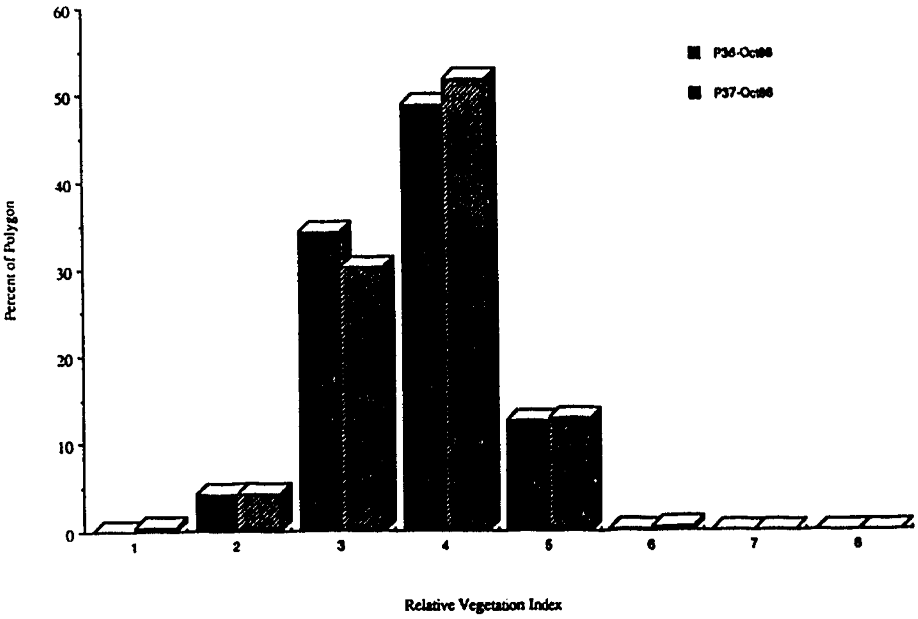
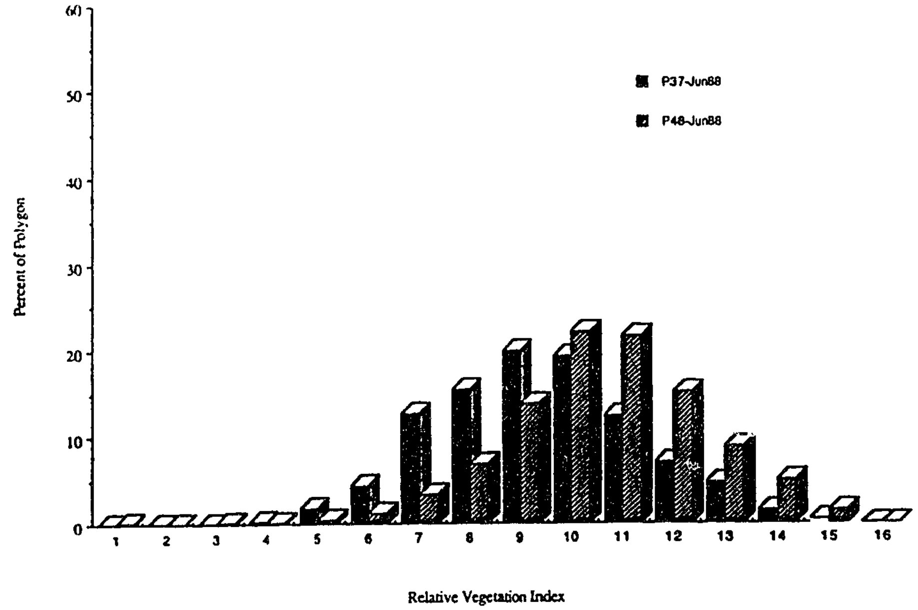


Figure 14: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 36 and 37 (P36 and P37 respectively): October 1986.



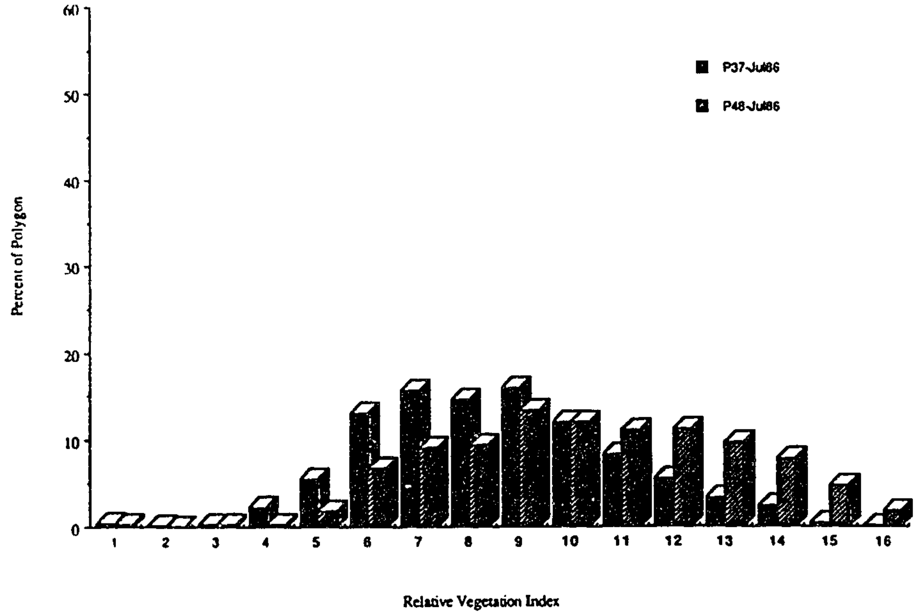


Figure 15: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 37 and 48 (P37 and P48 respectively): June 1988 above, July 1986 below.

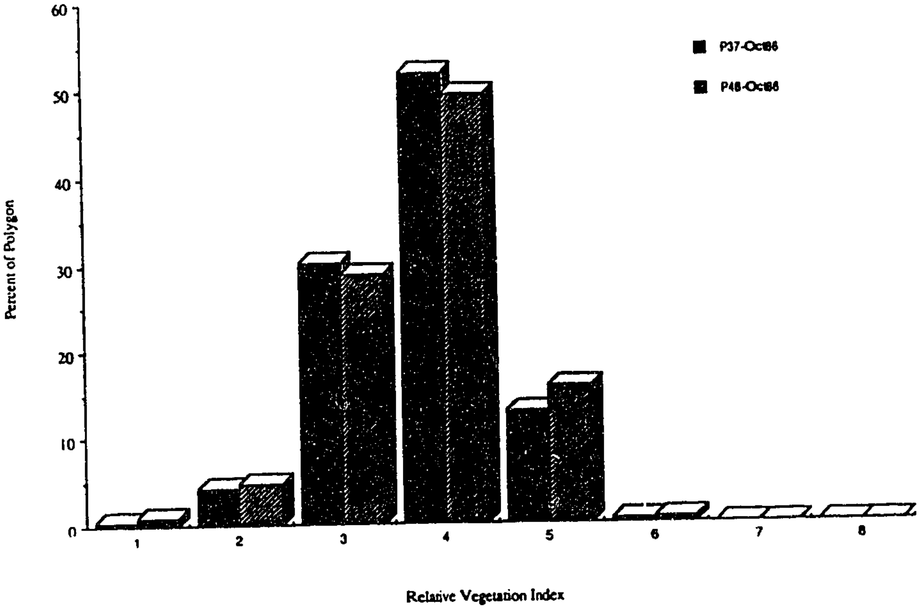


Figure 16: Frequency histograms for relative vegetation index classes from polygons (Agroecological Resource Areas) 37 and 48 (P37 and P48 respectively): October 1986.

Conclusions

Considering the data and the analysis procedures utilized, the following are concluded:

There are noticeable spectral response differences between Agroecological Resource Areas, based on the Normalized Vegetation Index. These differences are attributed to variations in the land cover pattern. It is assumed that base-line differences affect the way crop conditions are expressed spectrally, as a result of the "integration" made during the data acquisition process. Although specific crop conditions may be similar in different areas, the satellite data values are the result of all the cover elements or cover types occurring in a landscape.

The integration of effects of all the elements is very important with coarse resolution data like NOAA-AVHRR . Comparative analysis of vegetation index values from parts of the province with different cover pattern requires a landscape (land cover pattern) approach, and comparisons should be made within these stratified areas.

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CHAPTER 4

SYNTHESIS

Summary:

It is recognized that the AVHRR sensor records the 1.1 km integrated response from many fields containing several crops (in an agricultural area). Working with AVHRR data from the Nile delta, Tucker et al. (1984) concluded that these data were suitable for inferring the integrated growing season responses but were not suited for specific inventory purposes such as specific crop yields or specific crop acreages.

On the evidence from the discriminant analysis and calculations of vegetation indices from NOAA data, it is concluded that there are important spectral differences between Agroecological Resource Areas.

Mack et al. (1986) stated that natural vegetation areas are adapted to the regional climate and are less affected by stress caused by drought than are crops. Also, observations show that their reflectances are more stable than those of crops during the growing season. As a result, they act as a buffer to the global vegetative index and considerably reduce the system's sensitivity to fluctuations in the vegetative index in cultivated areas. In the present study, although specific crop conditions may have been similar in different areas the satellite data values were the result of all the cover elements or cover types occurring in a landscape. This integration of effects of all the elements was an important consideration in the analysis of coarse resolution NOAA-AVHRR data.

The observations and conclusions from this study are also supported by those of Merchant (1985) who discussed the importance of spatial pattern. He concluded that spectrally based classification algorithms have been found to be effective in distinguishing many types of land cover. They have been less successfully employed to identify and map landscape regions. Classification of ecoregions and land use recquires a polythetic procedure. Land cover composition, which can often be estimated via multispectral classification, is an important variable, but it alone does not permit differentiation among, or demarcation of, such regions. The relationships between components of landscapes and physical and biological process is almost always through "spatial pattern" or "structure" rather than through composition alone . The results were also supported by Logan (1985) who concluded that biomass-spectral relationships varied between ecologically different regions and also that these variations were affected by the spatial resolution of the image data.

Atmospheric effects:

A special mention ought to be made of the atmospheric effect on the satellite data. Low spatial resolution and wide scan angle result in atmospheric path effects in the data on a day to day basis, in a way that cannot be related to the crop condition.This radiance effect is strongly dependent upon the scan angle. In their study, Brown et al. (1982) found a significant linear correlation between the AVHRR channels 1 (Visible) and 2 (Reflected Infrared) data. Other studies (Shlien and Goodenough, 1973; Staenz et al.. 1980) have shown that there is little correlation between bands in these two spectral regions when using finer resolution Landsat data. It was then assumed that any correlation between these two spectral bands may not be caused only by the reflection of the sun's illumination by the vegetation but may be caused by other factors such as atmospheric path radiance and angular reflectance effects accentuated in the NOAA data. To reduce possible atmospheric effects, Townshend and Tucker (1981) suggested using just the central 600 km of the imaged area in vegetation studies. Saull (1985) suggested discarding the areas of the images falling outside an arbitrary value of scan angle. In this study the digital data used was taken as close to nadir as possible and the use of the N.V.I. should further reduce the overall effects mentioned above.

Future research:

A number of issues requires future research:

a) Digital data analysis techniques:

- Could another spectral analysis technique have been utilized (i.e. cluster analysis)?

- Would any atmospheric correction of the data alter these results?

b) Resolution of information:

- As expressed at the end of Chapter 2, the combination of digital and cartographic data, together with the analysis methodology, permitted the identification of very gross differences (north vs. south) for which the Agroecological Resource Areas map unit resolution was too fine. At the same time, the within polygons characterization presented a great confusion suggesting that the map unit resolution was too coarse in this case. A better agreement of resolution in the information being considered may be reached by either comparing this kind of remotely sensed data to an even more generalized presentation such as the Agroecological Resource Regions (Pettapiece, 1988) for the "between" polygons analysis, or subdividing each Agroecological Resource Area polygon using more detailed land cover data, for the "within" polygon analysis.

c) Within polygon variability evaluation:

Westin et al. (1986) proposed three different ways of evaluating the "dispersion" (Standard deviation) of the N.V.I. in different areas called hierarchical, independent and inductive approaches. These might be used to better characterize the Agroecological Resource Areas in a more statistical fashion.

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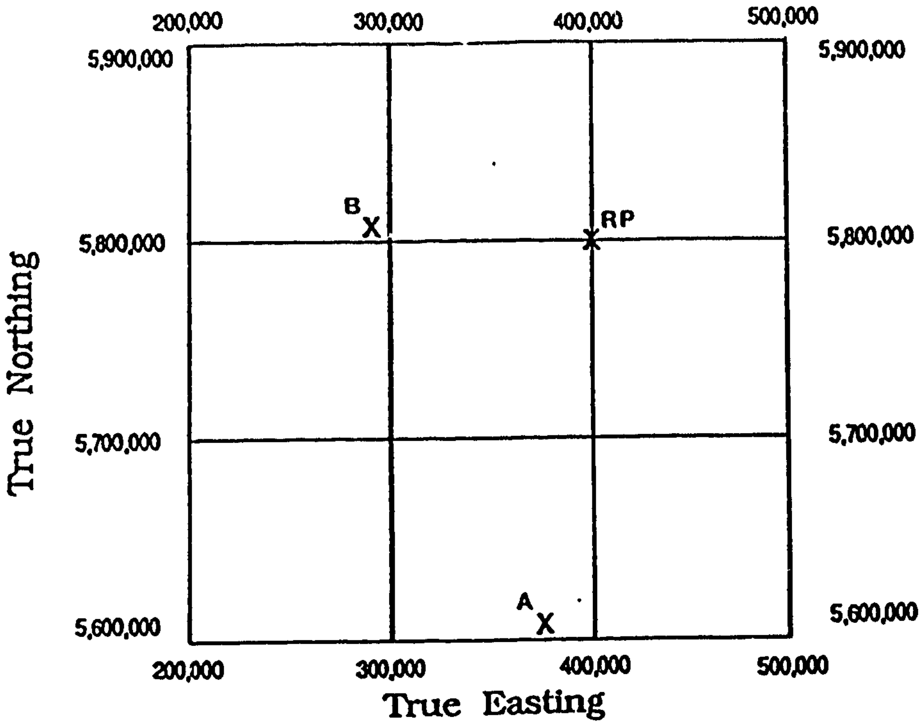
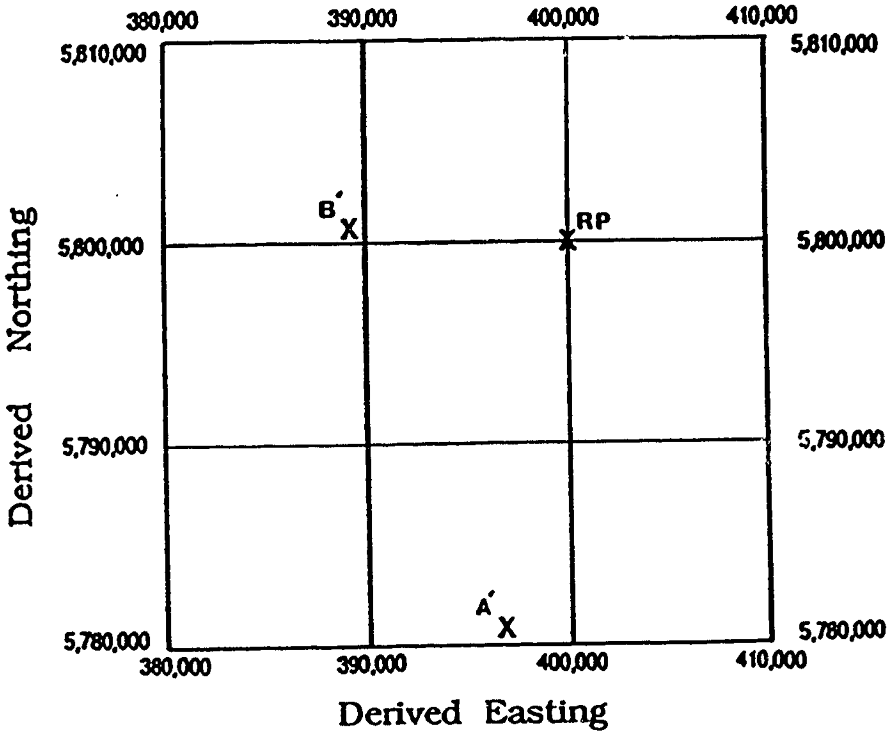
APPENDICES

Appendix 1: Eastings and Northings calculation sample.

R.P. = Reference Point.





Appendix II: October 1986 image-to-grid registration residual errors. (Second Order Transformation Statistics).

SLAVE PIXEL	SLAVE LINE	MASTER PIXEL ACTUAL	MASTER PIXEL EST.	MASTER PIXEL RESIDUAL	MASTER LINE ACTUAL	MASTER LINE EST.	MASTER LINE RESIDUAL	GCP Nº
548	2507	396550	396561.5	-11.5	5780150	5780205.0	-55.0	1
475	2525	404325	404328.9	-3.9	5783200	5783219.0	-19.0	2
512	2589	398675	398648.9	26.1	5789750	5789625.0	125.0	3
573	2709	389800	389799.5	0.5	5801575	5801572.0	3.0	4
470	2788	399500	399518.4	-18.4	5811500	5811588.5	-88.5	5
409	2926	404650	404645.4	4.6	5827075	5827053.0	22.0	6
486	2931	395300	395297.6	2.4	5826575	5826563.5	11.5	7

STANDARD ERROR OF PIXEL ESTIMATE: 11.05

STANDARD ERROR OF LINE ESTIMATE : 52.94

Appendix III-1: Discriminant analysis statistics, June 1988.

POLYGON	CHANNEL	# PIXELS	MEAN	VARIANCE	STD.DEVIATION
6	V	374	28.2326	3.4819	1.8659
	IR	374	35.2754	9.9588	3.1557
8	V	244	28.6516	2.1703	1.4732
	IR	244	34.8319	3.3337	1.8258
(15+16)	V	155	29.1870	3.1530	1.7756
	IR	155	36.7677	3.2444	1.8012
27	V	178	26.9269	1.8081	1.3444
	IR	178	35.9550	5.2409	2.2893
31	V	118	26.3898	2.5133	1.5853
	IR	118	34.5000	3.5000	1.8708
36	V	74	21.7701	1.2478	1.1170
	IR	74	34.4459	6.3326	2.5164
37	V	306	22.6176	2.1320	1.4601
	IR	306	33.7529	8.1651	2.8574
46	V	250	23.2400	1.9421	1.3936
	IR	250	35.4600	11.8879	3.4478
48	V	63	21.6031	2.4690	1.5713
	IR	63	35.2539	11.1280	3.3358

Appendix III-2: Discriminant analysis statistics, July 1987.

POLYGON	CHANNEL	# PIXELS	MEAN	VARIANCE	STD.DEVIATION
6	V	376	23.7134	4.0512	2.0127
	IR	376	37.5106	34.9918	5.9153
8	V	266	22.9962	3.1660	1.7793
	IR	266	33.7819	7.7862	2.7903
(15+16)	V	165	21.9030	2.7710	1.6646
	IR	165	38.8060	13.3889	3.6590
27	V	181	19.5580	3.7035	1.9244
	IR	181	44.3425	31.1375	5.5801
31	V	132	21.3484	6.9005	2.6268
	IR	132	34.8863	12.7121	3.5654
36	V	52	20.2500	13.4068	3.6615
	IR	52	41.1923	46.8642	6.8457
37	V	221	19.9638	5.2532	2.2919
	IR	221	38.7194	24.6754	4.9674
46	V	190	20.7105	5.7094	2.3894
	IR	190	40.4789	28.0286	5.2942
48	V	7	21.4285	9.2857	3.0472
	IR	7	37.2857	87.9047	9.3757

Appendix III-3: Discriminant analysis statistics, July 1986.

POLYGON	CHANNEL	# PIXELS	MEAN	VARIANCE	STD.DEVIATION
6	V	345	25.6405	8.2076	2.8648
	IR	345	39.0637	14.8447	3.8528
8	V	263	25.1634	4.9464	2.2240
	IR	263	35.7034	7.1178	2.6679
(15+16)	V	164	24.4573	4.4460	2.1085
	IR	164	36.6414	15.0237	3.8760
27	V	181	21.9116	1.6254	1.2749
	IR	181	35.0497	12.7364	3.5688
31	V	131	23.2748	3.5854	1.8935
	IR	131	34.8473	3.8072	1.9512
36	V	74	22.4729	5.2115	2.2828
	IR	74	35.2432	17.0359	4.1274
37	V	300	21.6766	1.5104	1.2290
	IR	300	34.2500	12.2015	3.4930
46	V	276	21.3405	2.5381	1.5931
	IR	276	33.4347	9.6139	3.1006
48	V	63	20.8888	2.3584	1.5357
	IR	63	36.3968	15.1786	3.8959

Appendix III-4 Discriminant analysis statistics, August 1986.

POLYGON	CHANNEL	# PIXELS	MEAN	VARIANCE	STD.DEVIATION
6	V	265	30.3132	8.3674	2.8926
	IR	265	37.1094	16.9160	4.1129
8	V	264	26.6515	3.7792	1.9440
	IR	264	33.9924	4.9657	2.2283
(15+16)	V	165	26.6909	4.5441	2.1316
	IR	165	35.5757	4.6116	2.1474
27	V	181	23.0220	5.9661	2.4425
	IR	181	40.1767	23.4907	4.8467
31	V	132	21.7803	2.4780	1.5741
	IR	132	38.1590	11.0813	3.3288
36	V	68	23.9852	7.8953	2.8098
	IR	68	42.0735	22.0989	4.7009
37	V	290	22.8310	7.7533	2.7844
	IR	290	40.5758	27.0340	5.1994
46	V	277	21.6209	2.1927	1.4807
	IR	277	41.4657	20.4163	4.5184
48	V	43	22.6511	25.8516	5.0844
	IR	43	39.3488	83.5182	9.1388

Appendix III-5: Discriminant analysis statistics, October 1986.

POLYGON	CHANNEL	# PIXELS	MEAN	VARIANCE	STD.DEVIATION
6	V	77	18.9610	3.2747	1.8096
	IR	77	21.2077	5.5878	2.3638
8	V	223	18.7937	0.8941	0.9456
	IR	223	20.9686	1.5891	1.2605
(15+16)	V	165	18.9515	0.8634	0.9292
	IR	165	21.7272	0.8215	0.9063
27	V	178	18.8876	0.9816	0.9907
	IR	178	22.0168	1.4742	1.2142
31	V	129	18.6821	0.5778	0.7601
	IR	129	21.3178	0.5778	0.7601
36	V	74	18.5270	0.8554	0.9248
	IR	74	20.2297	1.6588	1.2879
37	V	304	18.4473	0.8817	0.9389
	IR	304	20.2335	1.5789	1.2565
46	V	271	18.3394	0.7139	0.8449
	IR	271	20.5977	1.2783	1.1306
48	V	62	17.4838	0.9095	0.9537
	IR	62	19.1612	1.6456	1.2828