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MAPPING POLAR VEGETATION AT SPITSBERGEN BY USE OF LANDSAT

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ABSTRACT

Mapping of the polar environment is difficult due to a short working season and difficult accessability and climate. IBM in Oslo together with the Norwegian Man and Biosphere (MAB) UN project have made a study to determine how LANDSAT data can be used for mapping of vegetation cover and reindeer grazing areas.

Description of geometric correction, pattern recognition and enhancement (ratio and principal components) is included in the paper. A soil background curve has been established to separate the influence of bare soil. The carrying capacity for reindeers is evaluated.

INTRODUCTION

GEOGRAPHY AND CLIMATE

Svalbard is the geographical name of a group of islands situated between latitudes 74° N and 81° N, and longitudes 0° E and 35° E. The main area consists of the Spitsbergen group, where Spitsbergen is by far the largest island (39,000 sq.km), followed by Nordaustlandet (14.600 sq.km), Edgeøya (5.000 sq.km) and a whole series of smaller islands.

In 1920 the Treaty of Svalbard was agreed to by 15 nations. A novelty in international law, the treaty placed Svalbard under Norwegian sovereignty and law, but also stipulated that the area be open to economic exploitation by citizens of any treaty country. The treaty now has 41 signatories, including all the major powers.

Large parts of the archipelago, consists of mighty, rugged mountains, with steep flanks. In inland areas the permanently frozen ground extends to about 300 m below the surface, considerably less near the coast.

During summer time the uppermost layer thaws down to a depth varying from about half a meter to a couple of meters, depending on weather conditions, exposure, and texture. This is the biologically active layer.

Due to the permafrost, drainage is poor and the groundwater level often lies close to the surface, especially in flat or gently sloping areas, where the ground may be quite marshy. The humidity of the soil, therefore, is sufficient in most localities, and generally it is the short growing season that presents the minimum factor.

VEGETATION

Because of relatively favourable climatic conditions, the vegetation in several parts of Svalbard is more varied and vigorous than that of most other Arctic land areas in the same latitudes. Trees or shrubs in the ordinary sense do not exist. It is a characteristic feature of the plants that they creep along the ground, or grow closely together in mounds in order to seek shelter from the cold and often strong winds, and to take maximum advantage of the life-giving heat of the solar rays.

Because of the extreme growth conditions irreparable destruction may easily be occasioned, for instance by human activity. Revegetation is very slow in these regions, especially on dry soil. Lack of vegetation facilitates the erosion processes considerably. This is one of the reasons why certain specified areas have now been protected by environmental laws.

Besides, regulations are introduced for Svalbard in general to prevent or reduce damage to the environment through human activity. The aim is to create a balance between human activity and preservation of the vulnerable ecological systems in these regions(Hisdal 1976).

ANIMAL LIFE

Apart from the approx. 4.000 polar bears, Svalbard has two other indigenous mammals, the polar fox and the reindeer. Musk ox and hares have been introduced on Svalbard from Greenland but appear to be having difficulty surviving (Hisdal 1976).

In the late nineteenth century the Svalbard reindeer was hunted to near extinction. The remaining stock was totally protected against hunting by law in 1925. It increased from about 1000 to a 1976 population of about 12.000 animals. Animal density is assumed to be positively correlated with vegetation density.

The quantitative relationships between primary production and population density and stability for ungulates in general remains unsolved (Caughley 1970). At Svalbard the reindeer is the only mammalian herbivore and it is free from predation and insect harassement. The present population size is well above the optimal level of 6.000-7.000 animals suggested to be present before human exploitation (Norderhaug 1970). Thus, the question about the islands' carrying capacity for reindeers is pertinent. In the present work Landsat digital data have been utilized in determinations of the summer and winter grazing ranges for reindeer in the valley Adventdalen (Oritsland,1979).

LANDSAT IMAGE USED

For the study the Landsat image 2543-11162 obtained on July 18, 1976 was used. This image is obtained in the best part of the summer, but the sun elevation is only 33 degrees.

It is difficult to determine how much information is lost due to the low sun angle. Discrimination of landsurfaces is of course made more difficult with a low sun angle. On the other hand, the topographic forms seems to be enhanced with the low light.

ER-MAN II

The ER-MAN II system is based on NASA's Earth Resources Interactive Processing System (ERIPS) and consists of a set of software programs that perform a variety of functions related to digital image processing and a display system for user interaction. It runs on an IBM/360 or 370 computer with at least 512 Kbytes of real storage. ER-MAN II is relatively easy to use because it interactively guides the work of the analyst. The architecture of the system also permits the addition of new functions and features by the users.

The display system is a RAMTEK with two screens. One black-and-white screen allows the user to interact with the computer by presenting "menus". The second screen is a color monitor used to display images with a resolution of 512 lines of data, each containing 510 picture elements. The user can input to the menus in one of three ways. He may use the keyboard to enter information, use a trackball (cursor) to point to a decision box on a menu, or point (with a cursor) at the image screen to denote areas for analysis.

The map processor can create an image that can be viewed on either color or grey-level terminal screens; alternatively a character or grey-level map on the line printer. It is also possible to output to a Tectronix hardcopy or an Optronix P-1500 film writer.

METHODS

For the primary Landsat data two approaches were followed for the classification of "vegetation pixels". The first approach (nonsupervised) was to create 8-20 clusters for test areas which could accurately be located on the ground relative to water surfaces, river intersections, gravel deposits, etc. The values corresponding to landscape type were selected: Green vegetation can be separated from other land features by its absorption of light with wavelength 0,6-0,7μm (MSS 5) and reflection of light in the 0,8-1,1μm (MSS 7) band. Water has low reflectance in MSS 5 and close to zero reflectance in MSS 7.

The second approach (supervised classification) was to determine statistics for small uniform fields such as sea water, clay or siltfilled fresh water, gravel, grass/moss range and areas with dry vegetation typical of winter grazing range. Next the values corresponding to the above fields were used in classification of the whole valley. Another valley, Berzeliusdalen, was mapped without ground truthing by means of the same method.

Ratio was included as a possible enhancement technique to compensate for the low sun angle. A land surface will reflect light differently, depending on how it is facing the sun. With the hilly terrain the north side of the valley received the sunlight at nearly a right angle, while the south side experienced light rays almost parallel to the surface. The ratio of the different bands will however vary very little with variation in sun angle.

For construction of conventional vegetation maps with scale 1:50.000, the vegetation is classified in 8 major groups (Brattbakk unpubl.). For the present analysis, however, only two vegetation types separated by the Landsat/ERMAN system were used. One type is characterized as "wet land" vegetation, typically grasses (Dupontia) and mosses (Callerigon and Drepanocladus). This vegetation is found in the summer grazing areas for the animals. The second type is described as dry vegetation, typically containing Dryas, Casiope and Salix. These plants are found in the winter feeding areas.

PROCESSING

The Landsat image was first radiometrically corrected to reduce the striping effect, and then geometrically corrected to UTM projection.

The technique described in this paper makes use of principal component and ratio analysis. This analysis is not applied to the original data but to the combined result of enhanced data, in order to obtain a better enhancement of each part of the image under study.

Clustering is not applied to the full test area, but to small training fields which can be easily recognized as related to recognizable land features. The statistics developed are later applied to the full test area.

The eigenvalues used in the principal component analysis were generally determined using either all the pixels in the test area or only a given set of samples. The eigenvalues are different depending on which samples have been selected. If all the pixels of the image are taken into account, only a "mean" enhancement can be obtained which is not optimum for any part of the image, or similar areas showing the same spectral signature, are correctly enhanced. But if the analysis is applied separately on each multispectral class, a better enhancement can be obtained for each part of the image, whatever its spectral signature may be.

The field work involved a visit to the terrain, and served mainly to select areas suitable for sample elements. Several typical characteristics of the ground cover, which are of interest for spectral imagery, were also observed.

RESULTS AND DISCUSSION

ESTIMATE OF ANIMAL DENSITY

The wet land vegetation had a lower radiance than the dry winter range vegetation both for MSS 6 and 7. Such a separation was not apparent for MSS 4 and 5.

Reindeer population size in Adventdalen was determined by direct counts on the ground. Summer (July-August) and winter (April) census during 1975-78 indicated that 400 - 500 reindeer inhabit the Adventdalen year round. The summer grazing area of Adventdalen was estimated at 34 and 42 sq.km. dependent on the criteria used.

The dry winter range was estimated at 25-62 sq.km. Thus, the animal density found was 9,3-14,7 animals/sq.km. for the summer range and 6,5-20 animals/sq.km. for the winter range. For the total vegetated area in Adventdalen the animal density was 4,0-7,4 animals sq.km. In comparison the total valley area in terms of habitat area, as indicated by the tagging and direct observations of reindeer, was estimated at 414-655 sq.km. representing a density of 0,62-1,2 animals/sq.km.(Oritsland,1979).

PRINCIPAL-COMPONENT-TRANSFORMATION

The principal-component (PC)-transformation is of special significance for data reduction purposes. The PC-transformation represents basically a linear combination of the original bands by calculating the weighting factors for the transformed images via the covariance matrix. For four spectral bands, four new transformed and not correlated images of decreasing information content can be calculated. Experience with multispectral data has shown, that by using the two first components, normally more than 90 percent of the information present in the original bands can be expressed(Donker,1977).(See Fig. 4).

A close study of the Landsat data revealed a marked correlation between MSS channels 4 and 5 and between 6 and 7. It was also a surprise to note that the MSS 6 seemed to contain more detail and information than MSS 7. This condition seems to be special for areas with a very sparse vegetation.

The loadings of the four MSS channels on the first principal component suggest that the first principal component represents a general picture of overall radiance intensities. Every picture element has been transformed:

$$I_{PC_1} = 0.2 \times I_4 + 0.3 \times I_5 + 0.8 \times I_6 + 0.3 \times I_7$$

Table 1 Variance-covariance matrix, calculated from the four spectral intensities of the sample set of picture elements.

	MSS bands			
	4	5	6	7
4	4.64			
5	5.95	10.17		
6	2.92	5.05	20.78	
7	-0.13	0.15	8.36	6.06

Note the relatively low variance (4.64) of MSS band 4, and the relatively high variance (20.78) of MSS band 6. The sum of the diagonal elements is the total variance (41.65).

Table 2 Eigenvalues and matrix of eigenvectors

		EIGENVECTORS			
		1	2	3	4
	4	0.200	0.492	0.069	0.844
MSS	5	0.334	0.750	0.205	-0.533
band	6	0.854	-0.266	-0.447	-0.011
	7	0.345	-0.353	0.868	0.053
EIGENVALUES:		26.82	12.22	1.78	0.84
trace =		41.66			
Percentage of total variance contributed by each eigenvalue		64.38	29.33	4.27	2.02
Cumulative percentage		64.38	93.71	97.98	100.00

RATIO

A test was made to separate the individual ratios which contributed with the most information (variance), and should be included in the classification. With a dataset which included the four original MSS bands and the possible twelve ratio combinations of the same bands, a divergence test was made. In the first test (Table 3) it was specified that the new dataset should consist of 3 new bands. The result was that the best combination should include the original bands MSS 5 and 7 and a ratio of the two.

The second test requiring a dataset with four new bands (Table 3) resulted in a combination of the original bands MSS 4, 5 and 7 and the ratio 4/5.

Table 3

Best dataset with 3 bands:			
1.	5	7	7/5
2.	4	4/5	5
3.	5	6/7	7
4.	5	6/5	7
5.	6/5	7	7/5

Best dataset with 4 bands:				
1.	4	4/5	5	7
2.	4	4/5	5	7/4
3.	4	4/5	5	7/5
4.	4	4/5	4/7	5
5.	4	4/5	5	6/5

SEPARATING SOIL BACKGROUND

For mapping of surface vegetation it is a requirement to know the soil background signals which are superimposed on, or intermingled with, information about the vegetation. This is specifically significant when working with the sparse vegetation of the polar regions.

Kauth and Thomas (1976) determined that the data space distribution of soil reflectance variation in Landsat data is confined to a line or a plane in two- or three-dimensional data space. Reflectance variation of developing vegetation grows perpendicularly out of the soil background plane.

The measured CCT values were used to determine the Kauth's plane of soils (Fig.3). The best fit linear line for bands 5 and 7 is shown. The line has the equation: MSS 5 = 0.66 MSS 7 - 10

Field collected data were plotted with their CCT values relative to the plane of soils. Each type of vegetation has a certain biomass value assigned to it, and each datapoint deviates perpendicularly from the bare soil background line. Vegetation with a high biomass content also tended to be displaced furthest from the line. This indicated that a measure could be established for the biomass content as a function of distance from a line. Water deviates from the soil background line, but on the opposite side (Richardson, 1977).

VEGETATION INDEXES

Kauth and Thomas (1976) have developed a technique for transforming the information contained in four-dimensional data space into a soil brightness index (SBI) and a green vegetation index (GVI):

$$SBI = 0.433\ MSS\ 4 + 0.632\ MSS\ 5 + 0.586\ MSS\ 6 + 0.264\ MSS\ 7$$

$$GVI = -0.290\ MSS\ 4 - 0.562\ MSS\ 5 + 0.600\ MSS\ 6 + 0.491\ MSS\ 7$$

For the training areas in Adventdalen which contained vegetation we determined the principal components and found the following values:

$$PC_1 = 0.20\ MSS\ 4 + 0.33\ MSS\ 5 + 0.85\ MSS\ 6 + 0.34\ MSS\ 7$$

$$PC_2 = 0.49\ MSS\ 4 + 0.75\ MSS\ 5 - 0.27\ MSS\ 6 - 0.35\ MSS\ 7$$

We have a close relationship between the soil brightness index (SBI) and the first principal component (PC_1). The green vegetation index (GVI) is also related to the second principal component (PC_2).

CONCLUSIONS

The ERMAN system for digital analysis of Landsat data is used in mapping of Svalbard reindeer range. The work is focused on the valley Adventdalen which held about 500 reindeer in 1976. Classification of primary data and data transformed by principal components methods yielded summer grazing areas of 35 to 43 km^2. The winter range area varied from 25 to 63 km^2 and depends on the classification criterias used. The present animal density is above the level recommended for reindeer herding in Norway and control of parts of the population is recommended.

The conclusion is that both the soil background line (plane), where the distance from the line is a measure for the biomass, and computation of the principal components for the vegetative areas both are viable ways to go in an arctic environment.

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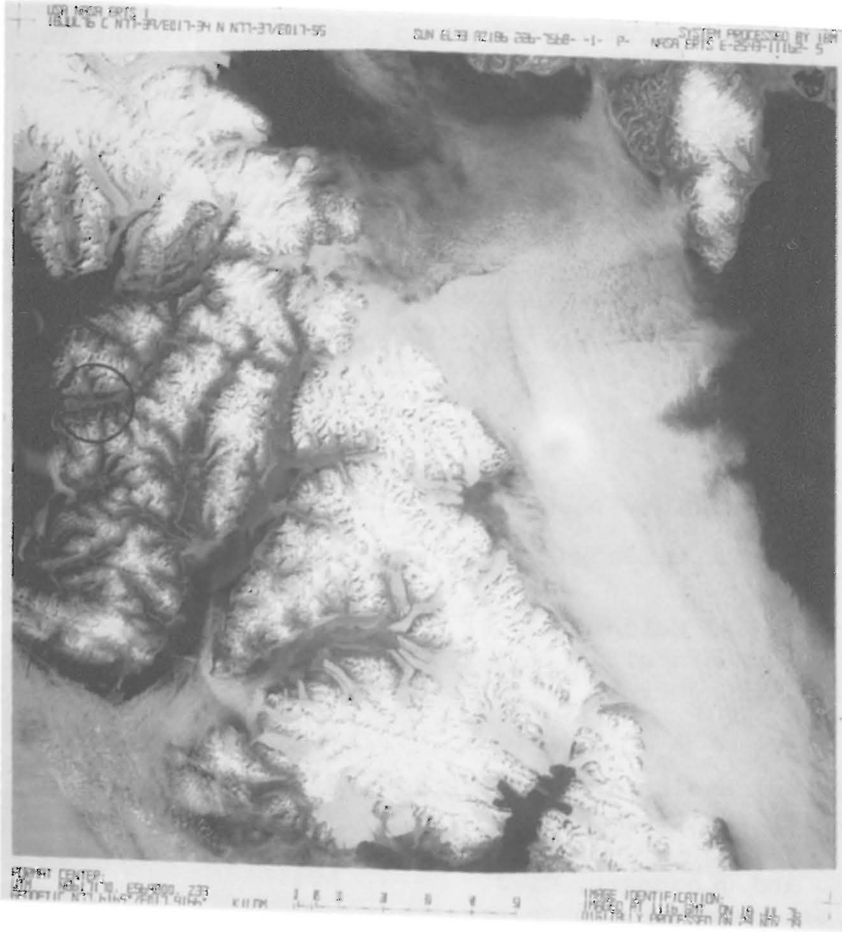

Fig 1. Landsat image 2543-11162-5 used for the analysis. The image covers an area of 180 x 180 km. Circle indicate Adventdalen.

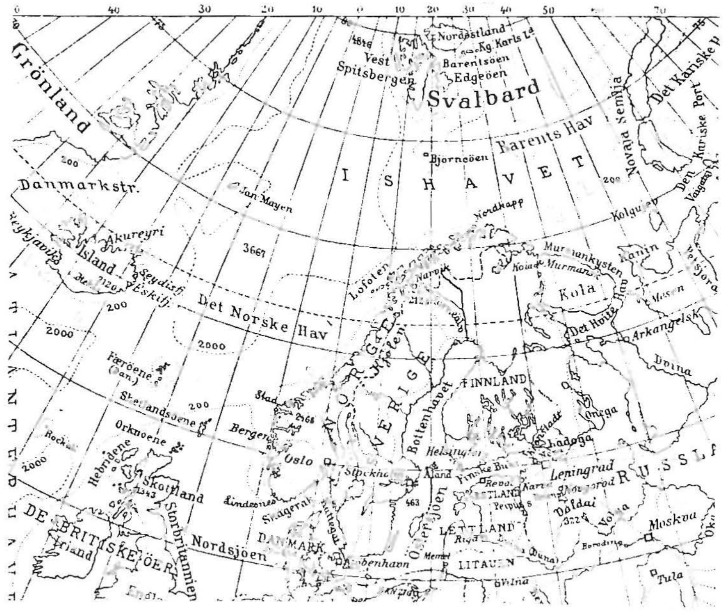

Fig 2. Location of Svalbard at 75^{o}n.

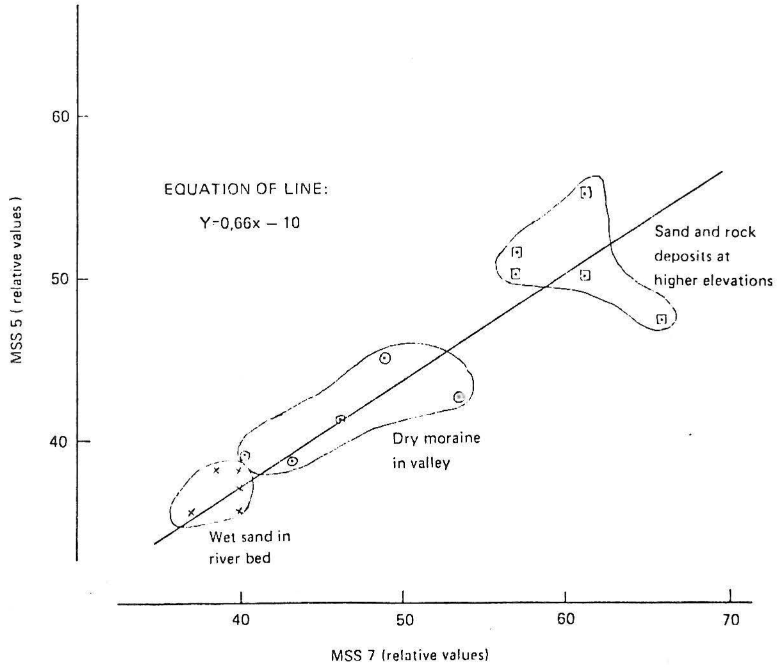

Fig 3. Plot showing relationship for bare soil without vegetation.

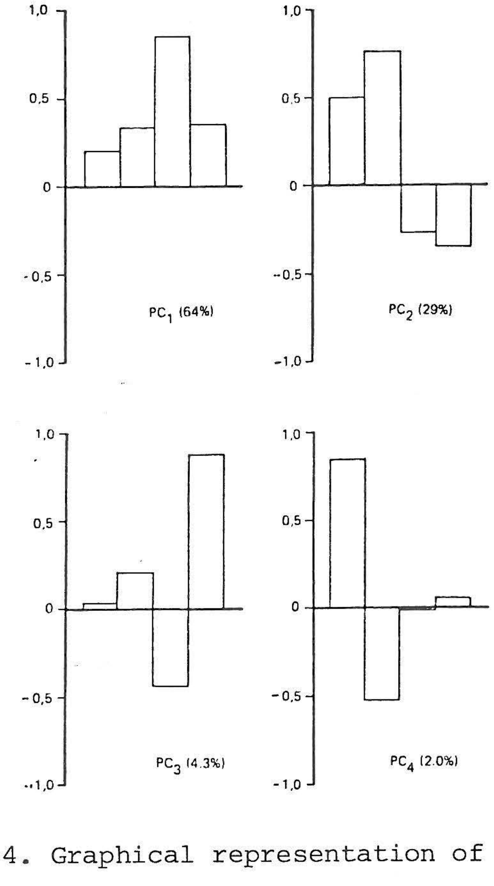

Fig 4. Graphical representation of the eigen-vectors used to establish the new principal component bands.