14th Congress of the International Society for Photogrammetry, Hamburg 1980.

Commission VII, Working Group 9

Presented Paper

Sipi Jaakkola and Pekka Saukkola
Technical Research Centre of Finland

# SPECTRAL SIGNATURES OF FIELD LAYERS AND CANOPIES OF PINE FOREST STANDS IN NORTHERN FINLAND

## Abstract

Spectral signatures of Scots pine stands were determined in Northern Finland both in laboratory and field conditions using a telespectroradiometer system. In the first part of the study, surface vegetation samples were measured both in laboratory and outdoors. The samples were taken from the ground- and field layers of mature Scots pine stands. The objective was to study the impact of surface layer on the spectral radiation reflected from timber stand.

In the second part of the study the spectral signatures of pine forests representing one site type but variable development classes were measured from a helicopter. The objective was to acquire spectral knowledge for numerical timber type classification.

In the paper, the measuring conditions, techniques and the results achieved are reported. The resulting spectral signatures are expressed numerically and illustrated graphically. The statistical significances of the differences between targets are also reported.

## 1. Introduction

The Laboratory of Land Use at the Technical Research Centre of Finland has participated in the work of the WG9/Commission VII in 1976-80 by performing various studies on the spectral signatures of timber stands. In the studies, helicopter has been used as a platform for telespectroradiometer measurements. This approach has been chosen in order to record the integrated spectral signatures of timber stands consisting of various reflectance components.

In the study at hand, the signatures were measured separately for the field layers and canopies of Scots pine stands growing in North-Finland. The objective was, first, to analyze the characteristic reflectance properties of the vegetative ground- and field layers of various forest site types. In the canopy approach, the spectral signatures of pine stands representing one site type but variable development classes were measured from a helicopter.

## 2. Measuring conditions

### 2.1 Field layer approach

In the field layer study, the surface analyzed consisted of the ground and field layer vegetation of four forest site types appearing and defined for North-Finland: HMT, EMT, MCClT and ClT. The characteristic species of each site type are listed in Table 1.

TABLE 1. The ground and field vegetation species characteristic to the forest site types studied (Source: J. Lehto: Käytännön metsätyypit. Kirjayhtymä, Helsinki, 1978.)

| Forest site type | Ground layer species | Field layer species |
|---|---|---|
| Hylocomium-Myrtillus Type (HMT) | Hylocomium splendens<br>Pleurozium Schreberi<br>Cladonia rangiferina<br>Nephroma arcticum | Vaccinium myrtillus<br>Vaccinium vitis-idaea<br>Empetrum nigrum<br>Ledum palustre<br>Vaccinium uliginosum<br>Linnaea borealis |
| Empetrum-Myrtillus Type (EMT) | Cladonia silvatica<br>" rangiferina<br>Pleurozium Schreberi<br>Dicranum fuscescens | Empetrum nigrum<br>Vaccinium myrtillus<br>Vaccinium vitis-idaea |
| Myrtillus-Calluna-Cladina Type (MCClT) | Cladonia silvatica<br>" rangiferina | Calluna vulgaris<br>Empetrum nigrum |
| Cladina Type (ClT) | Cladonia alpestris<br>Stereocaulon paschale<br>Cladonia spp.<br>Polytrichum juniperinum<br>" piliferum | - |

From every site type, 40 samples were chosen, carefully detached, put into boxes and transported to laboratory for spectral measurements. The geographical locations of the samples were as follows:

| | | | | |
|---|---|---|---|---|
| HMT | 26° 42' 35'' E/ | 66° 19' 25'' N/ | 260 m | A.S.L. |
| EMT | 25° 53' 23'' E/ | 66° 58' 56'' N/ | 250 m | " |
| MCClT | 25° 44' 51'' E/ | 66° 56' 08'' N/ | 230 m | " |
| ClT | 26° 03' 10'' E/ | 66° 15' 33'' N/ | 180 m | " |

The tree canopy coverage in sample sites was 20 to 30 % in terms of crown projection. The samples were measured with a telespectroradiometer on July 13 to 14, 1979 in the laboratory and on August 1, 1979 outdoors under direct solar illumination. In the laboratory, the samples were measured before and after irrigation. In the outdoor measurements the samples represented normal moisture conditions.

In the laboratory, the angle of illumination source was 45° and the proportion of indirect illumination about 15 %. The temperature was 20°, and the distance between the sample and instrument was 90 cm. The outdoor-conditions of measurements were as follows: day August 1, 1979, hour 13.00 to 16.00, sun elevation 35°, proportion of indirect illumination 13 %, distance between the target and instrument 90 cm.

The field of view of the telespectroradiometer was 10° which corresponds to the IFOV-diameter of 14 cm at the target. The wavelengthbands used were a continuous set of 20 nm intervals between 390 and 990 nanometers.

The reflection standard adopted was a $BaSO_4$-surface with about 98 % reflection capability. It was measured under the same conditions and specifications as the target itself.

2.2 Canopy approach

In the forest canopy study, the targets were chosen among the Scots pine stands growing on relatively dry mineral soil types in Kainuu, Finland. The sample stands chosen represented the typical variability of managed pine stands according to stocking, maturity, stem size and density as well as the species distribution of the field vegetation. The location of the site was 29° 23' 50'' E/ 64° 17' 20'' N.

The conditions of telespectroradiometer measurements were as follows:

- day June 29 and 30, 1978
- hour 11.10 - 14.00
- sun elevation 41.5° to 45.5°
- sun azimuth 340° to 38°
- observation angle 0° (vertical)
- measuring height 100 m

The instrument had a field of view of 10° which corresponded to a diameter of 18 m at the target. The wavelength band of 20 nm was varied within the interval of 390 to 990 nanometers.

The reflection standard used was made of white cardboard and spread on the ground for the measurements. These were performed at the height of 10 m due to the size of the standard. The spectral properties of the standard are illustrated in Fig. 1.

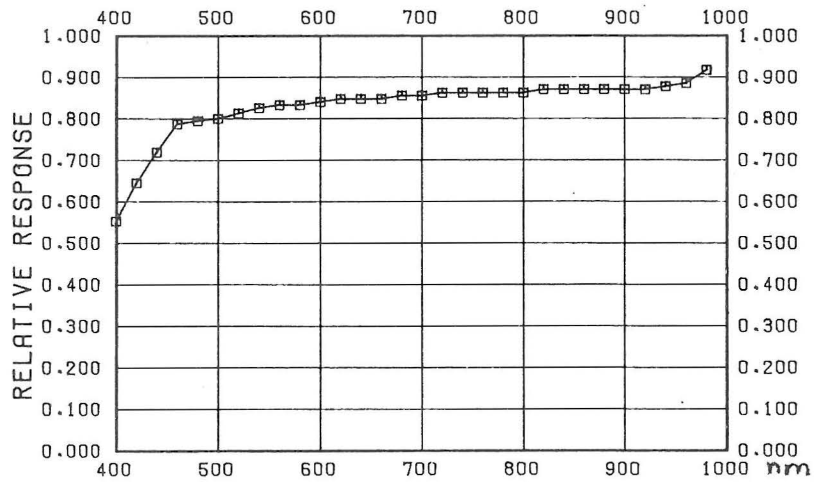



Figure 1. Relative response of the reflection standard used in the connection with Scots pine canopy measurements.

## 3. Measuring and analysis techniques

### 3.1 Telespectroradiometer system

The telespectroradiometer used in the study is a light-weight system consisting of conventional components, as illustrated in Fig. 2. The nominal spectral range of the detector is 400 to 1100 nm. The motion of the instantaneous wavelength band is implemented by stepping motor. The results are digitized and recorded on C-cassette. Each measurement through the spectral range takes about 15 seconds.

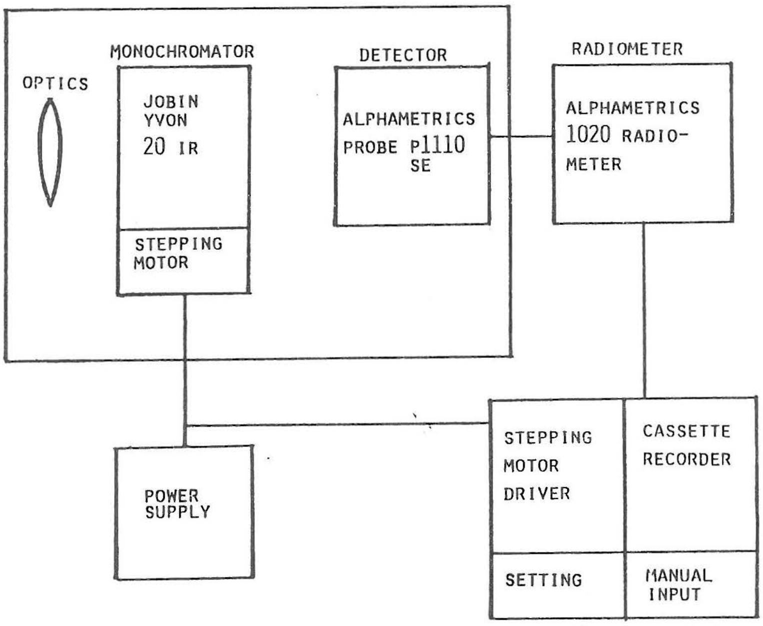



Figure 2. Block diagram of the telespectroradiometer system used in the study. The system is both AC- and DC-compatible.

### 3.2 Field layer measurements

During the field layer vegetation measurements in the laboratory, the samples detached from the various site types were, one by one, illuminated with a lamp, as shown in Fig. 3. Both the samples and the reflection standard, one after another, were placed under the optics for recording their reflected radiation.

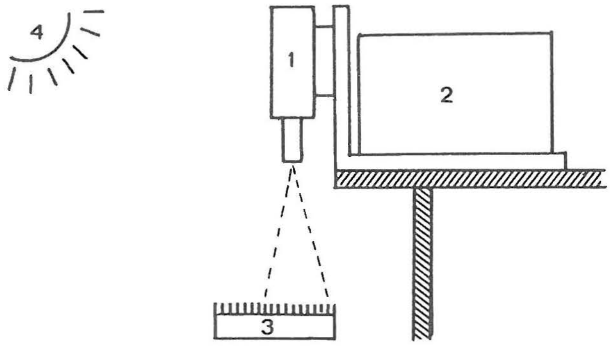



Figure 3. The arrangement of the measuring unit (1) and recording unit (2) of the telespectroradiometer system. The sample or reflection standard (3) was illuminated by a lamp (4).

The same arrangement was used in outdoor measurements, only the illumination was received from the sun. A total of 160 samples, 40 from each site type, was measured in a randomized order.

### 3.3 Canopy measurements

When implementing the reflected radiation measurements of pine stand canopies, each sample plot was first spotted with the help of cross targets put in the ground. The helicopter was then held above the plot (or standard) for 15 seconds to allow the recording (Fig. 4). The total number of observations was 80.

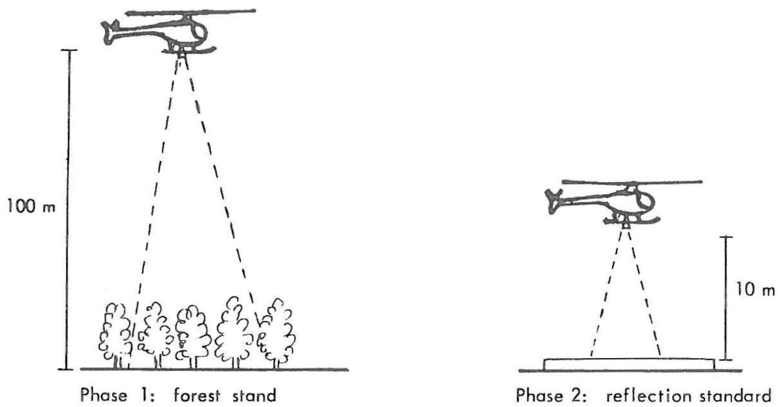



Figure 4. Implementation of the spectral measurements of the forest stand canopies and the reflection standard.

### 3.4 Data analysis

The data stored on cassettes was computer-processed by, first, performing the calibration and ratioing of the measured values by 20 nm intervals. The reflectance factors were then calculated and stored together with the corresponding ground truth data. The graphs of the observations were plotted for screening their quality.

Finally, the various statistical analyses and tests of significance were run, as illustrated in Fig. 5. The graphs of the reflectance factors and major results of the analyses were plotted as well.

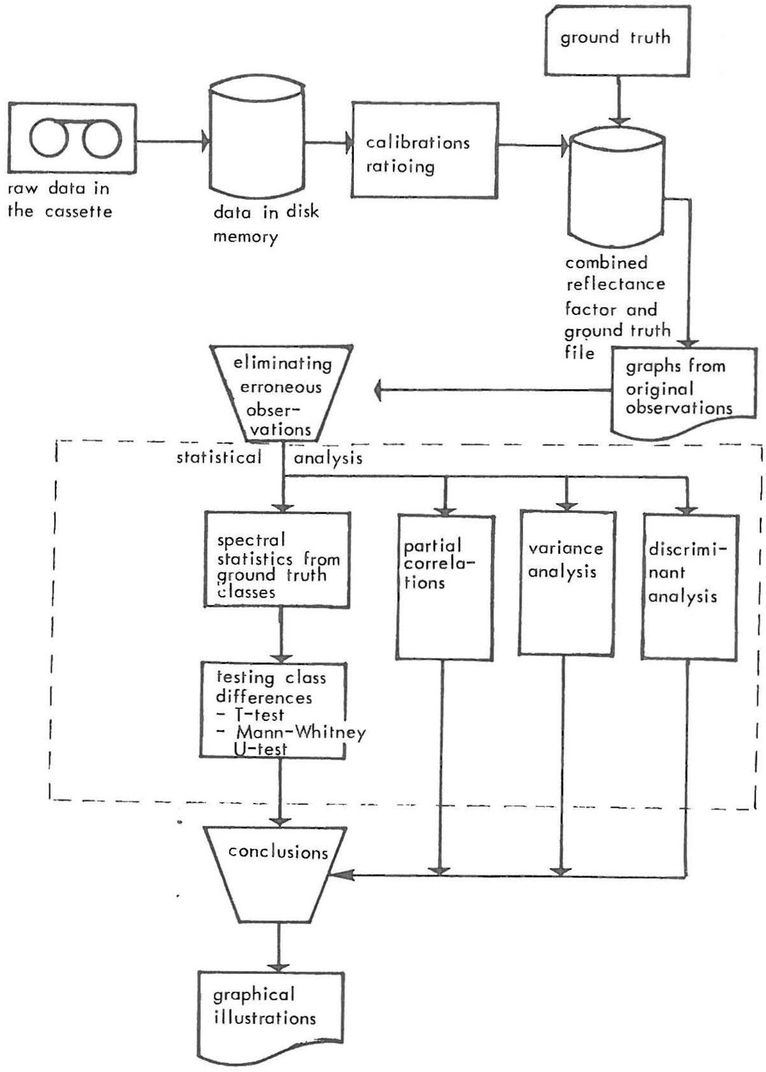
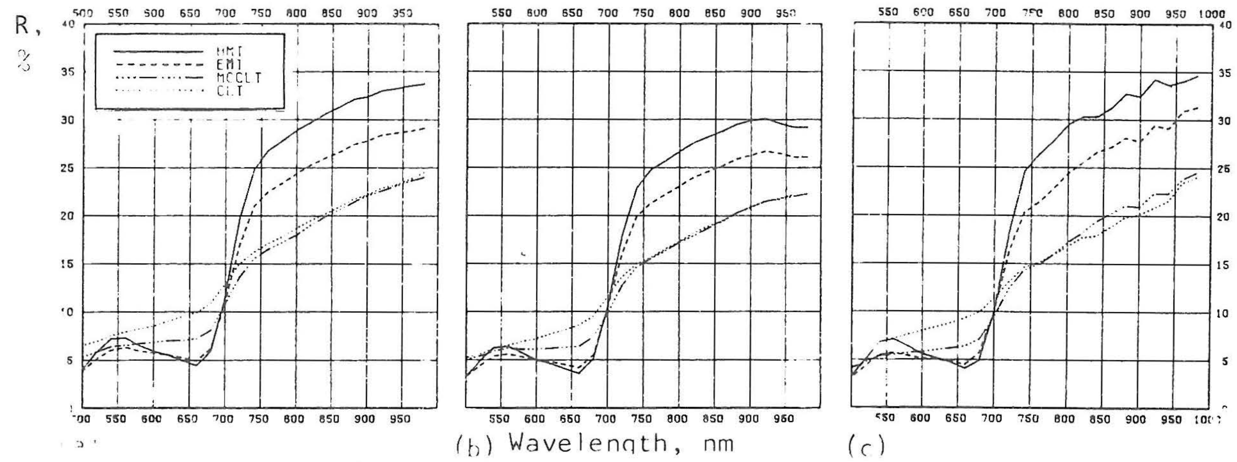



Figure 5. Block diagram of the preprocessing, statistical analyses and plotting of the spectral measurements.

## 4. Results

### 4.1 Spectral signatures of the field layers of various site types

As a result of the field layer vegetation analysis, the graphs of spectral signatures were plotted for every site type and treatment. Fig. 6 shows that the results were largely independent of the illumination source and of the irrigation. The most interesting wavelength bands seem to be red and reflective infrared. HMT-type assumes the lowest values on red and highest of all on infrared band. EMT-type follows largely the same pattern, whereas MCCIT- and CIT-types have high and separable signatures on red, and low mixed values on infrared.



(b) Wavelength, nm (c)

Figure 6. Graphs illustrating the spectral signatures of the field layer vegetation growing on the site types HMT, EMT, MCCIT and CIT: (a) nonirrigated, (b) irrigated samples measured in the laboratory, (c) nonirrigated samples measured outdoors.

The statistical analysis of the field layer signatures resulted in the outcome illustrated in Fig. 7. On the basis of the figure, MCCIT and CIT indicate a relatively good separability on the visible bands, and HMT is marginally separable from EMT on the infrared bands. The best way to separate EMT from HMT seems to be, however, to apply the ratio between the green and red bands.

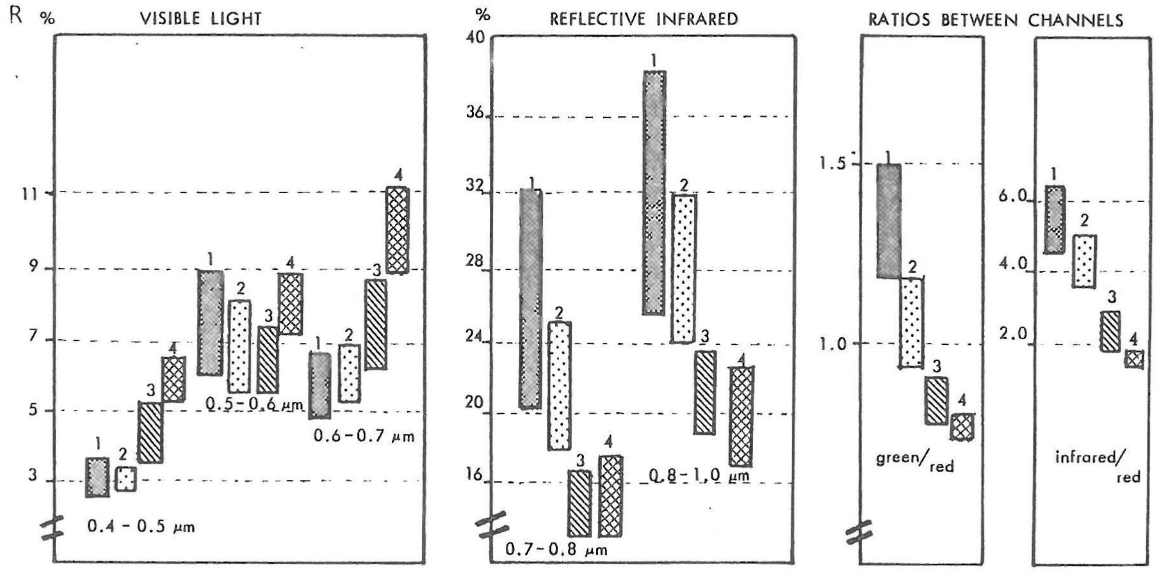



Figure 7. Spectral signatures of the field layers of the site types HMT (1), EMT (2), MCCIT (3) and CIT (4). The columns illustrate the variation (s) about the mean ($\bar{x}$) for three visible light and two infrared bands. Two ratios of the signatures (green/red, infrared/red) are also shown to illustrate the improvements in spectral separability among site types.

The potential separability among the site types referred to in Fig. 7 was analyzed more thoroughly by applying the Mann-Whitney U-test for pairwise differences. The test results are summarized in Fig. 8. As the figure shows, it is relatively easy to find wavelength bands that would provide a good separability among the types. In particular, the various ratios of spectral bands show high significances for the pairwise differences.

| Class pair \ Variable | Refl. factors by nanometer intervals | | | | | Ratios | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R 410-490 | R 510-590 | R 610-690 | R 730-790 | R 810-990 | R(550)/R(660) | R(510-590)/R(610-690) | R(730-790)/R(610-690) | R(810-990)/R(610-690) |
| HMT-EMT | - | xxx | - | xxx | xx | xxx | xxx | xxx | xxx |
| HMT-MCClT | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| HMT-ClT | xxx | x | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| EMT-MCClT | xxx | - | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| EMT-ClT | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx | xxx |
| MCClT-ClT | xxx | xxx | xxx | - | x | xxx | xxx | xxx | xxx |

Figure 8. Pairwise separability of the site types for various wavelength bands and their ratios. The significances of differences obtained by Mann-Whitney U-test are expressed as follows: xxx/highly significant (0,1 %), xx/significant (1 %), x/almost significant (5 %).

## 4.2 Spectral signatures of the Scots pine stand canopies

The spectral signatures of pine stands were analyzed in order to evaluate the spectral effect of stocking class, timber volume and basal area. The major results are summarized in Fig. 9, 10 and 11.

The average spectral signatures of the five stocking classes studied are illustrated in Fig. 9. The clear cut areas are separable from other classes, particularly on the red wavelength band. The differences between other classes are smaller, yet significant on certain bands as shown by Fig. 10. Highly significant differences between seedling stands and other classes appear on the green, red and near infrared bands. The young thinning stands differ from mature thinning stands on the 700 to 800 nm-band and from mature stands, in addition, on 500 to 600 nm-band. The maximum separability between the nearly mature stand and mature stand is achieved on the bands 540 to 580 and 600 nm, although the differences are not highly significant.

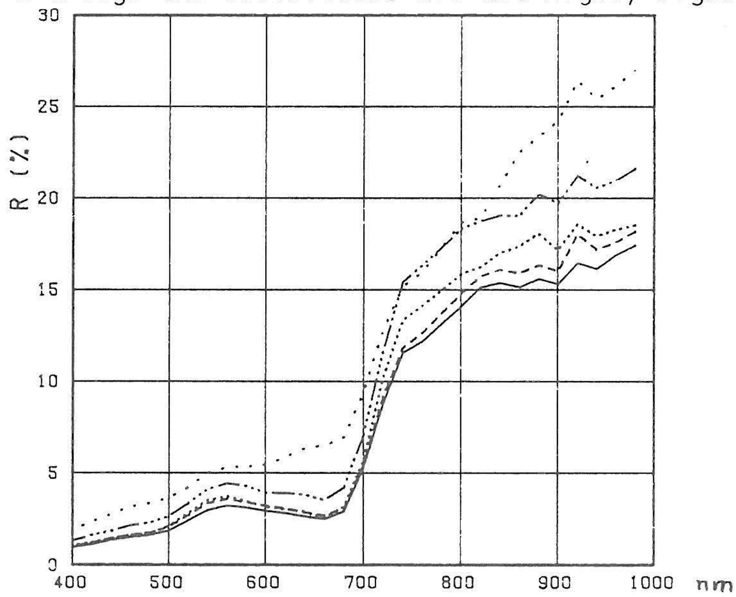



Figure 9. Graphs illustrating the average spectral signatures of pine stands in five stocking classes: . . . clear cut, ....-....- seedling stand (16 obs.), ..... thinning stand (20 obs.), ---- nearly mature (18), and —— mature stand (22).

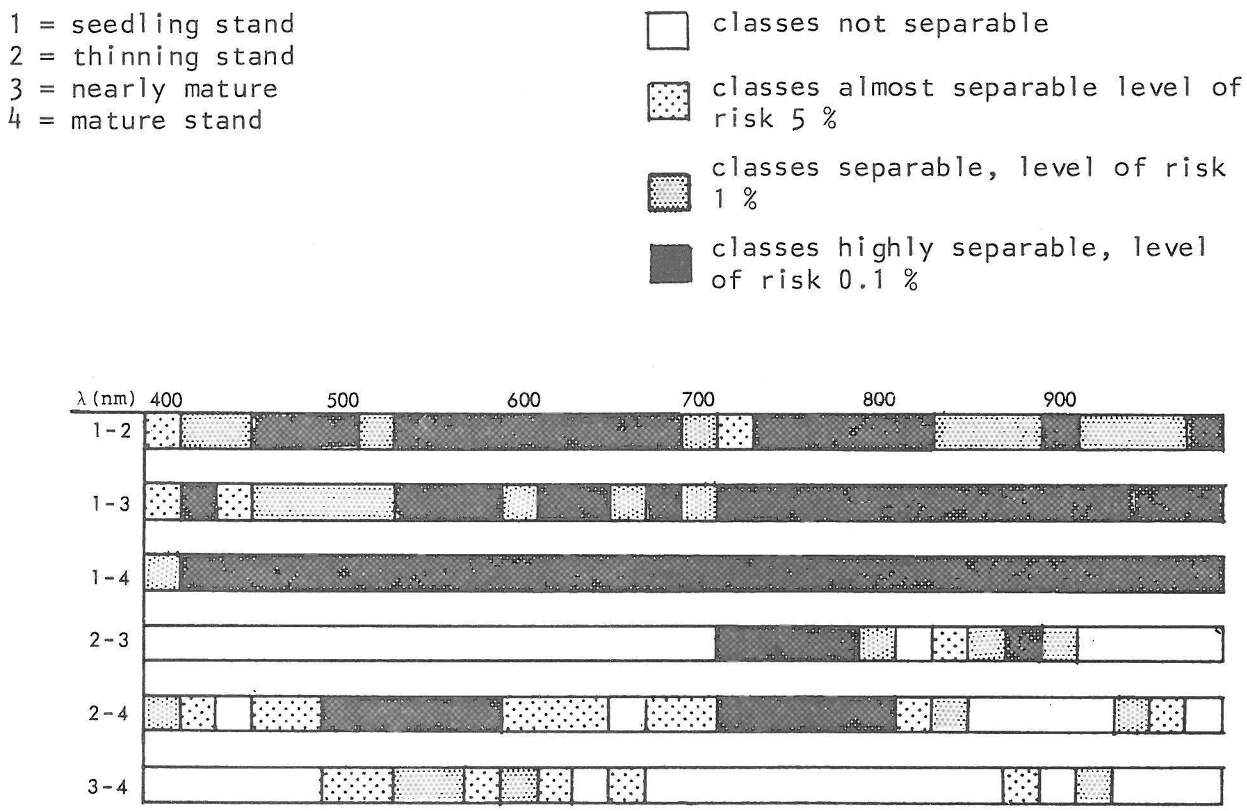



Figure 10. Pairwise separability of the stocking classes of pine stands as a function of spectral wavelength bands (Mann-Whitney U-test).

The impact of timber volume (V) and basal area (G) on the spectral reflectance factor was analyzed separately from stocking class. In a stepwise regression analysis, the volume or basal area or their transformation was chosen for independent variables. Basal area represented the stand density in the analysis.

The main results of the analysis are summarized in Table 2. The effect of timber volume is concentrated on the green band, where also the $R^2$ of the model is highest. On the blue and red bands, the basal area (density) is significantly better independent variable than volume. In the infrared region, the best independent variables are V and V·G. The peak of the explanation power of model (0.7) appears on band 730 to 790 nm. The value of infrared bands as dependent variables is reduced by the fact that the spectral differences between tree species are large.

TABLE 2. Timber volume (V) and basal area (G) as the explaining factors of the spectral signature of stand.

| R(λ) | $R^2$ | Indep. variables in the order of explanation power |
|---|---|---|
| 390 - 510 nm | 0.35 - 0.50 | G, $G^2$, $V^2$ |
| 510 - 550 nm | 0.50 - 0.60 | V, V * G, $G^2$ |
| 550 - 570 nm | 0.60 | V, V * G, $V^2$ |
| 570 - 650 nm | 0.55 | G, $G^2$, $V^2$ |
| 650 - 690 nm | 0.55 | G, $G^2$ |
| 710 - 990 nm | 0.40 - 0.70 | V, V * G |

The impact of field layer vegetation on the spectral signature of the whole timber stand was also studied in the canopy approach. The problem is of interest, especially, in site type interpretation from various imageries. Fig. 11 illustrates the spectral partial correlations of the area proportions of field layer species to the reflectance factor values. The effect of timber volume was eliminated. One can conclude from the figure that the abundance of Vaccinium myrtillus in the field layer correlates negatively to the reflectance factor values of 600 to 700 nm-band. Empetrum nigrum has a similar effect on the values of infrared bands. Bush in the field layer correlates positively to the reflectance factor values on blue and green bands. In summary, the analysis of partial correlations seems to give information on the background component of the spectral signature of timber stand.

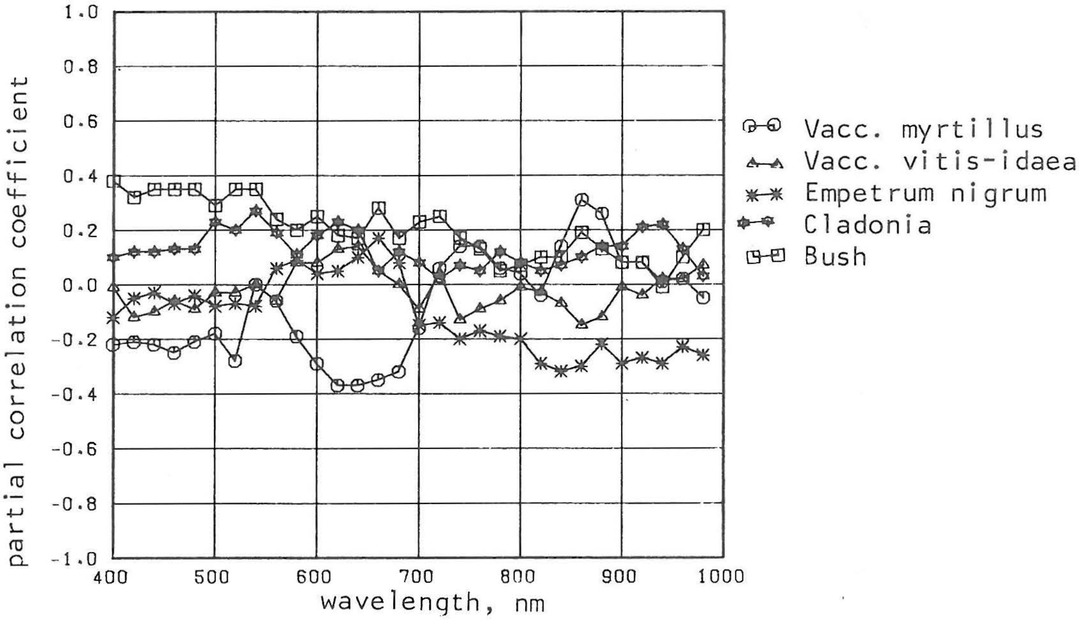



Figure 11. Correlation of the area proportions of field layer species to the spectral signature of Scots pine stand.

## 5. Conclusions

On the basis of the spectral signature studies performed in the conditions of North-Finland using the field layer and canopy approaches, the following conclusions seem justified: 1) The field vegetation of Scots pine stands is spectrally characteristic to each site type studied, and thus allows for multispectral interpretation of site types from remotely sensed data. 2) The correlation of the spectral reflectance factor of stand to the timber volume, stocking class and basal area is high enough to enable the interpretation of various stand characteristics from multispecrtral imagery.

In particular, the green wavelength band looks most informative for the evaluation of stand timber volume and stocking class. One can, finally, hypothesize that the interpretation of stand timber volume could be done, largely, on Landsat-band 4, and the interpretation of site type on bands 5, 6 and 7.