FOREST DAMAGE INVENTORY BY REMOTE SENSING METHODS.

EXPERIENCES FROM SWEDEN

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Abstract

The paper summarizes current research results from the Remote Sensing Laboratory, University of Stockholm that may from different aspects contribute to the discussion about forest damage inventory methods. The results of an extensive air photo survey of forest damage in western Sweden are presented; these are also related to a Landsat TM data set acquired on the same date. Spectral data,acquired from a helicopter over damaged coniferous forest stands, are presented and significant spectral parameters and 'confusion objects' are discussed. The prospects of satellite-based damage inventory methods are evaluated with special reference to the Swedish situation regarding forest damage and forest types. At present it is unlikely that a satellite-based forest damage assessment could provide sufficiently accurate information. The main background for this conclusion is the spectral similarities between damaged spruce stands and mixed stands of spruce and pine. Closed homogeneous and healthy spruce stands have a more or less unique spectral signature, but in the case of damaged spruce several other forest types can cause serious misclassification. The patchy occurrence of damaged trees within the forest aggravates the problem.

Introduction

The increasingly widespread forest decline attributed to the effects of air pollution reported from many countries in middle Europe in the early 1980's has drawn attention to the situation in the Swedish forest.

There was a need to get detailed information about the distribution of the 'new forest damage' within the most affected regions in south-western Sweden. Previous experiments at our laboratoy of using infrared aerial photographs for early detection of bark beetle infestations of Norwegian spruce (Arnberg and Wastenson 1973) have been carried out. Based on this experience and inspired by the successful use of large-scale aerial photographs in central Europe (e.g. Hildebrandt and Kadro, 1984; Schöpfer and Hradetzky, 1984; Katzmann, 1984) we investigated the possibilities of identifying and classifying the intensity of the needle loss of Norwegian spruces in Swedish forest types (Holmgren and Wastenson, 1985). In the present paper the result of an applied inventory in the southwestern part of Sweden is presented.

At the Laboratory of Remote Sensing, University of Stockholm an inventory of the needle loss of Norwegian spruces has been performed in the county of Göteborgs and Bohuslän and the western parts of Älvsborgs län (Wastenson and Wastenson, 1987)

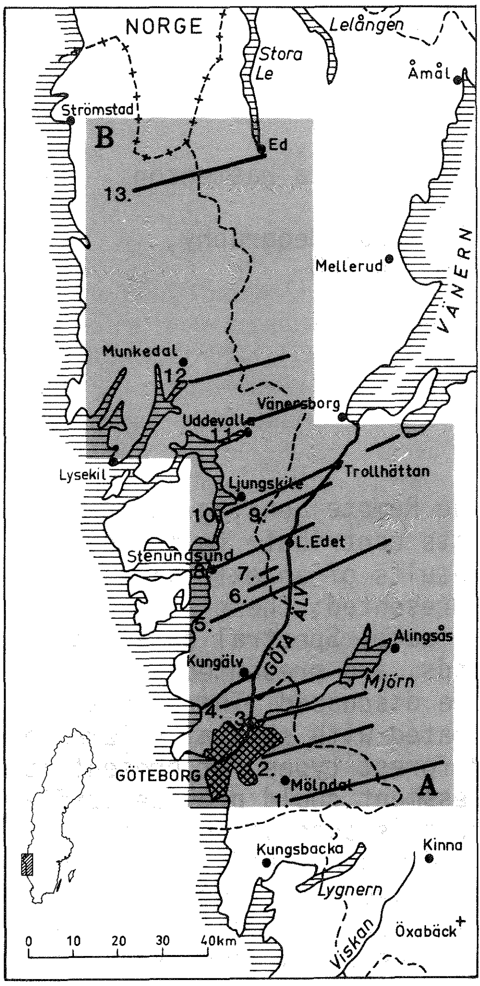

Figure 1. Map showing the strips of aerial IR-colour images on the scale 1:10 000 in which the inventory of the needle loss of Norwegian spruce has been performed. The coverage of the two maps showing the inventory result is marked in grey tone

The inventory is restricted to Norwegian spruce trees older than 40 years. The aim of the study is to investigate the geographical distribution of forest damages, to establish the damage level for the region and to document the situation for future comparisons.

About 400 IR-colour aerial photographs in 12 strips were photographed by the National Land Survey (figure 1) on 26 july 1985. On the same day a Landsat TM scene covering the area was registered. Strip number 11 was photographed on July 1986. The negative scale was 1:10 000. The strips were oriented in WSW - ENE direction in order to get profiles from the coast to inland and in order to get stereo models where the colour balance was similar in the two images of the stereo pair. The influence of the direction of the sun's illumination has been minimized. Each strip covers a width of about 2 km. The positions of the strips are random with regard to the damage situation.

The film used, Kodak 2443 Ectachrome Infrared, was developed with the negative process C22, which is the normal procedure at the National Land Survey. This gave us a good possibility to specify the colour balance of the diapositives for the inventory purpose.The interpretation has been performed in a Wild Aviopret stereoscope.

The inventory started with a field survey and observations from a small aircraft within all the inventory strips. This was done in order to calibrate the interpreter and to correlate the colour difference of the spruce trees in the photographs with the degree of the needle loss. The colours in the aerial photograph are quite different in different parts of the picture, due to the anisotropic directional reflectance properties of the forest. Therefore the used colour scale for classification is relative. Calibration was also done against other experienced field surveyors, in order to find a comparable level to other investigations based on observations from the ground. The comparison between ground observation and air photo interpretation has shown that the identifiable colour differences of the spruce trees (from brown/magenta to rose-pink coloured and further to different blue colour tones) approximately correspond to the following classes of needle loss:

1. 0- 10% of needle loss - no sign of damage
2. 11- 30% - slightly damaged
3. 31- 60% - damaged
4. 61- 80% - severely damaged
5. 80-100% - very severely damaged and dead

A systematically-arranged square grid with a cell size of 10X10 mm is used on the aerial photographs. The inventory area is thus about 1 hectare. In every area containing more than 25 spruce trees older than 40 years the frequency of spruces in the five needle loss classes has been determined by air photo interpretation. The determination has been performed in a generalized way by marking a code of three digits in each test area: the first marks the dominating class (2-3/6 of the spruces), the second the subdominating class (1-2/6) and the third another involved class (1-2/6). Based on the code an approximate mean value of the needle loss for each area can be calculated. The inventory includes in total about 15 000 inventory areas of the size 1 hectare.

The inventory results are presented in diagrams in two maps. An example from one of the maps are given in figure 2. For each inventory strip the percentage of the inventory areas in the five needle loss classes is presented in pie charts. The number of test sites in each strip is given in the map. The variation of the damage within each strip is shown in the bar diagram covering the geographical position of the strip. Each bar marks the percentage of test sites in the five damage classes within the area covered by the car. As a minimum each bar represents 10 test sites.

The investigation has shown that there are large regional variations of the forest damages, with the lowest level in strip 13 in the north at Strömstad-Ed and the highest level in the area between Stenungsund and Trollhättan (strip 5-10). The regional variations have been summarized in figure 3. In this diagram a comparison is also made with the damage situation in Baden-Württemberg in 1984 for Norwegian Spruce of comparable age (Schöpfer and Hradetzky, 1984).

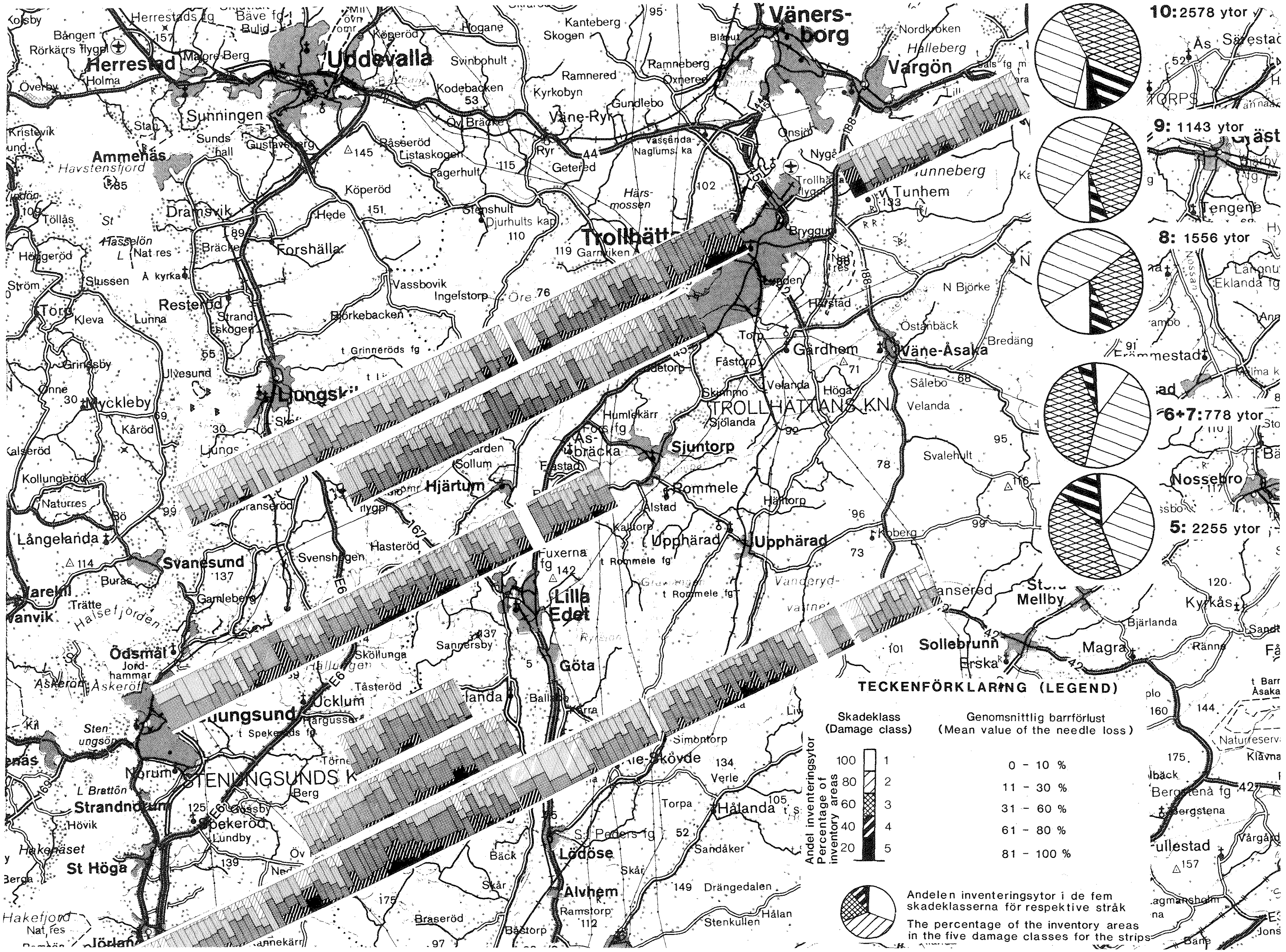

Figure 2. Part of a forest damage inventory map from the Stenungsund - Trollhättan area in Sweden.

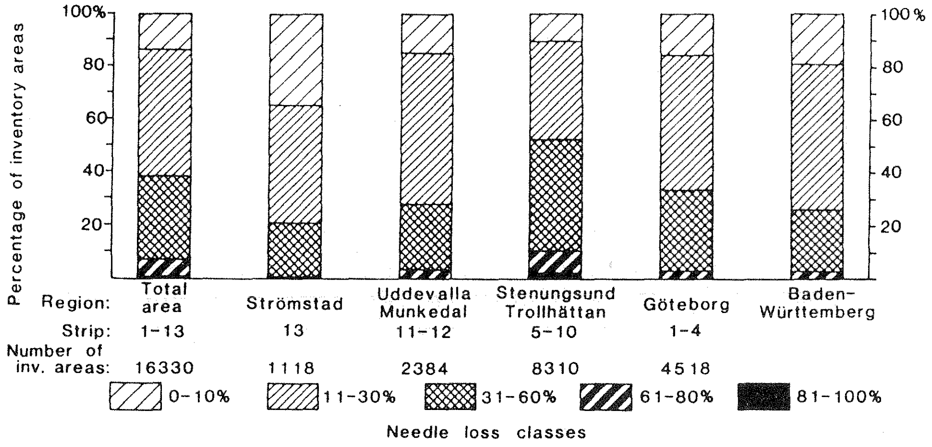

Figure 3. A summary of the regional variations on the investigated area,1985. The diagram shows the frequency of inventory areas of 1 hectare on the five needle loss classes. Only areas with more than 25 Norwegian spruces older than 40 years are involved. A comparison is made with the damage situation in Baden-Württemberg 1984, where the inventory was based on air photo interpretation of single trees in a systematic sample.

The used inventory technique provides a good base for further investigations of the correlation between the needle loss and geographical position and different stand factors. In figure 4 the variations of the intensity of the needle loss is shown in a digital terrain model produced from the aerial photographs. The interpretation of all the 15 000 test areas and all the observations from ground and from aircraft have given us a good view about the detailed pattern of the damage and the variety in stand parameters.

Spectral properties of damaged coniferous tree stands

In air photo interpretation, spectral and textural properties of single tree crowns are actually observed and separated from the background, whereas satellite-based methods must rely on the integrated spectral response from the canopy and the background.

In order to obtain a basic knowledge about the spectral properties for Swedish forest types, radiometer measurements from a helicopter have been performed since 1981. Spectral data for homogeneous spruce and pine stands with different densities and field layers have been presented in Kleman (1985b and 1986), and preliminary results of measurements over damaged spruce stands in Kleman (1985a). In the present paper an extended data set is presented and the results of tests with chromaticity techniques in field measured data, as well as in Landsat TM data, are discussed.

An understanding of the spectral, spatial and temporal characteristics of different forest types and damage levels is of fundamental importance in developing operational remote sensing methods. The geometrical resolution of present satellite sensors is inadequate to retain much textural information in forest canopies, leaving the pixlewise spectral information as the main tool that is presently available in the digital analysis.

Kleman (1985b and 1986) found that there are systematic differences between the spectral signatures of pure spruce and pine stands all through the summer season. Pine stands systematically had a higher reflectance than spruce. This was especially pronounced in wavelength bands corresponding to Landsat TM bands 1,3 and 5.

For the purpose of this study we have measured spectral signatures of the primary object, damaged spruce, and forest types that can give information of the misclassification risks.

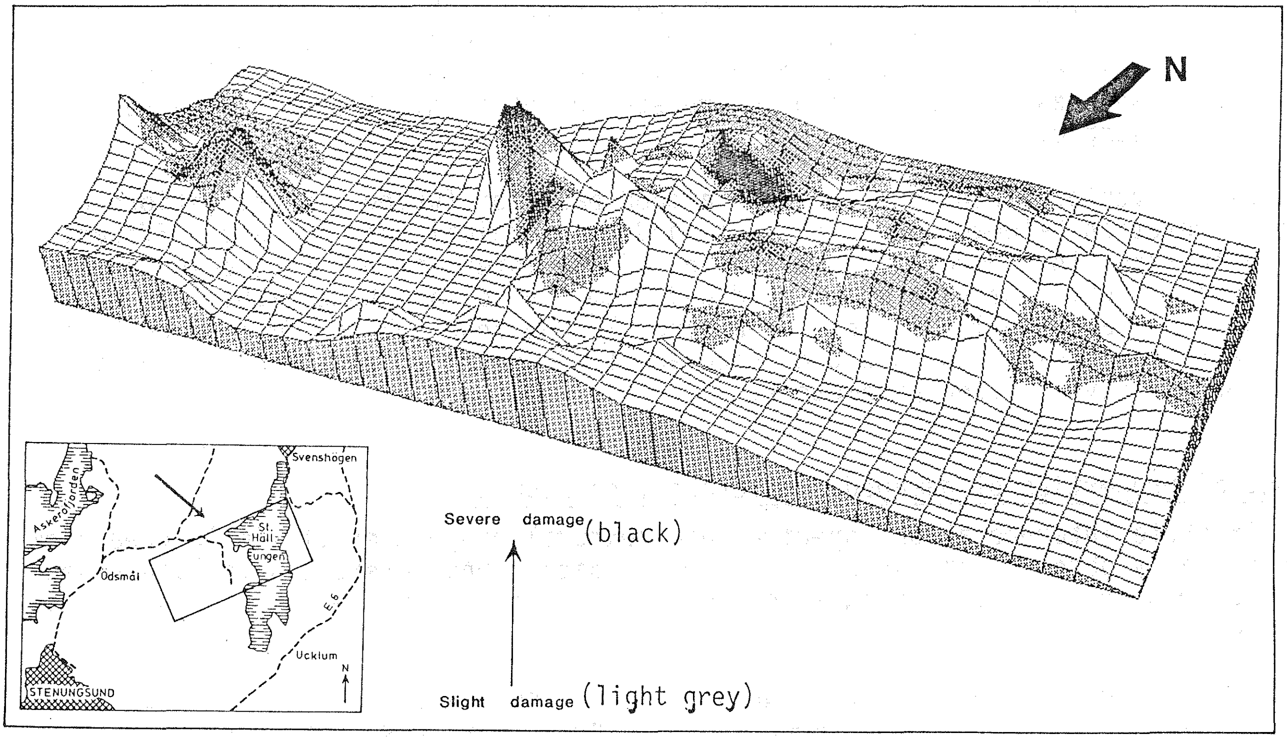

Figure 4. The correlation between topography and the level of needle loss of spruces is illustrated in a digital terrain model of an area about 10 km NE of Stenungsund. The model is produced by photogrammetry, and needle loss is calculated from detailed air photo interpretation data. For interpolation and presentation the software package UNIRAS was used.

To enable data acquisition over a large number of tree stands and for enabling integration over areas of approximately the size of a Landsat TM pixel, a helicopter was used as the radiometer platform. To be able to directly compare data acquired with different sun zenith angles, reflectance factors were determined.

The reflectance data were measured with a four-band hand-held radiometer assembly developed at the Remote Sensing Laboratory, University of Stockholm. The assembly is controlled from a programmable calculator. Three of the four spectral bands are defined by narrowband interference filters centered at 0.56, 0.68, and 0.80 µm. The middle infrared band is defined by a longpass filter that transmits radiation above 1.4 µm and by the upper limit of the germanium detectors sensitivity which is at 1.8 µm. The four wavelength bands are centered at approximately the same wavelengths as the corresponding Landsat TM bands. An 18^{0} field of view was used for all measurements. For the reference measurements an attachment with a fused silica or opal glass cosine recetpr was used during flight. Measurements of the tree stands were performed through a hole in the helicopter floor. A motordriven 35-mm camera was mounted on the measuring head to verify the position of the measured area. Full details about the equipment, methods of irradiance measurement and calibration techniques are given in Kleman (1985a),(1985b), and (1986).

In figure 5 the percentage of needle loss has been plotted versus the reflectance factors at 0.68, 0.85 and 1.6 µm and the band ratios R (0.85)/R (0.68) and R(0.85)/R(1.6). For single spectral bands the best correlation is found in the middle infrared band, while the near-IR band is virtually devoid of systematic information related to needle loss.

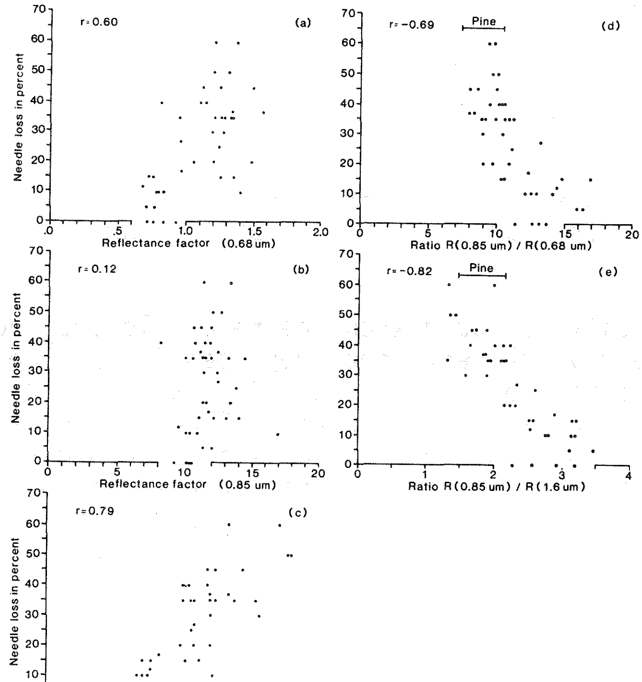

Figure 5. The relationships between field-determined needle loss data and five spectral parameters. Radiometer data were acquired from helicopter, integrating over an area approximately 30 m in diameter.

The rather large scatter in all the diagrams is caused essentially by three factors; the natural variation in the forest, measurement erros and uncertainities in the field estimate of needle loss.

By calculating different types of chromaticity indices the influence of different error sources in satellite data such as non-horizontal terrain, can be minimized. They are also more comparable between different satellite scenes than single band radiances. Chromaticity indices based on the wavelength bands at 0.68 µm, 0.85 µm, and 1.6 µm were calculated for the entire data set and are presented in figure 6 with data for a number of pine stands.

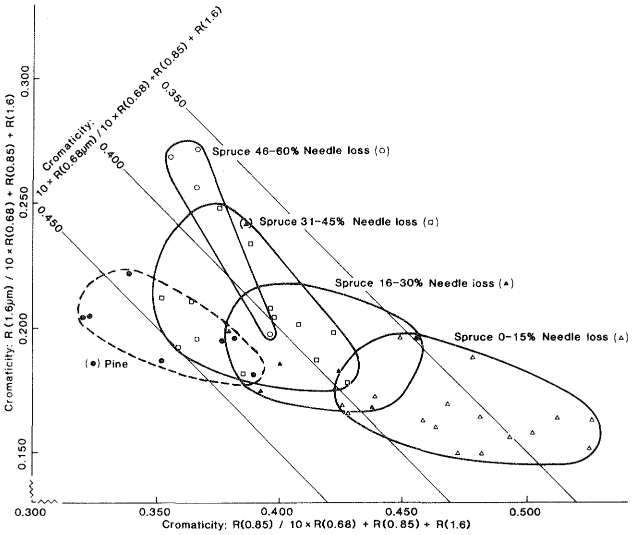

Figure 6. Chromaticity indices based on the 0.68, 0.85 and 1.6 µm bands for four spruce needle loss classes and a number of pine stands.

A systematic change in chromaticity is found when the needle losses increase but unfortunately, and most importantly, the envelopes representing spruce with increasing amounts of needle loss move towards the chromaticity region where the pine stands are found. This clearly indicates that in an application perfectly healthy mixed stands will be mis-classified as damaged spruce stands. A necessary prerequisite to a use of the chromaticity method for this purpose is therefore a data analysis step, capable of accurately separating the pure spruce stands. If this cannot be fulfilled, independent data sources may have to be used for the necessary step of species discrimination.

A study of forest damage in Landsat TM data

This study was initiated to investigate the possibilities to use Landsat TM data for regional forest damage monitoring in Sweden. A test was carried out in an area where we have a substantial amount of ground truth.The data used for this study consists of one satellite scene, quadrant 3 195/19 of 26 July 1985, and a set of infrared aerial photos on the scale of 1:10 000, photographed within a few hours of the satellite registration.

The correlation between the radiometric signal for different spectral parameters in the TM data and the degree of forest damage estimated from aerial photo interpretation is calculated. The damage is scattered and the forest types are very diversified in the area. It is actually hard to find test sites of forest stands that are homogeneous with respect to damage, tree species (Norwegian spruce) and canopy closure. The study is divided into two parts, dataset A, dealing with a pixel level resolution and another, dataset B, dealing with selected forest stands of about 10 pixels in size. In both parts a spectrum of damage levels is considered.

The satellite study is a single scene, single date study and no attempts are made to find the best phenological date for damage monitoring. The influence of the atmosphere on the radiometry is neglected for two reasons: The weather conditions that day were excellent, and the scene is not compared to any other satellite data. On the other hand a radiometric calibration was carried out transforming the digital counts into absolute radiance units ($W\ m^{-2}\ sr^{-1}$) using the gains and offsets read from the radiometric ancillary record on the tape. Only data from TM channels 3,4 and 5 are used for the extensive study. TM1 and TM2 are the bands most affected by the atmosphere, and TM5 and TM7 are usually highly correlated.

Satellite data were radiometrically corrected and transformed into several new features: TM4 over TM3 ratio, TM4 over TM5, TM4 over TM3+TM5 and TM5 over over TM3+TM4+TM5. The two latter tranformations are chromaticity indices and should be able to suppress some error sources like different illumination conditions.

The two datasets from the photos are:

Dataset A: 30 areas of a size of projected TM pixel selected by visual inspection showing an estimated forest damage in the range of 10 to 60% needle loss. In addition 4 Scotch pine 'pixels', 3 young pruce, 4 clearcut, 4 spruce/pine mixed, 2 deciduous, 2 water and 1 bare soil 'pixels' were picked out.

Dataset B: 8 Norwegian spruce forest stands, each made up of between 7 and 13 TM pixels ($\geqslant 6300\ m^2$ and $\leqslant 11700\ m^2$), where the damage could be considered evenly ditributed within the stand. Forest damage is ranging between 20 and 40% needle loss. No large severely damaged stands were found within the study area. An 8 pixel young spruce stand was added.

From dataset A the digital numbers from TM spectral bands 1,2,3 and 5 were extracted from the satellite image. A correlation coefficient (r) was calculated for all spectral bands and the forest damage in percent needle loss. No spectral band had a correlation coefficient larger than 0.24 which must be considered totally uncorrelated.

Figure 7 shows dataset B as mean values for the 8 spruce stands and a young spruce stand. From the mean values crosses are plotted representing ± 1 standard deviation. The correlation coefficients (r) between the eight mean values and the needle loss in percent are -0.17 for TM4 radiance and 0.31 for TM5 radiance. Dataset B does not show any significant correlation between damage class and spectral properties. More details of the results are given in Wastenson et al 1987.

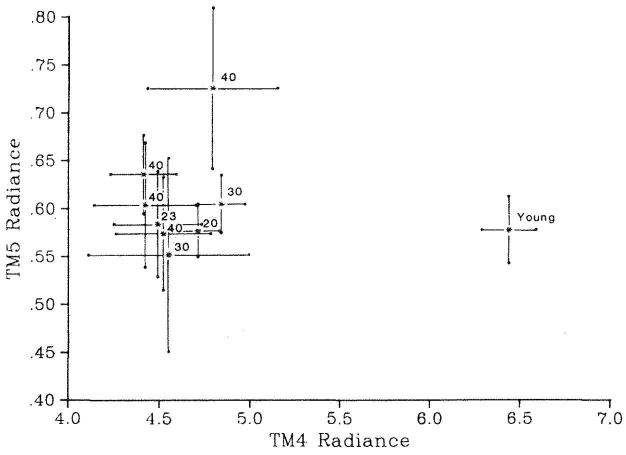

Figure 7. TM5 absolute radiance (W m^{-2} sr^{-1}) versus TM4 absolute radiance (W m^{-2} sr^{-1}) for the mean of 8 Norwegian spruce stands, dataset B. Figures indicate the percentage of needle loss of the stands. Crosses are ± 1 standard deviation from mean in the two dimensions. For comparison a young spruce stand is plotted.

Conclusions

The most important results obtained that are of interest in a discussion of the possibilities for satellite-based forest damage monitoring, can be summarized as follows:

- Scales down to 1:10 000 can be successfully used in air photo interpretation.

- The damage is geographically very scattered, and also within-stand variation is large and unsystematic, in principle necessitating observation of single tree crowns.

- The concentrations of damages to stand borders is unfortunate, since by necessity it will be situated in 'mixed' picture elements in satellite data.

- The radiometer measurements show that needle losses in spruce forests affect the spectral signatures in a systematic way with the best, although still very modest, correlation for the near-infrared to middle infrared ratio. For single spectral bands, most information was contained in the 1.6 and 0.68 m bands. However, the scatter is large for all parameters, indicating that the influence of differences in type of field layer and canopy closure will have a profoundly negative effect on classification results.

- The spectral signatures of damaged spruce are not unique, on the contrary serious mis-classfication will occur with more or less healthy mixed stands of spruce and pine. Therefore an accurate delimitation of pure spruce stands is necessary prerequisite to damage assessment. Even if this can be accomplished, which with remote sensing methods has yet to be demonstrated, precision in the estimate of damage level is likely to be poor.

- Tests in good-quality Landsat data over stands with known damage characteristics gave no indication that any reasonable damage detection potential exists in presently available satellite data for the conditions encountered in Swedish forests.

Acknowledgements

The study was initiated by Professor L Wastenson, who was the project manager. The air photo interpretation was performed by reserach assistant B Wastenson, and the analysis of the interpretation data was performed by her in cooperation with L Wastenson. Dr Johan Kleman was responsible for the study of the spectral signatures of damaged forest stands and Dr Göran Alm performed the study of forest damage inventory possiblities in Landsat TM data.

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