INFLUENCE OF FOREST STAND PARAMETERS ON VEGETATION INDICES USED FOR CONIFEROUS FOREST DAMAGE ASSESSMENT

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ABSTRACT

This study aims to investigate the influence from forest stand parameters (age, species composition, volume & annual increment), on six Landsat TM based vegetation indices which have been used for forest damage assessment of coniferous forests in previous studies. The study area consists of 198 non damaged, mainly coniferous forest stands in southern Sweden.

Correlation analysis and stepwise multiple regression analysis of the complete data set as well as of stratified subsets of the data were performed to quantify the influence from forest stand parameters. The results indicates that volume and species composition are parameters which significantly influence vegetation indices used for forest damage assessment. Different indices were found to be most stable when analysing different stratifications.

1. INTRODUCTION

The concern of the extensive forest damage, especially in central Europe and in eastern North America, and the need of reliable tools for assessment of damage over large areas have increased the number of studies performed on detection, quantification and mapping of forest damage. A common approach when studying forest damage with digital remote sensing techniques is to correlate a ground measurement of forest damage (% defoliation, % dead trees) to satellite data (Vogelmann & Rock, 1988, Rosengren & Ekstrand, 1988, Vogelmann 1990, Ekstrand, 1992). This is done either to individual wavelength bands or to different vegetation indices calculated from satellite data. Classification or estimation by regression methods of the damage parameters are then based on these relationships between damage parameters and satellite data.

Knowledge about the influence from stand parameters on satellite data (as well as the knowledge about the influence from non forest parameters) are important when working with forest damage assessments based on remote sensing techniques. The idea behind this study is to quantify the influence/disturbance from forest stand parameters *other* than damage

parameters on vegetation indices used for forest damage assessment. Possibly, this could result in information on the stability among the vegetation indices used.

Aim

This study aims to quantify the influence from forest stand parameters on six vegetation indices used in assessment of forest decline.

2. PREVIOUS STUDIES

Many interesting studies concerning the relationships between remotely sensed data and forest damage have been performed, only a few of them are mentioned below.

Rosengren and Ekstrand (1988) and Ekstrand (1990) used a chromaticity technique to study forest decline using Landsat TM data. The chromaticity technique were originally described by Alfoeldi and Munday (1978). *"The chromaticity can be interpreted as a measure of colour as seen by the satellite sensor, when applied to forest damages a chromaticity index using Landsat Thematic Mapper infrared bands TM4, TM5 and TM7 is used. The index i defined as a ratio between at-satellite reflectances by*

$$X_\rho(4,5,7) = \rho 4/(\rho 4+\rho 5+\rho 7) \qquad (1)$$

where $X_\rho(4,5,7)$ denotes the chromaticity X reflectances based on bands 4,5 and 7 and ρ_i (i = 4,5,7) is the measured at-satellite reflectances with in band i" (Rosengren & Ekstrand, 1988)

"Changes of spectral signature due to forest damages will decrease ρ_4 and slightly increase ρ_5 and ρ_7 leading to a decrease of the chromaticity X_ρ" (Rosengren and Ekstrand, 1988).

A chromaticity classification of the Izerskie forest in Poland yielded a classification accuracy of 76 % for four damage classes (Rosengren & Ekstrand 1988). When evaluating methods for multi-scene damage assessment, TM4/TM4+TM5+TM7 were found to be the most appropriate chromaticity index, partly due to a capability to detect severe damages, and partly due to lower atmospheric distortions in the near infrared (NIR) and short wave infrared (SWIR) bands. The most important error sources seem to be mixing of species and the accuracy with which spruce and pine could be separated. Small classification confusion between mixed forest (spruce-deciduous) and healthy spruce forest were found. In the middle infrared channel, TM7, pine was confused with dead or heavily impaired spruce forests and in the near infrared channel, TM4, with less impaired spruce (Rosengren & Ekstrand, 1988).

A study performed in Sweden (Ekstrand 1990) resulted in a correlation of -0.70 between a chromaticity index (TM4/TM2+TM4+TM7) and needle loss and a correlation of -0.80 of TM1+TM3 against needle loss. Included were 22 test sites with 85-100% spruce and < 5 % hardwood, on ground sloping < 5°. *"The main confusion between defoliation classes was caused by both large hardwood components (5-15%) and defoliation levels above 40 % needle loss".*

Ekstrand (1992) studied the relationship between satellite data (Landsat TM) and forest parameters, forest damage parameters and topographic parameters. A correlation of -0.75 were found between Thematic Mapper band 4 and needle loss. No significant correlation between satellite data and ground measured crown closure, nor between satellite data and timber volume (m^3 ha^{-1}) were found in an area with crown closure between 40% and 65%.

Investigations in the United States presents strong relationships between remotely sensed data and degree of forest decline (Vogelmann & Rock, 1986, 1988, Vogelmann 1990).

Vogelmann & Rock (1988) presented R^2 values of 0.92 respectively 0.84 for mean conifer damage versus TM5/TM4 (1.65/0.83 μm) respectively TM7/TM4 (2.22/0.83 μm) band ratios in a study performed in north-eastern United States. The use of SWIR/NIR ratios for damage detection are based on that spectral reflectance in the SWIR region are sensitive to moisture differences and the NIR region is sensitive to changes in cellular structure. It is stated in the study that *"it is reasonable that the indices used in this study (1.65/0.83 μm and 2.22/0.83 μm band ratios) measure not one but several different highly correlated and largely inseparable vegetation parameters (biomass, damage, water content)".*

Vogelmann (1990) performed a comparison between two Landsat Thematic Mapper derived vegetation indices for measuring forest damages in north-eastern United States. A evaluation of the relative effectiveness between the normalised difference vegetation index (NDVI) (TM4-TM3/TM4+TM3) and a SWIR/NIR (TM5/TM4) were carried out. Vogelmann found that *"mean 0.66 μm and 1.65 μm band values were consistently higher for the portions of the fir waves characterised by high levels of mortality then for the portions characterised by low levels of mortality. Conversely. mean 0.83 (TM4) μm band values were consistently lower for the portions of the fir waves characterised by high levels of mortality than for the portions characterised by low levels of mortality".*

Vogelmann (1990) suggests that a SWIR/NIR index is more appropriate than the NDVI for monitoring of damages in coniferous vegetation.

3. MATERIAL AND METHODOLOGY

Study area and field data

The study area is in the southern part of Sweden, 10 kilometres Southwest of Oscarshamn (57° 10' N, 16° 10' E). The area consists of 1335 hectares of productive forest land divided into 198 compartments with an average size of approximately 7 hectares. Scotch pine (*Pinus silvestris)* and Norway spruce (*Picea abies)* are the dominating species, and approximately 10 % is comprised of deciduous forest (*Betula* spp.). The area is *not* affected by severe forest decline.

Field work were performed during the autumn 1988. Volume (m^3 ha^{-1}), annual increment (m^3 ha^{-1} $year^{-1}$), species composition (per cent spruce, per cent pine and per cent deciduous) and age were measured with subjective methods commonly used in forest planning and forest inventories in Sweden. No forest damage parameters were collected.

Satellite sensor data and data extraction

Satellite sensor data used were Landsat-5 Thematic Mapper, path 192, row 20, registered June 6, 1988. Geometric correction, using a first order transformation and cubic convolution was performed with a standard error of less than one pixel (i.e. < 30 metre).

Radiometric correction of satellite sensor data to spectral radiance ($mWcm^2$ sr^{-1} μm^{-1}) were performed (Markham and Barker, 1986).

Delineation of the compartments was performed in a combined image processing system/Geographical Information System through visual interpretation and interactive delineation on the screen. Maps and aerial photographs supported the delineation. Uncertain delineation's were checked during the fieldwork and corrections performed. For each compartment, the mean spectral radiance value in each band was calculated from all pixels except the border pixels. The mean number of pixels per compartment were 69.

The six vegetation indices calculated were TM4/TM4+TM5+TM7 (4/457) (Rosengren & Ekstrand 1988) TM4/TM2+TM4+TM7 (4/247) and TM1+TM3 (1+3) (Ekstrand 1990), TM7/TM4 (7/4) and TM5/TM4 (5/4) (Vogelmann & Rock, 1988) and TM4-TM3/TM4+TM3 (NDVI).

Statistical methodology

Analysing all the 198 forest stands together will result in a rather non homogeneous data set. Three different stratifications were performed on basis of volume and species composition to increase the homogeneity in the data set and to minimise the influence from non wanted compartments (pine dominated compartments, plantations and clear cuts).

Multiple regression were performed through the method of least squares (William's, 1984). To identify the subset of parameters with largest influence a stepwise regression was used. The stepwise procedure looked for variables not yet in the equation whose F-statistics were greater than 4. Forest stand parameters were used as independent variables and the vegetation indices as dependent variables.

4. RESULTS

All correlation coefficients except one (r=0.02, between 4/247 and $m^3\ ha^{-1}$) between the six vegetation indices and forest stand parameters were significantly separated from 0 at the 0.05 significance level (Table 1). The strongest correlation was between TM1+TM3 and $m^3\ ha^{-1}$ (r = -0.72).

Table 1. Correlation coefficients between coniferous forest stand parameters and vegetation indices, n = 198.

Indices	**m^3ha^{-1}**	**$m^3ha^{-1}year^{-1}$**	**% spruce**	**% pine**	**% deciduous**
4/457	0.53	0.50	**0.48**	-0.59	0.30
4/247	-0.02	**0.56**	0.30	-0.63	**0.62**
1+3	**-0.72**	-0.30	-0.34	0.40	-0.19
7/4	-0.54	-0.44	-0.43	0.53	-0.29
5/4	-0.52	-0.49	-0.47	0.58	-0.30
NDVI	0.18	**0.56**	0.38	**-0.64**	0.54

Table 2a. No stratification. Selection criteria 1 and 2, n, first, second and third variable entered by stepwise multiple regression followed by their coefficient of determination (R^2), ind = index.

Criteria 1	**Criteria 2**	**n**	**1**	**R^2**	**2**	**R^2**	**3**	**R^2**	**index**
-	-	198	% pine	0.34	volume	0.55	% decid	0.62	4/457
-	-	198	% pine	0.40	% decid	0.53	age	0.56	4/247
-	-	198	volume	0.30	age	0.51	% pine	0.59	7/4
-	-	198	volume	0.53	age	0.65	% decid	0.69	1+3
-	-	198	% pine	0.33	volume	0.53	age	0.61	5/4
-	-	198	% pine	0.41	% decid	0.48	volume	0.53	NDVI

Table 2b. Compartments with > 75 % spruce included. Selection criteria 1 and 2, n, first, second and third variable entered by stepwise multiple regression followed by their coefficient of determination (R^2), ind= vegetation index.

Criteria 1	Criteria 2	n	1	R^2	2	R^2	3	R^2	index
> 75 % spruce	-	39	volume	0.26	% pine	0.49	-	-	4/457
> 75 % spruce	-	39	% decid	0.16	% pine	0.34	-	-	4/247
> 75 % spruce	-	39	volume	0.28	% pine	0.48	-	-	7/4
> 75 % spruce	-	39	volume	0.58	% pine	0.66	-	-	1+3
> 75 % spruce	-	39	volume	0.25	% pine	0.49	-	-	5/4
> 75 % spruce	-	39	% pine	0.17	% spruce	0.30	-	-	NDVI

Table 2c. Compartments with > 75 % spruce and > 50 $m^3 ha^{-1}$ included. Selection criteria 1 and 2, n, first, second and third variable entered by stepwise multiple regression followed by their coefficient of determination (R^2), ind= vegetation index.

Criteria 1	Criteria 2	n	1	R^2	2	R^2	3	R^2	index
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	ann. inc	0.14	-	-	-	-	4/457
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	age	0.32	% decid	0.58	-	-	4/247
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	-	-	-	-	-	-	7/4
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	volume	0.39	%spruce	0.49	-	-	1+3
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	ann. inc	0.14	% decid	0.47	-	-	5/4
> 75 % spruce	> 50 $m^3 ha^{-1}$	33	age	0.24	% decid	0.47	-	-	NDVI

Table 2d. Compartments with > 90 % spruce included. Selection criteria 1 and 2, n, first, second and third variable entered by stepwise multiple regression followed by their coefficient of determination (R^2), ind= vegetation index.

Criteria 1	Criteria 2	n	1	R^2	2	R^2	3	R^2	index
> 90 % spruce	-	20	age	0.24	-	-	-	-	4/457
> 90 % spruce	-	20	age	0.41	-	-	-	-	4/247
> 90 % spruce	-	20	-	-	-	-	-	-	7/4
> 90 % spruce	-	20	volume	0.57	-	-	-	-	1+3
> 90 % spruce	-	20	age	0.25	-	-	-	-	5/4
> 90 % spruce	-	20	age	0.34	-	-	-	-	NDVI

Three stratifications based on per cent spruce and on volume were performed (Tables 2b-d). **Criteria 1** and **Criteria 2** are the selection criteria used for the stratifications. The first variable entered in the stepwise multiple regression are denoted **1** followed by the $\mathbf{R^2}$ value for that variable, **2, 3** are the second and third variables entered by the regression followed by their $\mathbf{R^2}$ values, "**-**" means that no more variables were entered, **ind** is the index used as dependent variable (%decid = % deciduous).

Coefficients of determination between 0.53 (NDVI) and 0.69 (1+3) were obtained for the regressions calculated on the three first entered variables when no stratification were performed. Volume and % pine were the variables with strongest influence (Table 2a).

Coefficients of determination between 0.34 (2/247) and 0.66 (1+3) were obtained for the regression calculated on the two first entered variables when compartments with > 75 % spruce were included. Volume and % pine were the variables with the strongest influence (Table 2b).

Coefficients of determination between 0.14 (4/457) and 0.58 (4/247) were obtained for the regressions calculated on the one or two first entered variables when compartments with > 75 % spruce and > 50 m^3 ha^{-1} were included (Table 2c).

Coefficients of determination between 0.34 (NDVI) and 0.57 (1+3) were obtained for the regressions calculated on the first entered variable when compartments with > 90 % spruce included, (Table 2d)

The vegetation index 1+3 had the largest coefficients of determination in all stratification's except in table 2c were 4/247 had the largest coefficients of determination. In two cases, no variables where entered in the regression for the dependent variable 7/4 (Table 2c and 2d).

5. DISCUSSION

The results in Table 2a-2d indicates a difference in the influence from forest stand parameters on the vegetation indices studied. Analysing all the 198 compartments (Table 2a) including clear cuts, compartments dominated by pine and young compartments is not very representative for older spruce dominated forests exposed to forest decline

Analysing compartments with > 75 % spruce, with clear cuts and young compartments with low volumes still included, could partly explain the influence from the volume of the compartments in this stratification (Table 2b).

Compartments with > 75 % spruce and > 50 m^3 ha^{-1} (Table 2c) are perhaps most comparable to the sites investigated in other studies (see section 2). Significant influence from per cent deciduous forest in this stratification agrees with Ekstrand (1990) who meant that a hardwood component varying more than 5 % disturbs the damage detection. No significant influence where found on 7/4 and low influence on 4/457 (R^2=0.14).

Sources of error

There are differences in data processing, natural vegetation types and species composition between this study and studies mentioned above (section 2). These differences reduce the comparability between the influence from stand parameters on vegetation indices used for forest damage assessment in this study and in other studies. I.e. it is *not* possible to say that 47 per cent of the variation in TM5/TM4 (Table 2c) can be explained by m^3 ha^{-1} and %spruce in another environment (central Europe, North America) than the one were the study were performed (Sweden).

The area in this study are not affected by forest decline which make this results less comparable to results obtained in areas with sever forest decline.

6. CONCLUSION

Coniferous forest stand parameters significantly influence vegetation indices used for forest damage assessment. Knowledge about this influence can be useful in forthcoming work aiming to accurately localise and quantify coniferous forest damage.

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