Plot - Level Stem Volume Estimation and Tree Species Discrimination with CASI Remote Sensing

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Sammanfattning

Data från Compact Airborne Spectrographic Imager (CASI) inställd för fyra spektrala band (460-495nm, 550-580nm, 660-682nm, 740-762nm) inmätt för fastigheten Kättböle (Lat.60º00'N, Long.17º18'E) utanför Uppsala analyserades tillsammans med skogliga data från provytor med 10 m radie. Data från två flygstråk, ett med flygriktning mot solen och ett annat vinkelrätt mot solen, användes i detta försök. Information om stamvolym och trädsslagsfördelning fanns att tillgå för 138 provytor i det första och 120 provytor i det andra stråket.

Det fanns en positiv korrelation (R^2=0.51-0.53) mellan stamvolym och den inverterade radiansen för samtliga spektrala band på provytenivå. Det fanns även en stark korrelation mellan stamvolym och ett provat mått på skuggdensitet, vilket indikerar att mängden skuggor förklarar mycket av korrelationen mellan volym och radians. Korrelationen mellan volym och radians visade sig vara starkare för sidan mot solen jämfört med sidan bort från solen i det flygstråk som låg vinkelrätt mot belysningsriktningen.

Provytor med en volym > 120 m^3ha^{-1} i det första flygstråket klassificerades efter trädslagsfördelning (tall, gran, löv). Grupper bildades med hjälp av denna klassificering och hypotesen att det inte fanns någon skillnad i radians mellan dessa grupper testades. Det var möjligt att skilja mellan talldominerade och grandominerade ytor. Helt grandominerade ytor gick dessutom att skilja ut från grandominerade ytor med ett litet inslag av tall. Helt talldomierade ytor gick däremot inte att skilja från talldominerade ytor med ett litet inslag av gran. För att skilja på provytor med olika trädslagsfördelning var det närinfraröda bandet bäst att använda.

Abstract

Spectral data from the Compact Airborne Spectrographic Imager (CASI), with four bands (460-495nm, 550-580nm, 660-682nm, 740-762nm) acquired from a forest test area (Lat.60º00’N, Long.17º18’E), the Kättböle estate near Uppsala, was analysed together with forest data from a number of field plots. Data from two flight lines, one towards and the other perpendicular to the sun was used. Information about stem volume and species composition from plots with 10-m radius, 138 in the first and 120 in the second flight line, was available.

There was a positive correlation (R^2=0.51-0.53) between stem volume and the inverted radiance for all four bands on plot level. The strong correlation between stem volume and a shadow density measure indicates that shadows explain much of the correlation. For the flight line perpendicular to the sun, the correlation was stronger for the side towards the sun compared to the side away from the sun.

In the first flight line, plots with a stem volume > 120 m^3ha^{-1} were classified according to the tree species composition (pine, spruce, deciduous trees). Groups were formed based on the classification, and the hypothesis that there was no difference in spectral radiance between these groups was tested. It was possible to separate pine dominated plots from spruce dominated plots. It was also possible to separate spruce dominated plots from spruce dominated plots with a minor portion of pine, but not pine dominated plots from pine dominated plots with a minor portion of spruce. The near-infrared band was the best band for discrimination of tree species.

Introduction

Information about tree species composition and stem volume are important variables used for forestry planning. Therefore, there is a need for not only being able to separate forest types containing different species, but also estimating stem volume using remote sensing in combination with field inventories. Several studies have shown that satellite remote sensing data are related to stand parameters (Spanner et al. 1984, Peterson et al. 1986, Cook et al. 1989). However, it has been suggested that satellite data can not capture forest stand parameters with a high level of accuracy and are best restricted to large extensively managed areas with simple canopy structure and few species (DeWulf et al. 1990). Airborne sensors typically offer greatly enhanced spatial resolution compared to their satellite counterparts. They have been used in a number of tree-level (Hughes et al. 1987, Yuan et al. 1991) and stand-level forest surveys (e.g. Franklin et al. 1991).

Strahler & Woodcock (1986) break down scene models into two types: 1) Resolution cells larger than single trees, 2) Resolution cells smaller than single trees. The first allows use of simple algorithms for estimating compartment variables. The second makes it possible to gain information about the texture of the forest. However, it is necessary to use complex models for extracting forest information from this high-resolution spectral data. This is because high-resolution pixels could represent single trees or parts of trees that are illuminated differently or are dominated by shadows or understory.

CASI (Compact Airborne Spectrographic Imager) was used for this study. It is a commercially available lightweight push broom spectrometer (Babey and Anger 1989). For data used in this study, a pixel represented a square on ground with 1.5-m side. This resolution makes it difficult to identify single trees. No efforts were made to identify tree species and tree size on a single tree basis. In order to avoid the mentioned problems with high-resolution images, the value of each pixel was replaced with a mean of a local window representing a field plot on ground. The view angle effects (e.g. Yuan, X.& Leckie, D.G. 1992) could have an impact on the correlation between volume and spectral radiance. The possibility of discriminate plots with different tree species composition was also to be investigated.

The objectives of the study were:

- Find some models for estimating stem volume using spectral radiance on a plot level for different flight directions and distances to nadir.
- Test the difference in spectral radiance from plots with different tree species composition.

Material and methods

Study area

The test site was a 550 ha forest estate (Lat.60º00'N, Long.17°18'E) outside Uppsala, Sweden. There were 58% Scots pine, 36% Norway spruce, and 6 % deciduous trees (volume based). The land surface was flat with no large hills or depressions.

Image data

Data from CASI (Compact Airborne Spectrographic Imager) was used in this study. It is a commercially available lightweight bush broom spectrometer (Babey & Anger 1989). Borstad Associated acquired the data on the 7th of August, 1997. Data used in this study were collected in two flight lines, one with flight direction towards the sun (FL 1) and the other perpendicular to the sun (FL 2) (Table 1).

Table 1. *Data from the acquisition flight for FL 1 (towards the sun) and FL2 (perpendicular to the sun)*

FL	Start Time	Speed (km/h)	Altitude (ft)	Pixel Length (m)	Pixel Width (m)	Heading (d)
1	9:34:36	92	4000	1.47	1.46	136
2	9:43:33	96	4050	1.53	1.48	216

During image acquisition, roll and pitch of the airplane were corrected continuously with a two axis mechanical gyro. An average correction of yaw was applied in the entire flight line. Fifty ground control points (GCP) per flight line were digitised using an ortho-photo obtained from the National Land Survey. The images were rectified using rubber sheeting (rectification with triangulation in ErMapper 5.5).

The image data were calibrated to units of spectral radiance ($nWcm^{-2}sr^{-1}nm^{-1}$) at the sensor. For this mission, the sensor was set for measuring radiance in four spectral bands (Table 2). Pixels with electrical offset signals were replaced with the average of the pixels on each side in the scan line.

Table 2. *Wavelength interval (nm) for the four bands*

Band	Start wavelength	End wavelength	Colour
1	459.8	495.3	blue
2	549.5	580.1	green
3	659.7	681.6	red
4	740.3	762.2	near-infrared

Field data

A field survey of 677 circular plots with 10-m radius was available. The plots were located in clusters of four plots each, with 200 m between clusters and 50 m between plots. Some clusters contained two extra plots. Plots were surveyed according to the methods used in the Swedish National Forest Inventory (Ranneby et al. 1987). Of these plots, 120 were present in FL1 and 138 in FL2. Plots located on recently clear felled areas, with no recorded volume, were excluded because of their variation is not due to forest volume (Figure 1). A total of 110 in FL1 and 123 in FL2 remained after the reduction.

Models for estimating stem volume

A regression model (Equation 1) was tested for all plots in FL1 and FL2. Another model (Equation 2) was tested for all plots in FL2 and subsets of plots in FL2. The subsets were defined by intervals of distance to nadir. Interval A had plots >= 100 m from nadir on the side towards the sun, interval B plots < 100 m from nadir, and interval C plots >= 100 m from nadir on the side away from the sun. In order to have a similar volume distribution in each interval, plots with a stem volume > 400 m^3ha^{-1} were excluded in FL2 (4 plots). Model 1 and 2 have stem volume (m^3ha^{-1}) as independent variable (*vol*), the inverted spectral radiance ($nWcm^2sr^{-1}nm^{-1}$) of four different bands (*b1, b2, b3*, and *b4*) as independent variables and a random error ε with expected value zero. The spectral radiance for a plot was calculated as the average of the values from all pixel within an area representing the plot. Model 2 also includes distance to nadir, *dist* (m).

$$vol = \beta_0 + \beta_1 1/b1 + \beta_2 1/b2 + \beta_3 1/b3 + \beta_4 1/b4 + \varepsilon \quad (1)$$

$$vol = \beta_0 + \beta_1 1/b1 + \beta_2 1/b2 + \beta_3 1/b3 + \beta_4 1/b4 + dist + \varepsilon \quad (2)$$

Two models (Equation 3-4), with only one independent variable, were tested for all plots in FL1.

$$vol = \beta_0 + \beta 1/b + \varepsilon \quad (3)$$

$$vol = \beta_0 + \beta\sqrt{shd + \varepsilon} \quad (4)$$

b is the radiance from one of the bands (1-4). The shadow density measure (*shd)* was introduced in the fourth model. This was derived as follows: For all bands the mean and standard deviations of spectral radiance measured in the entire image were calculated. Pixels with a value less than the mean minus one standard deviation were set to 1, the other to 0. The average of the values from all pixel within an area representing the field plots was used.

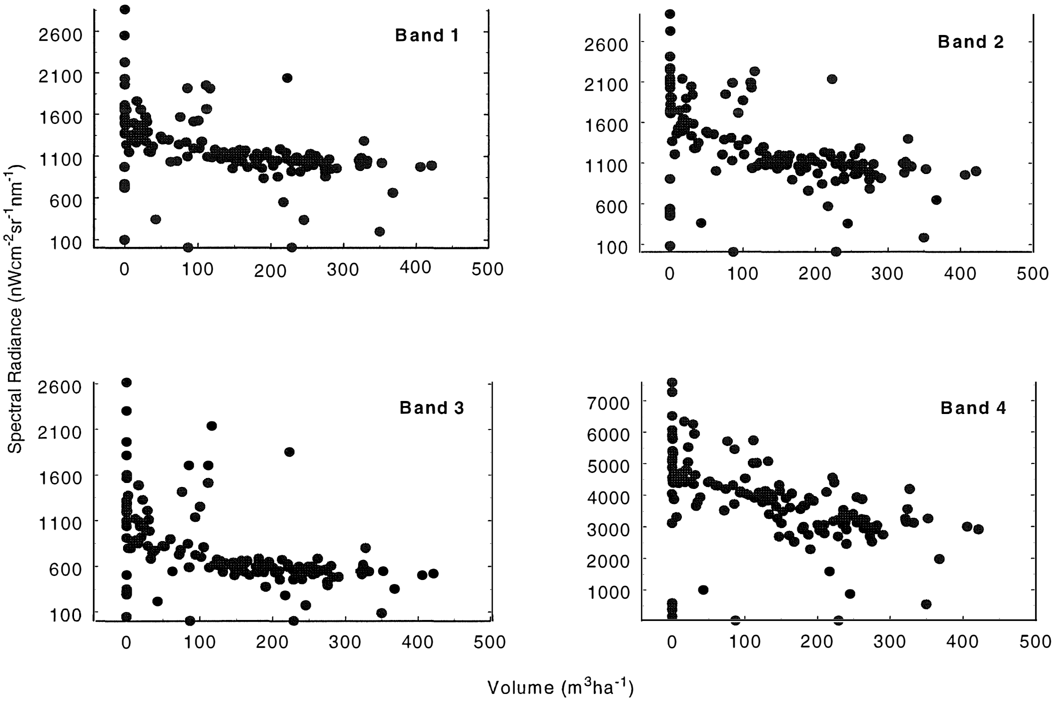

Figure 1. *Radiance ($nWcm^{-2}sr^{-1}nm^{-1}$) for the four different bands plotted against the stem volume (m^3ha^{-1}) for the field plots in FL1.*

Discriminate plots with different tree species composition

The hypothesis of no difference in radiance between plots with different tree species composition was tested for plots in FL1. To avoid view angle effects the hypothesis was not tested in FL2. Plots with stem volume < 120 m^3ha^{-1}were excluded because the radiance variance was too large for these plots (Figure 1). Classes with 25 % interval of species portion for pine, spruce and deciduous trees were defined (Table 3). In order to have sufficient sample sizes the plots were grouped into larger groups. The groups of plots were: pine dominated, spruce dominated, deciduous trees dominated, pine dominated with a minor portion of spruce, and spruce dominated with a minor portion of pine (Table 4). A t-test for equality of variance was used. The hypothesis of equality of variance was refused on a 5 % significance level. Depending on the result from this test, the t-test for equality of means was either used with or without assumption of equal variances.

Table 3. *Classes with different components of tree species and the number of field plots with a stem volume > 120 m^3ha^{-1} for FL1*

class	pine (%)	spruce (%)	deciduous (%)	*frequency (n)*
1	0-25	75-100	0-25	8
2	0-25	50-75	0-25	1
3	0-25	50-75	25-50	0
4	0-25	25-50	25-50	1
5	0-25	25-50	50-75	1
6	0-25	0-25	50-75	0
7	0-25	0-25	75-100	0
8	25-50	50-75	0-25	21
9	25-50	25-50	0-25	0
10	25-50	25-50	25-50	2
11	25-50	0-25	25-50	2
12	25-50	0-25	50-75	2
13	50-75	25-50	0-25	9
14	50-75	0-25	0-25	5
15	50-75	0-25	25-50	4
16	75-100	0-25	0-25	54

Table 4. *Groups used for testing the difference between means of spectral values. Classes are defined in Table 3*

statistics / group	pine	spruce	deciduous	pine-spruce	spruce-pine
classes	16	1	4,10,11,15	13	8
sample size (*n*)	19	6	6	8	20
mean volume (m^3/ha)	191	225	144	222	272
std. dev. volume (m^3/ha)	53	49	19	65	75
min volume (m^3/ha)	123	147	125	129	151
max volume (m^3/ha)	324	275	177	282	422
mean portion pine (%)	89	10	53	60	38
mean portion spruce (%)	4	88	12	34	60
mean portion deciduous (%)	7	2	35	6	2

Results

There was a trend of overestimating volume on the side towards the sun (A) and underestimating volume on the side away from the sun (B) for FL2 (Fig. 2). Also, the variation was increasing when going from A to B. The residuals for applying Model 1 on data from FL2 are presented in Fig. 2. Statistics from applying the two models on the data sets for the two flight lines are presented in Table 5.

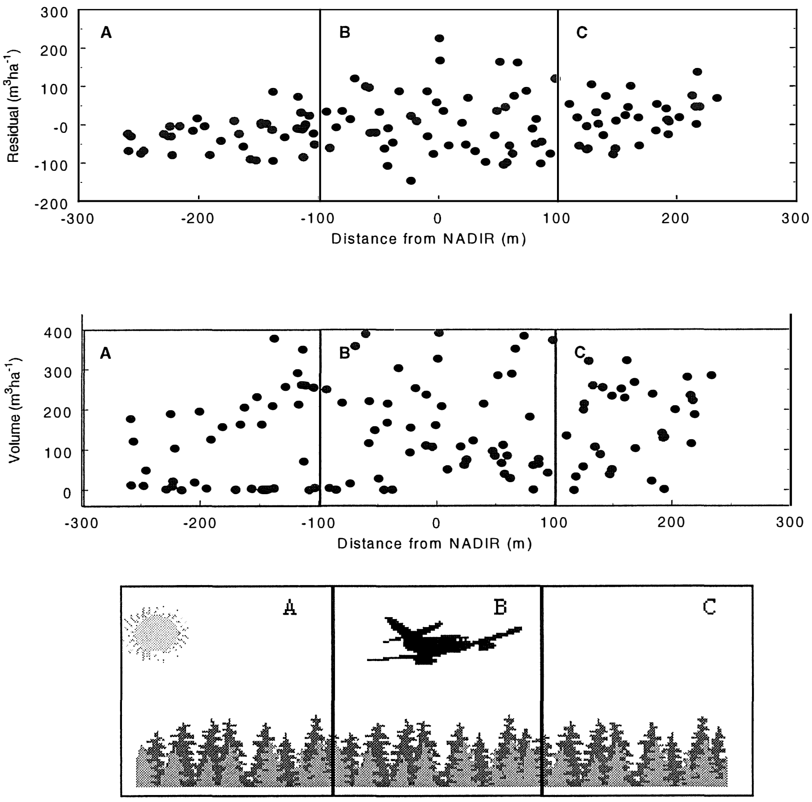

Figure 2. *The residuals ($v - \hat{v}$) for Model 1, and field measured stem volume (m^3ha^{-1}), plotted for different distances to nadir (m). Positive distances are away from the sun and negative towards the sun.*

Table 5. *Statistics (the standard error of the estimate and R^2) for the linear regression models, Model 1 for both flight lines (FL1 and FL 2) and Model 2 for FL2 and subsets of FL2*

model	flight line	selected data	sample size (*n*)	R^2	standard error (m^3ha^{-1})
1	1	all	109	0.60	71
1	2	A,B,C	120	0.65	68
1	2	A	37	0.88	42
1	2	B	50	0.60	79
1	2	C	33	0.77	50
2	2	A,B,C	120	0.69	64
2	2	A	37	0.91	38
2	2	B	50	0.60	80
2	2	C	33	0.79	48

Table 6. *Statistics (the standard error of the estimate and R^2) for applying Model 1 and Model. The models were tested for all data in FL1*

model	type	band	R^2	standard error (m^3ha^{-1})
3	spectral value	1	0.51	77
3	spectral value	2	0.54	75
3	spectral value	3	0.54	74
3	spectral value	4	0.53	76
4	shadow density	1	0.54	75
4	shadow density	2	0.57	73
4	shadow density	3	0.59	71
4	shadow density	4	0.51	77

The radiance for the different groups (Table 4) from the spectral bands (Table 2) are listed in Table 7. The difference in means was generally greater in band 4 compared to the other bands but the variance was also higher in this band. Note that the group named deciduous is not dominated by broad-leafed trees, it contains more pine than deciduous trees (Table 4). This was because of a lack of plots dominated by deciduous trees.

Table 7. *The radiance for different groups of field plots in four spectral bands (Table 1)*

	Band 1		Band 2		Band 3		Band 4	
	mean	std.dev.	mean	std.dev.	mean	std.dev.	mean	std.dev.
pine	1161	221	1184	243	692	283	3672	480
spruce	948	75	943	118	484	74	2735	270
deciduous trees	1107	29	1110	61	598	33	4114	548
pine-spruce	1066	72	1119	119	579	61	3494	471
spruce-pine	1023	49	1035	85	540	37	3048	246

The result from the t-test for testing equality of means is presented in Table 8. The groups with pine and pine-spruce could not be separated in any spectral band with 5 % confidence. The fourth band was most effective for separating all groups except deciduous from spruce, deciduous from spruce-pine and spruce from spruce-pine, where the first band was equal in the first case and better in the two other.

Table 8. *The significant level of the t-test for equality of means*

Groups / Statistics	Band 1	Band 2	Band 3	Band 4
pine / spruce	5 %	5 %	5 %	0.1 %
pine / deciduous	□	□	□	□
pine / pine-spruce	□	□	□	□
pine / spruce-pine	5 %	5 %	5 %	0.1 %
spruce / deciduous	0.1 %	5 %	1 %	0.1 %
spruce / pine-spruce	1 %	1 %	1 %	0.1 %
spruce / spruce-pine	1 %	5 %	□	5 %
deciduous / pine-spruce	□	□	□	5 %
deciduous / spruce-pine	0.1 %	□	1 %	1 %
pine-spruce / spruce-pine	5 %	5 %	5 %	0.1 %

where □ indicates that the hypothesis of equal means can not be rejected on a 5 % confidence level.

Discussion

The correlation between stem volume and the square root of shadow density, comparable with the inverted radiance, indicates that the shadows play a major role in explaining the variation of stem volume. Franklin & McDermind (1993) analysed data from CASI flown over lodge pole pine stands and suggested the dependence of spectral response to stem volume to be a function of amount of shadows in the scene.

Forest looks darker in interval A compared to interval C, thereby giving an overestimation of volume in this interval. The correlation between volume and inverted radiance in interval A compared with B and C could be because more of the shadow side of the tree is seen from the sensor in interval A compared with the other intervals. An uneven distribution of plots with different volumes in the different intervals could affect the results. This is because the models tend to overestimate low volumes and underestimate high volumes. However, if the better correlation is an effect of the sun and sensor position this could be used in satellite remote sensing techniques. Planned satellite systems will have the availability to view along the track (Konecny 1996).

It is important to study how geometry of the forest affects the reflectance. Shadows from a spruce are much darker than shadows from a pine, which doesn't have as dense a canopy. The difference in radiance between different groups of plots with different species composition could be a result of factors other than species composition. This is especially true because of the small sample size for some of the groups. To reduce the effect of different radiance due to different volumes, plots with a volume > 120 m^3ha^{-1} were chosen for which correlation between volume and inverted radiance is relatively weak. The measured radiance is an effect of not only the trees but also of ground vegetation, which was not taken into consideration in this study. The deciduous group could not be separated from the pine group. This could be because the deciduous group had a large portion of deciduous trees but the dominating species was pine. This was a result of few plots with a large portion of deciduous trees in the available field data.

Accuracy of the positioning of field plots was not evaluated. Three components determine the accuracy: 1) The Global Position System (GPS) measurements of plot centre, 2) The image geometry, 3) Rectification of the image. Data from navigation systems on board the aircraft, for example a Global Position System (GPS) combined with Internal Navigation System (INS) for absolute positioning would had done the third stem unnecessary. For the rectification the result is better for positions close to a GCP compared to another far away from the closest GCP. Even if the plot location was poor in some cases, the spatial auto-correlation should make the effects small if the plot was not located next to a stand boundary.

In this study, an indirect relation between radiance and the stem volume, where the amount of shadows probably played a major role, was presented. The models were not tested with a set of validation plots. Even if the models were evaluated it is likely that they not would predict stem volume poorly for a different acquisition over a different forest . The ambition must be to use more direct relations. With high-resolution images (e.g. MEIS), such as a resolution of 0.1-1 m, trees can be automatically isolated from each other and their background vegetation, followed by tree species identification. The geographical positions of single trees, crown area and height would make it possible to create detailed forest inventories (Francois 1992). The position and the size of individual trees can also be measured with LIDAR (Aldred & Bonnor1985). There is also a synergism in combining different sensors on the same platform (e.g. Leckie 1990).

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