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Spectroradiometric characteristics of Scots pine and intensity of moose browsing

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TIIVISTELMÄ: MÄNNYN HEIJASTUSSPEKTRIEROJEN YHTEYS HIRVITUHOIHIN

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The light reflected from the crowns of pine clones was measured spectroradiometrically during and after the growing season. Standard deviations of the spectra of pine clones showing differences in moose browsing intensity were compared. A new algorithm was developed for predicting the browsing intensity of moose.

Männyn heijastusspektrimittaukset suoritettiin kasvukauden aikana ja sen jälkeen. Hirvituhoiltaan tunnettujen mäntykloonien heijastusspektrejä vertailtiin keskenään niiden keskihajonnan avulla. Työn kuluessa kehitettiin algoritmi, jolla voidaan arvioida mahdollista hirvituhon astetta mäntykloonin spektrisen heijastusarvon perusteella.

Keywords: reflectance, spectral analysis, aerial photography, multispectral photography, *Pinus sylvestris*.
FDC 451 + 174.7 *Pinus sylvestris*

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1 Introduction

The histochemical properties of plants browsed by herbivores influence the preferences of these browsers for different plant species as well as their choice of individual plants within species (Bryant et al. 1983, Radwan and Crough 1974). Haukioja et al. (1983) studied the chemical characteristics of Scots pine (*Pinus sylvestris* L.) needles preferred or rejected by moose (*Alces alces* L.) and found significant differences of the percentage dry matter and the ether-soluble fraction between totally browsed and untouched pine clones. Due to metabolic differences in the needles, the extreme types have been assumed to reflect light differently (Udenfriend 1962, Janza 1975, Knipling 1970). The light reflected from mesophyll, chloroplasts and other cell or-

ganelles may indicate other histochemical properties and metabolic changes. This reflected light can be analyzed by spectroradiometric measurements (Janza 1975, Knipling 1970, Silvennoinen 1989). The spectra of light reflected from individual pine trees is useful, e.g. in interpreting aerial multispectral pictures (Thorley 1975, Silvennoinen 1989, Silvennoinen et al. 1991).

In this study we measured the spectra of light reflected from the same pine clones and individuals as studied and classified in terms of moose browsing preference by Haukioja et al. (1983). The spectroradiometric characteristics of the pine clones measured were analyzed numerically and the standard statistic differences in wavelength dependence were compared with the relevant reflectance characteristics of the pine crowns preferred or rejected by moose.

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2 Materials and methods

The Scots pine clones used here were growing in Hirvensalmi (21 clones) clone archive (61°33'N, 26°58'E) and were the same as those used by Haukioja et al. (1983) (Table 1). In addition, clones located in Punkaharju (19 clones) (61°48'N, 29°19'E) and Iitti (7 clones) (60°52'N, 26°27'E) clone archives were also studied (Table 1). Spectroradiometric measurements were made in clear weather during the growing season in June 1990 and after the growing season in August of the same year. The total number of clones studied was 21. The number of rows of crowns in the 21 clones measured was 21 during the growing season and 46 after the growing season (clone K820 in Punkaharju was omitted because it was growing in shade).

The measurements were made with a PR 713/702 AM spectroradiometer (Fig. 1), working in the wavelength range 390–1070 nm, with a resolution of 4 nm (Specifications... 1984). The spectra of solar and sky radiation via a BaSO4 reference surface (Jackson et al. 1987), used as the baseline for interpretation, were recorded in the files of a computer attached to the spectroradiometer. Immediately after the reference spectra were taken, the spectra reflected from the row of pine crowns in the clone (focused on a single crown) were also recorded. The levels of the spectra were recorded simultaneously by using a BPW-20 photodiode based light meter. The specific reflectance of the pine crowns were then computed as a ratio of the corrected spectra reflected from the single ramets and those reflected from the BaSO4 surface (Silvennoinen 1991).

The standard deviation for reflectance values in each channel was calculated from five random reflectance samples registered during automatic spectrometer runs lasting 10 to 15 seconds. The measurements were made in 40–50 degrees to incoming light in the normal plane of the representative accumulations of crown needles dense enough to prevent background radiation. The calculations of variation coefficient, correlation coefficient and cross-correlation function of reflectance between crown categories was made by algorithms used in respective context by Brook and Wynne 1988.

For calculations of standard deviation in reflectance, the respective clones growing in Hirvensalmi, Iitti and Punkaharju were grouped into three categories according to intensity of moose browsing: (a) 0–9 % (8 clones before and 16 clones after the growing season), (b) 10–30 % (10 clones before and 24 clones after the growing season) and (c) 31–100% (3 clones before and 6 clones after the growing season) as reported by Haukioja et al. (1983). This classification was made again during our study.

Finally, the spectra of the clones measured during and after the growing season were divided into eleven spectral bands from 390 nm to 900 nm. Standard deviations for the mean reflectance values in these spectral bands were calculated for each clone during and after the growing season. Each clone was grouped into spectral bands of 50 nm width according to the range of the standard deviation of the reflectance.

Table 1. Scots pine clones growing in Hirvensalmi, Iitti and Punkaharju clone archives; a = not browsed, b = moderately browsed and c = heavily browsed by moose.

Clone number	Hirvensalmi	Iitti	Punkaharju
K685 (c)	x	-	x
K688 (c)	x	-	x
K696 (a)	x	-	x
K697 (b)	x	-	x
K743 (b)	x	-	-
K744 (a)	x	-	-
K801 (b)	x	x	x
K802 (b)	x	-	x
K804 (b)	x	x	x
K816 (a)	x	-	x
K817 (b)	x	x	x
K820 (a)	x	x	x*
K825 (c)	x	-	x
K827 (b)	x	-	x
K828 (b)	x	-	x
K831 (a)	x	-	x
K836 (b)	x	x	x
K908 (b)	x	x	x
K912 (a)	x	-	x
K924 (a)	x	x	x
K926 (a)	x	-	x

* Clone K820 in Punkaharju was in shade.

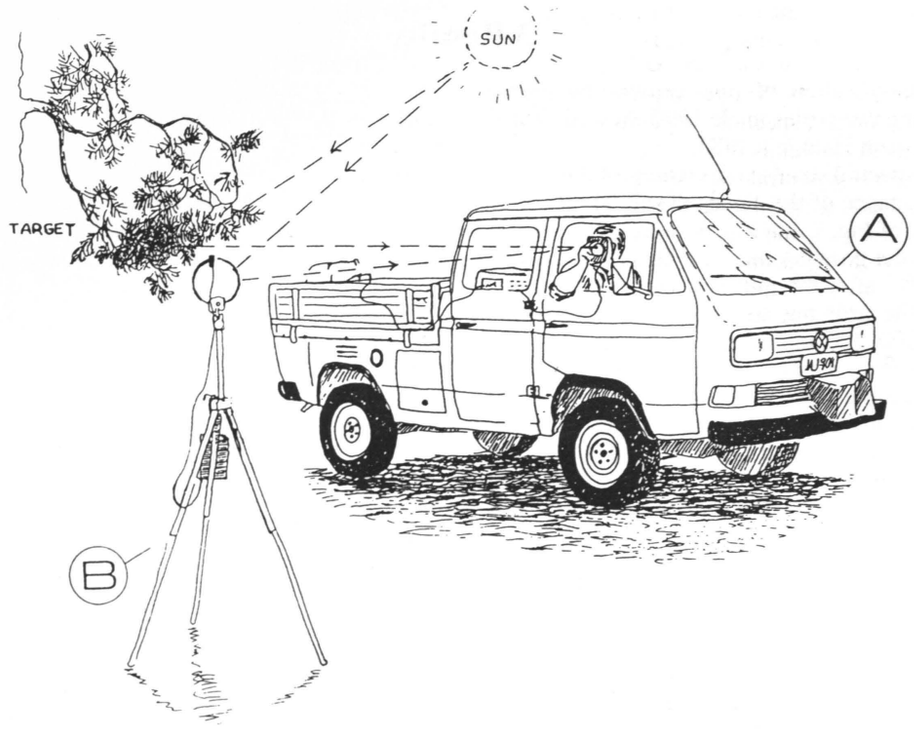

Fig. 1. The field equipment used in reflectance measurements of pine clones. (A) Mobile spectroradiometric unit: Photo Research 713/702 AM spectroradiometer and a 230 VAC power source mounted on a four wheel driving vehicle. (B) BaSO4 reflectance reference standard and a BPW-20 photodiode based light meter attached on a tripod.

3 Results

The classification of pine crowns by moose browsing categories made 1990 showed similar results as in Haukioja 1983.

The spectral standard deviations of the specific reflectance of the clones (Table 1) measured (A sets of Fig. 2 and Fig. 3) were 37.9 ± 9.5 % during the growing season (Fig. 2(B)) and 24.8 ± 2.0 % after the growing season (Fig. 3(B)) After the growing season, in the wavelength range 390–700 nm the relative deviations of the spectra (Fig. 4 (B)) for specific reflectance of all the clones (Fig. 4.(A)) studied in Hirvensalmi and Punkaharju clone archives were similar.

The mean values for spectral reflectance of the three browsing categories differed from each other during the growing season (Fig. 5(A)) but were strikingly similar after that (Fig. 6(A)) During the growing season, the standard deviations of the specific reflectance of the clones representing the moderately browsed (b), not browsed (a) and completely browsed (c) categories were 22.0 ± 4.6 %, 37.9 ± 9.5 % and 18.1 ± 5.8 %, respectively (Fig. 5(B)); and after the growing season were 21.7 ± 1.4 %, 27.4 ± 4.4 % and 26.2 ± 6.3 %, respectively (Fig. 6(B)). Curves a, b and c of Figs. 5 and 6 represent the variations in specific reflectance of the respective categories 0–9 %, 10–30 % and 31–100 % of moose browsing intensity. The paired-sample t-test for reflectance means of the categories showed significant differences during and after the growing season (Table 2).

The number of pine crowns in browsed categories b and c within the standard deviation range was highest (77.8 %) in the wavelength range 390–450 nm after the growing season (Table 3).

The correlation coefficients and cross-correlations of reflectances showed no significant differences between crown categories.

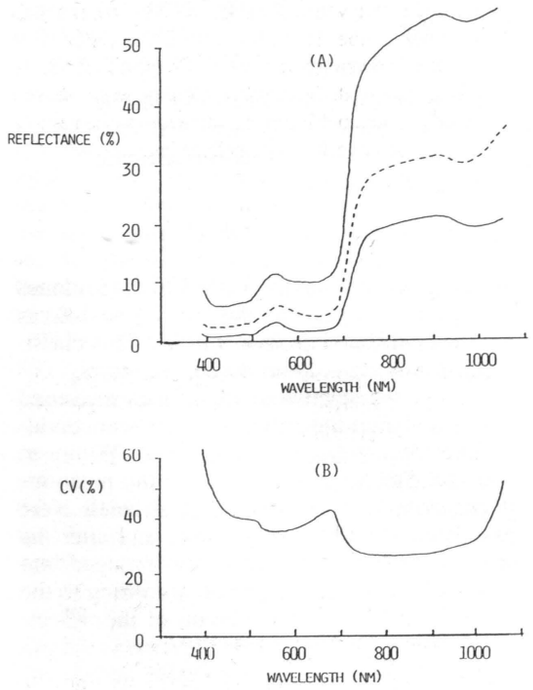

Fig. 2. (A) Variation (between the solid lines) and mean value (dashed line) of reflectance of the 21 pine crowns in the respective 21 clones during the growing season as a function of wavelength and (B) the coefficient of variation of the respective reflectance properties.

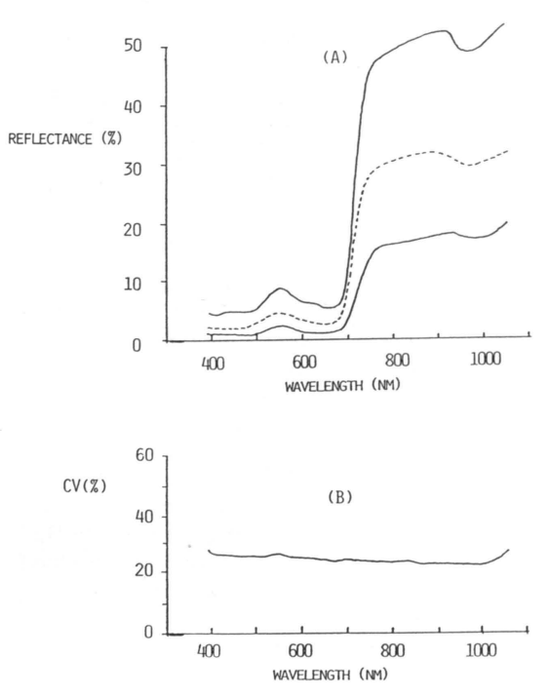

Fig. 3. (A) Variation (between the solid lines) and mean value (dashed line) of reflectance of the 46 pine crowns in the 21 clones after the growing season as a function of wavelength and (B) the coefficient of variation of the respective reflectance properties.

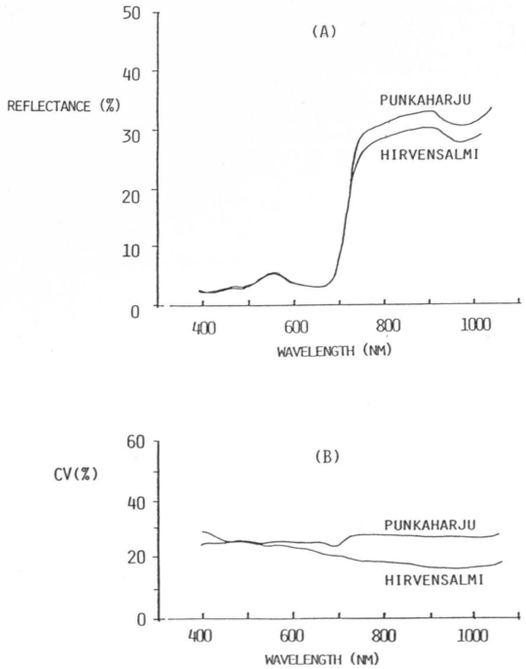

Fig. 4. (A) Mean values for the reflectance of the pine crowns growing in Hirvensalmi (21 clone) and Punkaharju (18 clones measured) nurseries after the growing season and (B) the coefficient of variation of the respective reflectance properties.

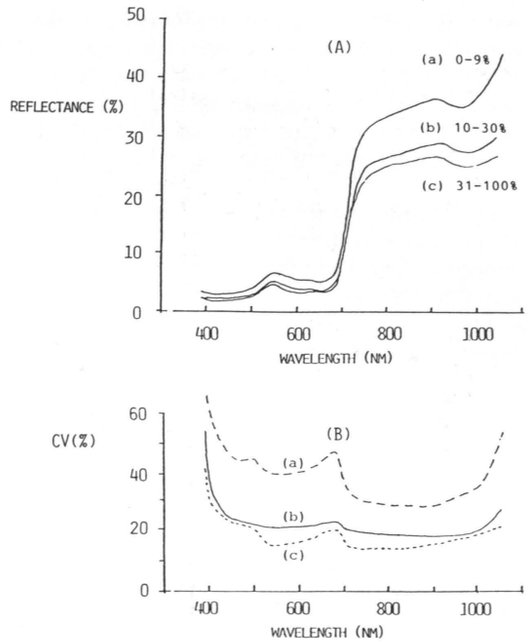

Fig. 5. (A) Mean values for the reflectance of the pine crowns in the 21 clones between categories of moose browsing intensity of 0–9 % (a), 10–30 % (b) and 31–100 % (c) during the growing season and (B) the coefficient of variation of the respective relative reflectance properties.

Table 2. Paired-sample t-test for pine category reflectance means in 390–1070 nm wavelength range; (a) not used, (b) moderately used and (c) completely used by moose.

Compared means	t_0	df	Difference
During growing season			
a to b	19.64	340	$p > 0.001$
a to c	23.19	340	$p > 0.001$
b to c	6.87	340	$p > 0.001$
After growing season			
a to b	16.10	340	$p > 0.001$
a to c	2.04	340	$p > 0.050$
b to c	9.10	340	$p > 0.001$

Table 3. Number of (b) moderately browsed and (c) heavily browsed pine clones within the ± 1 standard deviation range.

Spectral band (nm)	Number of clones in June (b and c)	Total	%	Number of clones in August (b and c)	Total	%
390–420	10	16	62.5	21	27	77.8
390–450	10	17	58.8	20	27	74.1
450–500	9	15	60.0	20	29	69.0
500–550	9	14	64.3	19	31	61.3
550–600	10	15	66.7	21	35	60.0
600–650	10	18	55.5	20	33	60.6
650–700	10	15	66.7	21	34	61.8
700–750	10	14	71.4	20	31	64.5
750–800	9	13	69.2	20	31	64.5
800–850	10	14	71.4	19	30	63.3
850–900	11	17	64.7	28	42	66.7

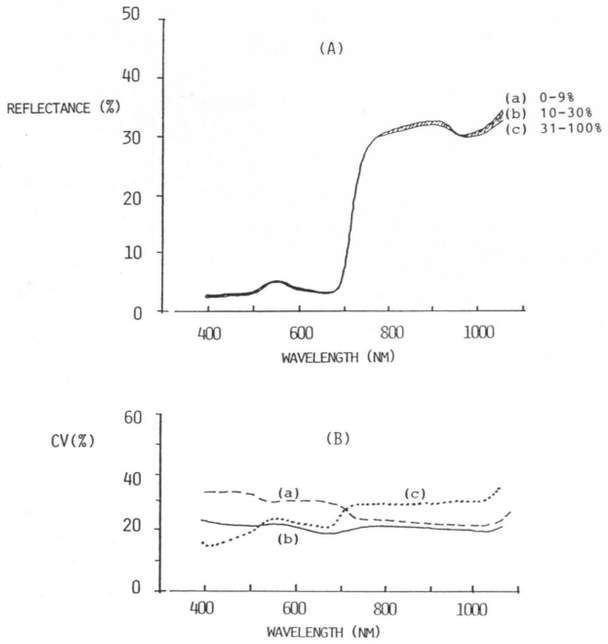

Fig. 6. (A) Mean values of the reflectance of the pine crowns in the 21 clones between categories of moose browsing intensity of 0–9 % (a), 10–30 % (b) and 31–100 % (c) after the growing season and (B) the coefficient of variation of the respective relative reflectance properties.

4 Discussion

The specific reflectance of the pine clones studied was in agreement with the reflectance ranges reported previously for Scots pine (Bäckström and Wellander 1953, Stellingwerf 1968, Csaplovics 1982 and Kleman 1985). During the growing season, the standard deviation of the relative reflectance values (37.9 ± 9.5 %) depended strongly on the wavelength. After the growing season, the standard deviation was nearly constant (24.8 ± 2.0 %), indicating no observable dependence on wavelength. The mean reflectance of the three pine categories during and after the growing season was strikingly similar representing the typical shape of the Scots pine reflectance.

The standard deviations for the moderately browsed (b), not browsed (a) and completely browsed (c) pine categories during the growing season were 22.0 ± 4.6 %, 37.9 ± 9.5 % and 18.1 ± 5.8 %, respectively. The standard deviation (21.7 ± 1.4 %) of the moderately browsed crowns after the growing season showed the same typical shape as for Scots pine in general. Both extreme categories, i.e. not browsed and completely browsed, showed higher standard deviations (27.4 ± 4.4 % and 26.2 ± 6.3 %) than the moderately browsed category (21.7 ± 1.4 %) did. These two categories, however, show wavelength dependence in opposite ways; the pine clones not used by the moose showed greater deviation in reflectance at shorter wavelengths and smaller deviation at longer wavelengths, whereas the clones heavily used by moose showed lower deviation at the shorter wavelength and higher deviation at longer wavelengths. The deviation at a wavelength of 700 nm was the same for both of the extreme categories (a and c). Evidently, the wavelength dependence of the deviations indicates histochemical differences in the Scots pine population. The standard statistic methods like paired-sample t-test are capable of showing wavelength dependence differences between the categories studied, but fail to reveal the relevant reflectance characteristics of the pine crowns preferred or rejected by moose. However, by comparing the number of the b and c category clones falling inside the ± 1 standard deviation range of the seasonal spectral mean values indicating similarity, we found significant wavelength dependence after the growing season.

Thus, the number of b and c clones within the standard deviation range indicated that during the growing season the deviations in reflectance caused by histochemical differences in these clones are higher in the shorter wavelength range than in the longer ranges and that after the growing season this is reversed. Our results also indicated that in the 10–30 % and 31–100% (practically 100%) categories of moose browsing intensity the spectral differences in the shorter wavelength range are strongest after the growing season.

The highest probability for an individual pine crown to be in the standard deviation range of the moderately and heavily browsed categories is 82.3 % in the wavelength range 390–450 nm measured after the growing season. Other wavelength ranges showed probabilities around 50 %.

5 Conclusion

In the wavelength range 390–700 nm, after the growing season the coefficient of variation in reflectance of pine clone categories was lower for moderately and completely browsed crown categories than for not browsed one. The wavelength dependence of the deviations indicates histochemical differences in the Scots pine population.

After the growing season, the probabilities for browsed clones of the pine population to be within the ± 1 standard deviation range were higher at shorter wavelengths than at the longer wavelengths. This also suggests that in the 82 % accuracy range, when the wavelength range 390–450 nm (blue and blue green) is used, the categories of moose browsing intensity identified by Haukioja et al. (1983), can be predicted by using multispectral pictures taken after the growing season.

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