14. Kongress der Internationalen Gesellschaft für Photogrammetrie Hamburg 1980, Kommission VII, Arbeitsgruppe 2

A SAMPLING TECHNIQUE TO ASSESS SITE, STAND, AND DAMAGE CHARACTERISTICS OF PINE FORESTS ON CIR AERIAL PHOTOGRAPHS

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Abstract

A test area of the severely damaged pine forests in the lower Swiss Rhone Valley was sampled systematically. Nine site, stand, and damage characteristics were rated and encoded for each sample plot using medium scale color infrared (CIR) aerial photographs. The objective of this study is to quantify the interdependences between these variables. Using a multiple linear regression in connection with a principal component analysis, the damage variable "pine mortality" is expressed in terms of site and stand characteristics.

Introduction

This study is part of a forest damage investigation carried out in the lower Rhone Valley, Switzerland (SCHERRER et al., in prep.). Some of its pine forests are severely damaged. This study was undertaken with the following question in mind: To what extent is it possible to explain "pine mortality" with those site and stand characteristics which can be clearly recognized on medium scale CIR-photographs? In this sense, it is an analysis of how the interdependent variables contribute to "pine mortality".

The surveyed area is 426 sqkm with 130 sqkm of forest land. The industrialized valley is more than 100 km long and relatively narrow, encompassed by alpine mountains rising to an elevation of some 3000-4000 m above the valley bottom. The frequent, low and stable inversion layers enclose an atmospheric volume of a limited dilution capacity for air pollutants. Not only air pollution but also periodic drought and other natural stress factors might be possible causes of the observed forest damage.

Methods and results

The 781 sample plots, arranged in a systematic network covering a test area of 196 ha, were examined on CIR-aerial photographs (23x23 cm, f=153 mm, scale 1:13000) using an autograph Wild B8. Each plot of 0.25 ha was rated according to the nine criteria given in Tab. 1.

Tab. 1 Rating criteria

a) site characteristics	b) stand characteristics
1 **elevation above sea level** 50 m intervals (1 = 451–500 m ... 15 = 1151–1200 m)	4 **stand type** 6 classes: composition of pine, deciduous and other coniferous species
2 **exposure** 9 classes: 8 azimuth segments and horizontal plots without exposure	5 **canopy coverage** 4 classes: 0.1–0.3, 0.3–0.6, 0.6–0.8, >0.8
3 **topography** 5 classes: trough, horizontal, gentle slope, steep slope, ridge top	6 **age of stand** 4 classes: young, intermediate, old, heterogeneous
	7 **site index** 3 classes: poor, intermediate, good
c) damage characteristics	
8 **pine mortality** 4 classes: expressed in % of all pine trees per plot	9 **age of the dead pine trees** 5 classes: no dead pine trees, young, intermediate, old, heterogeneous

The frequency distributions of the 781 observations per criterion provide a first quantitative information (SCHERRER et al. 1979). They are illustrated in Fig. 1 for the two criteria "topography" and "exposure". 83 % of all sampled plots are located on slopes, 8 % on poor ridge top sites and only 9 % on fairly productive sites in depressions (troughs, Fig. 1a). The predominant exposure is NW (63 %, 489 plots) which is perpendicular to the valley axis (Fig.1b). Frequent and strong winds, mainly from the west, aggravate the effects of drought periods on W-exposed sites (11 %). On N-facing slopes the water regime is more favorable. The

Fig. 1 Absolute frequencies of stand characteristics of the sampled plots

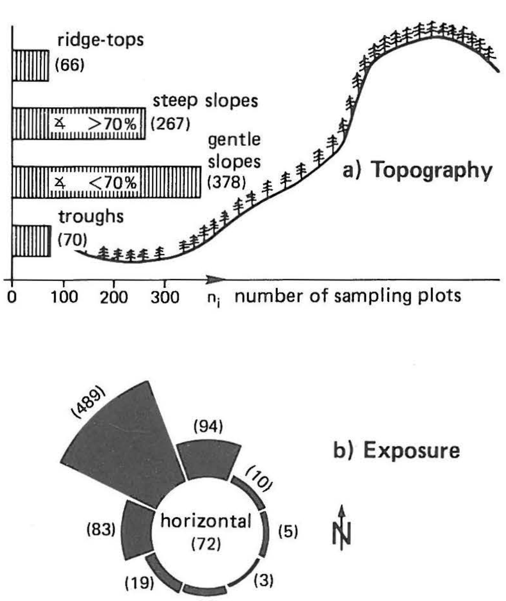
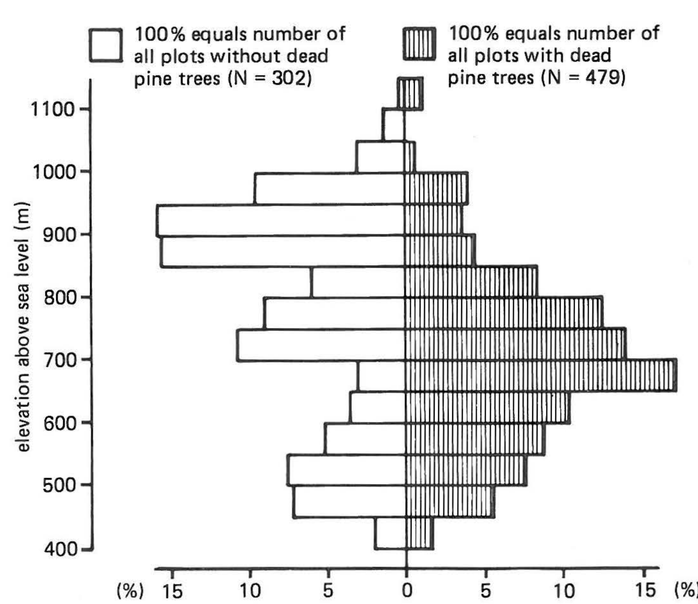


Fig. 2 Sampling plots with and without dead pine trees in different altitudes

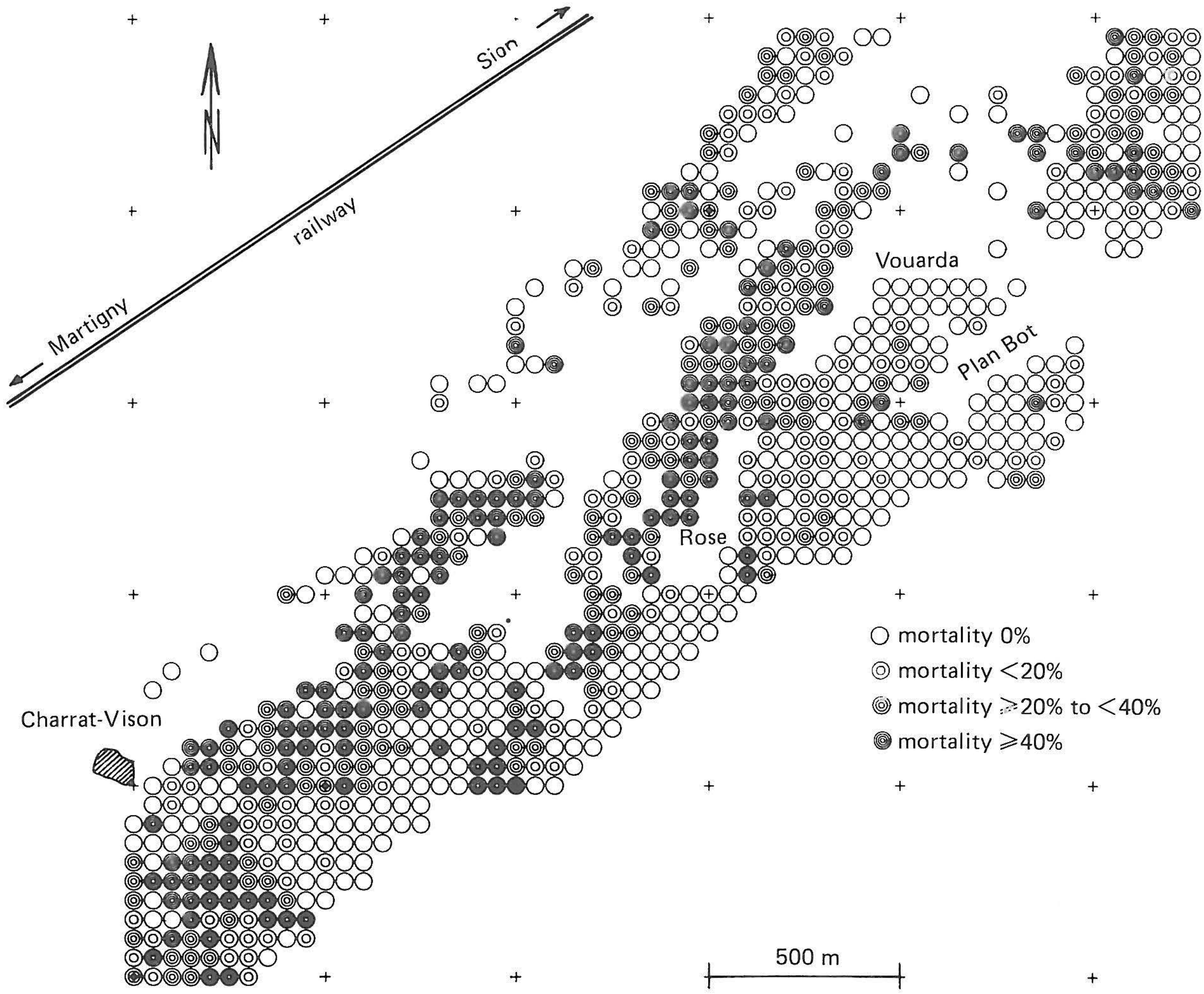


variable "exposure" contains information about several climatic factors such as wind, precipitation and insolation.

Stratification of the sample plots according to one variable, i.e. "damaged" vs. "undamaged" stands, provides insight into mutual interdependences of the correlated variables. Fig. 2 shows the relative occurence of damaged and undamaged stands at different elevations. The maxima and minima of the two distributions are complements of eachother. The most severely damaged stands are located at the average elevation of typical pine sites.

A systematic multifactorial sampling network yields a mosaic-type map for each variable which is a useful tool for forest management. This information about the spatial distribution of the nine characteristics is obtained in a way as by-product of the analysis (Fig. 3).

Fig. 3 Mosaic-type map of pine mortality



WALDSCHADENKARTIERUNG CHARRAT-SAXON (VS), MORTALITAET DER FOEHREN

In the context of this study, "pine mortality" is of prime concern. It might be considered as the dependent variable y_i expressed as a function of the other eight variables which were included in this study.

In order to apply a multiple linear regression model (MLR) two conditions must be met. First, the eight "independent" variables should be uncorrelated and second, the average "pine mortality" per criteria class of the individual variables should exhibit an either increasing or decreasing trend. Whenever it can be logically justified the code classes should be rearranged to satisfy this requirement. For certain criteria such as stand type, topography and exposure one cannot objectively define the sequence and especially the ranking codes because they were arbitrarily chosen and encoded. Four criteria were partially re-classified. Since for a given pine mortality the relative frequencies per observation class are unevenly distributed the following procedure was applied:

The observed frequencies were expressed as percentages per code class of the re-examined variable. Doing this, the unequally represented frequencies are weighted. As shown in Tab. 2a and 2b, and in Fig. 4a and 4b the original code classes

Tab. 2a Absolute and relative frequencies of different exposures per pine tree mortality class

exposure / pine mortality	W	SW+NW	S+O	SE+N	E+NE
1 (0%)	17 (20)	186 (37)	30 (39)	60 (62)	9 (60)
2 (<20%)	16 (19)	116 (23)	14 (18)	12 (12)	3 (20)
3 (≥20% to <40%)	19 (23)	103 (20)	15 (19)	15 (16)	0 (0)
4 (≥40%)	31 (38)	103 (20)	19 (24)	10 (10)	3 (20)
total	83 (100)	508 (100)	78 (100)	97 (100)	15 (100)
original code	8	7+9	6+1	5+2	4+3
rearranged code	1	2	3	4	5

(percentages in parentheses)

Tab. 2b Absolute and relative frequencies of different forest stand types per pine mortality class

stand type / pine mortality	p<10% d~0% c>90%	p<10% d>90% c=0%	p≥10% to <40% d~0% c≥60% to <90%	p≥10% to <40% d≥60% to <90% c=0%	p≥40% to <90% $\left.\begin{matrix}d\\c\end{matrix}\right\}$ ≥10% to <60%	p≥90% $\left.\begin{matrix}d\\c\end{matrix}\right\}$ <10%
1 (0%)	137 (88)	96 (72)	21 (36)	22 (17)	23 (12)	3 (3)
2 (<20%)	8 (5)	6 (4)	22 (36)	29 (22)	65 (32)	31 (30)
3 (≥20% to <40%)	5 (3)	7 (5)	8 (14)	37 (29)	57 (29)	38 (36)
4 (≥40%)	6 (4)	25 (19)	8 (14)	41 (32)	53 (27)	33 (31)
total	156 (100)	134 (100)	59 (100)	129 (100)	198 (100)	105 (100)
original code	5	1	6	2	3	4
rearranged code	1	2	3	4	5	6

(percentages in parentheses)

p = pine trees
d = deciduous trees
c = other coniferous trees

were rearranged in a way that the relative frequencies either increase or decrease within each pine mortality class.
The average "pine mortality" of the nine exposure classes exhibits a maximum on W-facing, a minimum on E-facing, and an intermediate value on horizontal sites. Note, that only the code sequence but not the numerical value of individual observations was adjusted.

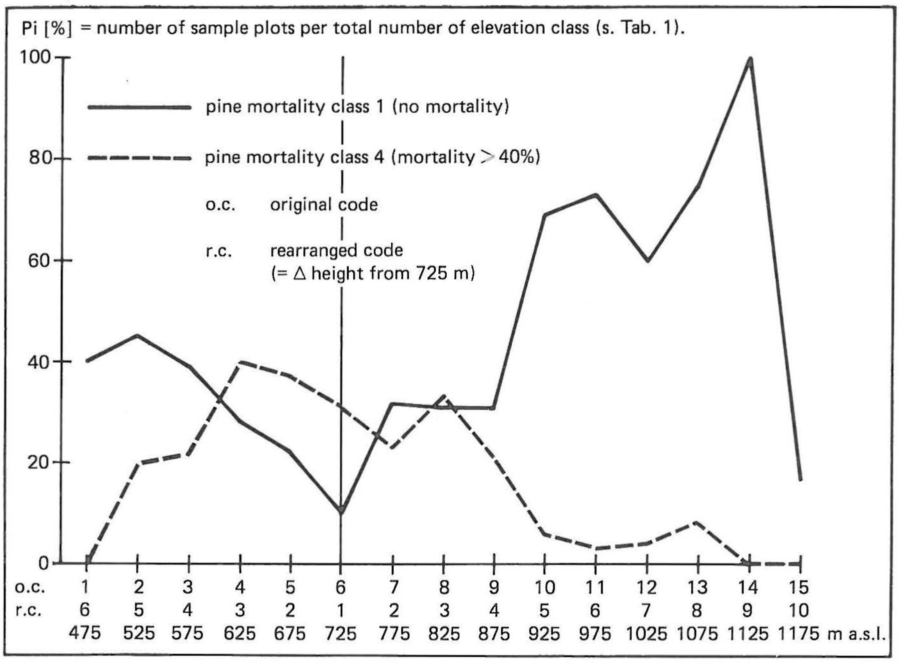


Fig. 4a Relative frequencies of different elevations for two pine mortality classes.

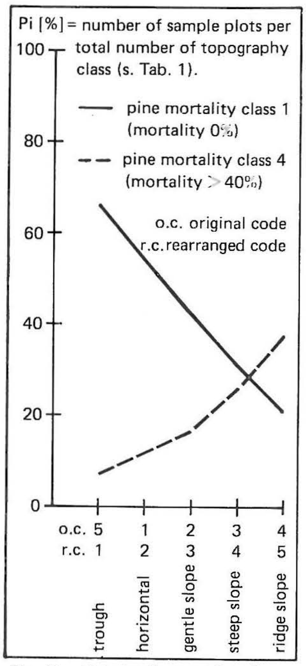


Fig. 4b Relative frequencies of different topography classes for two pine mortality classes.

Most of the nine variables, each with 781 observations, are highly correlated (Tab. 3). Correlation coefficients higher than 0.09 or 0.12 are significant at a 95 % or 99 % level, respectively. Hence these variables are not "independent" as required for a regression analysis.

Tab. 3 Correlation coefficiants between the rated variables

	elevation	exposure	topography	stand type	canopy coverage	age of stand	site index	pine mortality	age of dead pine trees
elevation	1.00	0.07	−0.10	−0.26	0.03	−0.02	0.28	0.37	−0.32
exposure		1.00	0.06	−0.20	0.13	−0.03	0.17	0.19	0.21
topography			1.00	0.17	−0.18	−0.05	−0.40	0.25	0.21
stand type				1.00	−0.17	0.08	−0.50	0.54	0.63
canopy coverage					1.00	0.00	0.47	0.11	−0.09
age of stand						1.00	0.07	0.22	0.33
site index							1.00	0.42	−0.38
pine mortality								1.00	0.83
age of dead pine trees									1.00

In order to obtain truly "independent" variables the observations x_{ij} (variable j, plot i) were normalized, $X_{ij}=(x_{ij}-\bar{x})/s_{x_j}$, and then transformed by means of a principal component (PC) analysis which yields the orthogonal, uncorrelated variables $^*X_{ij}$ 1/. The multiple linear regression program for "pine mortality" (y_i), run with the $^*X_{ij}$'s returns the regression coefficients for both, the orthogonal and the original coordinates, $^*X_{ij}$ and X_{ij}, respectively. This technique was used by FRITTS et al. (1971) for a similar statistical problem in the field of tree ring analysis.

The response functions which are the regression coefficients computed with the $^*X_{ij}$'s and projected onto the coordinates of the X_{ij}'s reflect the relative importance of the individual variables with respect to pine mortality (y_i).

$$\hat{y}_i = \bar{y} + s_y \sum_{j=1}^{k} a_j X_{ij}$$

In a first run (model A) of the PC-MLR-program all variables (k=8) were included. This model explains 69.9 % of the observed variance in y_i (Fig. 5a). Those variables with coefficients significantly different from zero were included in a second run (model B, k=4) which still accounts for 69.9 % of the variance (Fig. 5b). With only the two most significant variables (k=2) of run A and B ("age of dead pine trees" and "elevation") 68.8 % of the variance is explained (model C, Fig. 5c). Almost no information is lost due to the drastically reduced number of variables. A simple linear regression versus the most significant variable ("age of dead pine trees") accounts for 67.7 % of the variance. The role of the remaining site and stand variables is obviously covered up by the dominant "age of dead pine trees" variable. Without this variable but including all the others, model D (Fig. 5d, k=7) leads to the interesting conclusion that all remaining site and stand variables significantly contribute to the predictor of y_i. However, in this last run only 42 % of the variance is explained.

1/ Program package RESPONS Version 1971, H.C. FRITTS, Tree Ring Laboratory, Univ. of Arizona, Tucson.

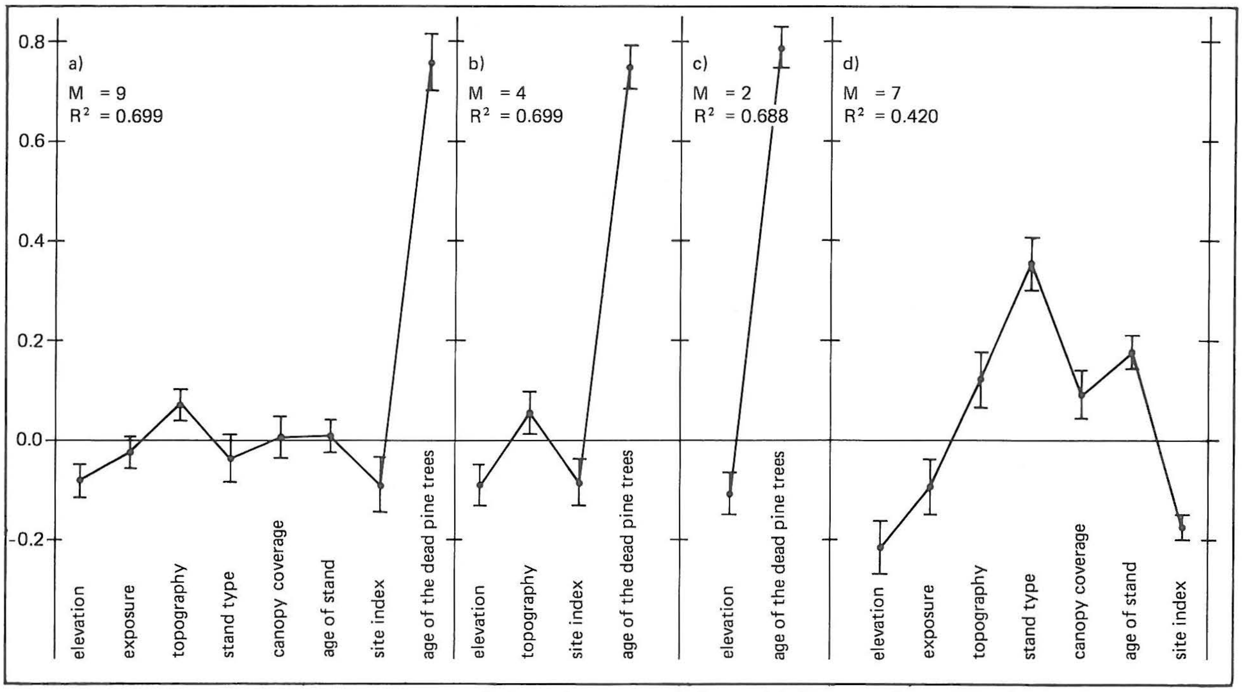


Fig. 5a–d Regression coefficients of damage prediction models (M = normalized variables)

Conclusions

This statistical approach overcomes the difficulty that part of the information of a single variable is contained in others, too. It must be recognized that this analysis is no proof of cause and effect but it is a strong indication of possible synergisms between different factors. In this sense we might hypothesize that natural or premature aging is either the cause itself or a prerequisite for the observed severe forest damage. Under the influence of adverse site conditions such as drought and/or shallow soils on steep slopes or eroded ridge tops this trend appears to be more pronounced.

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