PERIODICUM BIOLOGORUM
VOL. 110, No 2, 157–161, 2008

UDC 57:61
CODEN PDBIAD
ISSN 0031-5362

Original scientific paper

Assessing the health status of beech-fir forests using remote sensing methods

RENATA PERNAR
ANTE SELETKOVIĆ
MARIO ANČIĆ
MISLAV VEDRIŠ
KRUNOSLAV TESLAK

Faculty of Forestry
Svetošimunska 25
HR-10000 Zagreb, Croatia

Correspondence:
Renata Pernar
Faculty of Forestry
Svetošimunska 25
HR-10000 Zagreb, Croatia
E-mail: rpernar@sumfak.hr

Key words: color infrared (CIR) aerial photographs, beech-fir forests, health status, multivariate analysis, geomorphological factors

Received November 12, 2007.

Abstract

Background and Purpose: *Forest health evaluation may be performed through terrestrial monitoring or with the application of remote sensing methods. Of remote sensing methods, interpretation of color infrared (CIR) aerial photographs is particularly suitable. The primary goal of this research is to assess and evaluate the health status of beech-fir forests, obtain data on surface damage distribution and investigate some features that affect forest health in the area of Velebit through CIR aerial photograph interpretation.*

Material and Methods: *Forest damage inventory was made for the entire surveyed area using the raster method (100x100m) overlaid on the infrared digital orthophoto. Damage indicators for particular tree species and overall for the entire surveyed area were calculated. Regression analysis was used to determine inter-dependencies of geomorphological parameters and damage indicators.*

Results: *Photointerpretation of individual trees in a systematic sample in the study area covered a total of 21,011 trees. As for fir, 61.96% of the trees were severely damaged. Within this percentage, the mean damage for fir was 51.03%. In the entire surveyed area, severely damaged beech accounted for 6.56%, which confirms that beech is the least damaged tree species. Geomorphological factors also affect a stand's health status. According to the obtained results, an increase in the slope is directly proportionate to the increase in the fir damage index.*

Conclusion: *CIR aerial photographs were photointerpreted in order to determine and analyze the health condition of beech-fir forests in the area of Velebit and obtain data on surface damage distribution. According to results, the damage degree of inventoried forests is at transition from slight to moderate. It can be concluded from the results that damage increases with rising terrain slope and growing distance of terrain orientation from the west.*

INTRODUCTION

In many parts of Croatia forest dieback is assuming alarming proportions. Beech-fir forests in the Dinaric mountain range are particularly affected (*1*). In-depth research is carried out to study and control the phenomenon. The primary task involves the evaluation of forest health, degrees of damage, size of the affected areas, number of the affected trees of particular species and similar. Forest health evaluation may be performed through terrestrial monitoring or with the application of remote sensing methods. Of remote sensing methods, interpre-

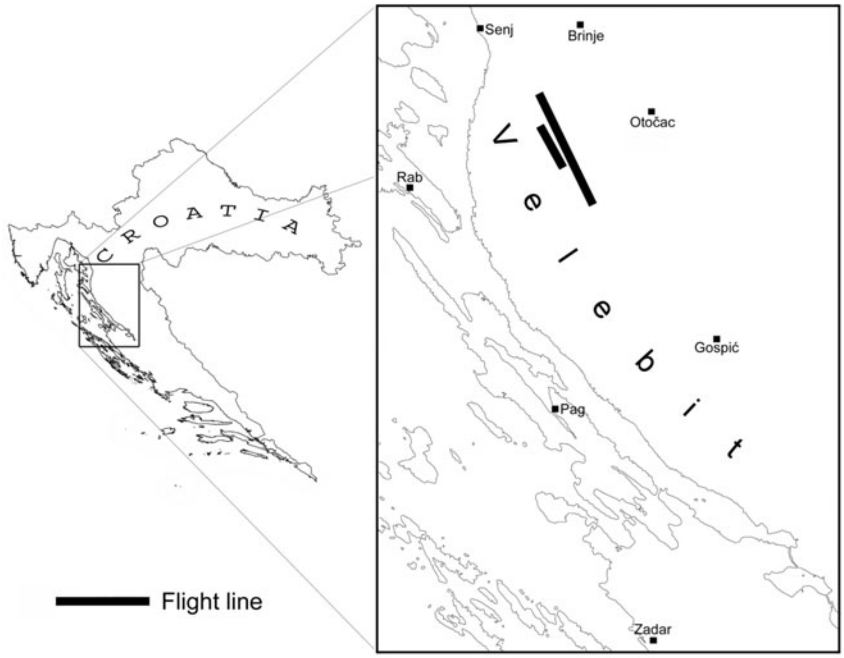

Figure 1. *Photographed area with drawn flight lines.*

tation of color infrared (CIR) aerial photographs is particularly suitable. In some cases, due to changes in the spectral reflection of affected vegetation, damage may be detected in a CIR aerial photograph even before the signs visible to the naked eye occur in the nature.

According to the results of field forest damage assessment in Croatia (a method prescribed by the ICP Forests), severe damage gradually rose from 2003 to reach the highest level ever of severely damaged silver fir (*Abies alba*, Mill.) trees (76.7%) in 2005. Thus, silver fir remains the most endangered tree species in Croatia. In contrast, common beech (*Fagus sylvatica* L.) continues to manifest low levels of severe damage (10.9%), thus being the least damaged tree species in Croatia *(2)*.

Some authors attribute increased fir dieback to the impact of harmful air pollutants *(3, 4, 5, 6, 7, 8, 9, 10, 11)*. Recent research has linked increasing tree dieback with the impact of various site and stand characteristics (altitude, exposure, slope, soil, structure, etc.), and abiotic and biotic factors (fir needle mining moth, mildew, mistletoe). However, real causes remain unknown *(12, 13, 14, 15, 16, 17)*. In terms of accuracy the application of CIR aerial photography to assess forest condition is just as valuable as field assessment methods, but in terms of speed and objectivity it has proved to be much more efficient *(18)*.

AIM OF RESEARCH

The primary goal of this research was to assess and evaluate the health status of beech-fir forests, obtain data on surface damage distribution and investigate some features that affect forest health in the area of Velebit through CIR aerial photograph interpretation. Aerial photographs with color infrared film for the purpose of detecting beech and fir damage was initially used on Velebit in 1988, and then repeated in 1998 *(19)*. These surveys confirmed the benefits of photointerpretation in forest damage assessment (gaining an insight into the situation in the field in as short a period as possible is vital for timely application of dieback control measures), so a decision was made to use CIR films to survey the areas with stands that are severely affected with dieback.

MATERIAL AND METHODS

Aerial survey of the study area was conducted in July 2005. The survey area was determined with strips (Figure 1). The position of the beginning and the end of a strip, as well as strip length, were determined with Gauss-Krüger coordinates from a topographic map 1:25 000. A total of 88 aerial photographs were made. Aerial photogrammetric survey was made over an area of 5,548 ha. To collect the photointerpretation key data, work in the field was done in the same period. This involved selecting trees in the surveyed areas that could easily be detected in aerial photographs. Care was taken that a sample contained a sufficient number of trees in every damage degree. Each selected tree was categorized in an adequate damage class and its position was outlined in relation to recognizable environmental topographic details in a separate outline. A photointerpretation key was defined for principal tree species on the basis of an idea of how a particular tree species or damage degree may be reflected. Using the obtained photointerpretation keys, the health status of sample trees (crowns) taken in the field and identified in the photographs was assessed and the crowns were classified into damage degrees.

TABLE 1

Damage indicators for particular species and total (%).

Tree species	Damage indicators			
	O	IO	SO	SO1
	%			
Silver fir	96.29	61.96	37.81	51.03
Beech	52.84	6.56	12.61	32.79
Total	71.79	30.73	23.60	48.84

Based on earlier research (1988, 1998), a forest damage inventory was made for the entire surveyed area using the raster method (100 x 100 m) overlaid on the infrared digital orthophoto (DOP). The central parts of the photographs were used to make the DOP. The pixel size of a particular orthophotograph was 0.5 m. Orthophotomaps were modelled according to the Croatian basic map (CBM) 1:5000. Even distribution of interpreted crowns over the entire surveyed area was achieved with the raster method (Figure 2). The crown closest to the raster point in the bottom left and right, and in the upper left and right angle was interpreted. In this way, the damage degree of 4 individual trees (crowns) was assessed in every raster point according to the following scale:

Damage degree	Damage percentage
0	0 – 10 %
1	11 – 25 %
2.1	26 – 40 %
2.2	41 – 60 %
3.1	61 – 80 %
3.2	81 – 100 %
4	Snags

Damage indicators (O = Damage, SO = Mean Damage, IO = Damage Index, SO_1 = Mean Damage1) for particular tree species and overall for the entire surveyed area, including the management units (compartments/subcompartments) affected by survey were calculated using the formulas 1–4 *(20)*.

1. Damage (O)

$$O\% = \frac{\sum f_{(1-4)}}{\sum f_{(0-4)}} \cdot 100 \quad (1)$$

Damage (O) is not the best indicator of the condition because it takes into account only the total number of damaged trees. Damage status is much better expressed by those indicators which include the number of damaged trees in a particular damage degree.

2. Mean Damage (SO)

$$SO\% = \frac{\sum f_i \cdot x_i}{\sum f_i} \quad (2)$$

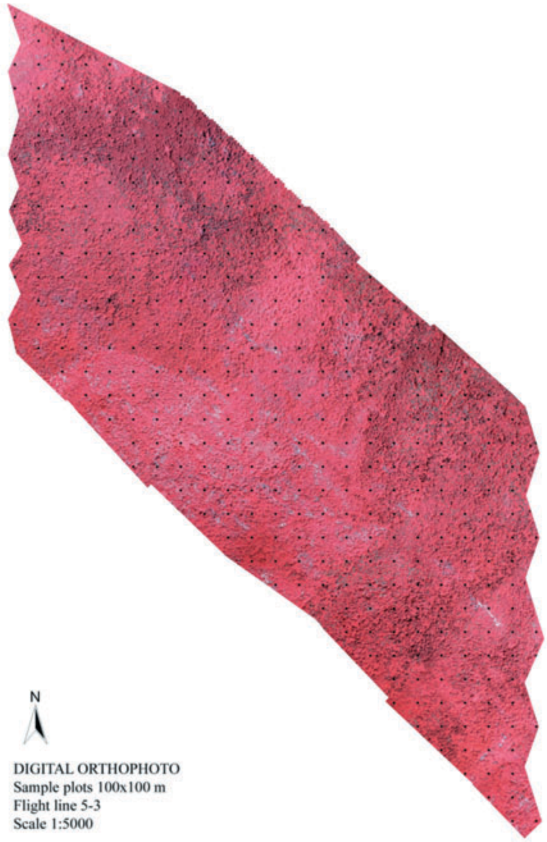

Figure 2. *Raster points 100x100 m overlaid on the infrared digital orthophoto (1:5000).*

The formula uses a complex arithmetic means with the number of trees in a particular damage class as weight to provide the mean damage degree in the observed area (sample), where:

f_i – number of trees in i- damage stage

x_i – i- stage interval center in the damage stage scale for single trees

0=5% 1=17.5% 2.1=32.5% 2.2=50% 3.1=70% 3.2=90% 4=100%

3. Damage Index (IO)

$$IO\% = \frac{\sum f_{(2-4)}}{\sum f_{(0-4)}} \cdot 100 \quad (3)$$

Damage index provides a percentage share of trees in the sample, which are classified in damage degree 2.1. and higher. The damage index may be identified with the category of severely damaged trees, which is usual for terrestrial damage assessments.

4. Mean damage (SO_1)

$$SO_1\% = \frac{\sum fx_{(2-4)}}{\sum f_{(2-4)}} \quad (4)$$

TABLE 2

Results of univariate and multivariate (stepwise) regression.

Dependent variable	Variable	Univariate regression			Multivariate stepwise regression		
		Parameter estimate (beta)	p-level	Adjusted R^2	Parameter estimate (beta)	p-level	Adjusted R^2
Fir damage index (IO)	slope	0.249863	0.003121	0.055538	0.225142	0.008326	0.064519
	south	-0.181084	0.064077	0.009006	-0.118970	0.162136	
	east	-0.132538	0.133252	0.009006	-0.110598	0.187036	
Beech mean damage (SO)	west	-0.273095	0.002262	0.059039	-0.259538	0.002456	0.076975
	altitude	0.155678	0.073559	0.016787	0.130461	0.122914	
Total damage index (IO)	altitude	-0.213896	0.007935	0.039432	-0.251229	0.002643	0.050505
	slope	0.067834	0.404767	–	0.136531	0.098679	

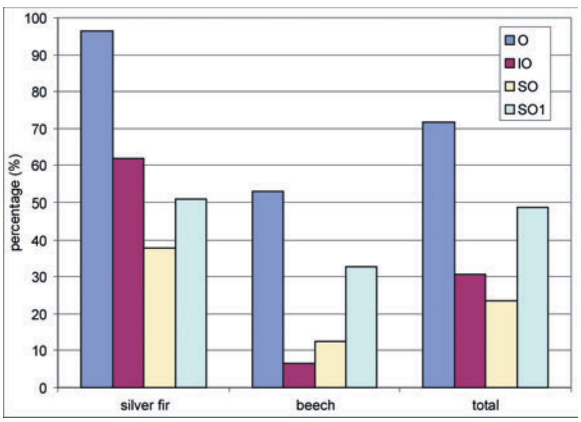

Figure 3. *Damage indicators for particular species and total (%).*

This number provides the mean damage degree of trees classified into damage degree 2.1. and above.

The surveyed strips partially cover 6 management units, for which a database containing exposition, altitude and slope data was made from their management plans. In order to establish any possible inter-dependence of the above geomorphologic parameters and damage indicators, the data were processed in StatSoft, Inc. *(21)*.

RESULTS

Photointerpretation of individual trees in a systematic 100x100 m sample in the study area covered a total of 21,011 trees. In the interpreted area of 5,548 ha, mean damage (SO) of all tree species was 23.60%, of fir 37.81%, and of beech 12.61%. These results suggest that the damage degree of inventoried forests was at transition from slight to moderate. As for fir, the damage index (IO) amounted to 61.96%. Within this percentage, the mean damage 1 (SO_1) of fir reached 51.03%. In the entire surveyed area, the percentage of severely damaged beech was 6.56% (Table 1; Figure 3).

Based on the obtained research results, cartographic models of spatial distribution of stand damage per management unit (compartments/subcompartments) were made in ArcGIS 9.2 *(22)* program. The maps show spatial distribution of mean damage and damage index for all tree species (overall), spatial distribution of mean damage and damage index for fir (Figure 4), and spatial distribution of mean damage and damage index for beech.

Regression analysis was used to process the data on damage indicators (SO and IO) and site factors. Altitude, slope and exposition were taken as independent variables to model spatial damage distribution.

Since it was difficult to assess the influence of a particular variable on damage, we selected those models that proved statistically important for the principal tree species and overall.

Both in multivariate analysis for all variables and the *forward stepwise* procedure and in univariate analysis,

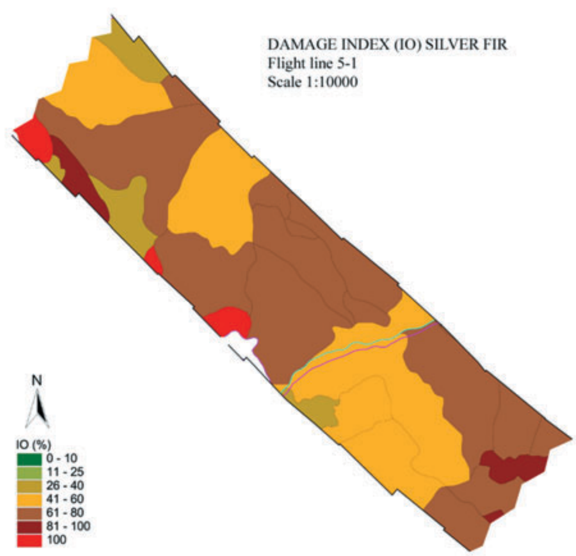

Figure 4. *Spatial distribution of the damage index (IO) for silver fir.*

slope proved to be a statistically important variable for the fir damage index. According to obtained results, an increase in the slope was directly proportionate to the increase in the fir damage index. As for terrain orientation, southern and eastern expositions showed a tendency toward lower fir damage index, although these results are not statistically significant. It is not possible to conclude from the analysis that exposition has an impact on severe fir damage. Multivariate analysis (all variables together and a *stepwise* choice) and univariate analysis showed that the mean damage of beech was higher at western expositions. Also, there is a tendency of an increase in beech SO with rising altitude, but it is not statistically significant. There is negative correlation between altitude and damage: with an increase in altitude there is a trend of decrease in the damage index, but this inter-dependence is not statistically significant. According to the regression analysis results, the damage index decreases (overall) with an increase in altitude. A *stepwise forward* choice in the regression analysis also included slope into the model (although not statistically significant), so that the overall damage index is higher on a greater slope (Table 2).

DISCUSSION

CIR aerial photographs were photointerpreted in order to determine and analyze the health condition of beech-fir forests in the area of Velebit and obtain data on surface damage distribution. According to results, the damage degree of inventoried forests was at transition from slight to moderate. As for fir, 61.96% of the trees were severely damaged. Within this percentage, the mean damage (SO_1) for fir was 51.03%. In the entire surveyed area, severely damaged beech accounted for 6.56%, which confirms that beech is the least damaged tree species.

Geomorphological factors (terrain orientation, slope and altitude) also affect a stand's health status. Regression analysis was used to determine inter-dependencies of geomorphological parameters and damage indicators.

It can be concluded from results that damage increases with rising terrain slope and growing distance of terrain orientation from the west direction, which is assumed to be the direction of air pollutant movement. Some possible bearers of air pollution in the study area are cyclonic currents from the west. The obtained results are compatible with the results published by Antonić and Legović *(23)*, Pernar *(18)*, and Božić *et al. (17)*. Since this study made use of the geomorphological variables taken from management plans, it is recommended that the same variables, prepared from DEM, be used for modelling in future research.

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