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Investigation of Hungarian forest health condition with special respect to climate change

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ABSTRACT

The defoliation and crown dieback data of trees are typical indicators of forest health condition. In Hungary the data are collected in the frame of the national forest monitoring program and based on Forest Protection Network from 1987. In the paper these two data lines are investigated: (i) trend analysis was performed in respect of the examined time period according to different criteria, (ii) the relationships between healthy features and basic and derived climatic variables were examined by correlation analysis.

The paper gives a general overview of the Hungarian forest health condition. Detectable general trends and statistically significant relationships are defined for all examined species and for 12 groups (subsets) of species. The received general results help us to determine further directions of deeper and more detailed investigations.

Keywords: forest health condition; defoliation; crown dieback; climate change; trend- and correlation analysis

INTRODUCTION

Nowadays one of the new challenges is the climate change including the protection against its negative impact, to identify the needed and possible mitigation and adaptation measures. According to the predicted climate scenarios the climate will become warmer and drier at certain regions, including Hungary (Gálos et al., 2007, Bartholy et al., 2009, Pieczka et al., 2011).

The article focuses on these issues based on the available forestry healthy data previously collected under the forest monitoring activities. In Hungary the national forest monitoring program started in 1987 with the development of the Forest Protection Network. The defoliation and the crown dieback were the main attributes, that were considered by survey and they were adapted for the characterization of healthy conditions. Since that time several other components were added to the ecosystem monitoring and the scope of the collected data was significantly extended.

In the paper two data lines of 15 years are investigated, trends of them as well as relationships between these data and the fundamental climatic components (precipitation and temperature) are examined and identified.Although the 15 years period under review is relatively short compared to the scale of the climate change, we believe that the analysis of the data collected in the forest area, and the exploration of interrelationships with other environmental data sets can contribute to better understanding of this issue.

CHARACTERIZATION AND DESCRIPTION OF DATA INPUTS

The aim of the analysis was the investigation of time series collected relating to forest health (defoliation and crown dieback) and the interrelation between these data and the data associated with meteorological components in the context of forest monitoring. The data used in this research were obtained from two main sources: (i) Forest Protection Network; (ii) meteorological data. The main characteristics of the data can be summarized as follows:

Forest Protection Information Network (level I)

From the 80-ies of the last century in all European countries - including Hungary - forest health deterioration has been observed (E.D. Schulze, 1989). As a consequence of the significant strengthening of environmental factors on the forest the development of a program observing the damages as well as the regular and systematic monitoring of forest health have got special importance.

As a part of the international cooperation the Hungarian national surveillance network joints the program (International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests, briefly ICP Forests). The program was setup on the third meeting of the Executive Body for the Convention on Long-Range Transboundary Air Pollution in 1985. Using uniform methods the ICP Forests program thus primarily examines the effects of air pollution on forests in European level. In longer term the aim is to identify the key factors decisively influencing the health status of forests and to explore relationships among the factors. In Hungary the development of the forest monitoring program began in 1987, the first field recordings and the evaluation of the data started in 1988, and since that time every year complete annual sightings have been performed. In our investigation the data are taken from 1990, after the stabilization of Forest Monitoring Program and the measurement technology.

Data collection methodology

In level I wide-area health records are collected based on systematic sampling. The sampling sites are established according to a theoretical 4x4 km grid covering the entire territory of the country. The sampling sites of the grid situating in forest area are referred hereinafter to as sample points. In 2004, there were more than 1,200 sample points in the country (Fig 1). These points are geo-referred by GPS coordinates.

The examined healthy data are from 1990 to 2004, so the length of the examinable time series are 15 years. There are 12 groups of examined tree species (more than 150 tree species). The dataset contains more than 335000 records, with 36437 tree individuals.

Table 1. Groups of tree species

groups	Tree species groupped
GY-T	Eg.: *Quercus robur, Quercus petraea, Carpinus betulus, other Quercus species*
CS	*Quercus cerris*
B	*Fagus sylvatica*
A	*Robinia pesudo-acacia*
K	*Fraxinus excelsior, Fraxinus angustifolia, Fraxinus pennsylvanica*
EKL	Other hard broadleaved species
NNY	Improved poplars
HNY	Native poplars
ELL	Other soft broadleaved species
EF	*Pinus sylvestris*
FF	*Pinus nigra*
EgyF	Other conifers

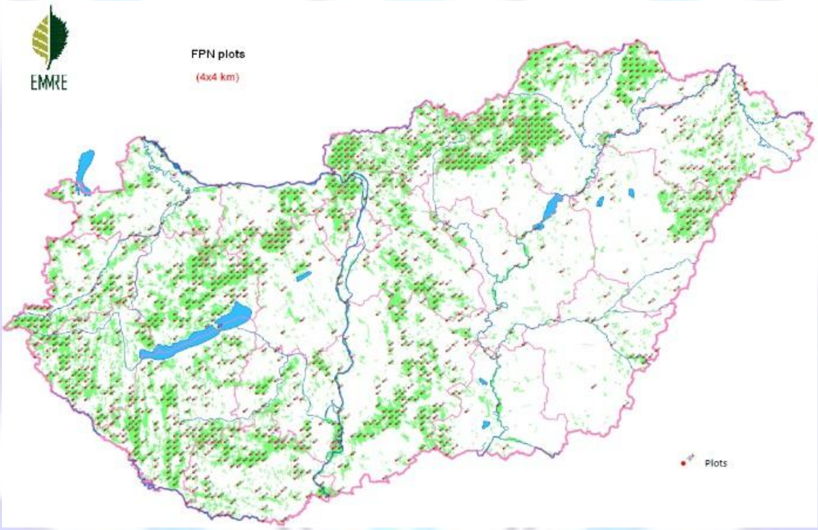

Fig 1: Sample points in Hungary

Within the sample plots four sample circles and 6 sample trees in each circle are selected (Fig 2).

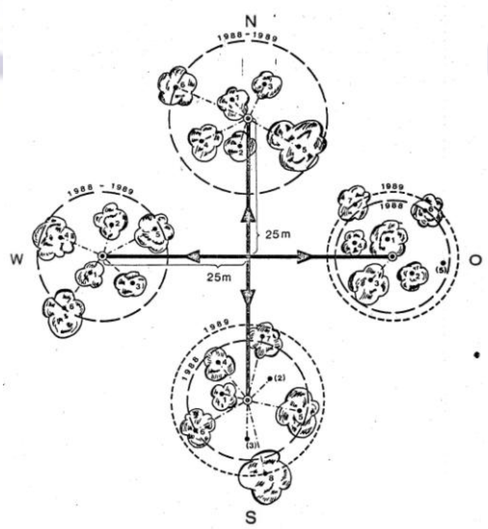

Fig 2: A description of a sample point

In accordance with the ICP Forest Manual the damages in the field observation are measured with 10 % accuracy. Defoliation of the sample trees including damages caused by known and unknown decaying agents, and furthermore crown dieback are recorded. The recordings are always collected in the same period of the year.

The sample trees are classified according to height classes using Kraft classification, and only classes 1-3 are considered in the investigation.

Meteorological data

The homogenized and interpolated monthly precipitation and temperature data series are derived from the network of the Hungarian Meteorological Service (HMS). These meteorological data covered the country approximately in a 10*10 km grid. In the paper the monthly precipitation and the average temperature data of 1961-2010 are used.

Derived independent parameters

- Tyear: Yearly average temperature (the average of monthly average temperature of one year)
- Tsdev: The deviation of monthly average temperature of one year, it can characterize the continental climate
- Tmax: The maximum of monthly average temperatures
- Tmin: The minimum of monthly average temperatures
- Tcont: Tmax-Tmin, it can characterize the continental climate
- Tveg: The average temperature of monthly average temperature in vegetation period (apr-oct)
- Twin: The average temperature of wintertime (dec-jan-feb)
- Tspr: The average temperature of springtime (mar-apr-may)
- Tsum: The average temperature of summertime (jun, july, aug)
- Taut: The average temperature of autumn time (sept-oct-nov)
- Tffree: The number of months above the freezing-point; it can estimate the length of frostless period
- Tpos: The sum of monthly average temperature above freezing-point; it can estimate the positive heat sum
- T5: The sum of monthly average temperature above 5 °C
- T10: The sum of monthly average temperature above 10 °C
- T15: The sum of monthly average temperature above 15 °C
- Pyear: Yearly precipitation sum
- Pstdev: The deviation of monthly precipitation sum of one year
- Pmax: The maximum of monthly precipitation sum
- Pmin: The minimum of monthly precipitation sum
- Pveg: The precipitation sum in vegetation period (apr-oct)
- Pacc: The precipitation sum of storage period
- Pwin: The precipitation sum of wintertime (dec-jan-feb)
- Pspr: The precipitation sum of springtime (mar-apr-may)
- Psum: The precipitation sum of summertime (jun-july-aug)
- Paut: The precipitation sum of autumn time (sept-oct-nov)
- Ppos: The precipitation sum of months above freezing-point
- P5: The precipitation sum of months above 5°C
- P10: The precipitation sum of months above 10°C
- P15 The precipitation sum of months above 15°C
- Dr2: $Dr2 = \sum_{i=jun}^{aug} \left(\frac{precipitation\_sum_i}{3} - average\_temp_i \right)$

Beside the above mentioned indices the Forest Aridity Index (FAI) (Führer et al., 2011) and the Palfai's Drought Index (PaDI) (Pálfai, Herceg, 2011) were used to examine the join effect of precipitation and temperature on forest health conditions. FAI was developed for Hungary and by this index the relationship between the meteorological parameters and increment of trees can be characterized using the monthly precipitation and the average temperature values.

$$FAI = \frac{T_{VII-VIII}}{P_{V-VII}+P_{VII-VIII}} * 100,$$

where $T_{VII-VIII}$ is the average temperature in July and August (°C), P_{V-VII} is the precipitation sum (mm) in the period from May to July, and $P_{VII-VIII}$ is the precipitation sum (mm) in July and August.

PaDI characterizes the strength of drought for an agricultural year with one numerical value. Since the definition of PaDI uses the weather characteristics of the previous three years, therefore the PaDI series starts only from the 3th years of investigations.

$$PaDI = PaDI_0 \cdot k_1 \cdot k_2 \cdot k_3,$$

where

$PaDI_0$ – base value of drought index

k_1– temperature correction factor, it represents the relation between examined and annual summer mean temperature

k_2 – precipitation correction factor, it represents the relation between examined and annual summer precipitation sum

k_3– correction factor, and represents the effect of precipitation circumstances of previous 36 month

$$PaDI_0 = \frac{\frac{\sum_{i=apr}^{aug} T_i}{5} \cdot 100}{c + \sum_{i=oct}^{sept} (P_i \cdot w_i)}$$

where

T_i – monthly mean temperature from April to August, °C,

P_i – monthly sum of precipitation from October to September, mm,

w_i – weighting factor,

c – constant value (10 mm).

Similarly to the forestry data the meteorological data are also geo-referred by GPS coordinates. The average values of the corresponding meteorological sample points were used in our investigations.

APPLIED METHODOLOGY

In each year the values of the defoliation and the crown dieback were measured in the 0-100% range with accuracy of 10%. Therefore, health of each group is characterized by a 15-year long data set. The first research direction was the analysis of temporal changes in these series. To do this, for each year the original data obtained by measurement or observation are transformed to percentage of plants showing at least x% of defoliation and crown dieback, where x = 10, 20, ..., 90. The exactly 0% and 100% defoliation and crown dieback were studied separately.

Trend tests were performed in order to decide whether the studied data sets showed statistically significant tendency in the given period. A linear trend line was fitted to each time series of 15 years and a t-test with n-2 degrees of freedom and with α = 0.05 level was applied for the significance test. The slopes of the resulting significant trend lines were examined to detect whether any upward or downward tendencies in the data set can be identified.

The other main direction of the investigation was the study of correlation among the health status and the fundamental or derived meteorological parameters as it is discussed in Chapter Meteorological data. The separate and combined effects of meteorological parameters of the given, the previous and the second previous years were analyzed on the defoliation and the crown dieback. In this analysis for each meteorological parameter as independent variable the following periods were generated:

- the actual year (a)
- the previous and actual year (p1a)
- the last but one and last previous years and the actual year (p2p1a)
- the previous year (p1)
- the last but one and last previous years (p2p1)
- the last but one and last two previous years (p3p2p1)

It is worth mentioning that in all cases when the independent variables are taken from any previous years the derivation of certain parameters (e.g. PADI) only permits the examination of shorter series.

In the studies the average annual rate of defoliation and the crown dieback were used as dependent variables and they were generated for all specimens as well as for each group of tree species. In order to identify relations among the parameters linear correlation analysis was used, where the significance of the obtained correlation coefficients (r-values) was examined by t-tests with n-2 degrees of freedom with α = 0.05 level. This also means that the significance of the r-values is strongly affected by the length of the data series (n) (see Table 2).

The above investigations were carried out both for defoliation and crown dieback in case of all specimens and for the 12 groups of tree species as well. Considering that the length of the basic time series for both the meteorological and for the forest health parameters there are exactly 15 years between 1990 and 2004 and the significant r-values with α = 0.05 are summarized in table 2.

Table 2. The border of significant r-values as a function of available data length (n)

		a	**p1a**	**p2p1a**	**p1**	**p2p1**	**p3p2p1**
PaDI	n	13	12	11	12	11	10
	$\lvert r \rvert$	0.55	0.58	0.60	0.58	0.60	0.63
other	n	15	14	14	15	14	13
	$\lvert r \rvert$	0.51	0.53	0.53	0.51	0.53	0.55

The statistical analysis was made in the open source R (R 2.15.2. version) environment.

RESULTS

The results basically show the details of averages for all specimens and only the results of the individual groups of tree species differing significantly from the averages are discussed separately. In the paper our aim was to investigate the general trends of healthy conditions and the relationships between the healthy conditions and the basic and derived meteorological parameters. Therefore these results give a general overview of the relationships and give assistance to identify further research directions.

Results of the trend analysis

Defoliation

Table 3. The proportion of defoliation for all species [%]

year	0%	min 10%	min 20%	min 30%	min 40%	min 50%	min 60%	min 70%	min 80%	min 90%	100%
1990	33.87	66.13	38.91	20.78	10.89	6.26	4.19	2.75	1.88	1.19	0.72
1991	31.74	68.27	38.27	20.01	10.28	5.77	3.64	2.39	1.78	1.09	0.63
1992	31.51	68.49	38.21	19.33	10	5.68	3.69	2.66	1.88	1.2	0.64
1993	30.96	69.04	42.24	23.56	12.45	7.64	5.07	3.83	2.85	2.1	1.11
1994	26.66	73.33	44.9	23.93	12.49	7.71	5.58	4.43	3.69	2.89	1.66
1995	30.82	69.19	38.19	19.49	10.06	6.03	4.42	3.56	2.82	2.17	1
1996	33.43	66.58	35.04	17.81	9.25	5.91	4.35	3.43	2.77	2.02	0.89
1997	35.43	64.57	33.61	16.82	8.78	5.57	4.07	3.21	2.54	1.91	0.82
1998	37.17	62.82	30.56	14.47	7.58	4.75	3.58	2.76	2.17	1.64	0.55
1999	34.83	65.19	29.56	13.47	7.06	4.79	3.54	2.83	2.23	1.66	0.68
2000	33.69	66.32	32.66	15.33	8.44	5.56	4.15	3.29	2.58	1.98	0.97
2001	32.18	67.83	34.02	15.41	8.06	5.34	3.97	3.13	2.42	1.73	0.71
2002	33.16	66.84	33.73	16.19	8.42	5.51	4.12	3.24	2.58	1.9	0.85
2003	30.28	69.72	36.01	17.26	9.23	6.1	4.52	3.51	2.67	1.93	0.76
2004	32.48	67.53	35.83	18.12	10.38	7.3	5.53	4.44	3.65	2.76	1.19
m:	0.10	-0.10	-0.53	-0.45	-0.20	-0.04	0.02	0.05	0.05	0.05	0.00
R^2	0.03	0.03	0.33*	0.41*	0.30*	0.04	0.02	0.12	0.17	0.19	0.01

Note: * statistically significant R^2 values at $p<0.05$

Taking into account the slope (m) of the trend lines fitted to the data series (last but one row of Table 3) it can be stated that the defoliation level is slightly declining during this period since the slope of the regression line in case of minimum 10% defoliation is m = -0.1, but it is not significant. Statistically significant trends at level 0.05 can be observed only in the range of minimum 20-40%. The largest absolute value is obtained for minimum 20% defoliation where the value is -0.53, and the appropriate functions are $y = 1097.8 - 0.53\,x$ with $R^2 = 0.3308$. Similarly, high slope value (m = -0.45) was found in case of at least 30% defoliation. However, the downward trend in at least 60% defoliation rate turns and it shows very slightly growing but not significant trends. Finally, the 100% defoliation rate is practically stagnant in the period under review.

The results described above are summarized and displayed in Figure 3 with the regression lines fitted to the data set and with the corresponding R^2 values.

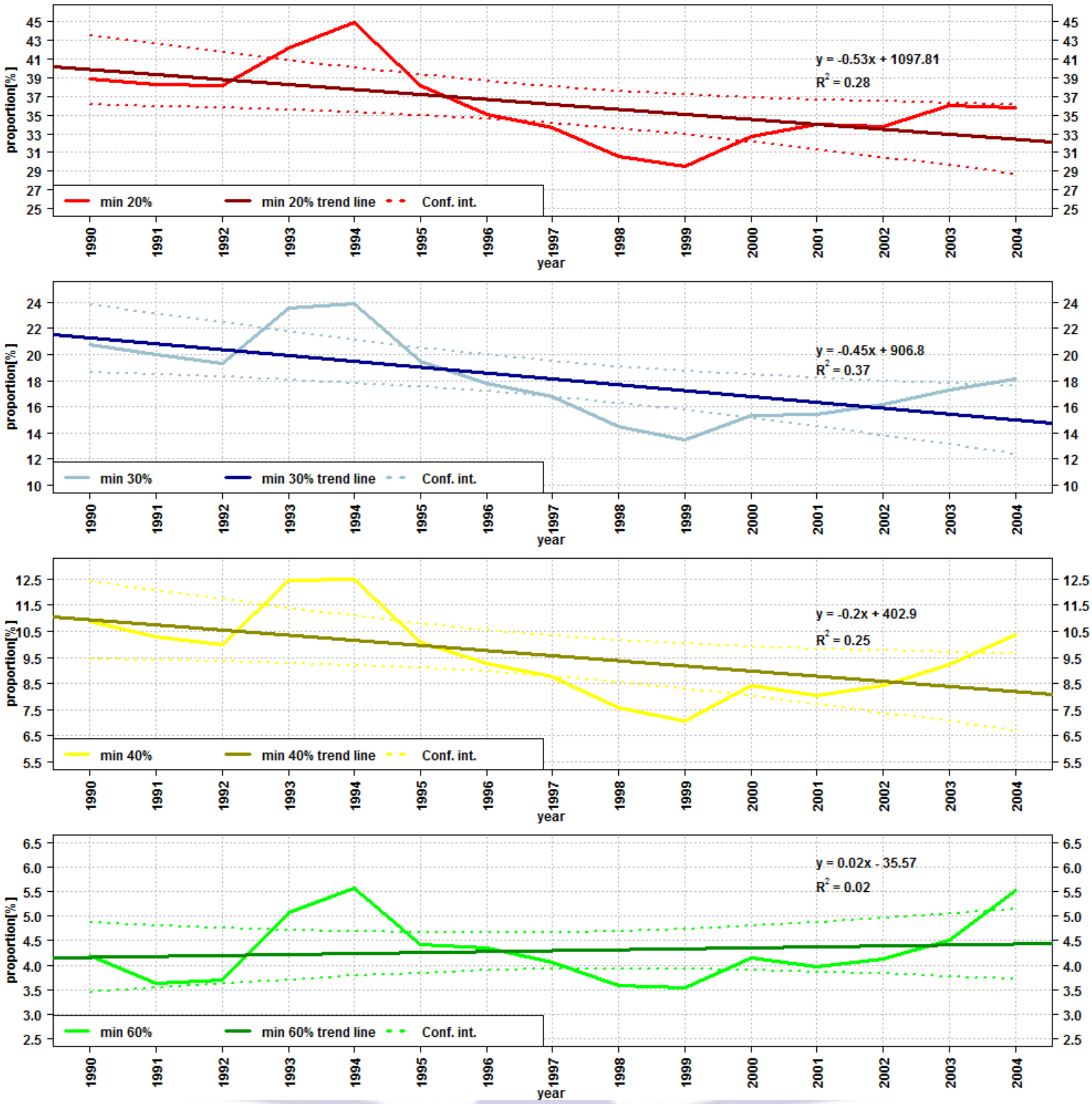

Fig 3: The trend of defoliation proportion for all species

It can be generally declared that the groups of tree species A, B, CS, EKL, ELL, GYT K and NNY follow the general trend, in the examined priority range (minimum 20-40%) and the trend turning-point (minimum 60%) as well.

The groups EF, EGYF, FF, HNY show an opposite trend direction compared to the above mentioned general trend. The upward trend in the range of minimum 20-40% defoliation usually are statistically significant and the slope values are relatively high.

Table 4. Range min. 20-40 % of group HNY

	min 20%	min 30%	min 40%
m	0.73	0.36	0.31
R^2	0.37	0.23	0.31

Crown dieback

Table 5. The proportion of Crown dieback for all species [%]

year	0%	min 10%	min 20%	min 30%	min 40%	min 50%	min 60%	min 70%	min 80%	min 90%	100%
1990	52.52	47.46	23.11	9.99	4.72	2.72	1.68	1.1	0.77	0.41	0.04
1991	57.19	42.82	19.53	8.6	4.32	2.56	1.59	1.09	0.8	0.43	0.02
1992	61.58	38.4	15.19	6.85	3.42	2.1	1.41	1.15	0.83	0.5	0.06
1993	62.69	37.31	14.59	6.47	3.55	2.38	1.85	1.46	1.17	0.8	0.11
1994	62.15	37.84	13.34	6.12	3.71	2.65	2.13	1.76	1.33	1.01	0.1
1995	66.25	33.75	11.33	5.3	3.4	2.59	2.1	1.74	1.32	0.96	0.06
1996	68.41	31.6	9.67	4.5	3.09	2.51	2.1	1.7	1.29	0.95	0.1
1997	67.22	32.77	10.43	4.7	3.04	2.44	1.93	1.62	1.3	0.97	0.06
1998	67.6	32.4	9.56	4.4	2.91	2.28	1.77	1.43	1.18	0.88	0.01
1999	69.56	30.45	8.51	4.11	2.75	2.14	1.75	1.39	1.11	0.81	0.02
2000	68.63	31.35	8.6	4.14	2.86	2.16	1.64	1.29	1.04	0.82	0.01
2001	66.48	33.53	9.46	4.72	3.09	2.32	1.86	1.51	1.18	0.89	0.05
2002	67.7	32.29	9.18	4.45	2.91	2.21	1.77	1.41	1.04	0.79	
2003	67.78	32.21	9.69	4.79	3.23	2.41	1.98	1.61	1.27	0.93	0
2004	67.37	32.63	10.69	5.33	3.58	2.71	2.29	1.9	1.59	1.22	
m:	0.85	-0.85	-0.77	-0.30	-0.08	-0.01	0.02	0.03	0.03	0.03	0.00
R^2	0.63*	0.63*	0.65*	0.59*	0.44*	0.063	0.16	0.25*	0.34*	0.47*	0.19

Note: * statistically significant R^2 values at $p<0.05$

Based on the derived slope (m) values the rates of minimum 10-40%, of crown dieback also show significant downward trend, and then, from the 50% level the data series are practically stable (not significant trends at level 0.05) as it is shown in Table 3. Moreover, these regression lines are statistically significant on the basis of the obtained R^2 value, and this is in nature consistent with those experienced in the context of defoliation. These results are characteristically similar to those obtained by defoliation.

The results with the corresponding R^2 values described above are summarized in Figure 4 with the regression lines fitted to the data set.

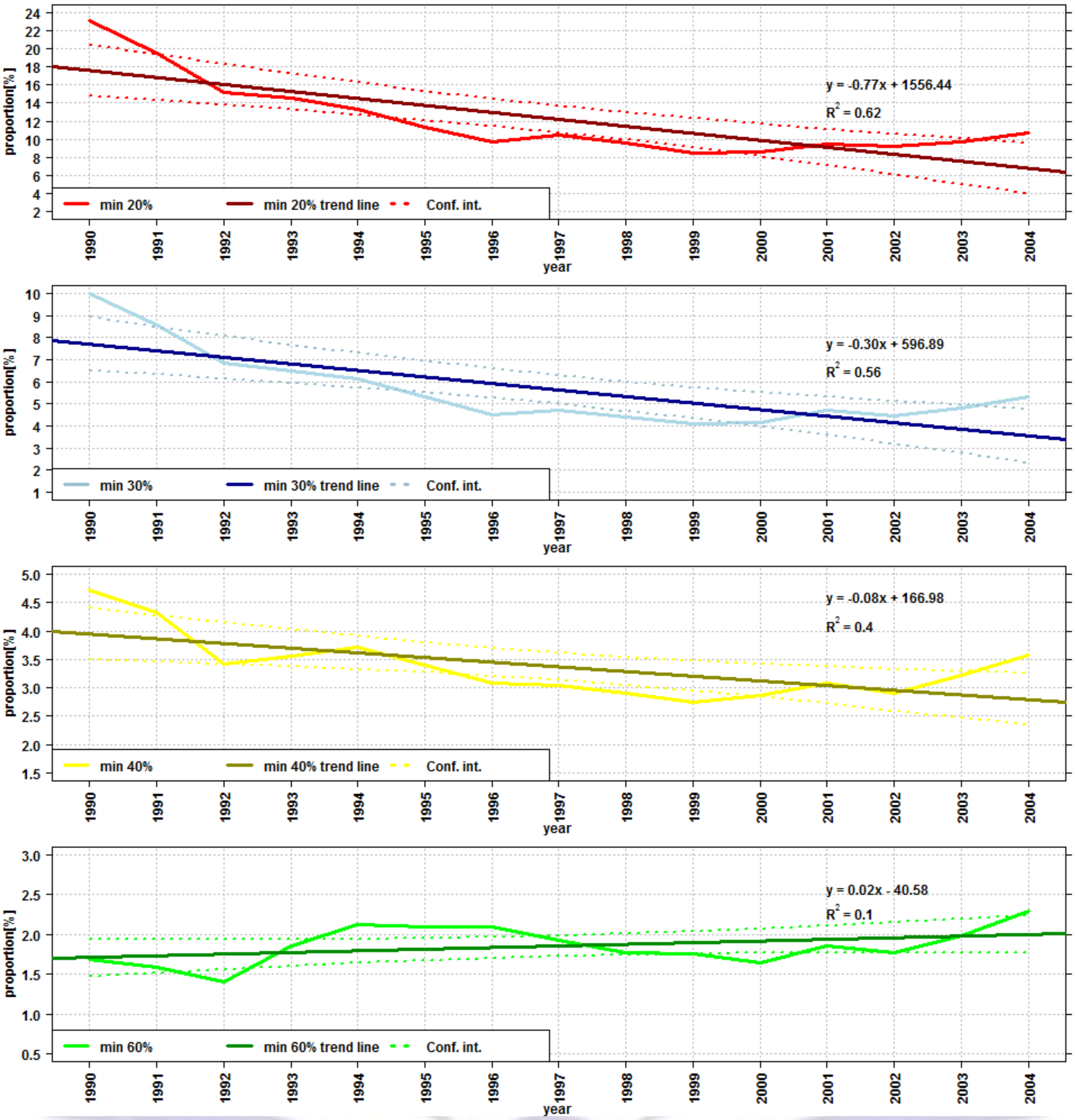

Fig 4: The trend of crown dieback proportion for all species

10 groups from all 12 show generally similar trend to the results of all species. There are only two groups of tree species where the results significantly differ from the main tendencies. In case of HNY and NNY the minimum 10-40% defoliation rates show an upward trend and the 0% defoliation reduces. In this sense, it is just the opposite to what all the other individuals and groups of tree species showed.

Results of the correlation studies

The pre-eminent r-values, the numerical results of the linear correlation analysis are basically depicted in tabular form where the significant relationships are highlighted with green colour in order to increase transparency.

Defoliation

Table 6. The result of defoliation relations in respect of each species

	a	p1a	p2p1a	p1	p2p1	p3p2p1
Dr2	-0.5	-0.78	-0.82	-0.46	-0.65	-0.65
FAI	0.53	0.84	0.88	0.64	0.8	0.7
P5	-0.36	-0.67	-0.79	-0.48	-0.51	-0.63
P10	-0.42	-0.66	-0.8	-0.47	-0.64	-0.82
P15	-0.52	-0.71	-0.8	-0.51	-0.65	-0.74
Pacc	-0.08	-0.1	-0.18	-0.05	-0.16	-0.33
PADI	0.41	0.77	0.91	0.72	0.87	0.87
Paut	0.01	0.16	0.38	0.17	0.42	0.47
Pmax	-0.46	-0.7	-0.78	-0.38	-0.49	-0.69
Pmin	0.28	0.35	0.21	0.07	-0.15	-0.35
Pneg	-0.03	-0.12	-0.23	-0.14	-0.23	-0.39
Ppos	-0.26	-0.45	-0.57	-0.34	-0.43	-0.63
Pspr	-0.09	-0.44	-0.64	-0.49	-0.68	-0.82
Pstdv	-0.5	-0.7	-0.7	-0.32	-0.37	-0.52
Psum	-0.51	-0.78	-0.81	-0.45	-0.61	-0.63
Pveg	-0.33	-0.58	-0.72	-0.44	-0.55	-0.7
Pwin	0.01	-0.09	-0.3	-0.14	-0.38	-0.63
Pyear	-0.3	-0.52	-0.68	-0.39	-0.52	-0.73
T5	0.04	0.19	0.33	0.23	0.42	0.42
T10	-0.13	0	0.03	0.14	0.11	-0.05
T15	0.04	0.21	0.31	0.27	0.29	0.24
Taut	-0.01	0.06	0.27	0.09	0.33	0.4
Tcont	-0.26	-0.23	0	-0.07	0.14	0.27
Tffree	0.17	0.17	0.27	0.05	0.12	0.1
Tmax	0.19	0.39	0.72	0.35	0.65	0.66
Tmin	0.44	0.61	0.61	0.38	0.44	0.27
Tneg	0.18	0.29	0.34	0.18	0.24	0.2
Tpos	0.01	0.12	0.24	0.16	0.31	0.29
Tsdv	-0.07	0.03	0.13	0.1	0.15	0.09
Tspr	-0.05	0.09	0.11	0.19	0.19	0.19
Tsum	0.1	0.25	0.49	0.25	0.47	0.47
Tveg	-0.01	0.14	0.22	0.24	0.27	0.16
Twin	0.12	0.14	0.16	0.04	0.07	-0.01
Tyear	0.07	0.2	0.32	0.2	0.36	0.33
VK	-0.51	-0.81	-0.85	-0.52	-0.73	-0.66

Considering the statistically significant relationships it can be declared, that the effect of the actual and previous year is less pronounced in itself than the previous years or the current year merged with the previous year or years. The effect of more neighbouring years (two, or three years) looks stronger than the effect of any single years (a or p). More relations can be observed for the precipitation based indices and in addition indices FAI, VK, PADIshow typical relationships from other parameters. The sign of FAI, PADI are positive and the sign of P15 and VK are negative. As it is expected the signs of precipitation indices are usually negative and the signs of temperature are usually positive. From the examined climatic variables the precipitation based indices show valuable relationships.

From the examined 12 tree species group (Table 1) the GY-T, CS, B, EKL ELL and EgyF show very similar results considering the number and the quality of relationships. By the K, NNY and HNY groups the temperature indices have much more significant effect, but the precipitation do not. The A and EF species groups show significant relationships in the actual year too and FF does not show anything altogether. Vocational explanation of the given statistically significant relationships requires other, more deeply investigations.

Crown dieback

Table 7. The result of crown dieback relations in respect of each species

	a	p1a	p2p1a	p1	p2p1	p3p2p1
Dr2	-0.33	-0.35	-0.46	-0.11	-0.4	-0.54
FAI	0.34	0.36	0.46	0.17	0.45	0.53
P5	-0.15	-0.25	-0.38	-0.17	-0.32	-0.38
P10	-0.37	-0.42	-0.63	-0.2	-0.49	-0.71
P15	-0.5	-0.59	-0.71	-0.34	-0.62	-0.75
Pacc	-0.21	-0.51	-0.47	-0.43	-0.45	-0.52
PADI	0.48	0.72	0.77	0.78	0.84	0.84
Paut	0.23	0.01	0.24	-0.2	0.05	0.32
Pmax	-0.4	-0.6	-0.62	-0.32	-0.56	-0.66
Pmin	-0.02	-0.03	-0.09	-0.02	-0.03	-0.29
Pneg	-0.09	-0.27	-0.22	-0.31	-0.19	-0.2
Ppos	-0.22	-0.38	-0.5	-0.28	-0.46	-0.62
Pspr	-0.19	-0.14	-0.35	0.01	-0.32	-0.53
Pstdv	-0.32	-0.48	-0.44	-0.23	-0.47	-0.51
Psum	-0.37	-0.44	-0.53	-0.17	-0.45	-0.57
Pveg	-0.21	-0.3	-0.45	-0.19	-0.39	-0.53
Pwin	-0.31	-0.57	-0.61	-0.53	-0.55	-0.69
Pyear	-0.26	-0.47	-0.58	-0.36	-0.51	-0.67
T5	-0.07	-0.08	-0.03	-0.05	0.08	0.22
T10	-0.48	-0.45	-0.49	-0.22	-0.3	-0.35
T15	-0.3	-0.43	-0.36	-0.31	-0.29	-0.2
Taut	-0.15	-0.18	-0.04	-0.08	0	0.22
Tcont	-0.33	-0.53	-0.34	-0.43	-0.38	-0.04
Tffree	0.06	0.1	-0.07	0.07	-0.05	-0.15
Tmax	-0.04	-0.15	0.15	-0.17	0.02	0.38
Tmin	0.33	0.5	0.49	0.35	0.47	0.36
Tneg	0.19	0.37	0.27	0.27	0.28	0.13
Tpos	-0.16	-0.17	-0.17	-0.08	-0.06	0.03
Tsdv	-0.39	-0.63	-0.47	-0.46	-0.48	-0.28
Tspr	-0.12	0.02	-0.12	0.16	0.1	0.02
Tsum	-0.2	-0.37	-0.17	-0.33	-0.21	0.09
Tveg	-0.43	-0.45	-0.38	-0.31	-0.29	-0.19
Twin	0.15	0.29	0.08	0.2	0.15	-0.06
Tyear	-0.08	-0.05	-0.09	0.01	0.02	0.08
VK	-0.44	-0.52	-0.58	-0.22	-0.55	-0.59

In case of the crown dieback data much fewer statistically significant relationships were found (Table 7) than by defoliation (Table 6) data. The impact of the actual year is less pronounced in itself than the previous years or the current year merged with the previous year or years. Much more relationships can be observed for the precipitation indices and indices VK, PADI, P15, Pmax and Pwin show typical relationships among other parameters (but the FAI not). This table is similar to the result of defoliation, but we have here less significant relationships than in the other case.

The groups of GY-T, B, A tree species show similar results than the result table of all species. The CS, EKL, NNY, HNY, EgyF groups have similar correlation table, but the number of statistically significant relationships is less characteristic than in case of all species (Table 7). In the case of groups K, EF and FF the temperature indices show some relationships, but the precipitation usually not. Further and more detailed studies are needed to comprehesive interpretation of these results.

SUMMARY

In the paper based on a quite huge forest health condition dataset (defoliation and crown dieback data) general relationships and trends of them were searched and identified. The performed investigations and the received results give general overview and help to identify further research directions and tasks. It is necessary to refine the resolution of examined forest health condition data for the more detailed interpretation of the retrieved results and for the exploration of deeper relationships. This includes the examinations of simple sample points and based on the received results we can use some kinds of grouping methods (e.g. clustering, classification) to understanding the deeper relationships.

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Zoltán Pödör received the M.Sc. degree in Mathematics and Computer Science from the University of Szeged in 1999. In 2006 he joined to the Institute of Informatics and Economics at the University of West Hungary as a Ph.D. student under the supervision of Prof. László Jereb. He earned his Ph.D. degree in 2014, and He is now an assistant professor in the same institute. His research interests cover the time series analysis and data mining techniques in practice.

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