New Holistic Approach for Tree Eustress Assessment and Influenced Climatic Types Classification (Example with Mountain Forest Trees in Bulgaria)

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Abstract

The paper deals with meta-analysis of 259 dendrochronological series of mountain trees – Bosnian pine, Norway spruce and beech from 14 locations in Bulgaria for eustress investigation. The chronologies were analyzed by the original SPPAM 2.0 application. The tree ring width sequences were approximated with polynomials with determination coefficients, $\boldsymbol{R^2} \geq 0.45$. The growth index (***It*** – the ratio between measured and approximated value of tree ring width) was computed. Years with ***It*** less than the threshold values were considered as eustress ones. The four grade scales for assessment of frequency, duration and depth of eustress was proposed. For the studied tree species and locations, the obtained eustress periods are as follows, respectively for the Bosnian pine, Norway spruce and beech: 42 (K=9.1), 30 (K=3.4) and 37 (K=3) on average. The obtained eustress characteristics are respectively: Average Depth, $\boldsymbol{A_{av}}$ = 0.16, 0.26 and 0.28; Average Duration, $\boldsymbol{D_{av}}$ = 2, 2.5 and 2.3 years; and Average Frequency, $\boldsymbol{F_{av}}$ = 10, 33 and 34 years over 100 years. The risk for The stands of two studied locations of spruce and three locations of beech were established to be in some risk. They require further monitoring. The predominance of cold-dry and hot-wet years in total number of adverse climatic years (with eustress) for the Bosnian pine, as well as hot-dry and cold-wet years for spruce and beech stands was established. The influence of climatic types of years on the eustress appearance for tree years periods have also been investigated. Proposed holistic approach for meta-analyses of series (eustress identification in radial growth of stems) is convenient for the fast monitoring of forest communities state and for recognizing the stands under risk. The capability of approach allows expression of reactive functional types of trees (PFTs) as groups of trees with the similar behavior to the influence of climatic types of years, and with similar characteristics of eustress periods. These PFTs can support the development of different local, regional and global models. The originality of approach applied includes: meta-analysis, new software, characteristics, indixes and coefficients.

Key words: meta-analysis, eustress, climatic type of year, classification, dendrochronology, SP-PAM application, *Pinus heldreichii* Christ., *Picea abies* (L.) Karst., *Fagus sylvatica* L**.**

Introduction

Mountain ecosystems are among the most sensitive to environmental changes (Lloyd 1997, Körner 1998, Moiseev 2002, Camarrero et al. 2003, Esper et al. 2004). This is one of the reasons, why many studies on climate change have been focused on treeline forests (Panayotov et. al. 2008). Among the frequently used research method for the forest-climatic impact investigations is dendrochronology (Fritts 1976, Schweinguber 1996, Briffa et al. 2001). The studies are based on the tree rings, which formation is strongly dependent on environmental factors and especially on the temperature and precipitation (Fritts 1976). Once formed, tree rings do not change with time makes tree-ring chronologies a "natural archive", containing information on past climate and historical development of individual sites. In the last decades numerous proxy climate reconstructions based on tree line sites from high elevation and northern environments, have been created for various parts of the world (e.g., Briffa 2000, Esper et al. 2002, Cook et al. 2004, D'Arrigo et al. 2006). Limited knowledge is available about the growth of Norway spruce - saplings related to spring climate, especially snow duration, in high mountain forests**.** After conducting tests, the impact of above-mentioned factors was proven as very important for the growth of Norway spruce saplings (Cunningham et. al. 2006). Other studies of *Abies alba* Mill. and *Picea abies* (L.) Karst. have found out that the precipitation in the first period of the growing season, i.e. early spring, is a major factor influencing the annual growth of native *A. alba* trees, although they proved to be sensitive to drought. *P. abies* showed a higher tolerance to summer drought stress. According to Henne et. al. (2011) temperature alone cannot account for important changes in tree species abundance. For example, population expansion by Norway spruce (*Picea abies*), a dominant higher mountain species, link with lagged suitable temperatures by about 3000 years in eastern and by 6000 years in western Switzerland. Trackbacks study of *P. abies* for the link between individual factors, incl. growth, and mortality in space and time are resulted in development of more accurate mortality models and increasing the reliability of forest dynamics predictions (Bigler et al. 2004). The influence of waterlogging on growth of common beech (*Fagus sylvatica* L.) and pedunculate oak (*Quercus robur* L.) has been studied intensively on seedlings under experimental conditions. The results indicate that under the projected future climatic scenarios, beech may suffer from increasing drought stress even on hydromorphic soils. Oak might be able to maintain a sufficient hydraulic status during summer droughts by reaching water in deeper soil strata with its root system. Wet phases with waterlogged soil conditions during spring or summer appear to have only a little direct influence on radial growth of both species (Scharnweber et. al. 2013).

Recently, researches into new holistic approach to assess the "behavior" of tree species and their communities under the climatic influence (temperature-precipitation patterns) by Lyubenova (2012), Lyubenova et al. (2014ab) and others were published. In this approach the eustress periods in radial growth of trees as the statistically proven reduction in the tree rings width, reflecting the overall result of the interactions tree species - community – environment have been analyzed. The multi-annual survey of eustress periods and their assessment by frequency, duration and depth (using developed scales) allows for categorization of communities, risk assessment and the sustainable existence of forest areas prediction. The relationships between eustress periods and temperature-precipitation patterns by defining the climatic norms (CN) in temperature and precipitation and climatic types of years (CTYs) have also been tested. CNs are calculated as average values of annual temperatures (CNs for T) and annual sum of precipitations (CNs for P) for 30 – years' periods. CTYs are defined according to the annual T deviations from CNs for T and annual P deviations from CNs for P. The defined in this way CTYs are nine: hot and dry (HD), hot and wet (HW), hot with precipitations in the norm (HN), cold and dry (CD), cold and wet (CW), cold with precipitations in the norm (CN), with temperatures in the norm and wet (NW), with temperatures in the norm and dry (ND), with temperatures and precipitations in the norms (NN). These studies have the origin of meta-analysis of dendrochronology and climatic data from various international bases and own research. For this purpose, the SP-PAM software has been developed, which includes classic dendrochronology analyzes and novel ones. The application is evolved in several versions (Lyubenova et al. 2015). So far, the results of approach applied to four conifer and 5 deciduous species from 102 locations in Europe (total 1674 dendrochronological sequences, incl. 171 from Bulgaria) have been published. These investigations should help the global forest monitoring, modelling and prediction, as well as should help to define criteria for sustainability - effective forest management, forest services usage and conservation. The main goal of present research is to apply the holistic approach for eustress periods identification and valuation for 3 mountain tree species, as well as to study their relationships with climatic types of years for included locations, and comparative analysis of results for these species in the light of upcoming climatic changes.

Materials and Methods

Analyses were conducted for 259 dendrochronological series of 3 mountain tree species in 14 Bulgarian locations – 3 in Pirin Mount. for *Pinus heldreichii* Christ., 4 in the Balkans for *Picea abies* (L.) Karst. and 7 in the Rhodope Mount., Western Balkans, Fore Balkan and Osogovo Mount. for *Fagus sylvatica* L. The average annual temperature ($T_{av.}$) of the selected locations varies from 7.1 to 11.8^0 C; average annual precipitations (P_{avg}) are from 500 to 653 mm – Table 1. The parameters of Bosnian pine chronologies, 74 in number, are: 48 – 655 years age, encompassing the period from 1721 to 2008; DBH (diameter at breast height) is about 26 to 47 cm and EPS (expressed population signal) is from 79 to 85%. The parameters of Norway spruce chronologies, 76 in number, are: 16 – 118 years age, encompassing the period from 1886 to 2011; DBH is about 31 to 38 cm and EPS is from 83 to 96%. The parameters of beech chronologies, 89 in number, are: 42 – 151 years age, encompassing the period from 1853 to 2011; DBH is about 30 to 55 cm and EPS is from 53 to 89%. Despite the studied chronologies do not match by age and do not cover the same periods (matched only for the years 1853 to 2008), monitoring the nature of eustress allows for analysis of the behavior of species under the influence of unfavorable factors for hundreds years and assessment of respective tree ecosystems. It is almost impossible to examine the chronologies with similar parameters even for one species in different locations, unless the plantations will be created and wait 100-200 years for their development.

Table 1. *Object characteristics*

Sampling area	Long.	Lat.	Alt., m	Tav, 0C	Pav, mm	Cl. Period, y		Age_{min}, y	Age_{max}, y	DBH, cm	Period, y		N	EPS,%
***Pinus heldreichii* Christ.**														
1.Vihren, Pirin Mount.	23.30	41.42	2150	8.8	591.6	1901	2008	48	260	25.7	1721	2008	42	82.95
2.Vihren, Pirin Mount.	23.23	41.46	1920	8.8	602.6	1901	1981	87	261	45.2	1721	1981	22	85.12
3. Pirin Mount.	23.42	41.82	1862	7.1	652.7	1901	2002	103	655	47.3	1348	2002	10	78.65
***Picea abies* (L.) Karst.**														
1.Chuprene W. Balkan	22.37	43.26	1600	10.8	558.1	1901	2002	16	116	37.9	1886	2002	40	93.26
2.Yundola, Rila Mnt.	23.50	42.02	1400	8.8	590.3	1901	2009	31	118	31.3	1894	2011	27	95.70
3.Sipenski prohod, Kazanlak t.	23.00	42.44	1300	9.6	626.4	1922	1981	40	60	32.7	1922	1981	9	83.45
4.Groba, W.Balkans	22.59	43.17	1078	11.7	508.2	1937	2009	63	76	64.7	1937	2012	4	91.14
***Fagus sylvatica* L.**														
1.Chuprene	23.38	43.62	1596	11.5	519.6	1901	2003	80	151	34.6	1853	2003	23	75.43
2.Petrohan, W.Balkans	23.12	43.13	1200	11.8	499.7	1901	2009	42	108	28.4	1900	2010	14	75.97
3.Kyustendil t.	22.38	42.15	890	8.9	597.3	1920	2009	49	92	29.7	1920	2011	13	65.05
4. Brekovitsa t.	23.22	43.22	820	11.8	504.8	1916	2009	77	95	49.1	1916	2010	7	89.40
5. Velingrad t.	23.59	42.01	812	8.6	614.4	1926	2009	54	86	40.9	1926	2011	9	56.94
6.W.Balkans	23.22	43.21	800	11.8	499.8	1901	2008	45	108	33.4	1893	2008	14	71.88
7. Sevlievo t.	25.06	43.02	752	11.6	528.4	1917	2009	39	95	55.1	1917	2011	9	53.19

SPPAM, version 2.0 is applied for the data analysis; its functionality encompasses classical analyses in dendrochronology (Cook 1990, Schweingruber 1996, Fritts 2001, Mirchev et al. 2000) and new developments (Lyubenova et al. 2014). Sequences with $R^2 > 0.45$ and locations with EPS >80% are included in the analysis. The studies on the expression of eustress and its assessment are conducted by analysis of the average growth index sequences (It = MW/AW, where MW is measured tree rings width and AW – computed width, only for the sequences with trusted approximations). The index allows removing the strong influence of age on the radial growth, because of usually different ages of the studied chronologies and the detection of climatic impact. As an eustress year (SY), the year for which more than half of the available sequences (from one location) have It <1 - δ_i (where δ_i is the confidence interval for a level of significance, $\alpha = 0.05$) was accepted. The eustress is represented of one or more consecutive eustress years and is characterized by: duration (D), i.e. the number of consecutive eustress years which comprises it; frequency (F) – the number of eustress years for 100 years and depth (A) described reduction in growth -

$A = \frac{1}{s}\sum_{i=1}^{s}(1 - It_i)$, where It_i are the growth index sequences for which the eustress has been found. These characteristics were assessed by the creation for each tree species 5-graded scales – Table 2. The additional dendrochronology data for the scales evaluation was used (International Tree Ring Data Base).

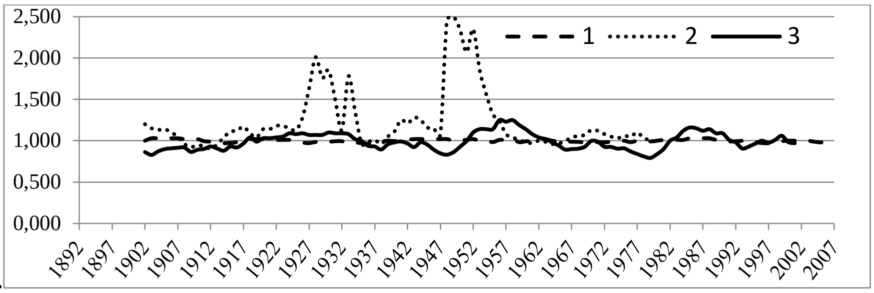
Table 2. *Five-graded scales for assessment of eustress features*

F			**D**			**A**		
Group		Value	Group		Value	Group		Value
Pinus heldreichii Christ.								
1	Very rarely	≤1.12	1	Very short	≤1.12	1	Very small depth	≤0.08
2	Rarely	>1.12 ≤4.23	2	Short	>1.12 ≤1.62	2	Small depth	>0.08 ≤0.14
3	Normal	>4.23 ≤10.44	3	Normal	>1.62 ≤2.61	3	Normal depth	>0.14 ≤0.26
4	Offen	>10.44 ≤13.55	4	Long	>2.61 ≤3.11	4	Deep	>0.26 ≤0.32
5	Very Offen	>13.55	5	Very Long	>3.11	5	Very Deep	>0.32
***Picea abies* (L.) Karst.**								
1	Very rarely	≤11.78	1	Very short	≤1.91	1	Very small depth	≤0.19
2	Rarely	>11.78 ≤17.86	2	Short	>1.91 ≤2.15	2	Small depth	>0.19 ≤0.22
3	Normal	>17.86 ≤30.04	3	Normal	>2.15 ≤2.63	3	Normal depth	>0.22 ≤0.26
4	Offen	>30.04 ≤36.12	4	Long	>2.63 ≤2.87	4	Deep	>0.27 ≤0.28
5	Very Offen	>36.12	5	Very Long	>2.87	5	Very Deep	>0.28
***Fagus sylvatica* L.**								
1	Very rarely	≤15.85	1	Very short	≤1.60	1	Very small depth	≤0.25
2	Rarely	>15.85 ≤21.3	2	Short	>1.60 ≤1.88	2	Small depth	>0.25 ≤0.28
3	Normal	>21.3 ≤32.18	3	Normal	>1.88 ≤2.44	3	Normal depth	>0.28 ≤0.33
4	Offen	>32.18 ≤=37.62	4	Long	>2.44 ≤2.71	4	Deep	>0.33 ≤0.36
5	Very Offen	>37.62	5	Very Long	>2.71	5	Very Deep	>0.36

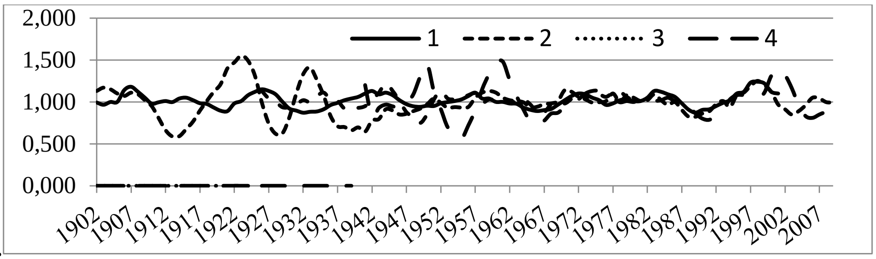
The calculated coefficients are as follows: cardinality (Card) – the number of indexed series of the investigated species with the same stress years; “Ct”- coefficient - the ratio between cardinality (Card) and the total number of analysed sequences from one location (Total n); coverage (Cov) = 100*Card/N, where N is the number of indexed series with measurements for the same periods; “K”- coefficient - the ratio between the number of years for which the analysis was performed (Period) and the number of stress years (SY) by Lyubenova et al. (2014). The climatic type of every year from periods of studied series (CTY) was also calculated using the deviations of average annual temperatures and precipitations from the average values for the 30-years periods and their confidence intervals. The adverse year (AY), or eustress year (SY), was considered as CTY in which the eustress is established. Source of data on temperatures and precipitations was taken from the CRU – TS Climatic database and covers the period 1901-2009.

Results and Discussion

The mean growth index (It) of model chronologies is as follows: for studied locations of Bosnian pine - 1.126 ± 0.166 and ranged from 0.998 ± 0.030 (3 location) to 1.382 ± 0.461 (2); for studied locations of Norway spruce – 1.017 ± 0.082 and ranged from 1.009 ± 0.080 (2) to 1.025 ± 0.095 (4) and for studied locations of beech – 1.041 ± 0.107, ranged from 0.993 ± 0.0059 (6) to 1.203 ± 0.229 (5). The variation of It_{av} by locations is presented in Fig. 1. The synchronicity in the changes of values is weak in general. The directions of change for some locations and periods are different, which is probably due to the local environmental features, the influence of other, non - climatic factors, and different age ranks.



A.



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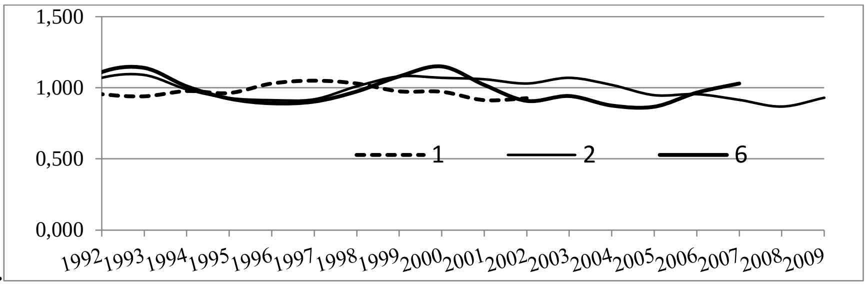

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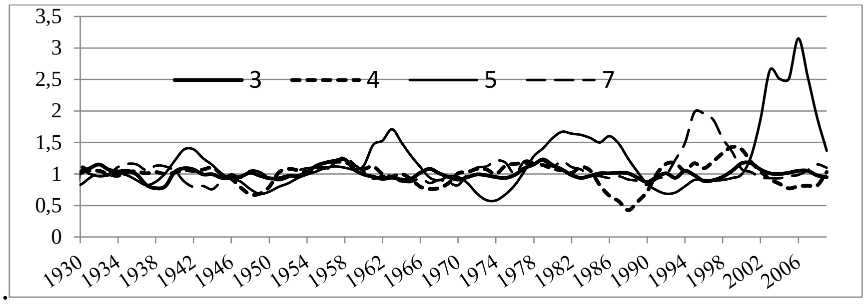

C2.

Fig. 1. *Growth index variation by locations and years for: A. Bosnian pine; B. Norway spruce and C. Beech*

As a result of statistical analysis of chronologies the eustress periods were detected for studied species and locations, as follows: for the Bosnian pine - average 42 in number (from 28 to 57), for the Norway spruce – average 30 (from 20 to 46) and for the beech – average 37 (from 20 to 49) – Table 3. Due to the different number of chronologies analyzed and different duration of investigated periods, the results cannot be compared by locations and species. So, the coefficients calculated allow comparative analysis based on a non-homogeneous data. The average Cov is similar for three species series - 0.7 and is ranged from 0.6 to 0.8 by locations. In other words, the homogeneity of the analyzed series by locations is similar - the number of total periods of stress, relative to identical measured periods varies to a small extent. The average Ct values are between 0.5 for spruce and 0.4 for pine to 0.2 for beech. The species and locations with lowest Ct - values are more likely to have a more pronounced influence of stress factors than other studied locations. The average K - coefficient is 9.1 and 3.4 to 3.0, respectively for pine, spruce and beech. The species and locations with maximum K-values are more likely to have more eustress periods in comparison to the others.

The obtained values for the three eustress characteristics are presented in Table. 4. The depth varied in the ranges, respectively for the pine, spruce and beech: 0.058 - 0.212, 0.229 - 0.304 and 0.235 - 0.365. The absolute maximums in A-values was in 1929 (A = 0.379) for the pine, 1951 (A = 0.719) for the spruce and 1990 (A = 0.713) for the beech. The years, in which the maximum values in depth of eustress were established for investigated species, were published as adverse years for other tree species and their communities (Lyubenova 2012). The average values of eustress duration (D) vary from 1 to 3 years. The absolute maximums in D-values for pine and beech were in 1905-1914 and 1972-1981 (10 years) and 1959-1970 (12 years), while for the spruce, the absolute maximums were in previous centuries.

Table 3. *Characteristics of investigated series*

Species / SA	Period, y	It (av)	μ (av)	SY, n	Card	Cov	Ct = Card/N	K = P/SY
***Pinus heldreichii* Christ.**	**392**	**1.126**	**0.166**	**42**	**7.2**	**0.7**	**0.4**	**9.1**
1. Vihren, Pirin Mount.	260	0.999	0.008	40	6.6	0.7	0.2	6.5
2. Vihren, Pirin Mount.	261	1.382	0.461	28	9.6	0.6	0.4	9.3
3. Pirin Mount.	655	0.998	0.030	57	5.5	0.7	0.5	11.5
***Picea abies* (L.) Karst.**	**93**	**1.017**	**0.082**	**30**	**8.1**	**0.7**	**0.5**	**3.4**
1. Chuprene v., W. Balkan	116	1.021	0.077	46	11.2	0.6	0.3	2.5
2. Yundola, Rila Mnt.	118	1.009	0.080	20	13.6	0.7	0.5	5.9
3. Sipenski prohod, Kazanlak t.	60	1.012	0.076	25	5.2	0.7	0.6	2.4
4. Groba, W.Balkans	76	1.025	0.095	27	2.3	0.8	0.5	2.8
***Fagus sylvatica* L.**	**105**	**1.041**	**0.107**	**37**	**3.1**	**0.7**	**0.2**	**3.0**
1. Chuprene v.	151	0.999	0.062	48	7.1	0.6	0.3	3.1
2. Petrohan, W.Balkans	108	1.000	0.062	49	3.1	0.7	0.2	2.2
3. Kyustendil t.	92	1.005	0.078	23	3.2	0.7	0.2	4.0
4. Brekovitsa t.	95	1.018	0.104	35	2.2	0.8	0.3	2.7
5. Velingrad t.	86	1.203	0.229	20	1.1	0.6	0.1	4.3
6. W.Balkans	108	0.993	0.059	40	3.4	0.7	0.2	2.7
7. Sevlievo t.	95	1.068	0.154	43	1.4	0.7	0.2	2.2

The established absolute maximus for A and D not matched by years, but they were in years identified as eustress years for the investigated species. These years have been proved as adverse years for other tree species and their communities (Lyubenova 2012). The average frequency of eustress seems to be higher in beech (31 to 45 years in a hundred years), then in Norway spruce (16-41) than it in Bosnian pine (8-13 years). The species in surveyed locations exhibit various features on the different characteristics studied. The largest number of SP for equated time was for the B. pine, but they are with the lowest average and maximum depth in comparison to other two species. According to D_{av} – values, the species are slightly different, but the greatest value of absolute maximum is for the beech trees, where and the frequency of SP for 100 years is the greatest.

Table 4. *Characteristics of eustress and functional type (PFT)*

Species / SA	A_{av}	A_{max}	$A_{max, y}$	D_{av}	D_{max}	$D_{max, y}$	F_{av}, 100 y	PFT
***Pinus heldreichii* Christ.**								
1. Vihren, Pirin Mount.	0.058	0.100	1933	2	5	1911-1915	13	F4D3A1
2. Vihren, Pirin Mount.	0.212	0.379	1929	2	4	1952-1955 1962-1965	10	F3D3A3
3. Pirin Mount.	0.198	0.367	1978	3	10	1905-1914 1972 -1981	8	F3D5A3
***Picea abies* (L) Karst.**								
1. Chuprene, W. Balkan	0.229	0.409	1893	3	7	1890-1896	39	F5D4A3
2. Yundola - Rila Mnt.	0.258	0.335	2001	2	5	1952-1956	16	F2D1A4
3. Sipenski prohod, Kazanlak t.	0.246	0.469	1947	2	5	1936-1940 1945-1949	41	F5D1A3
4. Groba, W.Balkan	0.304	0.719	1951	3	6	1951-1956 1962-1967	35	F4D5A5
***Fagus sylvatica* L.**								
1 .Chuprene v.	0.262	0.376	1910	2	5	1962-1966	31	F3D3A2
2. Petrohan, W.Balkans	0.235	0.524	1917	3	9	1913-1921	44	F5D4A1
3. Kyustendil t.	0.293	0.546	1993	1	2	1942 -1943 1950-1951 1973-1974 1989 -1990 1995-1996 2002-2003 2008-2009	25	F3D1A3
4. Brekovitsa t.	0.365	0.708	1988	2	6	1985-1990	36	F4D3A5
5. Velingrad t.	0.241	0.602	1972	3	6	1988-1993	23	F3D5A1
6. W.Balkans	0.265	0.524	1917	2	5	1915-1919	34	F4D3A2
7. Sevlievo t.	0.284	0.713	1990	3	12	1959-1970	45	F5D5A3

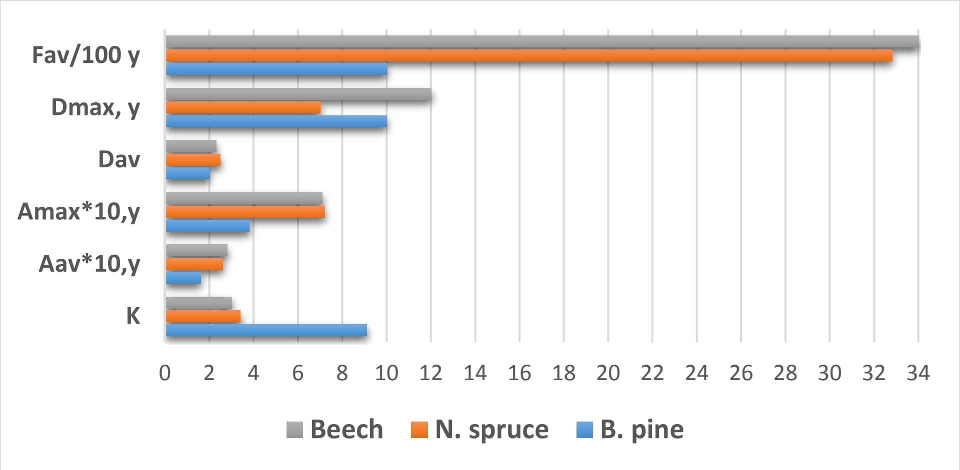

Fig. 2. *Comperative analysis of species by studied ckaracteristics*

The received functional types for the most of locations showed no risk for the forests of studied species. The risk exists if at least two characteristics are valuated with 4 th or 3 th balls. For the 1st and 4th locations of spruce, the obtained functional types are respectively: F5D4A3 (SP appeared very often and with long duration) and F4D5A5 (SP appeared often, with very long duration and are very deep). For the 2 th, 4th and 7th locations of beec, the obtained functional types are respectively: F5D4A1 (SP appeared very often, with long duration and with very small depth), F4D3A5 (SP appeared often, with very long duration and are very deep) and F5D5A3 (SP appeared very often, with very long duration). The forests in these locations are in need of state monitoring, especially the spruce community in location 4.

Table 5. *Correlation coefficients between growth index (It) and used climatic parameters*

Species/Parameter	**It, T_{av}**	**It, P_{av}**	**It, dT**	**It, dP**
Pinus heldreichii Christ.				
Av	0.024	-0.084	0.032	-0.101
Picea abies (L) Karst.				
Av	0.022	-0.065	-0.009	-0.054
Fagus sylvatica L.				
Av	0.003	-0.013	-0.041	-0.010

According to the correlation analysis, the estimated average correlation coefficients between the Itsequences and climatic parameters (Tab. 5), it is observed very weak correlation, ie the influence of climate on radial growth can not be analyzed, however, it was found the climatic dependence by physiological studies. So as to receive an objective picture about the climatic influence on the radial growth and obtained eustress, the climatic types of years was identified for studied periods and locations and their percent participation was calculated. The participation of different CTYs very much vary by locations, because of variation of their geographical and climatic parameters. The significance of CTYs for eustress appearance is presented in Fig. 3. For the Bosnian pine studied locations, cold - dry (CD) and hot – wet (HW) CTYs have the most eustress provoked influence, followed by hot – dry (HD) and cold – wet (CW) years. For the Norway spruce and beech studied locations, the opposite can seen - a paramount importance have HD and CW climatic types, followed by CD and HW types.

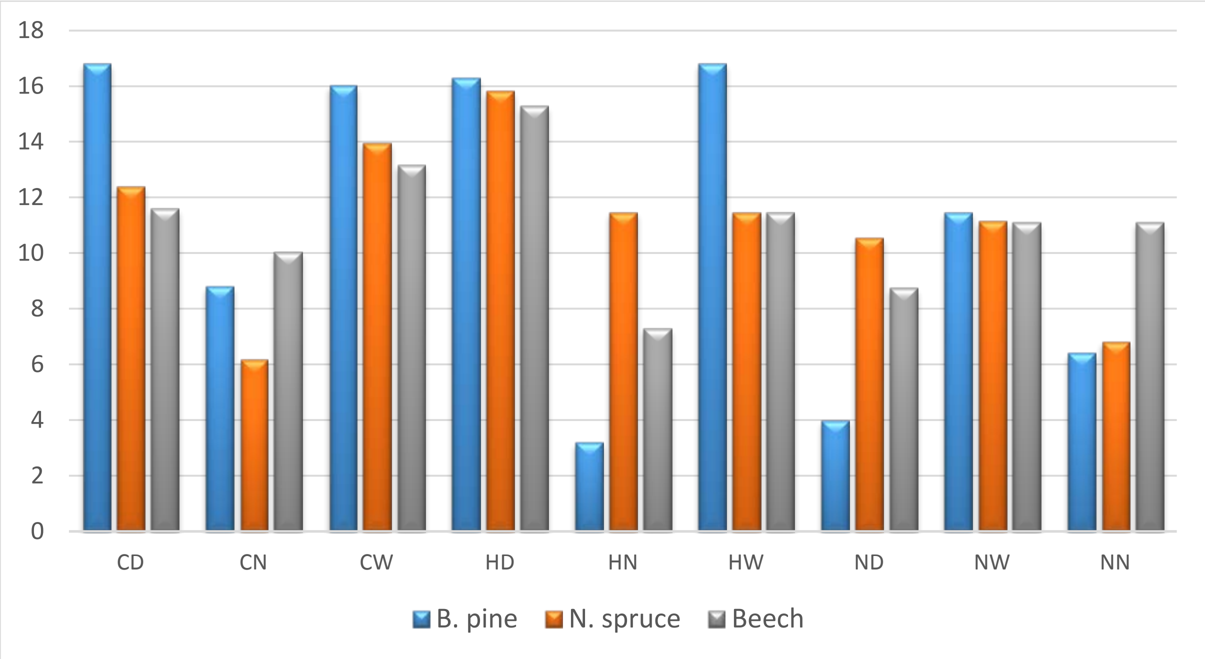

Fig. 3. *Eustress significance of different climatic types (%)*

As eustress climatic types (Fig. 3) the years with temperatures and precipitations in the climatic norm were involved, respectively 6.4%, 6.8% and 11.1% for the Bosnian pine, Norway spruce and Beech. That in many cases is due to the response inertia of tree species - the existence of eustress in the one or two previous years. Where this is not the case, eustress probably is caused by the other environmental factors, rather than climate change. So, the stress influence of climatic type depends on the temperature and precipitation in previous years - the accumulation of influence, also on the degree of deficiency of heat and humidity, and can be the result from the impact of other factors. Thus, the sequences of climatic types for two years before the current year were examined.

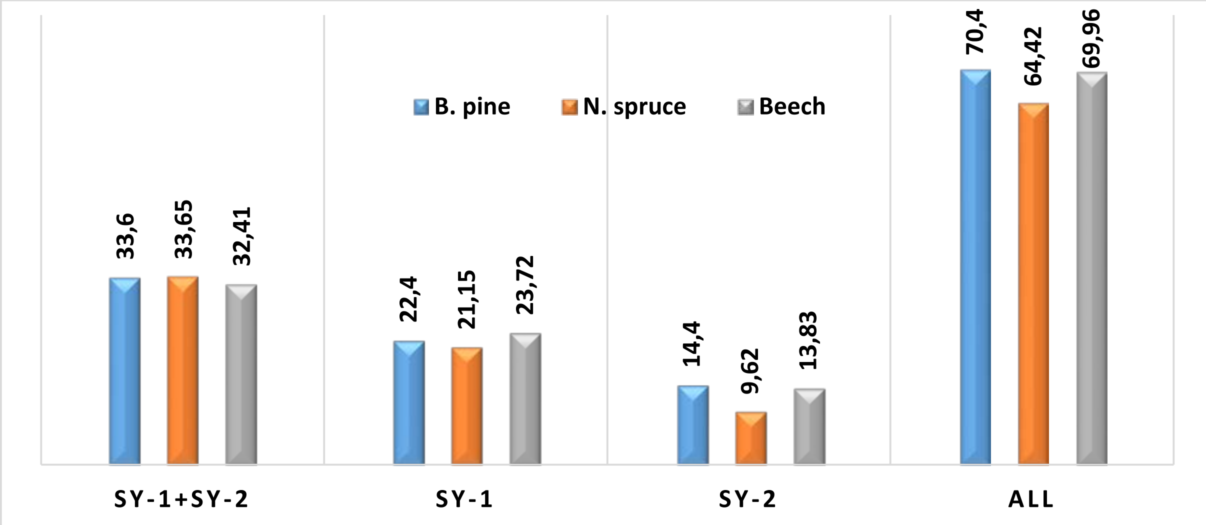

Fig. 4. *Percent participation of eustress years in preceding period of two years*

The pattern analysis show that the presence of eustress in the previous two years in 64 % to 70 % of the cases for the studied species has provoked eustres in current year. This in turn is related to the maintenance of one or both climatic regimes outside the climatic norms or the sudden changes in these regimes (Fig. 4). The cases, where eustres has existed in both previous years are more (32-34%), following the cases in which the previous year was eustress year (21-24%) and finally - when there was eustress two years ago (10-14 %).

Conclusion

For the studied mountain tree species and locations the original approach for meta-analysis, software, characteristics, indixes and coefficients were applied. The obtained eustress periods are maximal in number for the Bosnian pine, followed by beech. The average Depth, $\boldsymbol{A_{av}}$ = 0.16, 0.26 and 0.28; average Duration, $\boldsymbol{D_{av}}$ = 2, 2.5 and 2.3; and average Frequency, $\boldsymbol{F_{av}}$ = 10, 33 and 34 years over 100 years were obtained. Through the combined evaluation of the characteristics of eustress, the risk is established only for two studied locations of spruce and three locations of beech. The predominance of cold-dry and hot-wet years in total for the Bosnian pine number of adverse climatic years (with eustress), as well as hot-dry and cold-wet years for spruce and beech was established.

Pattern analysis presented proved that the change in one of two regimes - warm to cold or dry to wet, also the impact of adverse climatic type in at least two consecutive years and / or a presence of eustress in at least one of the previous years of three-yeas periods sure provoked eustress in the current year. So that sometimes the current adverse year belongs to normal or not so adverse climatic type.

The demonstrated holistic analysis allows to study and compare heterogeneous chronologies from different locations, differing in coverage, number of sequences, etc. These analysis would enable for better utilization of the existing international databases for assessing the adverse periods in the growth of the trees. Proposed holistic approach for meta-analyses of series (eustress identification in radial growth of stems) is convenient for the fast monitoring of forest communities state and for recognizing the stands under risk, where the eustress frequently appears, with very long duration and very deep depth. The capability of approach allows expression of reactive functional types of trees (PFTs) as groups of trees with the similar behavior to the influence of climatic types of years, and with similar characteristics of eustress periods.

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