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METHODOLOGY FOR ASSESSING OF ECOLOGICAL CONDITIONS IN FOREST ECOSYSTEMS UNDER CLIMATE CHANGES

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Abstract

A methodology for determining of ecological conditions in forest ecosystems in order to assess their future variations under expected climate change has been developed. Complex index for ecological conditions (K_{ec}) was established including hydrothermal (precipitations, temperature and duration of drought period in the region), soil (depth and erosion) and relief (exposure and inclination of slope) parameters. The expected changes of climatic elements were assessed based on data from climatic scenarios. Model verification was performed for Sedelska River basin, a tributary of Struma River, South-western Bulgaria. Distribution and division into 5 groups of main tree species within the watershed area was performed in accordance to the values of K_{ec}. Distribution of forest ecosystems in groups according to expected ecological conditions for the period of 2021–2049 and 2071–2099 was established and their spatial distribution for Sedelska River basin was mapped. It was established that nowadays about 30 % of stands and forest plantations are in the first group – under 'bad' ecological conditions. The results showed that for the period 2021–2049 the area of these forests will increase and will reach 36.9 %, and for the period 2071–2099 more than the half of these forest ecosystems (51.2 %) will be under 'bad' ecological conditions.

Key words: complex index, drought periods, hydrothermal parameters, erosion, tree species, Sedelska River.

Introduction

The climatic characteristics, such as temperature and amount of precipitation, are important for forest growth, regeneration and optimal distribution. The long-term data about precipitations and temperatures show trends, which, together with soil and relief characteristics, could explain the present ecological conditions for the development of vegetation. For assessment of the simultaneous effect of these ecological factors, De Marton index and climatograms after Walter (1963) were used as complex climate characteristics. The bioclimatic modeling determines climatic characteristics as limits of the species distribution within certain climatic niche (Box et al. 1993, 1999). The relation between vegetation and climate was included in the model developed by Holdridge (1967). Within this model an elaborated life zone classification is based on biotemperature, mean annual precipitation and on a potential evapotranspiration ratio. This classification was used to assess the climate change impact on vegetation (Emanuel et al. 1985, Leemans 1990). Box (1981) involved in a model several factors including minimal and maximal values of precipitation and temperature, evapotranspiration, etc. Other models, which divide plant species into functional groups and can be applied under different climate regimes, especially for scenarios of future developments, are BIOME models (Prentice et al. 1992, Cramer 2002). Ecological models were used to predict the climate change threshold for shift of geographic distribution of tree species. As a result of climate change some terrestrial plants have shifted their ranges and likely migrate to areas with more suitable climates (IPCC 2007, 2014; Penuelas et al. 2007) but it is important to project the changes in ecological conditions on regional level – economic regions, watersheds, etc. In this case the planners and managers will know which measures for adaptation of tree species should undertake. Adaptation to climate change could occur naturally, through natural regeneration and tree migration, and could also be facilitated by human action if managers replant disturbed forests by species or varieties more suitable to the changed climate and establish new, replacing plantations in more suitable locations (Sedjo 2010).

Many researchers studied plant – climate relationships and estimated impact of climate change on forested ecosystems. The results showed that deterioration of the vitality and stability of forest ecosystems may lead to a degradation of forests and soil, aridification of the region, change of species distribution area, which impose the necessity of activities for adaptation (Rehfeldt et al. 2006, Crookston et al. 2010, Matyas 2010, Matyas et al. 2010, Halofsky et al. 2013).

The indicator values of tree species for temperature (temperature index) and for soil moisture (humidity index) are accepted as the most important factors, which could be affected by climate change and are used in tree-ecogram method (Ellenberg et al. 1992). The estimation of possible changes in forest stands due to climate change should focus on the tree species. The indicator values do not describe ecological demands of the trees in forest stands but they indicate their ecological behaviour. If a tree species is found to beless adaptable under climate change conditions for a certain region, the tree-ecogram method gives opportunity to estimate the most appropriate alternative tree species for this region (Ellenberg et al. 1992). This method was applied in the SEE-Project 'Climate Change and Impacts on Water Supply CC-WaterS', supported by European Regional Development Fund (Koeck 2012).

In Bulgaria, during the last decades the problem of establishment of sustainable forest ecosystems and agricultural crops according to climatic conditions, which is in relation with expected trends for climate change, has been discussed (Raev 1995, 1997; Raev et al. 1996; Raev and Slavov 1996; Slavov and Aleksandrov 1996; Knight et al. 2004). Underestimation of this problem could have serious ecological and economic consequences. In Bulgaria such an example is the afforestation with coniferous tree species out of their ecological optimum. The coniferous plantations suffered the chronic water deficit in the drought period from 1982 to 1994, which affected the plantations up to about 800 m a.s.l. and caused destruction of about

18 % of the established coniferous forest ecosystems (Knight et al. 2004). The main reason for this is unconformity between climatic conditions and ecological characteristics of coniferous species used for afforestation (Raev 1995, Raev et al. 1996). Knight et al. (2004), after applying Holdridge's model, determined that in XXI century changes could be expected in lowland of the country from 'moderate cool fresh forest' towards 'moderate warm dry forest'. In southern parts of the country, including Struma River basin area, in the area below 800 m, transition to 'subtropical dry forest' could be expected. Elements of a strategy for limitation of the consequences for forest vegetation, with a view to preserve vitality of tree species in changing climatic conditions are suggested.

Rationale and Purpose

Air temperature in Europe is expected to increase between 2.5 °C and 4.0 °C by 2071–2100. Expectations for Southern Europe include decreasing of precipitations as a whole, but increasing the number of days with heavy precipitation and as a result – decreasing of forest growth (EEA 2012). These projections show that climate change will have crucial impact on the natural resources and in particular on the development of forestry and forest industry.

European Commission is developing European Adaptation Strategy, which includes further proposals for adaptation actions across EU. All this is recognised in the developed 'National strategy for sustainable development of the forestry sector 2013–2020' (Anonymous 2013), where the main priority is given to 'maintaining of the vital, healthy, productive and multifunctional forest ecosystems favouring mitigation of negative consequences of climate change' and measures for enhancing the resilience and adaptability of forest ecosystems to climate change are foreseen.

Applied climatic scenarios for Bulgaria are allowed to define the 'areas of vulnerability' of forest ecosystems (risky regions such as North-eastern Bulgaria). On this basis, a 'Programme of measures for the adaptation of forests to climate changes in Bulgaria and reduce the negative impact of climate change on forests' was developed (Raev et al. 2011). In the Programme, the measures for adaptation of forests that are largely applicable to most countries of Southeastern Europe as well as some specific measures for Bulgaria, are presented. The connecting link between the programme and the specific practical approach is not clearly defined, i.e. how the stands (plantations) on a given area will be classified as stands subjected to the risk for normal development as a result of climate change (first of all to the increases in temperature, changes in precipitation and snow). Implementation of adaptation measures to all existing forest vegetation within the risky regions is uneconomic. It is necessary to be able to apply the measures just to those stands in which the habitat changes due to climate change are expected to take place until the end of the century, and which will affect negatively the function and structure of plantations. For these stands appropriate forestry activities will be planned in the forest management plans with priority and will be applied in order to adapt to climate change.

The methodology for determining the ecological conditions of forest ecosystems was developed with the aim to assess climatic, soil and relief conditions, under which tree species grow and the change of these conditions under the expected climate change. A complex index for ecological conditions (K_{ec}) has been developed. It was applied to ecological (site) conditions (soil, relief, precipitation and temperature) assessment of ecosystems, defined by dominating tree species in the stands, according to the data of forest management plans. The change of climatic elements was assessed on the basis of data taken from climatic scenarios. It should be taken into account that K_{ec} values do not give estimation of the ecological requirements of trees in forest stands, rather a rating of site conditions and the ability of a site to provide conditions for normal development of forest vegetation and production of wood.

The necessary forest activities for adaptation and future forests composition could be determined on the basis of obtained values of index K_{ec}. The forest management plans contain data about the structure and composition of stands, and habitat conditions (exposure, topography, soil, erosion) there are data about each stand, representing a management operational unit (compartments and subcompartments). These parameters, together with climatic characteristics (rainfall and temperature) can be used to assess the current environmental conditions, and also changes in these conditions using the climatic scenarios for future periods. Depending on the purpose of the study an object of survey may be a part of a forestry administrative unit, or could include the territory of several such units, most often within one catchment area. The use of GIS allows processing of large datasets characterising of the conditions in all of the surveyed area.

Methodology Description

The methodology was based on environmental factors including hydrothermal, soil and relief conditions, and dynamics of precipitation and temperature, obtained from climatic scenarios. Description of the methodological approach for assessment of environmental conditions is presented in the project 'Climate Change and Impacts on Water Supply – CC-WaterS' (Marinov et al. 2012, Koeck 2012). Testing of methodology in real conditions has shown that in order to reflect in more details the changing weather conditions it is necessary to make a correction in the initial version, related with the values used for precipitation and temperatures. The change is insignificant – instead of 'maximum average monthly temperature' and 'maximum average monthly rainfall' for period April – October, the average monthly data were used as indicators. It does not change the essence of methodology but is done just for higher precision of estimations, particularly for regions where climate scenarios do not show (prognosticated) significant changes in the climatic characteristics.

The complex index for ecological conditions (K_{ec}) was determined by hydrothermal (precipitations, temperature and duration of drought period in the region), soil (depth and development of erosion processes) and relief (exposure and inclination of the slope) conditions through the equation:

$$K_{ec} = K_t \cdot K_p \cdot S_m \quad (1),$$

where: K_{ec} – complex index for hydrothermal, soil and relief conditions; K_t – temperature index; K_p – index of precipitations; S_m – combined/integrate index for soil conditions, erosion processes, relief and drought.

Methodology Parameters

Temperature conditions. For determining temperature conditions, only data for the period of the year – from April to October, was used. These conditions were expressed through temperature index (K_t), determined by average, maximal and minimal average monthly temperature °C during these months:

$$K_t = [(T_{v\,max} - T_{v\,min}) \cdot T_{v\,av}]/100 \qquad (2),$$

where: $T_{v\,max}$ – maximal average monthly temperature °C in the period April–October; $T_{v\,min}$ – minimal average monthly temperature °C in the period April–October; $T_{v\,av}$ – average monthly temperature °C in the period April–October.

Precipitations. The vegetation growth was determined in considerable extent by the moisture, especially in warm months of the year. That's why the model showed the impact of precipitations in these months – from April to October. The index of precipitations (K_p) was calculated according to the following equation:

$$K_p = (P_v/P_y) \cdot P_{v\,av} \qquad (3),$$

where: P_v – amount of precipitations in the period April – October, mm; P_y – amount of annual precipitations, mm; $P_{v\,av}$ – average monthly precipitations in the period April–October, mm.

For the characteristics of main climatic elements (precipitations and temperature), data for each climatic stations were analysed for the present period (usually covering the previous 30–40-year period or that one accepted as basic climatic period), as well as data predicted from climatic scenarios (for one or two periods, from 30 to 50 years each). For the assessment of precipitations and temperature, a complex characteristic of climate was used through climatogram after Walter (1963), which determines durability of drought period for climatic stations in catchment area (region) for the present period and for one or two prognostic periods.

Soil, erosion, relief and drought. An integrate index (S_m) for soil conditions, erosion processes, relief and drought was calculated using the following equation:

$$S_m = [(K_{dp} \cdot K_e \cdot K_a \cdot K_s) \cdot K_d]/100 \qquad (4),$$

where: K_{dp} – depth of soil; K_e – soil erosion; K_a – slope exposure; K_s – slope inclination; K_d – drought period.

The individual parameters of S_m index were classified into classes, and they participated in the integrate coefficient by classes (Table 1).

Final assessment of ecological conditions has to be performed on the basis of obtained values for the index of ecological conditions (K_{ec}) listed in Table 2.

In order to distribute K_{ec} values in groups, the clustering algorithm could be used (MacQueen 1967). The studied territory could be distributed in 5 clusters (groups), according to ecological conditions. Based on the above mentioned algorithm for data distribution in the groups, the much higher percentage of the studied territory usually refers to the group of bad ecological conditions.

The complex index for ecological conditions (K_{ec}) was determined separately for all stands, distributed according to dominating tree species in ecosystems. Due to similarity in growing conditions of tree species K_{ec} could have equal values for two and more species, which will be referred (allocated) in the same group according to ecological conditions. The areas and spatial distribution of each group of ecological conditions determined according to the growing at these conditions tree species, their origin and soil conditions were defined by forest management

Table 1. Classification of soil conditions, erosion processes, relief and drought for determination of S_m.

K_{dp}		K_e		K_a		K_s		K_d	
Class	Depth, cm	Class	Erosion	Class	Exposure	Class	Inclination in degrees	Class	Drought
1	< 30	1	Yes	1	Sunny (S, SW, SE, W)	1	> 21	0.5	> 3 months
2	30–50	2	No			2	11–20	1	1–3 months
3	50–120	-	-	2	Shady (N, NW, NE, E)	3	< 10	2	< 1 month
4	> 120	-	-	-	-	-	-	3	no

plans and present and prognostic climatic data, using GIS data of maps developed for each forest vegetation belt in the studied territory.

Table 2. Classification of K_{ec} values and assessment of ecological conditions.

K_{ec}	Description of ecological conditions	Group of the ecological conditions
< 5	Bad	I
5.0–10	Relatively good	II
10.1–20	Good	III
20.1–50	Good to very good	IV
> 50	Very good	V

Obtained database allows to go back to the initial data about forest ecosystems with dominating tree species and to determine the precise location of compartments and sub-compartments (through the maps done by GIS), as well as the forest survey from the management plan for each sub-compartment, classified in groups according to ecological conditions. This capability of the model is particularly important, because it supports authorities in their decision about determining specific forest ecosystems, where activities should be directed to adaptation to changed climatic conditions. These activities will be different according to dominant tree species in sub-compartments and whether before the period of assessment some management activities in the stands and forest plantations have been performed (thinning, sanitary logging, etc.).

Testing of the Methodology for Sedelska River Basin – Approach and Results

Initial testing of methodology for determining of ecological conditions of forest ecosystems has been performed for Sedelska River (Marinov et al. 2012). Here the main results are presented in order to follow the sequence of parameters' practical defining.

Sedelska River is the right tributary of Struma River. Its catchment area covers 50.2 km^2 of eastern slopes of Maleshevska Mountain.

Defining of Parameters

Climatic elements

For characteristics of main climatic elements (precipitations and temperatures), data from Bulgarian National Institute of Meteorology and Hydrology have been used (Aleksandrov and Spiridonov 2010). The dynamics of annual precipitation and temperature was represented for the period until 2005 and from climatic scenarios up to 2049 and 2099. For assessment of common influence of precipitations and temperatures as factors for vegetation growth, a complex climatic characteristic was used. For this purpose the drought periods were determined by graphic method through climatogram after Walter (1963). Duration of these periods were determined for different climatic stations in Struma River basin for the period until 2005 and for the two periods of prognoses – 2021–2049 and 2071–2099. For Sedelska River basin data from neighbouring stations were used for each vegetation belt, according to altitude.

Climatograms showed that precipitations are sufficient in the higher parts of the mountains, where there is no drought and the hydrothermal conditions are adequate for forest vegetation growth. Durability of drought period for climatic stations in Struma River basin for the period until 2005 was about 4 months for Sandanski (191 m a.s.l.), about 3 months for Kresna (180 m), 2 – for Blagoevgrad (410 m), around 1 for Rila (470 m).

Determining of drought periods for 2021–2049 and 2071–2099

Climatograms for the periods 2021–2049 and 2071–2099 showed that considerable changes in climate will occur in the southern part of Struma catchment area and in Kyustendil region, which will lead to droughts with duration of 4–5 months in Sandanski, Kresna and Blagoevgrad (up to 6 months in Blagoevgrad for the period 2049–2099), in Rila, Kyustendil (520 m) and in Pernik (700 m) – more than 2 months. Only in the highest parts of catchment area (1150 up to 1640 m) there will not be drought period, which could have an impact on the growth of forest vegetation.

The main factor for drought is the Mediterranean climatic influence, which defines to a great extent the climate in Struma River basin and in particular in Sedelska River basin. Drought in the area up to about 600 m will be significant and an impact on forest vegetation and changes in natural vegetation could be expected. As a result of this drought part of forest ecosystems will deteriorate change their status. The range of main tree species will undergo substantial changes. Forest plantations on non-typical sites most probably will sustain significant losses. To prove this, however, a reliable assessment of ecological conditions at the present distribution of species and their modification as a result of predicted climate change is necessary.

Relief

For the assessment of topographic conditions (inclination and exposure of slopes) and presence of erosion, data from Forest Management Plans of State Forest Enterprise (SFE) Tsaparevo were used, as well as classifications according to Regulation No6/February 2004 (Regulation 6 2004).

Distribution of main tree species, provenance and soils

Distribution of main tree species in Struma River basin has been classified according to the altitude following Velchev et al. (1992). For Sedelska River basin the main tree species were identified according to the information of Forest Management Plan of SFE Tsaparevo (Anonymous 2005). The largest area is covered by Oaks (*Quercus* sp.) – 40.3 % of the investigated territory, followed by Scots pine (*Pinus sylvestris* L.) – 24.3 %, Austrian black pine (*Pinus nigra* Arn.) – 19.6 %, European beech (*Fagus sylvatica* L.) – 10.0 %, Hornbeams (*Carpinus betulus* L. and *C. orientalis* Mill.) – 4.7 % and Sweet chestnut (*Castanea sativa* Mill.) – 1.1 %. Sedelska River basin was divided into three vegetation belts – up to 1500 (1600) m using GIS. The belt of xerothermic oak forests was divided into two subbelts – up to 400 and from 400 to 600 m. In each of them the range of dominating tree species was determined.

The following codes assigned by letters have been used to identify tree species: sp – Scots pine, bp – Austrian black pine, bch – European beech, hor – Hornbeams, oak – Oaks, ch – Sweet chestnut and numerical codes: 1 – sp, 3 – bp, 11 – bch, 29 – hor, 76 – oak, 87 – ch. Hornbeam numerical code (29) includes codes 17 and 29 and Oaks code (76) includes codes 12, 13, 14, 15, 16, 28 and 76, according Regulation No6 (2004).

For the origin grouping with code 1 were assigned natural stands and with code 3 – forest plantations. Soils are grouped, based on the codes, used for practical purposes in Forest management plans of SFE Tsaparevo as follows: 2 – Leptic-chromic Luvisols; Leptic-chromic Cambisols + Rendzic Leptosols (14, 15, 16, 17, 27); 3 – Leptic Cambisols; Leptic-eutric Cambisols + Leptic-humic Umbrisols (19, 20, 21, 25, 28). In Sedelska River basin there are no soils from other soil groups identified in Struma River basin.

Possible combinations were determined for tree species, according to their origin and soil type. Each tree species gets a 3-numerical code in eight variants depending on the origin and soil type, in which: the first number is code for tree species, the second – origin and the third – soil type. For example Oaks have code *oak3* at the combination 76.1.3., i.e. natural origin of the stand (1) and soils from a third group (3).

To every code of tree species (8 options for each type) were given four-digit code formed by classes for: thickness of soil (K_{dp}), erosion (K_e), exposure (K_a) and slope gradient (K_s). For example *oak3 / res 17* (see Fig. 1) is a combination 2.2.1.2. equal to 17 res, i.e. K_{dp} = 2, K_e = 2, K_a = 1 and K_s = 2.

That is the first part of the integrate coefficient for site conditions (soil, relief and climate) (S_m) – formula (4) of the model for determination of K_{ec}. The second part is the period of drought.

Areas and spatial distribution in the belt up to 400, 400 to 600, 600 to 800 and 800 to 1500 m were determined with GIS and mapped (Marinov et al. 2012).

Current ecological conditions in forest ecosystems in Sedelska River basin

After mapping of the distribution in each group of dominant tree species, each distinguished group was classified using the model for determination of ecological conditions in forest ecosystems equation 1. The entire system of coefficients was constructed basing on the above described steps.

The current distribution of areas according to main tree species availability and the values of other parameters the complex index K_{ec} in Sedelska River basin

Table 3. Present distribution of the main tree species in Sedelska River basin according to K_{ec} values.

Group according to ecological conditions	K_{ec}	Altitude, m	Area, ha			Part from total investigated territory of the catchment, %
			Stands	Plantations	Total	
I – Bad	< 5	<400	231.4	25.3	1055.4	30.0
		400–600	324.4	384.3		
		800–1500	57.5	32.7		
II – Relatively good	5.0–10	<400	35.1	2.2	944.4	26.9
		400–600	111.0	65.1		
		600–800	160.5	418.5		
		800–1500	47.8	4.2		
III – Good	10.1–20	400–600	4.2	38.4	554.0	15.7
		600–800	217.7	123.1		
		800–1500	89.1	81.5		
IV – Good to very good	20.1–50	400–600	0.7	0.8	955.3	27.2
		600–800	305,5	241.8		
		800–1500	267.6	138.9		
V – Very good	> 50	600–800	1.9	-		
		800–1500	-	4.0	5.9	0.2
Total investigated area					3515.0	100.0

was obtained for each sub-compartment in vegetation belt. Then the stands were classified to their origin and altitude (Table 3).

The results show that 1055.5 ha, or 30 % of the investigated forest ecosystems in Sedelska River basin, are classified in group I – under 'bad' ecological conditions. This territory is occupied by dominating tree species, the most spread within Struma River basin.

These forests are predominantly in the belt up to 600 m, and insignificant part – 8.5 % –above this altitude, very close to the second group according K_{ec} (K_{ec} = 4.85). The dominant tree species in natural stands are oaks and hornbeams, and in the plantations – Austrian black pine and Scots pine. The site conditions for I group are mainly as follows: soils – Leptic-chromic Luvisols (smaller area with Leptic Cambisols), shallow (small share are with medium depth), eroded (small share non-eroded), predominantly on sunny exposures and drought period duration > 3 months (with small exceptions). Up to 400 m at 'bad' conditions the forests are presented mainly by natural stands. Within the belt from 400 to 600 m the areas of stands and plantations at 'bad' conditions are equal and above this altitude, the forest stands cover almost twice larger area.

The area of forest ecosystems within the belt 600–800 m, which is classified as group with 'relatively good' ecological conditions, exceeds 60 %. The area of the forest plantations within this belt is 3 times larger than that for the stands at this altitude. Stands and plantations at altitude higher than 400 m are only 4 % of the total area of this group, while their total area above 600 m is 22.5 %. Hydrothermal conditions at an altitude above 600 m are relatively favourable but probably other conditions of the environment (soil, relief and presence of erosion processes) are decisive for the classification of these stands in this group.

The distribution of stands and plantations between the other three groups (III – 'good', IV – 'good to very good', V – 'very good') can be seen in Table 3. The ecological conditions for these groups are good and very good and they most probably will not be influenced significantly by climate changes.

Distribution of forest ecosystems in groups according to ecological conditions for the periods 2021–2049 and 2071–2099

The distribution of part of catchment area with main tree species, according to values of K_{ec} for the periods 2021–2049 and 2071–2099 is presented in Table 4 and Fig. 1 (for K_{ec} > 5 and K_{ec} < 5).

The total area of xerothermic oak forests belt (up to 600 m) was 1222.4 ha. According to the current status of the vegetation here 965.4 ha are classified in first group ('bad' ecological conditions), which is 79 % of the total belt area. It is predicted that for the period 2021–2049 the space of forest ecosystems belonging to this group will increase with only about 12 ha. This insignificant change in the distribution of areas included in the group of forests under 'bad' ecological conditions reveals the dominant influence of environmental conditions (soils, erosion, relief) over precipitations and temperature changes, but also shows that almost all ecosystems in this vegeta-

Table 4. Distribution of the main tree species in Sedelska River basin according to K_{ec} values (prognosis 2021–2049 and 2071–2099).

Group according to ecological conditions	Altitude, m	2021–2049				2071–2099			
		Stands, ha	Plantations, ha	Total, ha	Investigated territory, %	Stands, ha	Plantations, ha	Total, ha	Investigated territory, %
I	<400	266.5	25.3			266.5	25.3		
	400–600	322.5	362.7			423.6	404.4		
	600–800	68.4	251.0	1296.3	36.9	160.5	518.6	1798.8	51.2
II	<400	0.0	2.2			0.0	2.2		
	400–600	101.2	41.6			15.8	83.2		
	600–800	92.0	267.6			217.8	123.1		
	800–1500	57.4	32.7	594.8	16.9	57.4	32.7	532.2	15.1
III	400–600	15.76	83.20			0.0	0.0		
	600–800	217.8	123.1			296.0	251.2		
	800–1500	61.78	41.65	543.3	15.5	61.8	41.6	650.7	18.5
IV	400–600	0.7	0.8			0.7	0.8		
	600–800	296.2	251.2			0.0	1.9		
	800–1500	342.7	183.0	1074.5	30.6	342.7	183.0	528.9	15.0
V	600–800	0.0	1.9			0.0	0.0		
	800–1500	1.1	3.0	6.0	0.2	1.0	1.3	4.0	0.1

tion belt are under 'bad' ecological conditions. From the point of view of single stands and plantations, it should be mentioned that in the lower zones of catchment area (up to 600 m) forest area assessed under 'bad' climatic conditions remains almost the same under conditions of climatic scenario for the period 2021–2049 (Fig. 1).

During the next period (2071–2099), however, the group under 'bad' ecological conditions will include significant part of the stands and plantations situated at higher altitude. There will be no change in the areas in the belt up to 400 m due to the fact that all stands and plantations in this period are under 'bad' ecological conditions. For altitude from 400 to 600 m, the area of stands included in this group is predicted to increase by 100 ha, and that of plantations – by 40 ha, compared to the previous projected period. The changes of vegetation in the belt from 600 to 800 m will be also considerable. Over twice will be the area of stands and plantations classified to 'bad' ecological conditions.

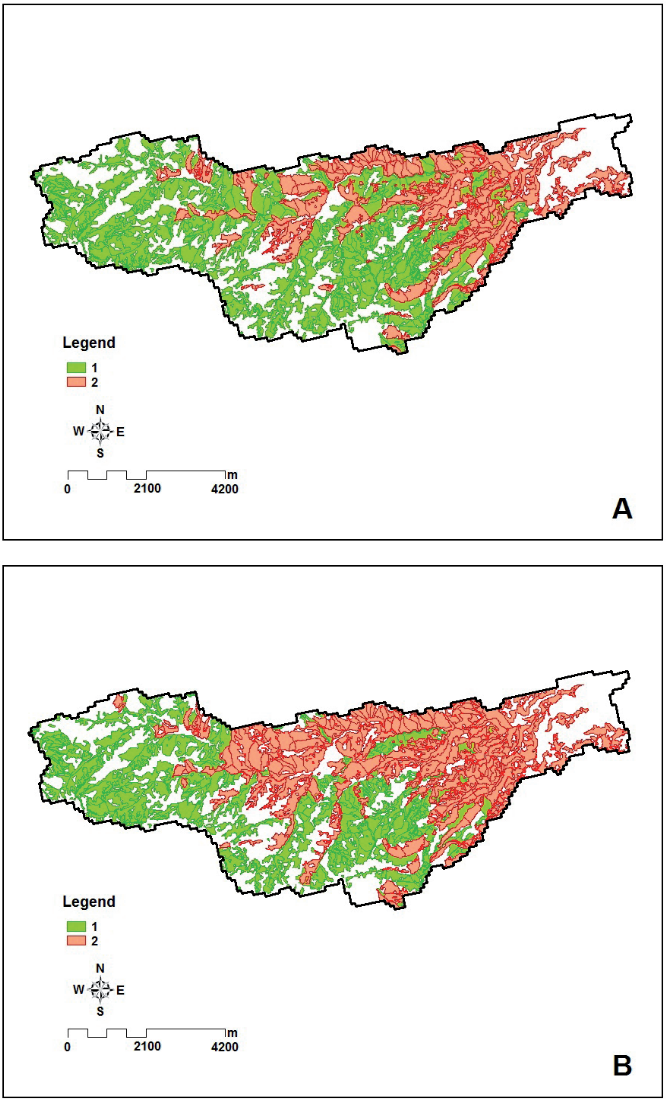

Fig. 1. Distribution of Sedelska catchment area according the values of K_{ec}: 1 – K_{ec} > 5, 2 – K_{ec} < 5; A – period 2021–2049, B – period 2071–2099 (Marinov et al. 2012).

A question that arises based on the results is about the future species composition of forests in the belts of xerothermic oak forests and xeromesophytic oak and hornbeam forests in the region of study. Evidently, appropriate activities and investment plans should be developed for adaptation of present forest ecosystems to expected climate changes, and at the same time for developing a strategy for conservation of autochthonous vegetation.

Conclusions and Recommendations

A methodology for determining of ecological conditions in forest ecosystems on the basis of a complex index (K_{ec}) was developed. For K_{ec} index calculation temperature and precipitation indexes and combined index for soil conditions, erosion processes, relief and drought have been involved. With K_{ec} index expected changes of ecological conditions in forest ecosystems as a result of climate change can be assessed.

Ecological conditions for forest ecosystems were determined for Sedelska River basin a tributary to Struma River, Southwest Bulgaria. The current distribution of main tree species in the watershed was determined according to the values of K_{ec} and they were divided into 5 groups according to ecological conditions. The spatial distribution of main tree species according to altitude was performed and after that mapped as a basis for their grouping in conformity of ecological conditions. Distribution of forest ecosystems in groups according their ecological conditions for the periods 2021 2049 and 2071–2099 in Sedelska River basin was done.

It was established that nowadays 30 % of the stands and forest plantations, are in the first group – under ’bad‘ ecological conditions, according to dominating tree species. Results show that for the period 2021–2049 their area will increase and will reach 36,9 %, and for the period 2071–2099 more than the half of these forest ecosystems (51.2 %) will be under ’bad‘ ecological conditions.

In the vegetation belt of xerothermic oak forests (up to 600 m a.s.l.), 79 % of the total investigated area was classified in the first group (‘bad‘ ecological conditions). After application of the model for determining of K_{ec} for first climatic scenario (2021–2049), the area of this group increases insignificantly, while during the next period (2071–2099), under ’bad‘ ecological conditions will increase till 92 % of forest ecosystems. These data show that in the belts of xerothermic oak forests and xeromesophytic oak and hornbeam forests in this part of the country it is necessary to apply activities for adaptation of present forest ecosystems to expected climate changes but they also show that it is necessary to develop a strategy for conservation of autochthonous vegetation, as well as methods for scientifically well-grounded selection of tree species for afforestation on the basis of specific ecological conditions.

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