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Faculty of Forestry in Skopje Original scientific article

Certain edaphoecological factors for upper treeline expansion of forest vegetation in the northern parts of Kozhuf mountain massif in the Republic of Macedonia

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ABSTRACT: This paper attempts to define what changes occur with forest vegetation on the northern slopes of the Kozhuf mountain range at upper treeline. For this purpose, we defined three sub-goals: defining the current upper timberline of the forest vegetation, distribution of forest communities on Kozhuf mountain range at the upper treeline, as well as modelling of possible upper timberline of the forest according to temperature indicators. Comparative analysis method was used. The period of analysis covers 80 years. Different cartographic and written materials served as a basic material for analysis. Required sections of topographical maps were geo-referenced and digitalized as separate layers in AUTOCAD software. With layers switching, and with so-called "over-lay analysis" we got the differences in the distribution area in terms of upper treeline shifting. Forest vegetation was surveyed with recording and mapping of vegetation types. Part of it is processed by the method of Braun-Blanquet. The vegetation types development was observed, and the dynamics of populations and species movement was observed through these changes. The obtained results show that with increment of upper treeline of the forest vegetation, the most represented is forest community of Scots pine *Fago-Pinetum sylvestris* on silicate geological substrate, and relatively smaller areas are accounted to the forest communities of mixed forest of fir and beech *Abieti borisii-regis – Fagetum*, and pure fir forest *Fago-Abietetum*, while the small area accounts for *Seslerio-Pinetum nigrae* and *Fago-Abietetum* forest communities on limestone geological substrate. Regarding the treeline of the forest in 30 years of the last century and the present state, the greatest expansion is on western exposure, in this case up to maximum of 400 m. The forest vegetation expansion is smallest on eastern exposure.
Keywords: topographic maps, AUTOCAD software, treeline, forest communities, expansion

1 INTRODUCTION

Forest vegetation permanently changes its distribution limit [12]. For the current picture of the vegetation cover at the upper treeline of the Kozhuf mountain range, the primary significance has: the development of vegetation in the past, the existing life conditions and the human influence, while a decisive role belongs to climate, relief and edaphic factors.

In this regard, a major environmental factor that strongly influences on the recent geographical layout, composition and growth of the forest is the climate with its elements: air temperature, precipitation, relative humidity, winds, insolation and other.

The upper treeline in terms of relief depends on the mountain massiveness, altitude, exposure, proximity to the sea and other.

In aspect of the massiveness and stretchiness direction of mountain ranges, the continentality or oceanic position of the mountains affect the limit of upper or alpine border of the forest cover. The mountain's massiveness affect the climate. The more mountain is massive it has more continental climate, as it is quickly heated and cooled. If the mountain is smaller, it has more oceanic character, as it is slowly heated and slowly cools. Because of such a role, the mountain's massiveness influence the position of the alpine treeline, the more mountain is massive and away from the sea, this alpine treeline is on higher altitudes, and vice-versa, as the mountain is less massive or closer to the sea, the alpine treeline is on lower altitudes.

An important feature of the elevation of the upper treeline is exposure. Namely, on the northern exposures the upper treeline is higher than those on southern exposures are. Here despite of the low temperatures, the fluctuations are smaller [10].

The elevation of the alpine treeline is actually determined by the elevation at which the July isotherm of 10° C is moving. At a temperature below that, the forest does not thrive anymore. Comparisons in older literature between timberline location and certain isotherms had already indicated that temperature during the growing season plays the key role in setting the forest limits. The 10°C July-isotherm agrees relatively well with the course [2].

Although the relief affects the formation of vegetation cover almost everywhere relatively equal, in some parts of the country there are big differences in appearance and layerness of the vegetation cover. The reason for these changes is the development of vegetation in the past and geographical location (latitude and longitude). The impact of the relief is not seen only in the establishment of the recent vegetation cover, but also in the formation of vegetation cover in the past (invasions and withdrawals and survival of certain plants and plant communities that lived in different geological periods) closely related to the climate and the form of relief.

The difference in latitude may be the reason for appearance of vegetation that the relief as a factor conditions somewhere.

The impact of the relief on the vegetation cover is reflected in two ways: on wider areas with joint action of mega relief, the climate of the wider area, the land configuration influence in the formation of climatogenic communities. On the smaller area with the impact of mezorelief or microrelief, the microclimate and atypical soils affect the formation of locally conditioned communities.

The Balkans and Macedonia are known for centuries – old quest to destroy the forest at the upper treeline, in order to obtain productive pastures in order to satisfy the extensive economic output in cattle breeding and manufacture operations in mountain areas over the centuries [13, 28]. The livestock in this part of Kozhuf is of semi-nomadic type. The presence of large livestock in the area of interest is insignificant. The potential for grazing the entire pasture area is about 3,500 sheep. By conquering the heaths vegetation, the number of sheep that could graze will be reduced by 50% [14]. All this, accompanied by the historical development of forest vegetation contributed to the reduction of the upper treeline in some Macedonian mountains by 400–500 meters.

In the past 50 years, a reversible process is visible. It is the process of returning of forest on places where long it has been superseded. This is due to reduction of the herds that graze in the mountains of Macedonia. On the Kozhuf mountain range in a negative direction is the existence of a sheepfold with a significant number of cattle that slows the regeneration potential of the sites where cattle grazing occurs.

In the last decades, the scenarios are present to increase the upper treeline in vertical gradient through impact in parts of the forest ecosystems. This in correlation with climate change is evident.

Analysed data for movement of the upper treeline based on research undertaken at Kozhuf mountain range in southern part in Macedonia will be presented here.

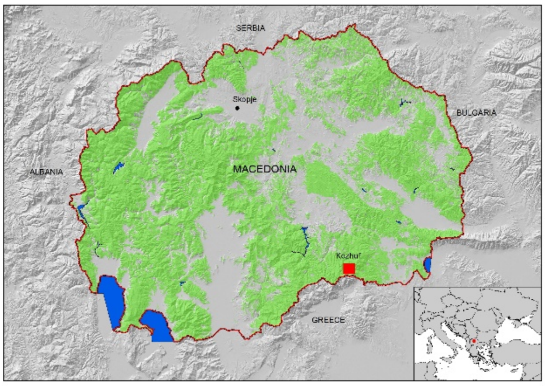

Figure 1: Investigation area – Kozhuf Mt. in the Republic of Macedonia

2 INVESTIGATION AREA

Kozhuf Mountain range is a situated in the southern part of Macedonia and northern part of Greece. It has extends in a southwest-northeast direction and has a rounded and undivided mountain ridge.

Kozuf Mountain is one of the oldest mountain massifs in Macedonia and from a regional aspect belongs to the Vardar geotectonic zone.

This research was conducted on central-southern part of the Balkan Peninsula in the northern parts of Kozuf mountain massif in the Republic of Macedonia (Figure 1). The vertical altitude of this research was in-between 1,400 and 1,800 (2,200) m in the altimontane and subalpine belt. According map of isohyets of Republic of Macedonia for Kozhuf Mt. average isohyets in subalpine belts more than 1,000 mm. According to short-term measurements made in the subalpine belt recently by the owner of the ski resort Kozhuf, the annual amount of precipitation is 1,220 mm. According to the same source, the depth of the snow cover varies depending on the altitude and the months in the winter shown on Table I. The heaviest snow cover was recorded in February [14]. Average temperature according to the Map of isotherm issued by the National Hidrometerological Service of Macedonia is 4℃ [31].

Table I: Depth of the snow cover on the Kozhuf Mt.

Month	Elevation	
	1,550–1,850 m	**1,850–2,200 m**
	Snow depth (cm)	**Snow depth (cm)**
November	35	45
December	50	60
January	70	80
February	90	110
March	40	60
April	30	40

3 METHODS

This paper attempts to define what changes occur with forest vegetation on the northern slopes of the Kozuf mountain range at upper treeline, and what the vertical distribution limit of forest vegetation is. For this purpose, we defined three sub-goals: defining the current upper treeline of the forest vegetation, distribution of forest communities on Kozhuf mountain range at the upper treeline, as well as modelling of possible upper treeline of the forest according to temperature indicators.

Comparative analysis method was used. The period of analysis covers 80 years. Different cartographic and written materials served as a basic material for analysis.

Study limitation: During the research were used various maps according to the scale and technique. Topographic maps from multiple time periods and methods of elaboration available for the Republic of Macedonia were used. Namely, the maps at a scale 1: 50,000 which were created on the basis of geodetic measurements during the thirties of the last century as a version of the same maps amended in the fifties of the last century, further topographic maps at a scale 1:25,000 created with photogrammetry in the seventies of the last century, topographic maps 1:25,000 issued by the Agency for Real Estate Cadastre of Republic of Macedonia in 2004 and latest state presented with satellite images from Google Earth as of 2014 [34]. In addition, written materials for forest vegetation from existing forest management plans elaborated for the region in different periods were used. Required sections of topographical maps were geo-referenced and digitalized as separate layers in AUTOCAD software. With layers switching, and with so-called "over-lay analysis" we got the differences in the distribution area in terms of upper treeline shifting.

Forest vegetation was surveyed with recording and mapping of vegetation types. The vegetation relevés were sampled according to the Zürich-Montpellier approach using the adapted Braun-Blanquet scale [32]. After drying and labelling the collected plant material was identified, using thereby a large number of floristic works – Flora of the (S) Republic of Macedonia [15–21]; Flora of Bulgaria [22–24]; Flora of SR Serbia [25], Mountain flora of Greece [26], Flora Helenica [27] and also some other floras and monographic works. The taxonomic nomenclature and the compliance of registered taxa of our vegetation relevés were done with the taxonomy and nomenclature of the species and lower taxa and their synonyms using the online EURO + MED PLANT BASE (database for vascular plants of Europe and the Mediterranean region – http://www.euromed.org.uk/). The vegetation type's development was observed, and from the tree measurement aspect, we provided the basic structural elements. The dynamics of populations and species movement was observed through these changes. Such data were compared with data from previous studies and management plans [33] related to the researched area.

We took soil samples from each investigated vegetation community on both mountain on different locations. Five (5) soil profiles were excavated and morphologically described on the field.

They were thereafter air-dried and taken to the laboratory at the Department of Soil Science – Institute of Agriculture, Ss. Cyril and Methodius University in Skopje, for analysis of chemical properties and some soil-forming factors.

Figure 2: Rendzinas on hard limestone and dolomites on plate limestone

4 RESULTS AND DISCUSSION

According to Mayer [2], the forest cover cannot thrive in areas, where in the period of four vegetation months (May–August) the precipitation is less than 50 mm, and relative humidity of the air is less than 50%. However, if precipitation during that period surpassed over 100 mm followed by a lower relative humidity of the air the forest cover can succeed. In this case, the relative lack of moisture in the air can be compensated if the level of groundwater is high. The forest cover does not thrive in any subpolar or alpine area where the average July temperature is less than 10°C.

In order to define up to which elevation the forest vegetation can thrive without the influence of external factors, according to temperature indicators, we designed the average July isotherm with different altitudes for the northern slopes of Kozhuf mountain range (Table IV). Regarding the July temperature in Macedonia, there are four thermally homogeneous areas differentiated with specific terms of the change in the average July temperature at different altitudes. The Kozhuf mountain range is covered in the first region according to which up to 500 meters, the mean July thermal gradient is 0.8/100, from 500 to 1,300 meters of altitude is 0.7/100 m, and over this altitude the gradient is 0,6/100 meters. For this purpose, we used data for climate monitoring stations in Gevgelija, Demir Kapija, and Kavadarci and climate data from the monitoring station at Ski resort Kozhuf open on the elevation of 1,625 meters.

According to own research on soil, in this locality there are more prevalent following soil types: rendzinas on hard limestone, brown forest soils and swampy gley soil. Three soil profiles were under forest vegetation of Austrian pine (*Pinus nigra*) and describe as rendzinas on hard limestone. One profile was under Scots pine (*Pinus sylvestris*) as a brown forest soils and one soil profile was excavated as swampy gley soil.

Figure 3: Brown forest soils (cambisol) on micashist

Table II: Chemical properties of the soils on Kozhuf Mt.

Number of samples	Locality	Type of soil	Horizon	Depth	$CaCO_3$	Humus	pH	
				(cm)	(%)	(%)	H_2O	MKCl
1	Chichi Kaja	Rendzinas on hard limestone and dolomites	A	5–15	31.94	21.22	7.6	7.2
			R					
2	Chichi Kaja	Rendzinas on hard limestone and dolomites	A	0–5	46.9	22.52	7.70	7.30
			R					
3	Adžibarica	Swampy gley soil	Gr	27–42	0	5.75	4.8	4
			R					
4	Adžibarica	Brown forest soils (cambisols)	A	2–20	0	11.91	4.6	3.6
			(B)v	20–78	0	1.84	5.25	4.3
			R					
5	Mala Rupa	Rendzinas on hard limestone	O	0–8	0	77.00	5.7	4.9
			A	8–25	1.49	4.79	6.3	5.7
			R					

Table III: Some soil-forming factors

Number of samples	Horizon	Depth (cm)	Vegetation	Altitude (m)	Parent material	Exposure	Inclination (%)	Occurrence of outcrops (%)	Stoniness (%)
1	A	5–15	*Seslerio-Pinetum nigrae*	1,670	plate limestone	West	30–40	0	0
	R								
2	A	0–5	*Seslerio-Pinetum nigrae*	1,670	plate limestone	West	40–50	13	0
	R								
3	Gr	27–42	*Fago-Pinetum sylvestris*	1,480	phyllite	0	0	3–5	3–5
	R								
4	A	2–20	*Fago-Pinetum sylvestris*	1,550	micashist	South	30–40		
	(B)v	20–78							
	R								
5	O	0–8	*Seslerio-Pinetum nigrae*	1,590	marbles	Northwestern	30–40	0	0
	A	8–25							
	R								

Figure 4: Upper treeline consist of Scots pine (*Pinus sylvestris*)

Figure 5: Initial stage of regeneration of *Pinus sylvestris* in heaths

After processing the collected soil samples, we obtained data for chemical properties shown on Table II, and of soils from the investigated forest communities and data for some soil-forming factors of soils in Table III.

From the data from the Table II, it can be seen that the soil samples in profile number 1 and 2 are very carbonate. Profile 3 and 4 are non-carbonate, except profile 5 that is less carbonate. The reaction of the soil is not high. Even in profile 1 and 2 the reaction is high in other profile is low. The reaction of the soil is very strongly acidic in profile 3 and 4 that is developed on silicate parent material. These are also the most favourable habitats for development of forest, mainly due to the deep solum and the physiologically active profile, i.e., the root of the tree penetrates deeper in the soil. The humus content in the examined soils is highest on profile 5 that is developed on marbles.

The presented soil properties show that the upper treeline of the forest conquers the terrains on a silicate parent material and brown forest soils (cambisols) faster than those on a carbonate one representing on rendzinas on hard limestone and dolomites.

The obtained results show that with increment of upper treeline of the forest vegetation, the most represented is forest community of Scots pine, *Fago-Pinetum sylvestris*, developed on silicate geological substrate and brown forest soils (cambisols), and relatively smaller areas are accounted to the forest communities of mixed forest of fir and beech, *Abieti borisii-regis - Fagetum*, and pure fir forest *Fago-Abietetum* also under brown forest soils (cambisols) and swampy gley soil, while the small area accounts for *Seslerio-Pinetum nigrae* and *Fago-Abietetum* forest communities on limestone geological substrate, which are developed on rendzinas on hard limestone and dolomites.

Regarding the treeline of the forest in 30 years of the last century and the present state, the greatest expansion is on western exposure, in this case up to maximum of 400 m. The forest vegetation expansion is smallest on eastern exposure.

The expansion of the western exposure is associated with topographic conditions prevailing on Kozhuf mountain range. Namely, these are flattened areas with deeper soils and with reduced impact human and animals where seeds of Scots pine committed a strong expansion, and as a heliophyte species, it expands its maximum limit (Figures 5 and 6).

The terrains on eastern exposure are steeper and rocky, and in combination with strong winds, they are slowing natural regeneration and suppress the greater increase of the upper treeline.

The southern exposure is covered the most difficult terrains, on shallow soil in its initial stage, where the Austrian pine as a pioneering species extend its upper limit.

It is important to note that progressive succession goes in the direction of deterioration of pastures with appearance of heaths of ass. *Bruckenthalio-Juniperetum*, and further connection of the heaths with high altitude forest communities.

On the surveyed sites there was no afforestation done in the past. The overall regeneration, and thus expansion of the upper treeline is of natural origin (Figure 4).

Based on a mean July isotherm constructed from the closest climate station, according to Mayer [2], the forest vegetation in the north parts of Kozhuf mountain massif can conquer the entire array, i.e., up to 2,250 meters elevation in our case for Kavadarci climate station shown in Table IV.

The current upper treeline is approximately 1,900 meters elevation. This is in addition to the size of the range, its northern orientation and the relative distance from the Aegean Sea.

Table IV: Mean July air temperature at 4 (four) monitoring stations

Climate monitoring stations							
Gevgelija		**Demir Kapija**		**Kavadarci**		**Ski Kozhuf**	
Elevation (m)	**°C**	**Elevation (m)**	**°C**	**Elevation (m)**	**°C**	**Elevation (m)**	**°C**
59	27.2	110	26	265	24.6		
159	26.4	210	25.2	365	23.8		
259	25.6	310	24.4	465	23		
359	24.8	410	23.6	565	22.2		
459	24	510	22.8	665	21.4		
559	23.2	610	22	765	20.6		
659	22.5	710	21.3	865	19.9		
759	21.8	810	20.6	965	19.2		
859	21.1	910	19.9	1,065	18.5		
959	20.4	1,010	19.2	1,165	17.8		
1,059	19.7	1,110	18.5	1,265	17.1		
1,159	19	1,210	17.8	1,365	16.4		
1,259	18.3	1,310	17.1	1,465	15.7		
1,359	17.6	1,410	16.4	1,565	15		
1,459	17	1,510	15.8	1,665	14.4	1,425	16.8
1,559	16.4	1,610	15.2	1,765	13.8	1,525	16.3
1,659	15.8	1,710	14.6	1,865	13.2	1,625	15.8
1,759	15.2	1,810	14	1,965	12.6	1,725	15.3
1,859	14.6	1,910	13.4	2,065	12	1,825	14.8
1,959	14	2,010	12.8	2,165	11.4	1,925	14.3
2,059	13.4	2,110	12.2	**2,265**	**10.8**	2,025	13.8
2,159	12.8	2,210	11.6	**2,365**	**10.2**	2,125	13.3
2,259	12.2	2,310	11	2,465	9.6	2,225	12.8
2,359	11.6	2,410	10.4	2,565	9	2,325	12.3
2,459	11	2,510	9.8			2,425	11.8
2,559	10.4					2,525	11.3

Figure 6: Upper stage of regeneration of *Pinus sylvestris* in heaths

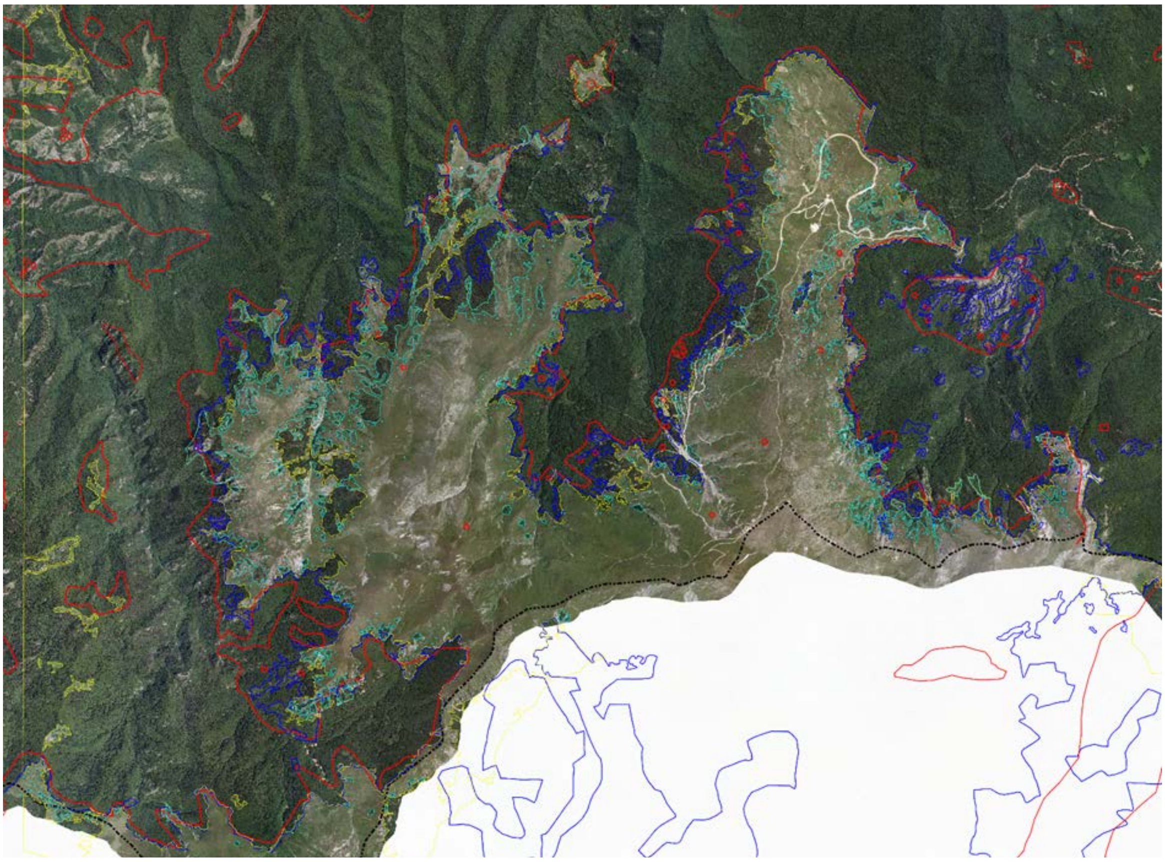

Figure 7: Expansion of forest vegetation at upper treeline in the north parts of Kozhuf mountain range through comparison of maps with time distance of 80 years on base of satellite images from Google Earth

The red line on the map shows a border line from map at a scale 1:50,000, which were created on the basis of geodetic measurements during the thirties of the last century as a version of the same maps amended in the fifties of the last century; Blue line represent a border line from a topographic maps at a scale 1: 25,000 created with photogrammetry in the seventies of the last century; Open blue line represent, a border of a line of the topographic maps 1:25,000 issued by the Agency for Real Estate Cadastre of the Republic of Macedonia in 2004, and latest state presented with satellite images from Google Earth as of 2014.

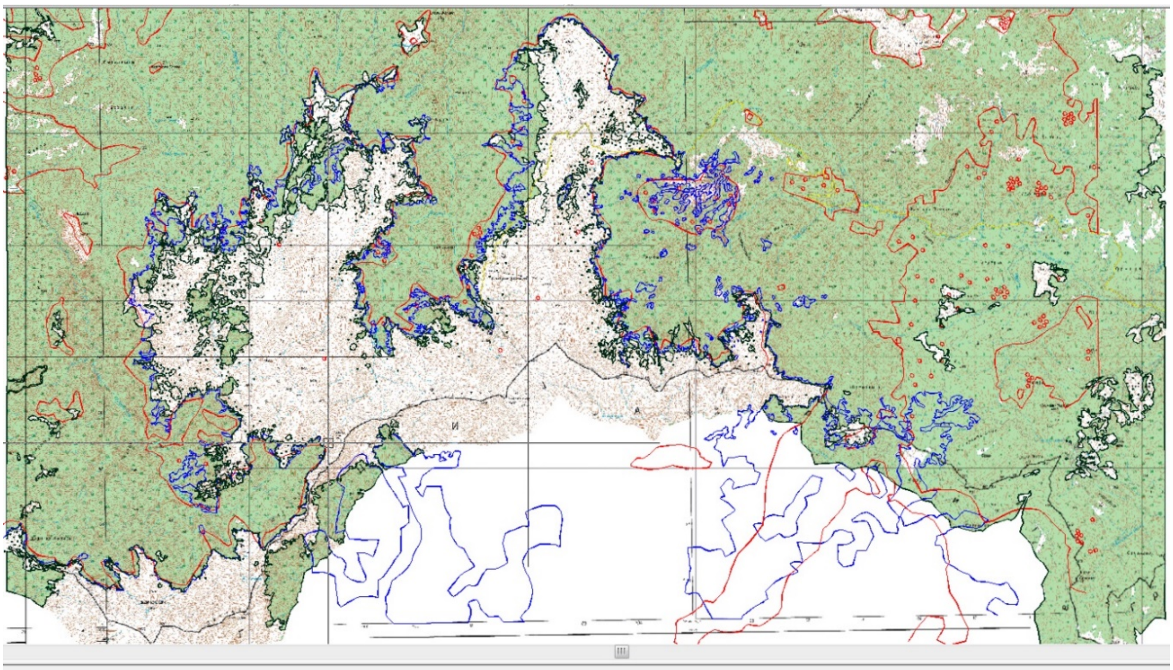

Figure 8: Expansion of forest vegetation at upper treeline in the northern parts of Kozhuf mountain range through comparison of maps with time distance of 80 years shown on topographic maps at a scale 1:25,000

5 CONCLUSIONS

According to own research on soil and studies presented in the soil map of Macedonia, in this locality there are more prevalent following soil types: rendzinas on hard limestone, brown forest soils and swampy gley soil.

Three soil profiles were under forest vegetation of *P. nigra* and describe as rendzinas on hard limestones. One profile was under *P. sylvestris* as a brown forest soils and one soil profile was excavated under *P. sylvestris* as swampy gley soil.

The obtained results show that with increment of upper treeline of the forest vegetation, the most represented is forest community of Scots pine *Fago-Pinetum sylvestris* developed on silicate geological substrate and brown forest soils (cambisols), and relatively smaller areas are accounted to the forest communities of mixed forest of fir and beech *Abieti borisii-regis – Fagetum*, and pure fir forest *Fago-Abietetum* also under brown forest soils (cambisols) and swampy gley soil, while the small area accounts for *Seslerio-Pinetum nigrae* and *Fago-Abietetum* forest communities on limestone geological substrate which are developed on rendzinas on hard limestone and dolomites.

Regarding the treeline of the forest in 30 years of the last century and the present state, the greatest expansion is on western exposure, in this case up to maximum of 400 m (Figures 7 and 8). The forest vegetation expansion is smallest on eastern exposure.

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Challenges of Skopje Green City – Establishing green corridors upon the rivers Lepenec and Serava

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ABSTRACT: For years, the City of Skopje has been facing the problem of increasing pollution, congestion, uneven construction, but also the problem of losing free public spaces, especially green. Unfavourable environmental conditions and the diminished quality of life, is mostly reflected in health of residents, but also in their satisfaction of living in the city. The city is becoming an inconvenient and undesirable place to live not only from an environmental point of view, but also from a sociological and economic point of view. Within the last ten years, the City of Skopje has intensified its efforts to attain the status of Green City by adopting the United Nations recommendations for achieving the goals of sustainable development. This article presents the urban aspects that are part of the research and results of the Study on the development of green corridors along the rivers Lepenec and Serava. Green corridors have been recognized as important elements for the enrichment of the green infrastructure of the city, whose basic functions and goals are related to improving the quality of life, mitigating the effects of climate change, preserving biodiversity, increasing the diversity of opportunities in urban areas and establishing sustainable transport corridors.
Keywords: sustainable development, green city, green corridor

1 INTRODUCTION

Since the second half of the twentieth century, the basis of the system of green areas within the urban structure of the City of Skopje is comprised of the riverbanks of Vardar, Treska and Lepenec, with the Kale fortress, Gazi Baba Park-Forest and the slopes of Vodno Forest-Park. These areas present the most important landscape aspect and visual landmarks of the City. They represent important urban and peri-urban green areas, embedded in the urban documentation for the development of the City since 1965, and accepted in all subsequent plans (1985, 2002, 2012) [1].

The city development policy, so far, has been mainly focused on providing land for green surfaces and design thereof. There is not enough analysis with regard to the multifaceted importance of public and open green spaces, and especially of their impact on environmental quality and biodiversity. The possibilities for establishing green corridors along the rivers Lepenec and Serava have been researched for creating modern policies for improving green infrastructure and the quality of life in the City of Skopje [2]. Green corridors along riverbeds are especially important given the valley character of Skopje and the need to improve climatic and general environmental conditions. So far green areas have only been established along the rivers of Vardar and Treska - parks, sport fields, tree lines. But, they are not categorised as ecological multifunctional corridors, but only have their protective and recreational purpose being emphasized.

The study on establishing of green/ecological corridors along the rivers Lepenec and Serava, also investigates the aspects of urban development of the City [2]. The research indicates several important aspects of this domain, which should be properly analysed during the process of preparation of urban documentation at all levels, to be incorporated in the policies for the future development of the City. This paper presents activities that should be undertaken by the City and the municipalities, and then incorporated in the analysis and concepts for future urban development. This is in line with the visions and accepted policies towards the development of Skopje-Green City.

2 URBAN GREEN CORRIDORS

The development and improvement of open green surfaces in urban areas implies their structural and functional connection within a single network. Important component of open green spaces in urban areas are the green corridors, which interconnect the green open spaces within an integral system and thus create the so-called green infrastructure.

2.1 Definition of green corridors

According to environmentalists Jongman and Pungetti [3], the primary purpose of green corridors is to provide opportunities for wildlife survival and migration, as well as opportunities for a variety of recreational functions. Five key aspects of environmental corridors have been identified: (1) they have a linear configuration, (2) provide connections, (3) are multifunctional, (4) are most closely related to the concept of sustainability, and (5) enable integration.

Green corridors provide a range of benefits to city life, they mitigate the damage of construction and urban development, and contribute to improving the quality of the environment. They are particularly important for sustaining ecological processes, for connecting and sustaining biodiversity and for maintaining a healthy environment. Their most important feature is the multifunctionality, and in their function within the urban environment is ecological, social and aesthetic.

Natural, coastal corridors and waterways include high-quality habitats and ecosystems [4]. They prevent soil erosion and absorb rainwater, thereby improving drainage, and protect against the urban heat islands [5].

The social benefits of the corridors are reflected in providing opportunities for recreation. They give people the sense of identity and of belonging, and allow users to feel free in a more structured environment such as the urban one [5].

Green corridors provide a high quality life through integrating nature into the urban environment. They play an important role in reshaping the urban spatial pattern and establishing connectivity for a wide variety context across the city [5].

2.2 Rivers as green corridors in urban areas

Rivers are special landscape structures, and modern ecology acknowledges them as complex ecosystems. As natural green corridors, linear and connecting systems in the network of urban green areas, they have important ecological functions in urban areas.

Green corridors along rivers and their riverside areas, called “riparian areas", cover the areas around the river, the riverbed, the surrounding land through which the river meanders, the river banks, the land that can be flooded by the seasonal influx of river waters and forests around river banks [6].

A group of authors [7] estimate that the riparian corridors have a great variety of species and ecological processes, which is related to the diversity of climatic conditions, biochemical cycles and more. The authors believe that “efficient management of riparian corridors can improve many environmental problems related to land use and environmental quality”, which can play an essential role in water management, aquatic systems regeneration and spatial planning. Therefore, rivers areas are given the status of green corridors, and the support for the restoration and sustainable management of rivers as presented in the European Water Directive continues to grow [8]. In recent decades, efforts have been made to restore the natural appearance and functioning of river systems, precisely because of their ecological significance. River restoration involves a number of environmental, physical, spatial actions and management measures. River restoration is an integral part of sustainable water management and is directly supported by national and regional water management policies in European countries [9].

2.3 Establishing of green corridors

In multifunctional urban areas, very important for green open spaces is: (a) to enable the fulfilment of their ecological function, (b) to reduce the impact caused by human activities – construction, traffic, industrial production, etc., and (c) to provide conditions for recreational activities.

Securing and preserving green corridors in urban areas is even more important due to the specific function of the corridors.

In order for green corridors to be established in urban areas, their biological values and ecological meanings are perceived and the possibilities for achieving a number of goals are defined. Thus, in Barcelona [10], for the design of green corridors a matrix of criteria has been used, whose identification is required so that an environmental corridor can be formed and goals that should be achieved through their implementation, such as: providing ecological connections, creating rich vegetation, introducing nature in the city, providing diversity of plant and animal species, reflecting the evolution of natural cycles, creating landscape identity, generating interest in nature, creating therapeutic areas, adapting social diversity of the urban environment, and increasing the values of natural and cultural heritage.

The above stated clearly states the multifunctionality, significance and complexity of green corridors. The establishing and shaping requires careful study of the conditions of each urban environment, it further requires political readiness and will to provide land and territory that can be used for undisrupted functioning of nature, and thus the quality of the environment. Cities around the world are increasingly engaged in creating green network, using green corridors as an important category.

2.4 Guidelines for determining the width of the ecological corridor in urban/rural area

The development of green corridors, both in urban and rural environments, generally strives for maximum protection of the natural state of the corridor. Labaree [6] indicates several guidelines for determining the width of the corridor and the shaping thereof. They refer to the hydrological and hydrographic features, the functions of providing habitats, the functions of biochemical and physicochemical processes, etc., so that rivers can perform their complex ecological functions.

These guidelines lead to a different perception of the riparian areas and observance of the acquired knowledge about the necessity for perseverance of natural landscapes along rivers. They should and must be incorporated in the concept of urban development as natural spaces of vital interest for the environment and as open, construction-free, publicly available spaces. The scope and the boundaries of these areas must be incorporated and respected in determining the purpose and future use of the land.

3 CASE STUDY

The spatial development of cities is focused on urban planning. Very often is the significance of environmental systems and processes that take place in cities and their relationship with the environment are neglected or insufficiently considered. In the urban plans in our country, the elements of green infrastructure (parks, park-forests, shoreline, tree lines, sports fields, etc.) are considered as type of land use in the city, for which the position and surface need to be determined.

The City of Skopje has always developed along the river. The Skopje valley has a developed river network, water canals, natural swamps, ponds, and several artificial lakes, which constitute the blue infrastructure. In the past, they played a major role in the persistence of the city. Nowadays they are interesting for the formation of comprehensive green infrastructure, because they are rich in lush greenery and they represent habitats of numerous flora and fauna, as well as “connectors” or “corridors” of the “green network”. The utilisation of this potential means creating new urban development policies aligned with the global trends of creating sustainable cities, a path chosen by the City of Skopje.

Although, for more than fifty years, through the urban documentation of Skopje the river corridors that are located in the city and gravitate towards it, have been planned as part of the system of green areas, the activities for their protection are modest and the measures undertaken for the design and utilisation thereof are even scarcer. Almost nothing has been done towards educating the population to recognize the values of rivers and their riparian belts and there have been very modest investments in more detailed professional and scientific research.

There is potential for activating the riparian areas of the rivers Lepenec and Serava, but has not exploited. Current conditions and trends indicate processes that threaten their values. Both rivers are located in the northern part of the city, on the left bank of the river Vardar, where future development has been planned. By acknowledging the values of the rivers Lepenec and

Serava, the river corridors can be preserved, and guide future utilisation as well as land use.

Exploring the values of the rivers Lepenec and Serava is of great importance for preserving and improving the quality of the environment and it represents a way of withstanding the pressure for construction and improper utilisation of riparian areas. If the local self-government and the citizens of Skopje are to recognize the values and the importance of the rivers and their shores, policies can be designed that will provide permanent protection and improvement of the river corridors. This is certainly an important step towards supporting the concept of sustainable urban development and the creation of Skopje - Green City.

In the race between creating policies, measures and guidelines for the protection of environmental corridors and the constant pressure to utilise the shores for other purposes and construction, it is necessary to point out the activities and guidelines that need to be incorporated in the urban development planning process. The purpose of which is to find a balance between different and often conflicting interests of the community. Therefore, by relying on and accepting the knowledge of environmentalists and biologists with regard to the values of ecological corridors along the rivers Lepenec and Serava, the paper presents: (a) knowledge of existing problems and critical areas arising from the state that was created and the weaknesses in the applicable urban documentation; (b) the guidelines to be followed in the process of preparing urban documentation; and (c) the activities of the city and local administration in order to achieve the set objectives: healthy environment and Skopje - Green City.

3.1 Methodology

The study for the establishing of ecological corridors along river flows was prepared with an inter and multidisciplinary approach, through expert observation of key aspects (hydrographic and hydrological characteristics of rivers, the characteristics of flora and vegetation communities, research of fauna and habitats of different animal groups, analysis of the planned urban development of the area where the rivers pass, the quality of the environment and the analysis of land ownership in the riparian zones) [2]. The key findings of the expertise are summarized in two important chapters. The first chapter refers to the values of the natural environment of river flows and determining opinions regarding the functions and purposes of green corridors. The second key chapter refers to detecting the requirements for implementation of the concept, with emphasis on the expected and possible problems, conflicting interests and collisions. These findings should serve the city and local administrations in taking concrete steps and activities toward the implementation of the corridors developing concept in order to achieve mutual benefit - preservation of rivers and their nature and development of society.

For the purposes of the Study, an expert report has been prepared which refers to the urban aspects, covering the topics:

- Urban development of the city of Skopje, historical overview;
- Current situation and planned development, regarding (1) the land use and (2) the green infrastructure;
- Critical points along the corridors;
- Conditions and guidelines for the establishing Green Corridors (borders, elements, etc.) within urban development planning.

Publicly available data, cadastral data, GIS tools and field research were used for the research.

The important goal of this expert report was to determine guidelines that should be accepted and observed during the process of urban planning in order to achieve the goals of preservation and/or renewal of the natural character of rivers in urban areas, without thereby excluding the human and the society. Hereafter we provide a short overview of these aspects.

3.2 Urban development of the City of Skopje

The fertile land of the Skopje valley, with its spread river network, has been considered as a suitable place for living since ancient times, so the urban development of Skopje can be traced back at least for two millennia. Several stages of spatial development are characteristic and several key periods in the disposition and growth of the city can be distinguished (Penchikj [11]). Over a long period, the city has been developing and relying first on the course of the river Lepenec, later on the course of the river Serava and then on the riverbanks of Vardar.

Since the second half of the 20th century, the riparian area of the river Vardar and the area near the confluence of the river Lepenec into the river Vardar have been part of the city recreational zones. After the earthquake (1963), until today, the city has had an expansive spatial development and the riparian areas of the rivers Vardar, Treska and Lepenec have been developing or kept as park and sports areas and main recreational areas. The river Serava is regulated, at some points it is induced into a deep canal and only on some sections, it has local significance as a recreational area. There is recreational potential only in the lower river flow, in the areas around the Aqueduct, but this part is deserted and still not activated.

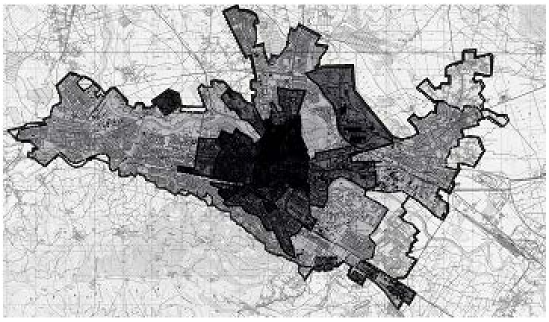

Figure 1: The growth of the City of Skopje [11]

The development policies of the City of Skopje and the current General Urban Plan 2012-2022 [12], follow the principles of sustainable development, by accepting and supporting the commitments for creating green network, in which the riparian areas are seen as important green corridors. However, their ecological function has not been sufficiently studied and substantiated. Hence the changes in the land use of riparian areas (along the river Vardar in the centre of the city and the municipality of Karpos), some sections remain unregulated, and on some sections the regulation is not in accordance with their environmental specifications and functions. The reason for such conditions, beside the ignorance of the ecological significance of rivers and riverside, is the fact that the urban planning documentation does not clearly define and incorporate binding requirements and guidelines for designing open spaces. A specific problem is that the existing practice of regulating riverbeds for protection against floods permanently changes and reduces the potentials for fulfilling the ecological functions of the river corridors (until now the riverbeds of the rivers Vardar, Lepenec and Serava have been partially regulated). This issue, however, requires very careful expert analysis and study that lead to the adopting of more modern policies for achieving balance between the needs for protection against high water and the protection of biodiversity and natural ecosystems, as a way of creating sustainable concepts of water management and urban development.

The City of Skopje has opted for the platform for creating Green City and strengthening the resistance to the expected climate change. Therefore, research on the importance and values of ecological riparian corridors can guide and significantly improve urban development policies and create conditions for a quality environment.

3.3 Current situation and expected future development

The conducted research shows that the two rivers, Lepenec and Serava, have different characteristics and their own specifics. However, both corridors are interesting due to their natural conditions, the manner of land use within the considered area, the critical points, the population and the settlements that gravitate towards the rivers as well as the planning solutions for the future development of the surroundings. In fact, the situation with the population and the construction (planned and spontaneous), as well as the planned solutions for urban development can significantly affect the prospects for establishing and preservation of the ecological corridor. Therefore, this paper presents the conditions, tendencies and guidelines for planning the future urban development.

3.3.1 Lepenec River

Conditions

The subject matter of research is the corridor of the river Lepenec, from the village Orman up to the inflow into the river Vardar, with a length of about 6.0 km.

The river is formed in the Shara region and it enters the state territory near Kachanik. From here up to the inflow into the river Vardar, with a length of 6-7 km, the river Lepenec flows through the plain area of the Skopje Valley. In this area the river meanders distinctly, and river ridges, sandbars and wet meadows are formed along the river. In the lower flow, before the inflow into the river Vardar, the riverbed of Lepenec is regulated along a length of 800 meters. The river is distinguished by large alterations for water after certain years, which affects the occurrence of floods.

When catastrophic flood waves occur, the overflow most often occurs from the entrance of the river Lepenec at the Macedonian border, up to the village of Orman and downstream, but mostly along the right bank. There is groundwater along the river and it is used for irrigation and water supply for the City of Skopje (from two well systems - Lepenec and Nerezi). The water quality of the river Lepenec is measured at several measuring points. In many places, the water quality is fifth class (much polluted water, which cannot be used for any purpose) [13].

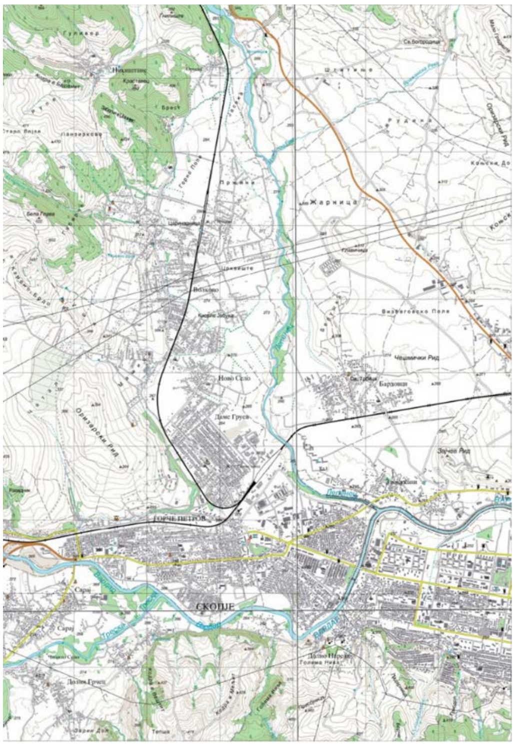

Figure 2: River Lepenec, from Kachanik up to the inflow into the Vardar River

The width of the riverbed, with meanders, sand bars and vegetation, ranges from 400 meters, under the junction near the village of Orman and the ring road, up to 70-40 meters near the confluence with the river Vardar. Downstream, in the industrial zone, the river turns into a wastewater canal from production facilities, it is undistinguishable, and its landscape values are marginalized.

Both sides of the surroundings of the river are confined. On the west there is a railway and on the east the highway to Kosovo. Several settlements are developing in the area and then there is the industrial zone in Gjorce Petrov, all of which have access to the river. In recent years there has been great interest in construction, so agricultural land is converted into construction land. Until recently, the construction was without proper planning regulations and therefore, the landscape looks unregulated and chaotic, but there are also regulated settlements, which do not have a proper connection to the city and the natural environment.

Figure 3: Lepenec River, conditions

The surrounding area consists of valuable architectural and cultural heritage, archaeological sites and numerous monasteries and churches, as well as places for recreation (the archaeological site Skupi, the cultural and historical monument Hamdi Pashini Konaci, picnic site above the village Kuckovo, several churches and monasteries).

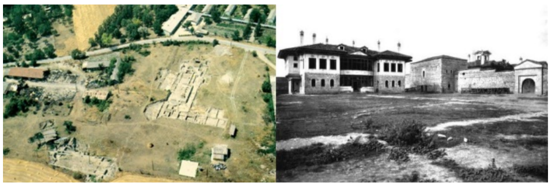

Figure 4: Lepenec River, significant contents: Skupi and Hamzi Pashini Konaci

Several critical activities and sites appear along the river that even today they endanger the survival and quality of the ecological corridor:

- In the urban part, near the industrial zone (West), the facilities, warehouses and services are located next to the river, which greatly narrows the corridor. This creates obstacles for the entire ecological functioning of the corridor. The riparian area is not used, because it is almost blocked and inaccessible. This makes the river marginalized as a landscape element in the urban matrix;
- There is a large sand separation located near the village of Orman, which exploits the riverbed for sand extraction;
- There is a large number of illegal landfills, practically all over the riverbed, and the largest ones are in the area east of the village of Novo Selo and in the industrial zone;
- The access to the inflow of Lepenec into the river Vardar is hindered, due to the busy road "Aco Shopov", which passes over the river and due to the fenced area of the wellhead protection area;
- The riverside is not maintained and the access to the river is difficult for both pedestrians and cyclists;
- The available, construction-free space is used for agricultural activities, so the river is exposed to pollution from fertilization, depletion of irrigation water and disruption of the riparian corridor;
- The population does not know and does not recognize the values of the river and the corridor. The habits of using the riverside for recreation have been lost.

Planned urban development

Upon inspection of the available planning documentation, it can be concluded that the area around the river Lepenec is of special interest for the local self-government. Both in close and extended proximity to the corridor, in conversion of agricultural land into construction land, for housing, but also for production, distribution and services and mostly light industry is planned. According to the General Urban Plan of Skopje 2012-2022 [12], a green belt with different width is planned along the river.

Figure 5: Lepenec River, unfavourable conditions

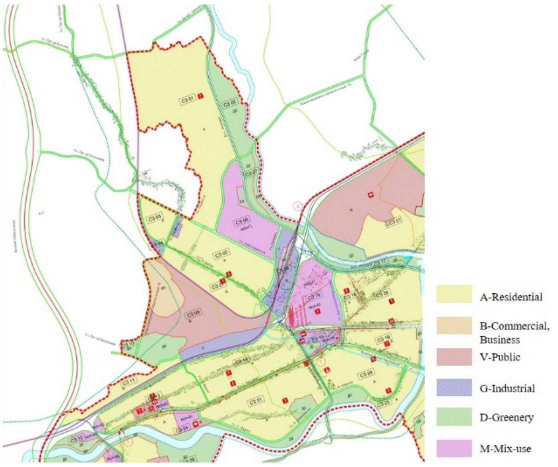

Figure 6: Excerpt from the GUP of Skopje 2012-2022 – land use along the Lepenec River

The planned urban development, determined with GUP 2012-2020 and the detailed urban plans for the urban quarters, which refer to the corridor of the river Lepenec, indicate several aspects that may affect the protection of the course of river and the riparian areas. Namely:

- The planned land use, such as housing, mixed use and industry, which are right next to the river, do not leave enough space for the ecological corridor, and the intensive construction and utilization thereof is expected to further create unfavourable conditions;
- The planned extension of the route of the boulevard Ilinden comes to close to the river in some places and it enters the existing riverbed;
- No measures have been provided in order to protect the villages from the expansion of the river, nor have any other natural barriers been established;
- The planned areas intended for greenery, sports and recreation have not been properly defined neither with regard to the scope nor with regard to the well-established conditions for landscaping;
- The planned housing along the river, towards the inflow into the river Vardar, is set to close to the river and allows for a very narrow corridor. A special problem is that it is located in the immediate vicinity of the first wellhead protection zone;

- The existing urban documentation does not provide for the development of green belts between the settlements, i.e. the development of green network within the wider area and its connection to the green corridor of the river Lepenec;
- The urban documentation does not pay enough attention to the value and importance of natural environment.

3.3.2 Serava River

The river Serava, formed by several smaller rivers in Skopska Crna Gora, has a length of 21.0 km up to the confluence with the river Vardar. It is an important corridor for the supply of fresh air masses to the urban area of Skopje. Therefore, it is of particular interest to determine the possibilities for the development of a green corridor along its course.

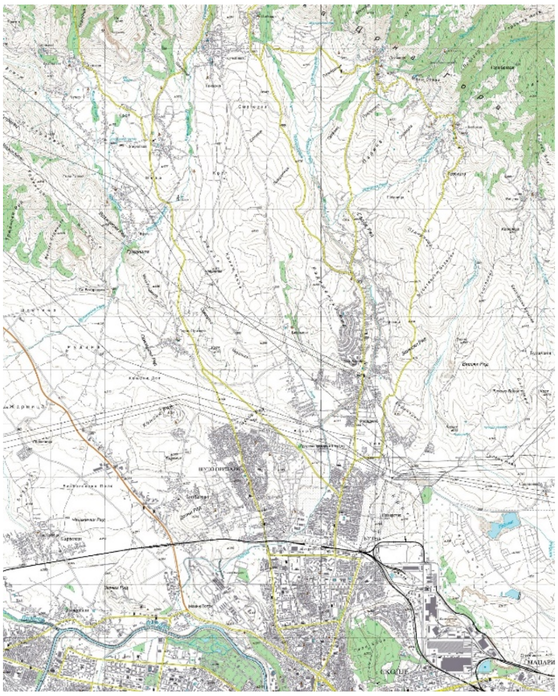

Figure 7: Serava River, from the springs up to the inflow into the Vardar River

Conditions

The basin of the river Serava in the upper part extends through the hilly-mountainous terrain, and in the lower part through the Skopje Valley and it has the characteristics of a plain. In the upper part, the waters have the character of rapids, and in the lower part, the flow is uniform. The steep falls cause erosion and undermining of the natural riverbed, which is of variable width (from several to 20 meters).

The riverbed of Serava is regulated in two sections - in the settlement Butel 1, in order to protect the settlement against floods, in a length of about 2.0 km and up to the inflow into the river Vardar in a length of 5.0 km. The Serava riverbed was diverted to the west to avoid the collapsing of the existing natural, closed riverbed, which used to pass through the central city area to the south. The regulation has different width.

Along the upper river course, in the highest mountainous areas and springs, the river can be difficultly accessed, with natural vegetation and fauna and with pronounced landscape values. The middle course of the river has been utilised for a long period of time for agriculture and there are vineyards and orchards, as well as pastures. The villages here are compact, located in sunny positions, on flat lake terraces, often separated from each other by deep river valleys. Starting from the settlement Butel all the way to the city, the river has no natural riverbed since the riverbed is regulated, and the shores are covered with stone slabs or with concrete. The Serava canal is available only through the settlements Butel 1 and 2, and at the Aqueduct. Further down, the regulated Serava riverbed is inaccessible due to the service and industrial zone, bridged by street infrastructure, and serves as a canal and recipient for wastewater. The most impressive is the section that passes through the area of the Aqueduct. Here, too, the river is regulated, flowing through interesting but neglected area. The space is constantly under pressure from various users, who appropriate it and often usurp it (improvised warehouses and waste materials), which strongly distorts the visual effect on the Aqueduct and the overall value of the landscape.

In the past, the river Serava used to provide Skopje (the core of the old town) with drinking water. Once the riverbed was regulated, the river Serava was a neglected and forgotten. Debris is dumped in many places and illegal landfills are created. Houses and production facilities, several makeshift passages and smaller bridges have been built along the canal. When there are large volumes of water, the water overflows the riverbed and endangers the infrastructure facilities. The river Serava is the main recipient of wastewater in the municipality of Butel, from Radisani to the confluence with the river Vardar, in a length of 12 km. The water quality of the river-canal Serava is not controlled.

Upstream, the streams and rivers that form the river Serava pass through or near several villages and several vacation settlements. In the area covered with hills, it passes through the village Radishani and close to the settlement Radishani, and enters the territory of the city after crossing the ring road. Near Krivi Dol, it flows into the river Vardar.

Figure 8: Serava River, conditions

There is an extremely valuable architectural and cultural heritage in the surrounding area, archaeological sites and numerous monasteries and churches, as well as places for recreation, and because of that the mountain is called "Skopje Holy Mountain".

Figure 9: Serava River, values of the area: Aqueduct; Monastery St. Elijah

Due to the length of the river and the diverse land use of the surrounding area, diverse problems arise. Especially in several critical sites and sections, due to which the river/canal cannot fulfil its function of green and ecological corridor that can be used for fresh air supply to the city:

- In the hilly areas and when passing through villages, the riparian area has deep and narrow cuts, it is not regulated and there is a lot of garbage;
- Throughout the villages, the riparian areas are private and inaccessible, and often end directly on the river (especially in the villages of Ljubanci, Ljuboten and Radisani). There is partial accessibility in places where local roads and village streets run parallel along the river, but access is difficult due to untidy and neglected riverbeds;
- In the industrial zone around the Railway Station Skopje-North, the river/canal is inaccessible, has no function. Illegal landfills have been created along the bridges and polluted wastewater from the surrounding industrial plants, warehouses and car washes is being uncontrollably dumped;
- The area where the canal/river Serava passes through the Ilinden barracks, towards the Aqueduct, has the greatest potential to be an open green space. This archaeological site, which is of great importance, was once an important picnic place for the city of Skopje, but today it is very neglected. The area is available to the public, but the negligence and the lack of regulation of its status (there is an on-going process for it to be declared as "cultural landscape"), has left it at the mercy of the weather, human negligence and inappropriate activities;
- The section that passes through the warehouse zone of Momin Potok and the settlement Krivi Dol is almost inaccessible and the local population uses the canal as a landfill and wastewater recipient. Some plots lay directly at the canal, which makes it difficult to move continuously along it. The riverbanks themselves are partly streets, but neglect and waste make them unattractive.

Figure 10: Serava River, unfavourable conditions

Planned urban development

The area around the upper course of the river Serava, is not a priority of the local self-government and there is no available planning documentation based on which the planned future development of the rural area could be assessed (in the Municipality of Chucher-Sandevo).

Figure 11: Excerpt from the GUP of Skopje 2012-2022 – land use along the river Serava

The planned urban development of the City, determined with GUP 2012-2020 [12] and the detailed urban plans for the urban quarters, which lay on the path of the river Serava, indicate several aspects that may affect the protection of the course of river and the riparian areas:

- The river Serava has not been drawn into the General Urban Plan of Skopje 2012-2022 at all and the planning solutions do not anticipate the existence of this watercourse;
- The treatment of the Serava canal is different in the detailed urban plans. In some instances, the Serava canal is not acknowledged as a course of river, and in others, it is not being mentioned, because it is treated as a sewage canal. In some plans, the canal has a width of 18-25 m;
- In most cases, local streets and access roads are directly aligned to the riverbed or canal, which

makes the belt around the river particularly narrow;

- In urban plans referring to the area of the Ilinden barracks, the canal is not acknowledged and is not drawn, except for the part around the aqueduct;
- The planned land uses, such as housing, mixed use and industry, which are right next to the river do not leave enough space for the ecological corridor, nor do they provide free access, and the intensive construction and utilization thereof itself will create further unfavourable conditions;
- No measures have been provided in order to protect the villages from the expansion of the river, nor have any other natural/green barriers been established;
- The planned land use for greenery, recreation has not been properly defined neither with regard to the scope nor with regard to the well-established conditions for landscaping;
- In particular, it should be noted that the surface area around the Aqueduct that is planned to be protected as a cultural landscape does not correspond to the guidelines given in the document Strategic Plan for Rehabilitation of the Aqueduct and its surroundings [14].

3.4 Establishing green corridors along the rivers Lepenec and Serava

The establishing of green corridors to the rivers Lepenec and Serava have been determined in accordance with the expert investigations of the natural values [2], the above stated Labaree guidelines [6] and past experiences of cities that have dealt with this issue [10], as well as other relevant globally acknowledged directives and guidelines. The mentioned Study [2], sets out proposals for:

- The scope of the green corridor as well as the width of the green belt.
- Future land use, expected users and possible activities;
- Key activities to be undertaken for the implementation of the concept of establishing of river ecological corridors.

The paper presents the activities that need to be undertaken in the process of urban planning. According to the legislation for urbanism, “The system of spatial and urban planning is in the service of design and humanization of space, the protection and promotion of the environment and nature, as well as of the social, economic and ecological sustainability of human settlements. This is to be achieved through the continuous process of preparation, adopting, implementation and monitoring of the implementation of the plans.“ Urban plans serve to protect the public interest, recognized as “the design and humanization of space, the protection and promotion of the environment and nature, as well as the preservation of natural and cultural values of space.” Urban plans regulate the boundaries of settlements and the boundaries of planned construction outside settlements, the organization, purpose, manner of space and land use and the manner and requirements for construction of planned construction inside and outside of settlements, as well as traffic and any other infrastructure, protection and regulation of the environment, immovable cultural heritage and other aspects of social, economic and ecological sustainability of human settlements [15]. Hence, the urban planning and the urban plans themselves have a key role in creating conditions for the establishing and implementation of the identified green corridors.

3.4.1 Ecological/green corridor of the river Lepenec

It has been proposed for the green corridor along the river Lepenec to be treated as a river park. The function of this park should predominantly have ecological, protective and educational functions.

The green corridor needs to be preserved and restored in order to preserve the ecological functions of the river valley. It is therefore proposed for the natural course and morphology of the riverbed to be preserved, for the indigenous characteristics thereof to be promoted and the indigenous flora and fauna, as well as their communities and habitats to be preserved. The riparian vegetation is typical of the plain river areas of the Balkan Peninsula. Although fragmented, discontinued, and at places destroyed, its potentials need to be fully exploited to ensure the habitat and survival of many animal species. The fauna has autochthonous characteristics that should and can be preserved and fostered (rare species have been registered, species protected on European and national level, species of international interest for protection of several groups of fauna and plethora of birds, some of which are sensitive at global and European level, some protected by the Berne and Bonn Conventions) [2]. Thus, the green corridor can contribute to improving the ecological function of the river and the riparian area in order to ensure the development of ecological connections with the environment.

The green corridor is suitable for sports and recreation, fishing and organic farming, but also educational and nature observation activities. The potential for recreation has already been determined with the urban documentation, which sees the riparian area as a green protection zone. The green corridor should also be used as an alternative connection for a green pathway (pedestrian and bicycle). The corridor represents an important landscape and spatial element that defines the urban structure, one that separates land with different land use and connects the green spaces of the city in a green network/infrastructure.

The scope that is being proposed for the Green Corridor-Lepenec stretches from the bridge near the village of Orman to the mouth of the river Vardar, with a length of 6 km. The width of the green belt is determined by the natural characteristics of the river, i.e. its meanders and the changing riverbed. According to the land cadastre, wider belts belong to the river, and in the upper belt the local pathways that go along the entire riverbank, are suitable for creating the border of the corridor. Along the upper segments, the width is larger and easier to secure. For those segments where the corridor passes through the urban area, it is proposed that a belt of at least 100 m from the regulated riverbed on both sides should be provided. At some places, a wider belt can be established.

Most of the riparian area is state land. With regard to private land, it is pointed out that the activities must not disturb the corridor (fencing, construction, etc.) or affect the water quality. Interventions, considered as natural, are allowed in these areas, with the purpose of stabilizing the riverside and preventing erosion: planting appropriate vegetation, use of natural construction materials for stabilization, etc.

Citation (APA style 6th ed.): Penchikj, D., & Hadzi Pecova, S. (2018). Challenges of Skopje Green City – Establishing green corridors upon the rivers Lepenec and Serava. *Forest Review, 49*(2), 37–48.

It is crucial that the corridor is open and accessible along its entire length on both sides. A bottleneck occurs only at the railway track, i.e. the arch of the Railway Station Skopje-West and where the ring road crosses the river. The current belt with service and warehouse contents on the left bank and at the confluence with the river Vardar should be used for greenery, protection and park.

Four segments with different characteristics have been identified along the corridor, which can accommodate different main land uses as green areas, but the absolute priority in establishing a continuous ecological belt is the rehabilitation of natural habitats and the provision of biodiversity.

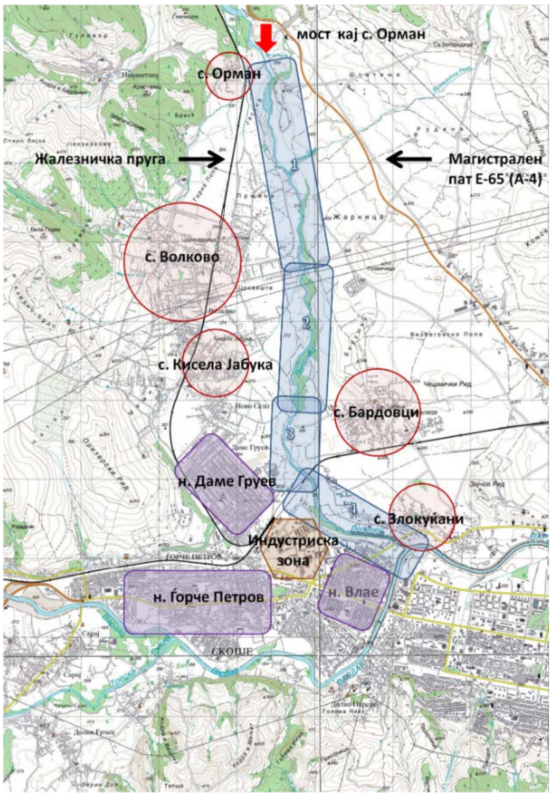

Figure 12: Proposed ecological/green corridor of the Lepenec River

Bicycle tracks can be created along the entire length of the riparian area, and at several key points, sports and recreational contents on small terrains, picnic points, etc. can also be established.

Access and movement along the corridor should be predominantly planned as pedestrian, by bicycle or by public transport, and only in some places by car (for which sufficient parking space should be provided). It is important to ensure the connection between the river banks, the improvement of the connections between the settlements and the easy access to natural landscapes.

It is expected that the green corridor of Lepenec will be attractive to the inhabitants of the surrounding settlements, but also to the entire city. It is estimated that a population of about 30,000 inhabitants gravitates toward this corridor, but given the intensive development and construction, it is expected that this number will rise.

In order to ensure the establishing of a green corridor on the river Lepenec, as well as continuity and functionality, in the process of defining the concepts for future urban development, and the preparation of the urban documentation, the following recommendations and guidelines should be respected and included:

- For urban development of the city, the settlement Gjorce Petrov and the other settlements, the river Lepenec are to be a central open green zone;
- To include the opinions and determinations for securing the green river corridor in the new urban plans and the revisions of the urban plans, which encompass or touch upon the riparian area;
- To develop a concept and plan for regulating the ecological corridor as an easily accessible multifunctional zone;
- The planned land use of the construction land to be harmonized with the character of the landscape and the corridor;
- To check and revise the recommendations of the environmental assessment studies in the project documentation;
- The space at the confluence of the river with the river Vardar to be converted into a new urban park that will mark the beginning of the green corridor;
- Reconsideration of the possibilities for establishing green corridor at the railway station and the railway bridge;
- Identifying the capacity of the corridor and the riparian area for recreational activities and introduction of modern forms that will coexist with the ecological functions of the green corridor;
- Reconsideration and/or finding an alternative route for the boulevard Ilinden and the connection with the village of Orman;
- Creating green protective belts to prevent the spread of settlements toward the corridor and development of a green network in the wider area, connected to the corridor;
- In urban quarters, the lands that touch upon the corridor should be treated as park greenery;
- Pedestrian and bicycle tracks to be located on the outline between the proposed green corridor and construction or agricultural land;
- Determining the sites where natural pools should be made to retain the water that spills over, which in dry periods represent beautiful natural places;
- Detecting places where content for socialization, sports and recreation can be located;
- In the urban part, the plots that are next to the river, should be arranged so as to enable continuity of the corridor (with subdivision of parcels and purchase of state-owned parts; with allowed passage through them). The parcels in the parts towards the river should be designed as landscape with natural and porous materials and greenery.

3.4.2 Ecological/green corridor – Serava

In the upper basin of the river Serava, the fauna and flora habitats are in a natural state with a diversity of species, especially of some groups of fauna, some of which are of international and national interest for conservation [2]. The regulated riverbed of the river Serava in the urban area of Skopje has lost the attributes of a natural riverbed and due to the strong anthropogenic pressure; the wildlife in urban areas is extremely devastated and cannot fully function as an ecological corridor. The diversity and richness of the fauna in the upper basin should be protected and conditions for functional habitats, movement and connection with the surrounding nature and urban green spaces should be provided. The estimation is that if space is provided for a green belt along the canal in the urban area, two important goals will be achieved: space will be provided for the movement of some groups of fauna and air circulation from the mountainous areas to the city shall be enabled. Therefore, the basic commitment is to exploit the advantages to the maximum in order to form a linear park along the course of Serava, which will serve for the movement and communication of citizens and bringing the surrounding natural and recreational areas closer. Hence, the course of the river Serava can have a function of a green linear park, but also of an ecological corridor, with a length of more than 18 km. Five segments with different features and editing capabilities are identified: (1) creating a park area with several contents under the settlement Radishani, (2) arranging the green belt above the settlement Butel for walks and movement, (3) to provide a belt for movement and bridging through the service and industrial zone, (4) perceiving and planning the space of the archaeological site of the Aqueduct as a public green space with the status of "cultural landscape" [14, 16], (5) providing access and opportunity for movement of pedestrians and bicycles, erecting tree lines and thus developing green infrastructure for movement from the inflow of the Serava canal in Momin Potok to the inflow into Vardar. A very important determination is the planting of trees along the pedestrian and cycling trails, which will absorb air masses from the mountain and direct them towards the city. Only in this way will the green corridor be able to fulfil its primary function. At the same time, as a green linear structure to define the urban structure.

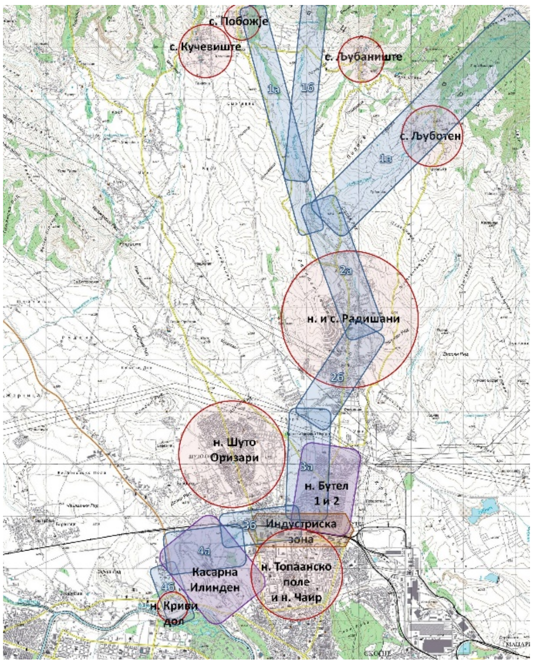

Figure 13: Ecological/green corridor – Serava

The green corridor of Serava is attractive to the inhabitants of the surrounding settlements, but also to the entire city. Access to should preferably be on foot, by bicycle or public transport, and in exceptional parts by car (for which sufficient parking space should be provided). The population of about 50,000 now gravitates towards this corridor, but given the planned intensive development and construction of housing, this number is expected to grow. The green corridor in the upper part of the river course is suitable for sports and recreation, especially walking, hiking and fishing, and on the immediate agricultural areas, for organic farming. In the middle and lower part of the corridor, at several sites sports-recreational facilities, small picnic points, etc. can be established. Along the entire length of the linear park, both in the urban area and in the rural areas, a pedestrian and bicycle trails have been planned. In this way, the northern part of the city will be accessible by alternative traffic, pedestrian and bicycle traffic. It is important to connect both river banks, to improve the connections between the settlements and to provide easy access to natural landscapes.

In order to for the concept of linear park along Serava to be implemented, the following recommendations should be respected and appropriately incorporated in urban and other development documentation, in the process of preparation of the concepts for future urban development:

- Incorporating in the urban documentation knowledge about the values of the green corridor, i.e. the river/canal, continued treatment as a green belt with appropriate security and protection measures;
- Analysis of the strategic documents of the municipalities, for evaluating the opinions/or incorporating the opinions on the significance, suitability and threats to the river/canal of Serava;
- Re-evaluation of the urban documentation around the Ilinden barracks and the Aqueduct, so as not to jeopardize the possibility of forming a public green space, and the area to be perceived as a cultural heritage site;
- Regulating/planning the area around the Aqueduct as a public green area by taking special protective measures, shaping measures, etc.;
- Providing space for establishing a protective belt around Serava at the railway station and the railway bridge Skopje-Server;
- Arranging the area at the confluence of Momin Potok in Vardar as a park area to mark the inflow and to connect it with the greenery of the riparian area of Vardar;
- Review of the strategic development documents in order to emphasize the importance of the green corridor, determining of links between urban-peri-urban and rural areas, according to the recommendations of the Global Sustainable Development Goals (GDP 11) [17];
- A spatial plan is needed for the area of Skopska Crna Gora, which will provide the most suitable guidelines for all the different activities;
- Examining possible recreational activities in order to develop a concept for the use and

landscaping of open urban spaces along the corridor;
- The priority for the municipalities should be to create policies for harmonizing water conservation and management activities with biodiversity and urban development;
- Creation of green protection belts in order to prevent the spreading of the settlements toward the corridor;
- The urban documentation should provide for space for pedestrian and bicycle trails, more transverse connections across the river/canal, it should also make sure that streets and roads do not approach the corridor and to provide space for sidewalks and tree lines;
- Detecting places where content for socialization, sports and recreation can be located;
- When providing access to the green corridor, the natural features should be respected. Certain sites should be accessed with sustainable means of transport: by foot, bicycle or public transportation. For the sites where a larger number of visitors is expected, green solutions for car parking should be provided, but not on a large scale;
- In the urban part, the plots that are next to the river should be arranged to enable continuity of the corridor (with subdivision of parcels and securing land for general use with the means of expropriation or at least with allowed passage through them. The parcels in the parts towards the river should be designed as landscape, with natural and porous materials and greenery.

4 CONCLUSIONS

The above stated observations, suggestions and guidelines clearly present the multifunctionality, significance and complexity of Green Corridors. The establishing and shaping thereof requires careful study of the conditions in each urban environment. Both political readiness and will are needed to secure and preserve land that functions as a green corridor.

Enabling the nature and natural process to function freely and safekeeping biodiversity should be the priority when defining future development and when determining land use.

The research investigated the possibilities for establishing green corridors along the rivers Lepenec and Serava, detected the characteristics, the critical points and showed that the establishing thereof and their future regulation demands strong determination, use of knowledge and investment in continuous research.

Creating a green network in urban and peri-urban environments should incorporate and use green corridors as an important category. This is of course directly related to urban planning at all levels. Thus, it was important for the Study on establishing ecological/green corridors to provide an overview of the existing urban documentation and to present which aspects need to be incorporated or revised in the future documentation.

By paving its way toward creating a vision and preparing a strategy for ,,Green City - Skopje”, the City of Skopje can incorporate the potentials of the two proposed green corridors on the rivers Lepenec and Serava, as significant elements in its platform and program for achieving better quality of life for all citizens of the city, and for the entire population of the Skopje region as well.

Urban planning and preparation of urban plans for Skopje requires a revision of the planning solutions and incorporation of modern understanding of the city, of the needs of citizens and it needs to provide conditions for dealing with challenges in terms of climate change, protection of biodiversity, establishing of larger ecological/natural areas, pollution reduction etc.

5 NOTES

This paper does not present the findings from other areas (hydrology, flora and vegetation, fauna, biodiversity, social aspects, ecology), which have been used in the analysis, evaluation and determinations for the establishing of ecological/green corridors.

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Original scientific article

Down dead wood in a montane beech forest stands on Deshat Mountain: Down dead wood biomass

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ABSTRACT**:** Down dead wood in forest ecosystems plays a very important role in major ecosystem processes such as decomposition, pedogenesis, erosion prevention, biogeochemical cycles of carbon and nutrients, natural regeneration and provides microhabitats for different organisms. Different aspects of down dead wood have received broad attention in scientific literature especially in terms of carbon sequestration and climate change, biodiversity conservation, etc. However, there are no studies on down dead wood in Macedonian forests. This paper presents the results for the amount of down dead wood biomass (dead branches and dead trees) in five montane beech forest stands in Deshat Mountain, Mavrovo National Park. The investigated forest stands represent five different types of forest in terms of degradation and forestry practices. Large branches (3-5, 5-10, and 10-20 cm) were collected by linear transect with test surfaces of 1 m². The down dead wood biomass (branches and logs) was divided into five categories according to the degree of decomposition. Following, the biomass of all fallen logs on a specific test area was assessed. The highest amount of down dead wood was estimated in the most preserved forest (19.04 t·ha^{-1}), and the lowest in the most degraded forest (2.68 t·ha^{-1}). Biomass of large branches ranged between 1.03 and 9.73 t·ha^{-1}, while the biomass of fallen trees varied between 1.65 and 11.64 t·ha^{-1}. It can be concluded that the old forests are the main accumulators of down dead wood biomass.
Keywords: Down dead wood, biomass, beech forest

1 INTRODUCTION

Aboveground coarse dead wood in forest ecosystems consists of standing and down dead wood and stumps [1]. In terms of quantity, the down deadwood (DDW) in forest ecosystems is usually much more important [2, 3].

DDW is an integral part of the natural forest ecosystem. It has a significant role in many of the ecosystem processes, especially in decomposition, pedogenesis and erosion prevention, biogeochemical cycles of carbon and nutrients, natural regeneration, etc. [4–8]. It has also a certain impact on forest microclimate and serves as an important water storage component of the forest floor [4, 9]. Down deadwood has also an important part of biodiversity in forest ecosystems. It provides key microhabitat for many species of invertebrates, fungi, birds, and mammals as well as many other species that use down dead wood as a food source or shelter [3, 9, 10]. It is well known that proper management of down dead wood in forest ecosystems (sustaining varied down dead wood or even creating dead logs by cutting of live trees) is of great importance for the survival of many species [2, 11–13]. The amount and biomass of dead trees are considered as indicators of sustainable use and management, degree of preservation of forests, and biodiversity [14]. On the other hand, DDW also supports insect outbreaks and high-severity fires [15].

The intensive and long-term exploitation of forests in Europe has lead to a decrease in the amounts of down dead wood. At present, DDW is much higher in European upland forests compared to the lowland ones, although the natural potential is opposite [3].

The research on dead organic matter in Macedonian forests is very scarce. Thus far, there are only a few studies regarding fine litterfall in an oak forest in Galichica National Park and beech forest in Mavrovo National Park [16–18]. The studies also include data on the biomass of coarse branches in the forest floor for both ecosystems. Hristovski [19] determined the standing deadwood biomass in the beech forest in Mavrovo and estimated a value of 1.58 t·ha^{-1}. Apart from these publications, we are not aware of any other research targeted towards the coarse down dead wood in Macedonian forest ecosystems.

Therefore, there is a clear need for more comprehensive research on the amount of down deadwood in the forests, as well as determining optimal management practices that will maintain the optimal amount of down dead wood.

In response, in 2015 we researched DDW in a montane beech forest on Deshat Mountain aiming to estimate DDW biomass, carbon content and mineral composition, decomposition stages, and impact of forestry practices on the amount of DDW.

Results from the research will be presented through series of consequent papers focusing on:

- Down dead wood biomass;
- Carbon sequestration in DDW;
- Mineral composition and quantities;
- Decomposition patterns;
- Impact of forestry on DDW.

This paper is the first in the series of five and presents the results on DDW biomass (both logs and coarse branches) in natural beech forest stands on Deshat Mountain with differences in their structure and anthropogenic impact.

2 MATERIALS AND METHODS

2.1 Research area

Deshat Mountain is situated in the west part of Macedonia. Natural beech forests are the dominant forest type. The climate is mountainous with an influence from the continental climate as well as the Mediterranean climate at lower altitudes [20]. The mean annual temperature is 7.1˚C and drops for 0.5˚C every 100 m in altitude [21]. Mean monthly temperatures during the winter months are below zero (-2.2˚C in January). The temperature during the spring months is 5.8˚C. The highest mean monthly temperature occurs in July (8.2˚C). The absolute minimal temperature (January) is -25˚C and the absolute maximum temperature (August) is 33.0˚C. Annual precipitation amounts to 1103 mm. The average duration of snow cover is 166 days.

The selection of five stands was made on 08.06.2015, based on different differences in forest management and the general structure of the stands. These five stands were named: Old-growth forest (OF), Preserved forest (PF), Good forest (GF), Resprouting forest (RF), and Degraded forest (DF). The main field research was conducted in the period 28.09-01.10.2015.

All stands are of montane beech forest, association *Calamintho grandiflorae-Fagetum* (Em 1965) Rizovski & Džekov ex Matevski (syn: *Fagetum montanum* Em). The montane beech forest belt spreads between 1300 and 1600 m a.s.l. The dominant soil type is calcomelanosol [22].

Three plots (15 in total) were selected in each of the five forest stands. All of these plots were selected based on field observations and they represent the variability within the forest stands. Stand tree density was estimated as an average of tree density of the three sampling plots within each of the five investigated stands. The surface of the plots depended on tree density and ranged between 100 and 300 m^2 (Table I). In each of the 15 plots we recorded the number of trees and we measured the DBH (diameter at breast height) of each tree. DBH of trees ranged from 3 to 85 cm. At the same time, we recorded the number of shrubs in each of the 15 plots.

2.2 Determination of decay classes wood density

The decay classes were determined based on the different stages of wood decay assessed by visual inspection of the down deadwood. We categorized fallen tree logs and fallen branches into five categories (I-V). Most of the similar studies defined four decay classes and their description corresponds to our classification [6, 23–25]. However, we added category V which refers to deadwood in the last stages of decomposition with very low wood density (sponge-like wood).

Wood density was estimated for both logs and branches. Discs from logs were cut during the fieldwork. They were photographed and their surface (s) including bark was estimated using Photoshop CS6 v13.0. The thickness of the discs (h) was measured by calliper. The volume of the discs (v) was calculated by multiplying the surface and thickness. The discs were measured after drying at 105˚C to constant mass. The density (ρ) was calculated by dividing the mass with the volume of the discs: $\rho=m/(s\cdot h)$.

2.3 Estimation of down dead wood biomass in fallen tree logs

All of the fallen tree logs within five investigated stands were recorded. The area covered ranged from 1.07 to 3.12 ha (Table I). The following parameters were observed or measured: decay classes, length, and three diameters (at the base, in the middle, and at the apex of the tree log).

The volume (V) was calculated with mathematical formulas for truncated cone ($V=\pi r^2 l/3$) or cylinder ($V=\pi r^2 l$) depending on the general shape of the log [26] where V is volume, r is the radius and l is the length of the logs.

The biomass (b) of each tree log was calculated by multiplication of wood volume and wood density ($b=V\rho$).

2.4 Estimation of down dead wood biomass in fallen coarse branches

The biomass of fallen branches was estimated in three transects in all five investigated forest stands. Each of the 15 transects consisted of 10-20 sampling quadrats with the surface of 1m^2. Sampling quadrats were placed on a 3m distance.

All branches within the sampling quadrats were classified into three diameter classes (3-5, 5-10, and 10-20 cm), weighed on a field scale (0.5 g accuracy) and their decay classis was recorded. During the fieldwork, we took samples (on average 400 g) of each diameter classis and decay class to measure the dry weight and water percentage. In total, 37 samples were measured for the wet weight (on the field) and dry weight (in the laboratory) after drying at 105˚C to constant mass.

Table I: Main characteristics of the five investigated beech stands

Forest stand	Short description	Total stand surface (ha)	Sampling plots surface (m^2)	Number of sampling quadrats	Average DBH (cm)	Trees density (ha^{-1})	Altitude (m)	GPS coordinates	
Old forest (OF)	Presence of many old trees in good health condition and very large fallen logs. Canopy cover of ~70%. No recent human activities. Mild inclination.	3.12	300	3x10=30	12.0	1355,6	1580-1595	20.56249	41.63885
Preserved forest (PF)	Middle-aged trees are dominant with scattered old trees. Presence of a number of large fallen logs. Mild inclination.	1.07	300	3x10=30	13.5	2500	1570-1590	20.55987	41.63776
Good forest (GF)	In the vicinity of the sheepfold, next to Osmanova Livada locality. Visible signs of continuous use, mostly a collection of branches by the shepherds. Steep inclination.	1.76	200	2x10+1x20=40	9.2	2516,7	1635-1680	20.55802	41.63212
Resprouting forest (RF)	The forest consists of resprouting trees with great tree density. Intensive human use (firewood for the sheepfold that existed in the vicinity) can be observed, especially in the last 50 years. Mild inclination.	1.63	200	3x10=30	9.1	7816,7	1575-1595	20.56158	41.63655
Degraded forest (DF)	Intensive use by the inhabitants of villages Trebishte and Bitushe can be observed. Medium inclination.	1.15	100	3x15=45	11.8	2250	1305-1350	20.57627	41.62842


Old forest (OF)


Preserved forest (PF)


Good forest (GF)


Resprouting forest (RF)


Degraded forest (DF)

Figure 1: Photographs of the five investigated beech stands

3 RESULTS AND DISCUSSION

Wood density of fallen tree logs and branches varied between the decay classes (Table II). The statistical nonparametric analysis showed a significant decrease in wood density from category I to V ($p<0.05$; $r=-0.897$).

Table II: Wood density of fallen tree logs and large branches according to decay classes

Decay classis	Number of samples per decay class (discs)	Wood density
D1	38	0.72*
D2	8	0.54
D3	2	0.47
D4	10	0.32
D5	4	0.12

*The value of wood density for category I was taken from Hristovski [19]

The number of fallen tree logs varied between the forest stands. The highest number of fallen logs was recorded in PF, DF, and RF, and the lowest in OF and GF (Table III).

The length of fallen tree logs is another important measure of down dead wood since it implies the availability of microhabitat for a variety of different organisms (fungi, saproxylic insects, etc.). PF held the lengthiest fallen tree logs (Table III). DF had the lowest values when length parameters of tree logs were considered.

OF differed from the other beech stands by having the highest total volume (91.26 m^3/ha) as well as other measured volume parameters (Table IV).

The highest down dead wood biomass in fallen tree logs was recorded in PF (11.64 $t·ha^{-1}$), while the lowest was recorded in RF (1.15 $t·ha^{-1}$) (Table V). The average value in all investigated beech forest stands amounted to 5.78 $t·ha^{-1}$.

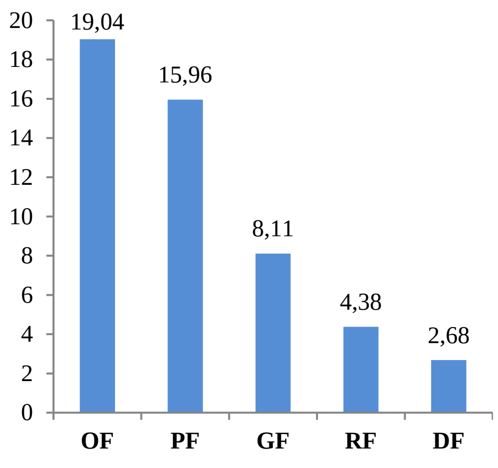

Figure 2: Total down dead wood biomass ($t·ha^{-1}$) in the five investigated beech stands

The greatest biomass of fallen tree logs was recorded for category IV. The lowest biomass was recorded for category I and V (Table V). The average down dead wood biomass in fallen branches was 4.25 $t·ha^{-1}$. The highest amount was recorded in OF (9.73 $t·ha^{-1}$), while the lowest in DF (1.03 $t·ha^{-1}$). Branches of category III were the most dominant across the investigated forest stands. According to the diameter of branches, the largest biomass was recorded in the 3-5cm category (Table VI).

The highest down dead wood biomass (fallen logs + branches) was accumulated in OF (19.04 $t·ha^{-1}$) and it decreased in the following order: OF>PF>GF>RF>DF (Figure 2). The average down dead wood biomass was 10.04 $t·ha^{-1}$.

The deadwood carbon pool in forests is generally similar to some other forest regions and a latitudinal gradient could not be established [6]. Values of 17-36 Mg C ha^{-1} were reported for boreal forests, 9-21 for undisturbed dry tropical forests; 2-25 for moist tropical forests, 15-25 for cold deciduous forests, and 10-12 $t·ha^{-1}$ for warm temperate deciduous forests [6, 27–36].

The amount of down dead wood depends on several factors among which forest age, type of management and use, soil, climate, and decomposition are the most important [37,38]. It is known that DDW changes with the maturing of the forest and generally follows a U-shaped pattern. Mature hardwood forest stands have smaller DDW biomass compared to young and old stands. In old stands, DDW continues to accumulate as stands age from 200 to 400 years [15]. The simple U-shaped pattern is not valid for all forest ecosystems and largely depends on the forestry practices and in different forests, it can develop into J or S-shaped patterns in time [5]. Unfortunately, we did not estimate the age of the stands and this hypothesis was not tested on the investigated beech forest stands on Deshat Mountain.

Although there is no targeted research on DDW in Macedonian forests, some of the studies may help in understanding the formation of DDW. Several studies have reported data on tree mortality in forest ecosystems. The global average is 1-2% mortality [39]. The mortality in a beech forest in Mavrovo National Parl was lower [19] while the mortality of beech forests on Osogovo was assessed to 0.6-1.0% and 0.5-1.4% for beech forests on Karaorman [40,41].

The average volume of down dead wood in the investigated beech forests on Deshat was 33.63 $m^3·ha^{-1}$. Down deadwood in European beech forests ranges between 32 and 310 $m^3·ha^{-1}$ [26]. This range is broader in beech forests of Great Britain with a minimal amount of 3 m^3 and a maximum of 456 m^3 [42,43]. The amount of down dead wood in beech forest reserves has an average of about 130 $m^3·ha^{-1}$ [3, 38, 44]. Only the OF (91.26 $m^3·ha^{-1}$) approaches the European average of beech reserves while DF (5.72 $m^3·ha^{-1}$) represents highly exploited forests with a very small amount of down dead wood. The average of beech forests on Deshat is close to the average of Slovakia where 31 $m^3·ha^{-1}$ of down dead wood was estimated [45, 46], but higher than the beech forests on Stara Planina in Bulgaria which hold 3.4-26.5 $m^3·ha^{-1}$, fine wood: 3.4-6.5 and coarse debris: 0-20.1 [24]. Down dead wood in managed forests in Serbia accounts for 11.21 $m^3·ha^{-1}$ or 1.24-24.53 $m^3·ha^{-1}$ [25].

The results of the study conducted in beech forests on Deshat Moutain show that the old forests are important storages of down dead wood, both logs, and branches.

Table III: Number and length of fallen tree logs in the five investigated beech stands

Forest stand	Average number of logs per hectare	Minimal length of single tree log (m)	Maximal length of single tree log (m)	Average length of tree log and standard error (m)
OF	23.4	1.70	19.20	6.54 ± 0.46
PF	43.0	1.30	18.80	7.30 ± 0.68
GF	23.9	1.10	19.50	5.22 ± 0.74
RF	38.6	0.90	12.52	4.64 ±0 0.27
DF	41.7	0.63	10.00	2.64 ± 0.27
Average	34.1	1.13	16.00	5.27 ± 0.81

Table IV: Volume (m^3) Length (m) of fallen tree logs in the five investigated beech stands

Forest stand	Minimal volume of single tree log (m^3)	Maximal volume of single tree log (m^3)	Average volume of tree logs and standard error (m^3)	Total volume of tree logs per stand (m^3/ha)
OF	0.013	23.14	1.25 ± 0.37	91.26
PF	0.013	9.78	0.88 ± 0.27	40.37
GF	0.004	9.34	0.63 ± 0.27	24.65
RF	0.005	2.75	0.09 ± 0.04	6.18
DF	0.001	0.88	0.12 ± 0.03	5.72
Average	0.007	9.18	0.59 ±	33.63

Table V: Biomass of down dead wood of fallen logs (t·ha^{-1})

Forest stand	Decay classes					Total
	I	II	III	IV	V	
OF	0.00	1.41	2.44	5.35	0.10	**9.31**
PF	0.12	1.11	2.53	7.86	0.00	**11.62**
GF	0.00	0.36	1.39	3.39	0.00	**5.14**
RF	0.00	0.08	0.44	0.63	0.00	**1.15**
DF	0.00	0.10	0.67	0.87	0.00	**1.65**

Table VI: Down dead wood biomass of fallen branches (t·ha^{-1})

Forest stand	3-5 cm				5-10 cm				10-20 cm			Total (with standard error)
	II	III	IV	Total	II	III	IV	Total	III	IV	Total	
OF	0.26	1.83	0.14	2.23	0.00	2.99	1.69	4.68	2.62	0.20	2.82	**9.73** ± 0.76
PF	0.15	1.85	0.15	2.14	0.72	0.59	0.86	2.17	0.00	0.00	0.00	**4.32** ± 1.47
GF	0.18	1.35	0.57	2.10	0.46	0.31	0.10	0.87	0.00	0.00	0.00	**3.22** ± 0.21
RF	0.97	1.29	0.65	2.91	0.00	0.00	0.31	0.31	0.00	0.00	0.00	**2.97** ± 0.16
DF	0.23	0.29	0.07	0.59	0.00	0.44	0.00	0.44	0.00	0.00	0.00	**1.03** ± 0.21

4 CONCLUSIONS

Down dead wood in a montane beech forest stands on Deshat Mountain depends directly on the quality and age of the forest. Most of the down dead wood was recorded in the old unmanaged forests, and the quantity of down dead wood decreases with decreasing quality and age of the forest. The highest amount of down dead wood biomass was estimated in the most preserved forest (19.04 $t \cdot ha^{-1}$), and the lowest in the most degraded forest (2.68 $t \cdot ha^{-1}$).

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Down dead wood in a montane beech forest stands on Deshat Mountain: Carbon sequestration

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ABSTRACT: Knowledge on carbon cycling and its sequestration in forest ecosystems is invaluable for understanding of climate change and consequences on the management of forest resources. The paper deals with the results on the content and quantity of carbon in down dead wood in five montane beech forest stands on Deshat Mountain in Mavrovo National Park. The stands were selected to represent five different types of degradation and management practices in beech forests (from highly preserved forest stands with old thick standing trees and large numbers of fallen trees with accumulated biomass, to degraded forest stands represented by a resprouting trees and small amount of coarse biomass). Carbon content was determined by using the Kotzman method. Carbon quantity was calculated based on carbon content and the biomass of dead wood (logs and branches of different sizes and decomposition stages). The highest quantity of carbon in down dead wood was found in the most preserved forest (9.7 $t \cdot ha^{-1}$), and the lowest - in the most degraded forest (1.4 $t \cdot ha^{-1}$). Carbon quantity in large branches ranged between 0.52 and 4.91 $t \cdot ha^{-1}$, while the carbon content of fallen trees varied between 0.59 and 5.98 $t \cdot ha^{-1}$. It can be concluded that the old forests represent very important storage of down dead wood carbon.
Keywords: forestry management, dead wood, biomass, carbon sequestration

1 INTRODUCTION

Forest biomass plays a key role in energy supply and climate change connected to carbon cycle in the biosphere and ecosystem processes. Scientific contributions in the past few decades were targeted towards the impacts of climate change on the resilience of forest ecosystems by measuring the sequestration of atmospheric carbon into live and dead biomass as well as soil carbon transformations [1]. The increase in temperature and more severe droughts may increase the dead wood and alter the biogeochemical processes in forest ecosystems [2].

This is highly relevant for the coarse dead wood in forest ecosystems that consists of standing trees, down dead wood (DDW) and stumps [3]. The accumulated DDW is important for all ecosystems, although its quantity is particularly emphasized preserved forest ecosystems for their high biodiversity value [4,5].

The research of carbon in forest dead wood of Macedonia is very scarce. Few research projects dealing with dead wood biomass have provided data for carbon quantities in litterfall and forest floor (including large branches, without logs) of oak [6,7] and beech forest ecosystems [8,9]. The latter estimated the carbon in dead standing biomass of large branches of 3.4 $t \cdot ha^{-1} yr^{-1}$ in the beech forest ecosystem in Mavrovo [9].

Being a party of the United Nations Framework Convention on Climate Change and Kyoto Protocol, Macedonia is committed to submit reports on carbon emissions. The changes in landuse and forestry practices impact the total emissions and storages of carbon (aboveground and belowground biomass, dead wood, soil carbon, etc.) and these parameters should be measured, estimated and reported. One of the priorities is to estimate carbon in different decomposition stages of dead wood as well as to assess carbon quantities in old forests (usually, forests in protected areas).

In 2015, we conducted research of DDW in a montane beech forest on Deshat Mountain. The research focused on estimation of DDW biomass, carbon content and mineral composition, decomposition stages and impact of forestry practices on the quantity of DDW. The methodology used during the fieldwork as well as the results on DDW biomass (both logs and coarse branches) have already been published [10]. In this article, the focus is on the carbon sequestration in DDW of a montane beech forests.

2 MATERIAL AND METHODS

2.1 Study area

Deshat Mountain is situated in the west part of Macedonia. Beech forests are the dominant forest type in the mountain.

Five stands were selected on 08.06.2015, based on the differences in forest management and the general structure of the stands. They were named as follows: Degraded forest (DF) – 1.15 ha, Coppice forest (CF) – 1.63 ha, Good forest (GF) – 1.76 ha, Preserved forest (PF) – 1.07 ha and Old-growth forest (OF) – 3.12 ha. The main field research was conducted in the period 28.09-01.10.2015. Coarse DDW was measured on the whole surface of the five stands while the biomass of dead branches was measured by line transects [10].

Three plots (15 in total) were selected in each of the five forest stands. All of these plots were selected based on field observations and they represent the variability within the forest stands. Stand tree density was estimated as an average of tree density of the three sampling plots within each of the five investigated stands. In each of the 15 plots we recorded the number of trees and we measured DBH (diameter at breast height) of each tree. DBH of trees ranged from 3 to 85 cm. In the same time we recorded the number of shrubs in each of the 15 plots. The applied methods were already published in detail [10].

2.2 Determination of decay classes of wood density

The decay classes were determined based on the different stages of wood decay assessed by visual inspection of the down dead wood. We categorized fallen tree logs and fallen branches in five categories (I-V). Most of the similar studies defined four decay classes and their description corresponds to our classification [11–14]. However, we added category V which refers to dead wood in the last stages of decomposition with very low wood density (sponge-like wood).

Wood density was estimated for both logs and branches. Discs from logs were cut during the fieldwork. They were photographed and their surface (s) including bark was estimated using Photoshop CS6 v13.0. The thickness of the discs (h) was measured by calliper. The volume of the discs (v) was calculated by multiplying the surface and thickness. The discs were measured after drying at 105˚C to constant mass. The density (ρ) was calculated by dividing the mass with the volume of the discs: $\rho = m/(s.h)$.

2.3 Carbon determination

Carbon content (% w/w) was determined by using the Kotzman method [15]. Carbon content was determined in 56 wood samples (39 branches and 17 logs) belonging to the five different decay classes. All dried wood samples were analyzed in three replicates and average value was calculated.

Carbon quantity in tons per hectare was calculated based on the carbon content and biomass of corresponding down dead wood fractions and decay classes.

3 RESULTS

3.1 Carbon content

Carbon content varied among the different decay classes of logs (Tab. I). During the research we did not collect dead log of D1 for analysis of carbon (for calculation of carbon quantity in D1 we used the value for carbon content in D2). The highest content of 51.80% was determined in D4 and the lowest in D2 (50.44%). The average carbon content was 50.94%.

Table I: Carbon content in different decay classes of dead logs

Decay classes	Carbon content (%)
D2	50.44
D3	50.49
D4	51.80
D5	51.02
Average	**50.94**

The average carbon content in dead branches was 50.00%. Carbon content in different decay classes and diameter fractions is presented in Tab. II. In average, the carbon content in DDW (logs+branches) was 50.78%.

Table II: Carbon content in different decay classes (D2-D4) of dead branches

Diameter of fractions	**3–5 cm**				**5–10 cm**				**10–20 cm**		
Decay classes	D2	D3	D4	**average**	D2	D3	D4	**average**	D3	D4	**average**
Carbon content (%)	49.75	49.81	50.56	**50.07**	50.44	50.49	50.97	**50.71**	50.54	49.46	**50.00**

3.1.1 Down dead wood carbon of fallen tree logs

Carbon quantity follows the biomass in down dead wood of tree logs (Tab. III). The highest carbon quantity was estimated in PF with 5.98 $t{\cdot}ha^{-1}$. The lowest was estimated in CF (0.59 $t{\cdot}ha^{-1}$). The average carbon quantity in the five investigated beech stands amounted to 2.96 $t{\cdot}ha^{-1}$. The highest carbon quantity was estimated in D4 (1.88 $t{\cdot}ha^{-1}$) and the lowest in D5 (0.01 $t{\cdot}ha^{-1}$)

Table III: Carbon quantity ($t{\cdot}ha^{-1}$) in tree logs according to decay classes (D1-D5)

Forest stand	**Decay classes**					**Total**
	D1*	**D2**	**D3**	**D4**	**D5**	
OF	0.01	0.71	1.23	2.77	0.05	**4.77**
PF	0.06	0.56	1.27	4.09	0.00	**5.98**
GF	0.00	0.18	0.70	1.76	0.00	**2.64**
CF	0.00	0.04	0.22	0.33	0.00	**0.59**
DF	0.00	0.05	0.34	0.45	0.00	**0.84**
Average	0.01	0.31	0.75	1.88	0.01	**2.96**

3.1.2 Down dead wood carbon of fallen large branches

The average carbon quantity in down dead branches in the five investigated beech stands is 2.14 $t{\cdot}ha^{-1}$. The highest carbon quantity was recorded in OF (4.91) and the lowest in DF (0.52 $t{\cdot}ha^{-1}$). The highest carbon quantity was recorded in the fraction of 3-5 cm and in decay classis D3 (Tab. IV)

Table IV: Carbon quantity in different size and decay classes of branches in the investigated beech stands ($t{\cdot}ha^{-1}$)

Forest stand	**3–5 cm**				**5–10 cm**				**10–20 cm**			**Total**
	2	3	4	Total	2	3	4	Total	3	4	Total	
OF	0.13	0.91	0.07	1.11	0.00	1.51	0.86	2.37	1.32	0.10	1.42	**4.91**
PF	0.07	0.92	0.07	1.07	0.37	0.30	0.44	1.10	0.00	0.00	0.00	**2.17**
GF	0.09	0.67	0.29	1.05	0.23	0.16	0.05	0.44	0.00	0.00	0.00	**1.49**
CF	0.48	0.64	0.33	1.45	0.00	0.00	0.16	0.16	0.00	0.00	0.00	**1.61**
DF	0.12	0.15	0.04	0.30	0.00	0.22	0.00	0.22	0.00	0.00	0.00	**0.52**
Average	**0.18**	**0.66**	**0.16**	**1.00**	**0.12**	**0.44**	**0.30**	**0.86**	**0.26**	**0.02**	**0.28**	**2.14**

3.1.3 Total down dead wood carbon

The average carbon quantity in down dead wood in the five investigated beech stands is 5.80 t·ha^{-1}. OF had the highest value (9.7 t·ha^{-1}) while DF (1.4 t·ha^{-1}) had the lowest one (Fig. 1).

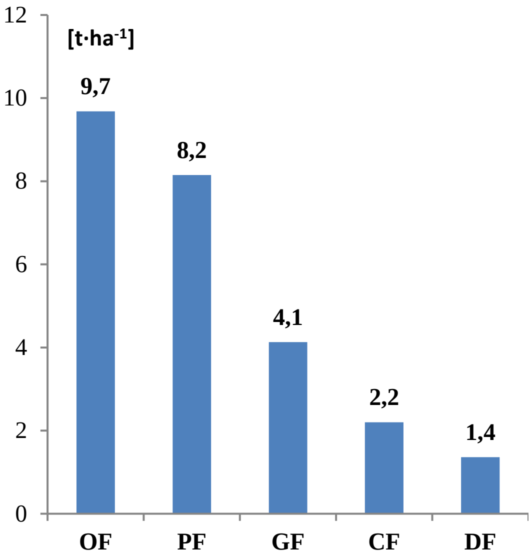

Figure 1: Total down dead wood carbon (logs+branches) in the investigated beech stands

4 DISCUSSION

4.1 Carbon content in DDW

Carbon quantity in DDW varies among different tree species (e.g. carbon content is different in *Picea abies* and *Fagus sylvatica* - [16]). Numerous studies have showed that the carbon content in DDW varies depending on the decomposition process intensity (according to the dominated tree species, wood properties, microorganisms abundance, soil properties, climate etc.) [17–20]. Some ecological factors are considered as specific triggers for certain decomposition stages, such as precipitation between D1 and D3 [16], microorganisms in the initial decomposition stage and temperature in the stages between D1 and D4 [21, 22].

Some of the studies show that the carbon content increases with decomposition [23], some of them recorded no significant changes [16]. The results from our study suggest increase in carbon content in the initial stages of decomposition (D2-D4) and rapid decrease in the late stages (D4-D5). The similar pattern was observed for the carbon content in small branches (0.5-1.5 cm) and leaf litter in another beech forest ecosystem in Mavrovo National Park [8,24].

Some studies on carbon quantities use DDW conversion factors instead of direct measurements of carbon content. For Russian boreal forest a content of 51% was used [11], while IPCC recommends simple conversion factor of 50% [25]. This value was used in the estimation of carbon in dead wood in beech forests in Serbia [14]. The commented conversion factors can be applied for estimation of carbon quantity in DDW in most forest ecosystems since the carbon content shows very small variations in different decay classes of logs and branches of different size.

4.2 Carbon quantity in DDW

The carbon quantity in logs in the investigated beech stands ranged between 0.59 and 5.98 t·ha^{-1} with average value of 2.96 t·ha^{-1}.

Carbon quantity in coarse branches ranged between 0.52 and 4.91 t·ha^{-1}. For the well preserved stands (OF and PF), the largest quantity of carbon was stored in the fraction 5-10 cm and D3. In the more degraded beech stands, the branches with diameter of 3-5 cm prevailed.

The total quantity of carbon in DDW varied between 1.4 and 9.7 t·ha^{-1}. OF and PF with 9.7 and 8.2 t·ha^{-1} had 2-7 times more carbon than the quantity stored in GF, CF and DF. These values clearly show that the old-growth and better preserved forests are much more important as storage of carbon in DDW. By the published data for forests in USA, the carbon in DDW range from 5 to 25 t·ha^{-1} [26]. Carbon stock in aboveground dead wood (down dead wood+stumps) of beech forests in Serbia was estimated at 3.03 t·ha^{-1}, or 1.47-4.60 t·ha^{-1} [14].

The power for carbon sequestration of forest ecosystem depends on annual net productivity, especially annual increment and carbon stored in DDW. The capacity of forest ecosystems for carbon sequestration through annual net productivity is enormous. Previous study in one beech forest in Mavrovo National Park reported value for carbon sequestration of 4.2 t·ha^{-1}·yr^{-1} [9]. Nevertheless, the potential of carbon sequestration in DDW is also very significant. We also calculated the total quantity of carbon stored in DDW in montane beech forests on Deshat by multiplying the values of carbon per hectare with the area of montane beech forests of 29.44 km^2 [27]. We found that carbon in logs and branches amounts to 8714.2 t and 6300.2 t, respectively.

Republic of Macedonia is a party of the United Nations Framework Convention on Climate Change and assessments of carbon in DDW are needed to report greenhouse gas emissions and carbon sequestration from land use and forestry sectors [3]. The quantity of sequestered carbon in fine litter fractions of forest floor of montane beech forests is 868 Kt [28]. This calculation was based on the value of 8.79 t·ha^{-1}, which contains fine litter fractions and coarse branches [29]. The value of 8.79 t·ha^{-1} should be increased for the quantity of carbon in logs which amounts to 2.96 t·ha^{-1} for the montane beech forests on Deshat Mt.

Having in mind the magnitude of DDW for carbon sequestration, it is very important to implement proper forestry management which will maintain and increase DDW in forest ecosystems. The forest growth i.e. annual net productivity plays significant role in sequestration of atmospheric carbon. Hence, the forest management should be a compromise between climate change mitigation and resource use priorities [30].

5 CONCLUSIONS

The studied old-growth and preserved beech forests stored more carbon than the young and degraded beech forests. As the rate of forest degradation increased, the quantity of stored carbon in the total biomass continuously decreased.

The average carbon content in dead branches was 50.00%. In average, the carbon content in down dead wood (logs+branches) was 50.78%. Carbon quantity followed the biomass in down dead wood of tree logs. The carbon quantity of logs in the investigated beech stands ranged between 0.59 and 5.98 t·ha^{-1} with average value of 2.96 t·ha^{-1}.

In the case of dead branches, the average carbon quantity in five investigated beech stands was 2.14 t·ha^{-1}. The highest carbon quantity was recorded in old-growth forests (4.91 t·ha^{-1}) and the lowest - in degraded forest (0.52 t·ha^{-1}). The highest carbon quantity was recorded in the fraction of 3-5 cm and in decay classis D3. The average carbon quantity in total down dead wood (logs+branches) in five beech stands was 5.80 t·ha^{-1}.

The total quantity of carbon in down dead wood varied between 1.4 and 9.7 t·ha^{-1}. Old-growth and preserved forests with 9.7 and 8.2 t·ha^{-1} had 2-7 times more carbon than the quantity stored in good forest, coppice forest and degraded forest stands. These values clearly showed that the old-growth and better preserved forests were much more important as storage of carbon in down dead wood.

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