Spatial Variability of the Bioclimatic Conditions of the Roztocze National Park Based on the Example of the Cycling Path to Florianka

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Abstract

The Roztocze National Park (RNP) is a typical forest park – 94% of its area is occupied by forest. A total of 13 forest communities are distinguished within RNP. The most valuable ones are Carpathian beech forest and uplands mixed fir coniferous forest, occupying almost 34% of the forested area of RNP. The microclimatic conditions occurring in forests differ considerably from those occurring in non-forested areas. Forests absorb dust and gas pollutants, suppress noise, and enrich the air in aromatic substances. The climate of the forest interior depends on aspects such as the species composition of the forest, density of crown trees, and habitat properties. Therefore, the effect of various forest communities on the human organism is different. This paper describes the forest communities appearing in RNP pointing out their therapeutic values, with particular consideration of the cycling path "to Florianka" ("do Florianki"). Based on GIS software, a spatial analysis of the properties of particular forest communities was performed. Maps were prepared presenting the bioclimate of the recreational layer of the forests, including: insulation, ventilation, humidity, oxygen and ozone production, ionisation, and content of aeroplankton and phytoaerosoles. The bioclimate occurring in particular communities was assessed as favourable/neutral/unfavourable for the human organism. The attractiveness of its environment makes RNP very popular among tourists (> 100 thousand annually). Tourist and didactic trails are established in the Park, with a total length of approximately 40 km. They run near the most interesting environmental, cultural, and historical objects. An example of such a trail is the cycling path "to Florianka" that was the subject of the detailed analysis. It has a length of approximately 10 km and is the longest trail established in RNP. The trail features the highest diversity of forest communities distinguished by a favourable effect on the human organism.

Keywords: bioclimate, forest communities, tourism, Roztocze National Park

Introduction

The growing social awareness of the importance of recreation for the quality of human life encourages an increasing interest in recreation in places not transformed by economic activity. Forests are quite obvious places of such recreation. They certainly feature high aesthetic and therapeutic values. A visit to a forest may be related to practicing a number of hobbies, such as camping, gathering mushrooms or forest fruit, taking photographs, bird watching, observation of animals, jogging, hiking or nordic walking, cycling, horse riding, outdoor games, etc. Fresh air and silence enriched by the songs of birds and the rustling of trees, as well as the green colour dominant in forests have a calming and relaxing impact on the human mind. Forests, however, can influence people in a more significant way. The microclimate occurring in forests (bioclimate) has a positive effect on things such as blood circulation, the respiratory and immunity systems.

The microclimatic conditions of forests largely differ from the conditions occurring in non-forested areas. Forests are generally distinguished by a more uniform course of temperatures in the daily and annual cycles, reduced access of solar radiation, higher humidity with lower daily fluctuations, lower wind velocity, and increased content of essential oils of paramount importance for

our health and well being (Bogucki 1988, 170; Flemming 1983, 214). A number of works have been published describing the effect of forests on the microclimate, and indirectly on its importance for recreation (Bogucki 1988; Brown and Cherkezoff 1989; Falencka-Jabłońska 2012; Fornal 2004; Grzywacz 2011; Kozioł and Muszyński 2009; Krawczyk and Błażejczyk 1999, 36; Krzymowska-Kostrowicka 1997, 239; Mayer and Höppe 1984; Moszyńska 2000; Schiller 2001; Ziółek, Kozieł, and Czubla 2012, 2013). The universal role of forests involves the improvement of the hygienic conditions of the air. Forests capture dust and gas pollutants from the atmosphere, suppress noise, and enrich the air in volatile substances (including phytoncides).

People in a forest are affected by a number of environmental factors, together constituting a specific bioclimate, a so-called recreational bioclimate. According to Toyne (see: Krzymowska-Kostrowicka 1997), the term refers to all of the variable external environmental conditions of the air layer called the recreational layer, covering the zone from 20 cm below the ground level to 2 m above the ground level (i.e., the zone in which human tourist and recreation activity is concentrated). The primary parameters developing the bioclimate of the recreational layer in forest communities are: sun exposure (insulation), humidity, ventilation, oxygen production, ozone production, air ionisation, presence of phytoaerosoles (essential oils, including phytoncides), and aeroplankton (pollen of plants, fungal spores, bacteria, and insects) (Krzymowska-Kostrowicka 1997).

The above list of factors constituting the bioclimate suggests that due to the varied species composition of the forest community (including the undergrowth), its age, density of tree crowns, or habitat properties, the effect of particular forest communities on the human organism is different. A longer stay in a forest may increase or decrease blood pressure, and have a calming or stimulating effect depending on the type of community. Therefore, not every forest has a positive impact on all people. In certain forests we might experience various bothersome conditions, related to stagnant air and stuffiness, or the presence of allergens or tiresome insects. In this context, it is important to perform the assessment of the bioclimatic conditions of particular forest communities, with particular consideration of their impact on human health and well being.

The research on the bioclimate of the forests of Roztocze National Park (RNP) concerns the spring and summer season, when the rate of tourist traffic is the highest. The application of GIS software allowed us to conduct a spatial analysis of the properties of particular forest communities in a given area, and for preparation of maps of bioclimatic conditions. The maps of the bioclimate provide guidelines—unfortunately rarely used—for the establishment of further tourist trails, didactic paths, nordic walking paths, etc. In addition to the environmental, landscape, and educational conditions of the surroundings, they also consider the bioclimate in designing particular trails and places of recreation in forests for specific groups of recipients and forms of recreation (Ziółek, Kozieł, and Czubla 2013).

1   Study area

The most valuable forest areas are under protection, including in the form of national parks. One of them is the RNP established in 1974, occupying an area of approximately 8.5 thousand ha in the part of Central Roztocze most attractive in terms of environment and landscape. It covers low (up to 350 meters above sea level) Cretaceous hills covered with loess, with extensive valleys filled with post-glacial sands in between (Wilgat 2004, 160). RNP is a typical forest park—94% of its area is occupied by forests (Tittenbrun 2013, 112). It is the most forested of all Polish national parks.

In RNP the hiking and cycling trails as well as didactic trails are established near the most interesting environmental, cultural, and historical objects. These are three transit trails: central, boundary and partisan, with a total length of approximately 17 km, 6 cognitive paths (13,5 km)[1], and a cycling trail to Florianka with a length of 9,6 km (three further cycling trails are only partly located in the Park, or run along the hiking trail) (Ziółek, Kozieł, and Czubla 2012). In 2012, the

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1. [In the journal (in both Polish and English texts) European practice of number notation is followed—for example, 36 333,33 (European style) = 36 333.33 (Canadian style) = 36,333.33 (US and British style). Furthermore in the International System of Units (SI units), fixed spaces rather than commas are used to mark off groups of three digits, both to the left and to the right of the decimal point.—Ed.]

Park was visited by 120 thousand people (Ochrona środowiska 2013). Tourist traffic in RNP is concentrated in the vicinity of Zwierzyniec, and is the highest in the summer season.

The subject of the detailed analysis is the cycling trail to Florianka established in the western part of RNP. It runs from the Educational-Museum Centre of RNP in Zwierzyniec to the south, next to the "Echo" ponds and the Rybakówka settlement, to the railway crossing, and then over a small bridge on the Świerszcz River. The further section of the trail runs to Florianka, and then along a larch alley with NW-SE orientation and sandy forest road, through a pine forest, to Górecko Stare. Attractions located in the direct vicinity of the trail include the Echo ponds and the Rybakówka settlement with the possibility of observing Konik horses, as well as Florianka — a 19th century forest settlement with a forester's lodge. Florianka features the Centre of Conservative Breeding of Konik Horses, and the Forest Chamber, as well as a dendrological path (featuring 66 species of trees and bushes over an area of 3,29 ha) and a landscape path with a vantage tower.[2] A detailed description of the trail with a schematic map is included in the paper by Kozieł (Kozieł 2012).

The trail to Florianka is among the most popular ones in RNP. According to research conducted by employees of Maria Curie Skłodowska University and RNP, depending on the weather, it is visited by 150–300 persons a day in the summer season (Studium uwarunkowań i analiza udostępniania Roztoczańskiego Parku Narodowego dla turystyki i edukacji oraz ocena jego wpływu na środowisko przyrodnicze i społeczne [not published]).

2 Forest communities and tree species in Roztocze National Park

The forests of RNP are characterized by high diversity of habitats and communities, dominated by the lowland group with a contribution of lower subalpine forest plants. According to the latest studies, RNP features 13 forest communities.[3]

The most valuable community of the Park is Carpathian beech forest (*Dentario glandulosae Fagetum*), occupying 21% of the forested area of the Park. It is a mixed beech or beech-fir forest with a contribution of hornbeam, small-leaved lime, sycamore, maple, and spruce. The beech forest is one of the most beautiful forests in Poland. Smaller areas are occupied by sub-oceanic pine forest (*Leucobryo-Pinetum*) — 13,5%, and upland mixed fir coniferous forest (*Abietetum polonicum*) — 13,1% (tab. 1). The communities are constituted of pine or fir with a contribution of spruce, beech, white birch, and oaks.

A considerable area (more than 33% of the total forested area) is occupied by anthropogenic substitute communities and degenerative forms of forest phytocoenoses developed as a result of introduction into the areas of exploited natural deciduous and mixed tree stands species inappropriate for the habitat, particularly pine. The highest contribution is reached by substitute communities from the *Querco-Fagetea* class (22,5%) — pine on a hornbeam habitat, and substitute communities from the *Vaccinio-Piceetea* class (12,1%) with pine included in the tree stand. RNP is conducting a transformation of the anthropogenic tree stands aimed at the restoration of their natural character. The per cent contribution of the 13 communities of RNP is illustrated in the diagram (fig. 1).

The tree stands of RNP are largely varied. The last survey conducted in 2012 recorded 27 tree species. Pine is the dominant species (approximately 58% of the number of trees in the Park), among others due to the high contribution of substitute communities. The following most abundant tree species are beech (approximately 24,5%) and fir (approximately 17%), reaching in the Park the north-eastern boundary of their compact occurrence in Poland (Tittenbrun 2013). The same species, although in a different order, are dominant in terms of area occupancy in the Park: pine — 57,8%, fir — 19,8%, and beech — 15,2% (Żybura 2004). The lower contribution (6,7–1,3% of the number of trees) is reached by: hornbeam, oak, spruce, alder, birch, and lime. The remaining species do not exceed 1% abundance (Tittenbrun 2013).

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2. See: http://www.roztoczanskipn.pl/.

3. See: Leśne zbiorowiska roślinne, 1:25 000; mapa do Planu Ochrony RPN na lata 2011–2030, Zwierzyniec, RPN, authors: B. Radliński and A. Tittenbrun.
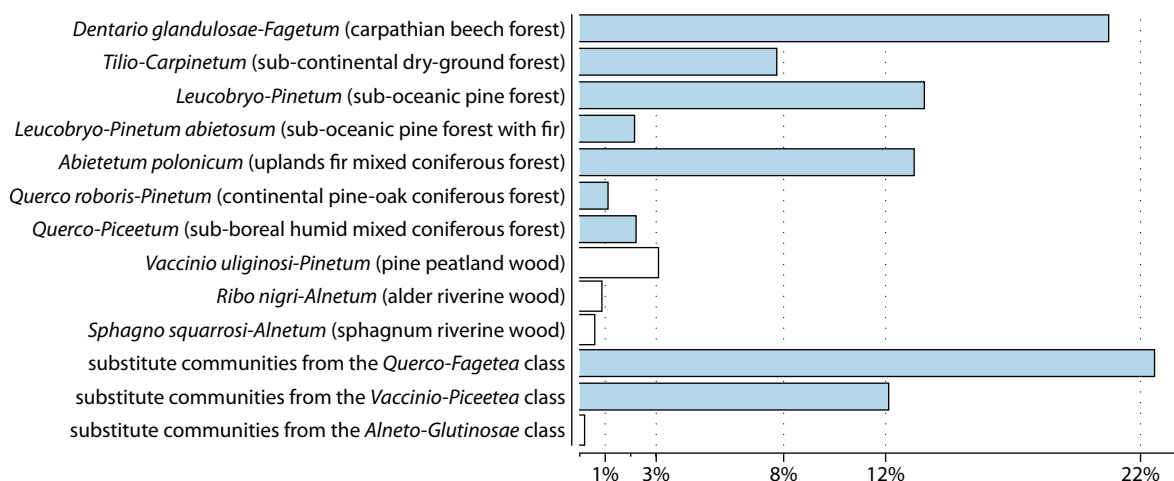
Fig. 1. Per cent contribution of forest communities in the forested area of RNP

Source: Own elaboration based on Leśne zbiorowiska roślinne, 1 : 25 000; mapa do Planu Ochrony RPN na lata 2011–2030, Zwierzyniec, RPN, authors: B. Radliński and A. Tittenbrun

Note: White bar indicates that the community does not occurr on the cycling trail to Florianka

3 Materials and methods

The starting material for the assessment of the bioclimatic conditions of forest communities was the map of forest plant communities of RNP prepared for the purposes of the park's protection plan for the years 2011–2030.[4] Its "numerical" version was developed in Quantum GIS 1.7.4. and ArcGIS 10.1 software.

The forest communities identified in RNP were described by means of eight parameters of the bioclimate of the recreational layer, characterised based on the paper by Krzymowska-Kostrowicka (1997). Each was ascribed a point score describing the kind of impact on human health and well being: **1** (favourable), **−1** (unfavourable), or **0** (neutral). Intermediate values were also adopted: 0,5 (favourable/neutral) and −0,5 (unfavourable/neutral) (tab. 1). The weight of the parameters was equal. The final value of the effect of a given community on the human organism was calculated as the mean value of all of the characteristics. The assessment of aeroplankton concerns the content of plant pollen, bacteria, and fungi in the air. Values for spring and summer were determined for two communities—carpathian beech forest (*Dentario glandulosae-Fagetum*) and sub-continental dry-ground forest (*Tilio-Carpinetum*)—because the bioclimatic assessment of sun exposure for these communities largely differs in various seasons of the year (tab. 1).

The composition of the mean values for the characteristics of the bioclimate of the recreational layer with the map of forest communities of RNP allowed us to obtain the map of bioclimatic conditions of the Park, described in detail in the paper by Ziółek, Kozieł and Czubla (2012).

4 Results and discussion

The application of the basic GIS techniques allowed us to obtain information on the distribution of forest areas with a specific impact on human health and well being, and provided the basis for the assessment of the bioclimatic conditions of the forest communities occurring along the cycling trail to Florianka (independently for each of the sides).

The cycling trail to Florianka is the most diverse of all the trails in RNP. It runs through 9 out of 13 forest communities recorded in the Park (tab. 2). This diversity is a great asset of the trail. Its relatively short length provides an opportunity to see the majority of forest communities typical of the Park. Unfortunately, the community of carpathian beech forest, the most typical of RNP next to fir forest, is only represented along a very short section (tab. 3).

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4. See: Leśne zbiorowiska roślinne, 1 : 25 000; mapa do Planu Ochrony RPN na lata 2011–2030, Zwierzyniec, RPN, authors: B. Radliński and A. Tittenbrun.

Tab. 1. Characteristics of the bioclimate of the recreational layer of the forest communities of RNP

Forest community	Community no.	Sun exposure	Humidity	Ventilation	Oxygen production	Ozone production	Ionic structure	Aeroplankton[a]	Phytoaerosoles	Mean value
Dentario glandulosae-Fagetum	1	1 (−1[b])	1	1	1	−0,5	0,5	0,66	−1	0,46 (0,21[b])
Tilio-Carpinetum	2	1 (−1[b])	0	−0,5	0,5	1	0	0,33	0	0,29 (0,04[b])
Leucobryo-Pinetum	3	1	1	1	−0,5	1	−1	0,66	1	0,52
Leucobryo-Pinetum abietosum	4	1	1	1	−0,5	1	−1	0,66	1	0,52
Abietetum polonicum	5	0	0	0			1		0,5	0,30
Querco roboris-Pinetum	6	−0,5	0	0	0,5		1	0,17	0,5	0,24
Querco-Piceetum	7	−0,5	0	0	0,5		1	0,17	0,5	0,24
Vaccinio uliginosi-Pinetum	8	−1	−1	−1	−1		−1	−0,33	0,5	−0,69
Ribo nigri-Alnetum	9	−1	−1	−1	0		0	−1	0,5	−0,50
Sphagno squarrosi-Alnetum	10	−1	−1	−1	0		0	−1	0,5	−0,50
Substitute communities from the *Querco-Fagetea* class	11	0	0	0	−0,5	1	−1	0	1	0,06
Substitute communities from the *Vaccinio-Piceetea* class	12	1	1	1	−0,5	1	−1	0,66	1	0,52
Substitute communities from the *Alneto-Glutinosae* class	13	−1	−1	−1	0		0	−1	0,5	−0,50

Source: Ziółek et al. 2012 (modified)
[a] Averaged assessment for fungi, bacteria, and plant pollen
[b] Summer

Tab. 2. Forest communities along the tourist trails of RNP

No.	Name of trail	Length (km)	Abundance	Community no.[a]
1	Cycling trail to Florianka	9,63	9	1–7, 11, 12
2	Partisan trail	7,91	5	1, 2, 5, 11, 12
3	Boundary trail of Roztocze	5,41	8	1–6, 11, 12
4	Central trail of Roztocze	4,04	5	1, 4, 5, 11, 12
5	Cognitive path to Piaseczna Góra	3,09	5	1, 3, 4, 5, 11
6	Environmental path to Bukowa Góra	1,93	6	1, 3, 4, 5, 6, 11
7	Historical-environmental path to Wzgórze Polak	2,11	3	1, 5, 12
8	Historical-environmental path to Wojda	3,76	4	1, 2, 11, 12
9	Path to the Echo ponds.	1,05	4	3, 4, 6, 11
10	Path across the dune to the Echo ponds	1,45	1	3

[a] Numbers of communities as in table 1

The variability of communities along the trail is also very high. A total of 48 patches (separations) occur on the left and right side of the trail (tab. 3). Sub-oceanic pine forest (*Leucobryo-Pinetum*) is the most frequently encountered community — 14 times on the left, and 10 on the right side. In addition to sub-oceanic pine forest, the trail features numerous patches of sub-oceanic pine forest with fir (*Leucobryo-Pinetum abietosum*) (6 on the left, 7 on the right side), uplands fir mixed coniferous forest (*Abietetum polonicum*) (6 and 7), and substitute communities from the *Vaccinio-Piceetea* class (5 and 3) (tab. 3, fig. 2).
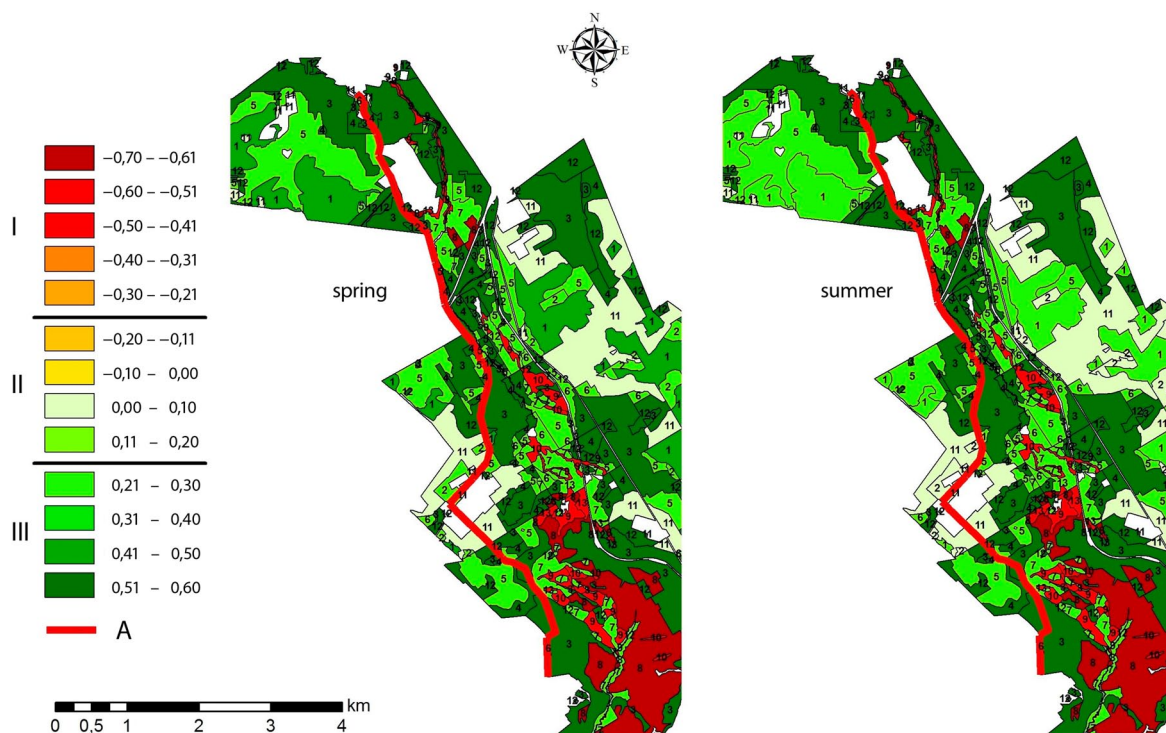
Tab. 3. Forest communities of RNP along the cycling trail to Florianka (by assessment of bioclimate in summer)

Forest community	No.[a]	Bioclimate assessment	Left side — eastern (E)			Right side — western (W)		
			freq.[b]	len.[c]	%[d]	freq.[b]	len.[c]	%[d]
Leucobryo-Pinetum	3	0,52	14	3 116	32,4	10	2 310	24
Leucobryo-Pinetum abietosum	4	0,52	6	993	10,3	7	1 148	11,9
Substitute communities from the *Vaccinio-Piceetea* class	12	0,52	5	1 414	14,7	3	860	8,9
Abietetum polonicum	5	0,30	6	1 009	10,5	7	981	10,2
Querco roboris-Pinetum	6	0,24	2	337	3,5	2	256	2,7
Querco-Piceetum	7	0,24	2	586	6,1	0	0	0
Dentario glandulosae-Fagetum	1	0,46[e]/0,21[f]	1	58	0,6	0	0	0
Substitute communities from the *Querco-Fagetea* class	11	0,06	3	882	9,2	3	846	8,8
Tilio-Carpinetum	2	0,29[e]/0,04[f]	3	620	6,4	3	602	6,3
Others[g]			6	615	6,4	13	2 625	27,3
Total			48	9 629	100,0	48	9 629	100,0

[a]Numbers of communities as in table 1; [b]Frequency; [c]Length (in meters); [d]Percent of length; [e]Spring; [f]Summer
[g]Separations of anthropogenic origin

A large share of the forest communities along the cycling trail to Florianka are those with very favourable bioclimatic conditions: sub-oceanic pine forest (*Leucobryo-Pinetum*), sub-oceanic pine forest with fir (*Leucobryo-Pinetum abietosum*), and substitute communities from the *Vaccinio-Piceetea class*—assessment 0,52 (fig. 2). They constitute 55% of the length of the trail on its left side and 45% on the right side. Favourable bioclimatic conditions—occurring in uplands fir mixed coniferous forest (*Abietetum polonicum*), continental pine-oak coniferous forest (*Querco roboris-Pinetum*), sub-boreal humid mixed coniferous forest (*Querco-Piceetum*), and carpathian beech

Fig. 2. Bioclimatic conditions of forest communities along the cycling trail to Florianka in spring and summer. I—unfavourable, II—neutral, III—favourable; A—the cycling trail to Florianka; numbers of communities as in table 1

forest (*Dentario glandulosae-Fagetum*) in the range from 0,21 to 0,30 — concern 21% of the trail on the left, and 13% on the right side. Neutral bioclimatic conditions occur along 15% of the trail (the remaining sections — separations of anthropogenic origin — were not assessed) (tab. 3).

The best bioclimatic conditions occur in coniferous forest communities: sub-oceanic pine forest (*Leucobryo-Pinetum*), sub-oceanic pine forest with fir (*Leucobryo-Pinetum abietosum*), and substitute communities from the *Vaccinio-Piceetea* class (tab. 1). The microclimate of coniferous forests has medicinal properties in the case of diseases of the respiratory tract, regulates blood pressure, and tones the nervous system. The present volatile substances have strong disinfecting properties. The "calming" bioclimate of mixed coniferous forests (sub-oceanic pine forest with fir — *Leucobryo-Pinetum abietosum*) and substitute communities from the *Vaccinio-Piceetea* class is almost universal in biotherapeutic and psychoregulatory terms. It is recommended for recreation by persons at various age and health condition. Longer stays in pine forests (sub-oceanic pine forest), however, are not recommended to persons with low blood pressure or hypothyroidism, or prone to migraines (particularly on hot and windless days). It should be remembered that the bioclimate of the forests temporarily reduces mobility and reflex, even in young and healthy persons (Krzymowska-Kostrowicka 1997; Moszyńska 2000).

In spring, very good bioclimatic conditions also occur in *Dentario glandulosae-Fagetum* (0,46) — carpathian beech forest. In summer, due to the high degree of shading of the forest floor, the total assessment of the bioclimatic conditions of beech forest decreases to the value of 0,21 (tab. 1). The bioclimate of the community has a slightly stimulating effect, and enhances the natural immunity of the organism. It is favourable for anyone except for persons with chronic respiratory disorders and very high blood pressure (Fornal 2004; Krzymowska-Kostrowicka 1997). Good bioclimatic conditions also occur in uplands fir mixed coniferous forest (*Abietetum polonicum*) (0,30), continental pine-oak coniferous forest (*Querco roboris-Pinetum*), sub-boreal humid mixed coniferous forest (*Querco-Piceetum*) (0,24), and sub-continental dry-ground forest (*Tilio-Carpinetum*) in spring (0,29).

The second community with temporal variability of bioclimatic conditions next to carpathian beech forest is sub-continental dry-ground forest. Its bioclimate changes from favourable in spring (0,29) to neutral (0,04) in summer (tab. 1). In spring, the effect of dry-ground forest is universally positive. Neutral bioclimatic conditions occur throughout the year in substitute communities from the *Querco-Fagetea* class — 0,06. The communities of pine peatland wood *Vaccinio uliginosi-Pinetum* as well as alder forests (alder riverine wood *Ribo nigri-Alnetum* and sphagnum riverine wood *Sphagno squarrosi-Alnetum*) and substitute communities from the *Alneto-Glutinosae* class are characterized by high humidity and weak ventilation strongly affecting the heart action. The characteristics listed above combined with bothersome insects more abundant than in dryer communities, do not favour longer stays in such communities (Krzymowska-Kostrowicka 1997; Moszyńska 2000). These communities, with the most unfavourable bioclimatic conditions in RNP (bioclimatic index −0,69 – −0,50) do not occur along the cycling trail to Florianka.

The communities dominant on the discussed trail are generally characterized by the most favourable characteristics of the bioclimate of the recreational layer in RNP. Tree stands dominated by pine, with a contribution of oak, fir, and spruce, show high sun exposure, low humidity, good ventilation, high ozone production, high level of phytoaerosoles, and a favourable composition of phytoplankton (tab. 1). Only substitute communities from the *Querco-Fagetea* class occurring in three patches along a short section of the trail to Florianka, and in summer sub-continental dry-ground forest (*Tilio-Carpinetum*) along a section of approximately 1,5 km, feature neutral bioclimatic conditions.

Conclusions

The cycling trail to Florianka features very high diversity of forest communities. As many as 9 out of 13 forest communities recorded in RNP is encountered there in 48 different separations. Uniform patches occur on the trail along a section of approximately 200 m. The most frequently encountered communities, and those accompanying the trail along the longest sections include: sub-oceanic pine

forest (*Leucobryo-Pinetum*), also with fir (*Leucobryo-Pinetum abietosum*), uplands fir mixed coniferous forest (*Abietetum polonicum*), and substitute communities from the *Vaccinio-Piceetea* class. These are communities showing favourable bioclimatic conditions. Conditions neutral for human health and well being only occur along short sections of the trail to Florianka: 882 m in substitute communities from the *Querco-Fagetea* class and 620 m in summer in sub-continental dry-ground forest (*Tilio-Carpinetum*). The cycling trail to Florianka features no communities with unfavourable bioclimate. The bioclimate conditions on the trail are the same in spring and summer, except for 620 m of sub-continental dry-ground forest (*Tilio-Carpinetum*). The cycling trail to Florianka is established in communities with a favourable effect on human health. Moreover, the trail features a number of tourist attractions, making it particularly interesting.

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