PICEA ABIES (L.) H. KARST. LEAF TEMPERATURE AS AN INDICATOR OF SPECIES RESILIENCE: A CASE STUDY OF THE ČEMERNIK MOUNTAINS IN SOUTHEAST EUROPE

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Abstract. Norway spruce (*Picea abies* (L.) H. Karst.) is one of the ecologically and economically most important species in European forestry. According to the latest genocenological tests, environmental factors have a significant influence on the species' survival, and there is no decrease in variability in the periphery of its areal, thus the research of its resilience requires work on "plus" trees. The paper analyzed differences in thermal data of leaves in the sun and shade, trunk bark in the shade, and control surfaces in the sun: dry grass, dry soil, asphalt, and concrete, to obtain data on temperature differences as indicators of species resilience and to understand the impacts of local climate change in mountainous regions. In the summer of 2022, surface temperatures were recorded with a thermal camera on Mount Čemernik in Southeastern Europe. Monitoring and analysis of air temperatures included interpolations using a digital elevation model (DEM) and was based on the percentile method. The research results confirm significant differences between the temperatures of leaves and control surfaces. The importance of this paper is in the wide application of selected, resilient, Norway spruce "plus" trees in forestry, landscape architecture, and horticulture in Southern European habitats where scenarios predict that the climate will change, and the Norway spruce will move north.
Keywords: *Norway spruce, climate warming, distributions, plasticity, dendroecology*

Introduction

Surface temperatures are very important in climatological research, especially when analyzing environmental factors that indicate climate changes in micro-locations. Surface temperatures might be influenced by various radiation effects, as well as humidity, thermal transmittance, and surface emissivity. Current ways to obtain information about the temperatures of different surfaces are the use of unmanned aerial vehicles (UAV) and satellite remote sensing. Unmanned aerial vehicles (UAV) su se pojavile kao tehnologija koja se brzo razvila i primenjuje u različitim sektorima zbog mogućnosti da funkcioniše u opasnim okruženjima (Yousaf et al., 2022). UAVs have emerged as a technology that has been rapidly developed and applied in various sectors due to the possibility of operating in hazardous environments (Yousaf et al., 2022). UAV detection systems use different algorithms and techniques depending on the application to detect, classify, locate, and track, using a hybrid fusion of radio frequency, radar, acoustic and visual sensors to improve detection. Over the years, the technology and characteristics of UAVs have improved significantly to meet the requirements of spatio-temporal coverage and remote sensing capabilities (Liu et al., 2014; Kannadaguli, 2020). However, it should be noted that flight control is necessary while using UAVs (Prisacariu, 2017). Satellite remote sensing technology is an important method for exploration, identification, classification, and monitoring of various resources (Prata et al., 1995; Sailesh, 2009). This technology enables the collection of data in a short period of time, and it is appreciated

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for its logistics and consistency of results over large areas. Thermal remote sensing has a wide application: for the assessment of surface temperature (sea/land), analysis of global warming changes (Eludoyin et al., 2019), but also for monitoring vegetation from local to global scales (Simović et al., 2022).

Different surfaces such as vegetation, soil, water, buildings, roofs, and asphalt have different emissivity and emit solar radiation energy in different ways (Caselles, et al., 1988; Arnfield, 2003; Voogt and Oke, 2003; Bian et al., 2021). During the last few decades, there has been an increase in the application of infrared thermography for collecting data on the temperature of different surfaces as well as monitoring the thermal parameters of plants (Stoll and Jones, 2007; Lapidot et al., 2019; Carrasco-Benavides et al., 2020; Zakrzewska et al., 2022). Portable devices such as thermal infrared cameras are used as an efficient method for the estimation of leaf temperature (Jones and Leinonen, 2003; Möller et al., 2007; Testi et al., 2008; Gonzalez-Dugo, 2014; García-Tejero et al., 2018a, 2018b; Petrie et al., 2019).

Measuring temperature using infrared rays is a very important indicator of climate change, and it enables adequate monitoring of the reflection and sensitivity of surfaces. Infrared thermography methods and variations of data obtained in this way can be used as an initial and reliable phase for determining stress in plants, but also as an indicator of their resistance in climate change scenarios. They also represent an effective approach to monitoring and analyzing temperature patterns and allow climate impact assessment. Infrared thermography provides basic information about urban and rural temperatures and enables the easy solution of problems at the microclimatic level, as well as the planning of a sustainable environment.

The paper studies the temperatures of Norway spruce leaves (*Picea abies* (L.) H. Karst.) as an indicator of the species' resilience in local climate changes, because Norway spruce is one of the most commonly used species for afforestation in Europe as well as in the practice of landscape architecture. Norway spruce, the subject of our research, is an element of the boreal-European flora. It is native to Southeastern Europe on different geological substrates, as well as different types of soil - cooler, fresher, acidic, loose, loamy, sandy, and humic with sufficient amounts of moisture (Ocokoljic and Petrov, 2022). The species is more vital in environment with sufficient and constant amount of air moisture and colder climate (Cvjetićanin et al., 2016; Petrov and Ocokoljic, 2022). The importance of the research is confirmed by certain studies that indicate that climate change causes pressure and initiates the drying of Norway spruce on large areas throughout Europe (Bošel'a, 2014). However, the study of Müller-Stark (1995) states that with vertical zoning of Norway spruce, there is no reduction of variability in peripheral areas that could be expected, which is why the breeding of the species and the research of variability in terms of resilience require work on smaller areas and on "plus" trees.

Materials and Methods

Study Area

The case study was conducted on Mount Čemernik in Southeastern Europe, in the Brod village (42° 50 ' 56 " North latitude and 22° 17 ' 02 " East longitude), Crna Trava municipality, at an altitude of 856m, in Serbia (*Fig. 1*). The research area is characterized by several forest species belonging to the *Fagion moesiacae* Bleč. et Lak. alliances, and sub-alliances: *Fagenion moesiacae submontanum* B.Jov.1976, *Fagenion moesiacae montanum* B.Jov.1976, *Fagenion moesiacae subalpinum* B.Jov.1976, *Luzulo-Fagenion*

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moesiacae B.Jov.1976 (Ćirković, 2005; Ranđelović and Zlatković, 2010), in the moderately continental zone, where the mountain type of climate prevails, rankers soil type (humic-silicate soil) and dystric brown soil (Škorić et al., 1985). At the aforementioned locality, three trees of the species *Picea abies* (L.) H. Karst. were selected which are not native to Čemernik and can be classified as a small monoculture. The trees were planted in 1925 and are 97 years old, isolated in a group which is a prerequisite for accurate measurement of leaf temperatures without the influence of neighboring objects and the substrate. The trees are chosen based on their age, habitus and canopy density, tree height, diameter at breast height (1.30 m), crown diameter, fructification (yield abundance), vitality and decorative value. Tree height was measured by the altimeter Haglof Vertex IV, and the trunk diameter at breast height was measured by tree calliper Mantax. The control group of 50 Norway spruce trees, at a distance of 100 m from the selected "plus trees", was chosen from a culture (1490 trees) that had been established in the 1970s.

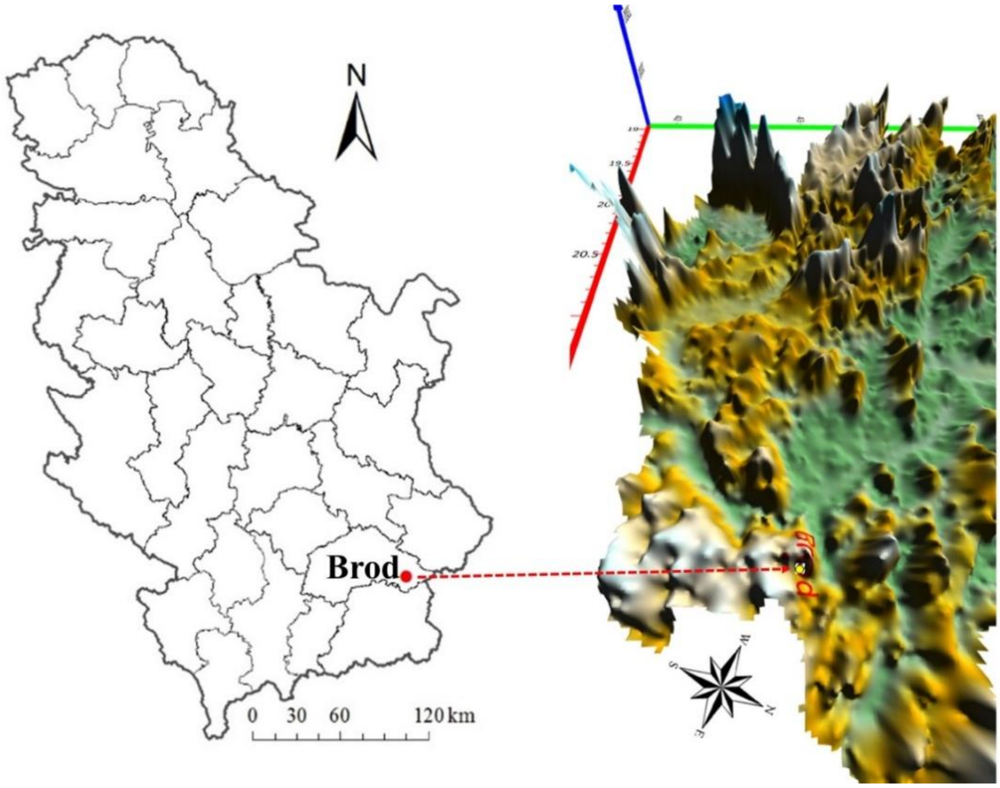

Figure 1. *The location of the village of Brod in the Crna Trava municipality, Mount Čemernik in Serbia*

Considering that phenotypic plasticity is the ability of one genotype to form alternative phenotypes in heterogeneous environmental conditions and that changes in development, morphology, and growth dynamics, potentially enable individuals to match their phenotypes with temporal and spatial variations in their immediate environment (Bradshaw, 1965; Sultan, 2003) according to Petrov and Ocokoljić (2022) the selective parameters are shown in *Table 1*. Individual characteristics are shown for "plus trees" and the mean value for the control group.

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Table 1. *Comparative characteristics of selected "plus trees" and control group of Norway spruce (2022)*

Tree	h (m)	d 1,30 (m)	Crown diameter (m)	Fructification (1-5)*	Vitality (1-5)**	Ornamental value (1-5)***
1	53.1	118	11.98	3	5	5
2	52.9	103	17.64	5	5	5
3	50.94	84	11.24	5	5	5
Mean value of control group	24,15	63.8	8.20	2.5	3.5	2.9

* Grade 2 - Number of cones 20>-≤40%; Grade 3 – Number of cones 40>-≤60%; Grade 5 - Number of cones (>90%).
** Grade 3: Individuals of average vitality, with some dead, broken or damaged branches, but in which it is possible to improve vitality through remedial management; Grade 4: Healthy individuals, with normal development but with minor stem defects; Grade 5: Healthy, normally developed individuals without visible signs of damage.
*** Grade 2: Damaged individuals that have reduced aesthetic value, where they have poor stem form, a dead crown, stem rot, or many damaged branches; Grade 3: Individuals of average ornamental value, with some defects, but whose appearance may be improved with management; Grade 5: Trees with well-developed stem form, growing in a location, that are aesthetically suitable

Field Sampling and Samples Processing

The research was conducted in the summer of 2022: July 29th, July 30th and August 18th, following the research methodology of Meerdink (2018) and Scherrer et al. (2011) who cite July and August as the most suitable months for monitoring surface temperatures using thermal imaging. The imaging days were, according to Ansari and Loomis (1959) and Grace (1988), selected based on climatic elements: clear/cloudy (a clear day with cloudiness less than 2/10) and wind speed (wind speed does not exceed 2 ms^{-1}, because a higher wind speed lowers the temperature on the leaf surface). Temperatures of Norway spruce leaves were registered by the thermal camera (hard, densely spirally distributed, dark green, and shiny, with a quadrangular section and 1-4 lines of stomata on all sides (Ocokoljić and Ninić-Todorović, 2003; Cvjetićanin et al., 2016)) in the sun, and for comparison, the imaging was made on the leaves and trunk bark (reddish-brown or gray, shallowly fissured (Ocokoljić and Ninić-Todorović, 2003; Cvjetićanin et al., 2016)) in the shade, as well as in the sun: dry grass, dirt road (macadam), asphalt and concrete (mortar) in a radius of 2 to 18 m relative to the selected trees, on unexposed terrain. TIR imaging was performed three times a day, at intervals of 60 minutes, on the 40 leaves of the focal tree and other areas at 12 pm, 1 pm, and 2 pm. Each measurement period was repeated for 4 times.

The method of thermal imaging (TIR) was used as a non-invasive method that does not disturb the environment whose temperature is measured because the thermal imaging camera collects data on the heat (infrared rays) emitted by the imaged surface. Namely, heat rays fall on the camera sensor, and depending on their intensity, a thermal image is formed on the display, i.e., a thermogram in the form of a spectrum of colors that represent the temperature of the surfaces being recorded. Infrared photographs were taken in the field using a thermal imaging camera FLUKE TiS45 (Fluke Corporation Everett, Washington, USA), with a resolution of 60x120 (19,200 pixels). FLUKE TiS45 infrared camera captures optimal images from as close as 0.15m (6in) provides a D:S of 257:1, offers a temperature measurement range from -20°C to 350°C (–4°F to 662°F), displays

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images on a 3.5 inch, 320x240 LCD and captures visible light images with built-in 5-megapixel industrial performance digital camera.

When measuring the temperature of different surfaces, the following emissions were taken: the emissivity for leaves was set to a value of 0.98, as recommended for bark 0.94, for dry grass 0.88, for macadam - dry soil 0.92, for concrete - mortar 0.9, and for asphalt 0.93 (Idso et al., 1969; Brewster et al., 1992; Kaňa and Vass, 2008).

The average distance between the camera and the leaves, trunk bark, and concrete was 1 to 2 m, and the imaging angle was horizontal (horizontally to the objects), while with dry grass, dry soil, and the asphalt the distance was 1 m, and the imaging angle was 45°. During the measurement, the camera was set to record both thermal and visual images simultaneously. A total of 117 infrared (TIR) and 117 visible photographs were taken. Smart View Classic 4.4 software was used for image analysis. The STATISTICA 10.0 program was used for statistical data processing.

Building Climate Data Chronologies

Cloud cover was observed visually (in tenths of 1/10), and wind speed (ms^{-1}) was measured with a handheld anemometer DEM6 in terms of TIR imaging. A digital multimeter “Mastech MS8209 professional” was used for measurements of the air temperature during the experiment at a height of 2 m, in the shade, near the selected trees. It can measure the temperature in the range from -20°C to 400°C with an accuracy of ± 3.0% at a resolution 0.1°C and range from -20°C to 1000°C with an accuracy of ± 3.0% at 1°C resolution. Additionally, two digital thermometers of the Duracell brand were used. Bearing in mind the sensitivity and possible deviation of the control instruments, in the paper we analyzed air temperature and its deviation in relation to the reference thirty-year period (1991-2020). Assessment of normality of mean monthly, mean daily, maximum monthly, maximum daily temperatures, and daily course of air temperatures was performed according to the method of Fries et al. (2012) by interpolation of data from 28 main meteorological stations of Republic Hydrometeorological Service of Serbia (RHMZ) and based on the percentile methodology (statistical criteria in climatology), in the Arc Gis/ ArcMap 10 program. In the aforementioned method for heatmap generation, the elevation gradient is taken into account for whose calculation a digital elevation model (DEM) and temperature data from meteorological stations are required. The altitude gradient method generates the new temperature values at a given altitude with greater reliability, especially for mountainous regions, and, therefore, the final interpolation of temperature data takes into account the altitude of the digital elevation model. In this work, the term "normal" refers to the climatological standard norm, i.e., mean and maximum values of the air temperature for July and August (1991-2020) and days of TIR imaging: July 29th, July 30th, and August 18th, for the corresponding reference period for Brod, i.e., the location where Norway spruce trees were isolated. Categories of mean and maximum daily, mean and maximum monthly temperatures are determined in relation to percentiles: extremely cold (< 2), very cold (>=2 - <10), cold (>=10 - <25), normal (>= 25 - <=75), warm (>75 <=90), very warm (>90 <=98) and extremely warm (>98). The nth percentile is the value of air temperature below which n percent of the data is found being previously arranged in ascending order.

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Results

Chronology of Air Temperatures

Given that the paper focuses on air temperatures based in relation to the referential thirty-year period, a trend of growth in mean annual air temperatures by 2.9°C was determined (*Fig. 2*).

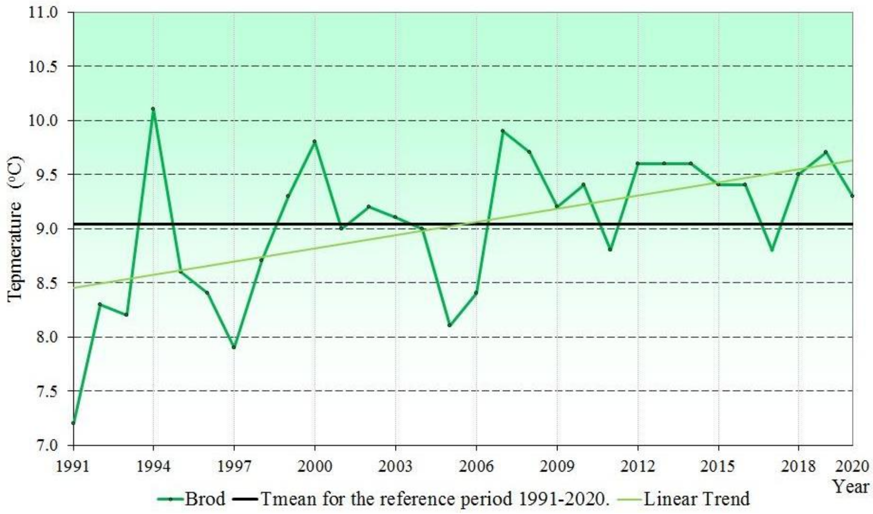

Figure 2. *Trend of mean annual air temperatures in the period 1991-2020*

Mean monthly air temperature during July, for the referential period 1991-2020 (norms), was 18.7ºC, and in August 18.9ºC. Spatial distribution of mean daily air temperatures for July 29th, July 30th and August 18th, for the same reference period (norms), is shown in *Figures 3 left, 4 left, 5 left* (19.3ºC, 19.5ºC, and 19.0ºC). The mean temperature on days during the research compared to the monthly norms for July and August were higher by 0.6ºC (July 29th), 0.8ºC (July 30th) and 0.1ºC (August 18th). Mean daily air temperatures, according to the percentile method, on July 29th and August 18th were within the category "warm", and on July 30th in the „normal" category (*Figs. 3 right, 4 right, 5 right*).

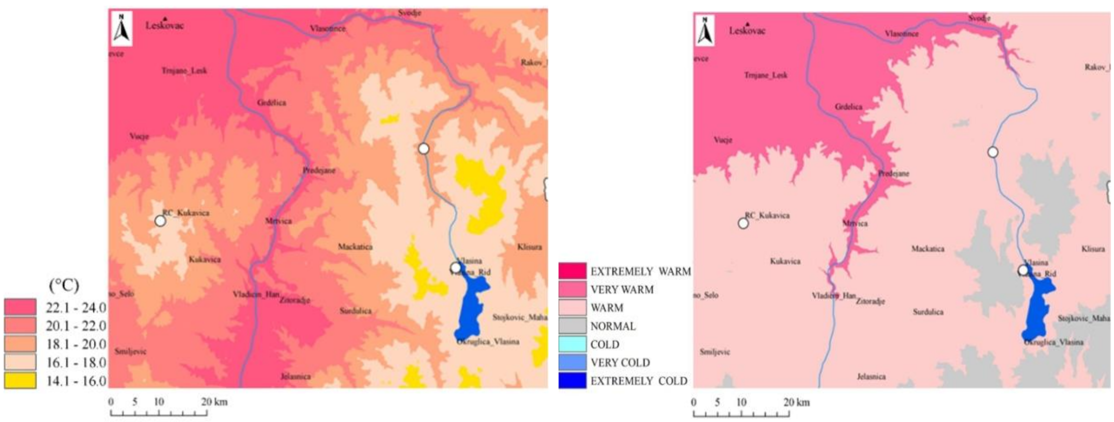

Figure 3. *The spatial distribution of mean daily air temperatures for July 29th (left) and based on the percentile method (right) in relation to the referential period 1991-2020*

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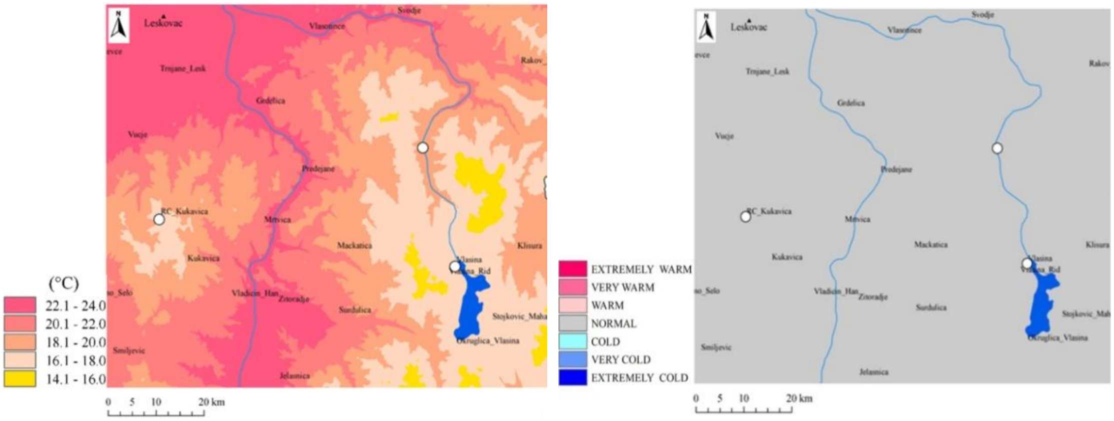

Figure 4. *The spatial distribution of mean daily air temperatures for July 30th (left) and based on the percentile method (right) in relation to the referential period 1991-2020*

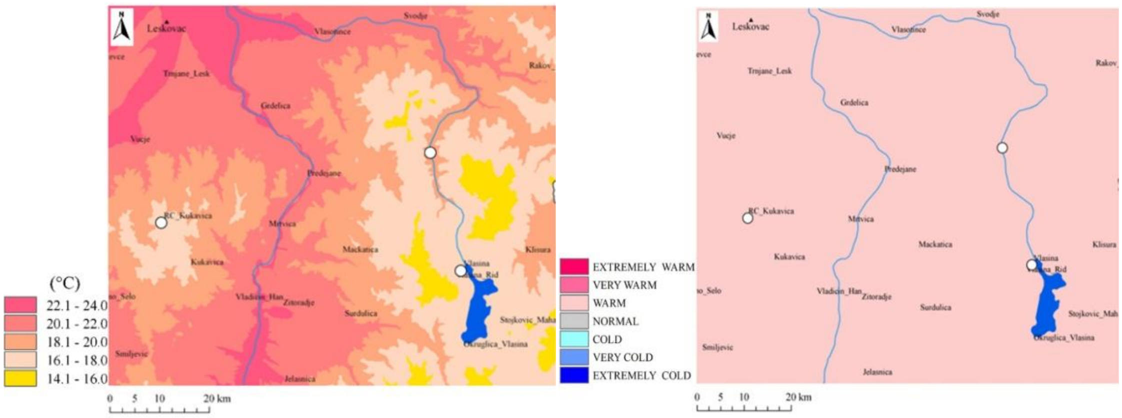

Figure 5. *The spatial distribution of mean daily air temperatures for August 18th (left) and based on the percentile method (right) in relation to the referential period 1991-202*

Mean maximum monthly air temperature (norm) for the referential period 1991-2020 in July is 25.7ºC, and in August 26.3ºC. Maximum temperatures for July 29th, July 30th and August 18th for the referential period (norm) is 26.2ºC, 26.4ºC and 26.8ºC. Normal maximum daily temperatures on the days of the research compared to normal average maximum monthly temperatures for July and August of the referential period were higher by 0.5ºC (July 29th), 0.7ºC (July 30th) and 0.5ºC (August 18th). Maximum daily air temperature, based on the percentile method, on July 29th and August 18th was in the „warm" category, and on July 30th in the „very warm" category.

Mean monthly air temperature in the research area in July 2022 was 19.3ºC, and in August 19.0ºC (*Fig. 6*). Mean daily air temperatures based on the percentile method in July 2022 were in the „warm" category, and in August 2022 in the „normal" category (*Fig. 7*). Deviations of mean monthly air temperatures in July and August 2022 compared to normal (mean monthly temperature for the period 1991-2020) were positive, that is, temperatures were higher by 0.6ºC (July) and 0.1ºC (August). The spatial distribution of mean daily temperatures for July 29th, July 30th, and August 18th for 2022 is shown in *Figure 8, 9, 10* (22.4ºC, 20.9ºC, and 21.5ºC). Mean daily temperatures in 2022 compared to the normal mean daily temperatures for the period 1991-2020. were higher by 3.1ºC

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(July 29th), 1.4ºC (July 30th) and 2.5ºC (August 18th). Deviations of maximum daily temperatures in 2022 in relation to the normal maximum daily temperatures for the period 1991-2020. were positive, i.e., temperatures were higher by 4.0ºC (July 29th), 5.6ºC (July 30th) and 4.0ºC (August 18th).

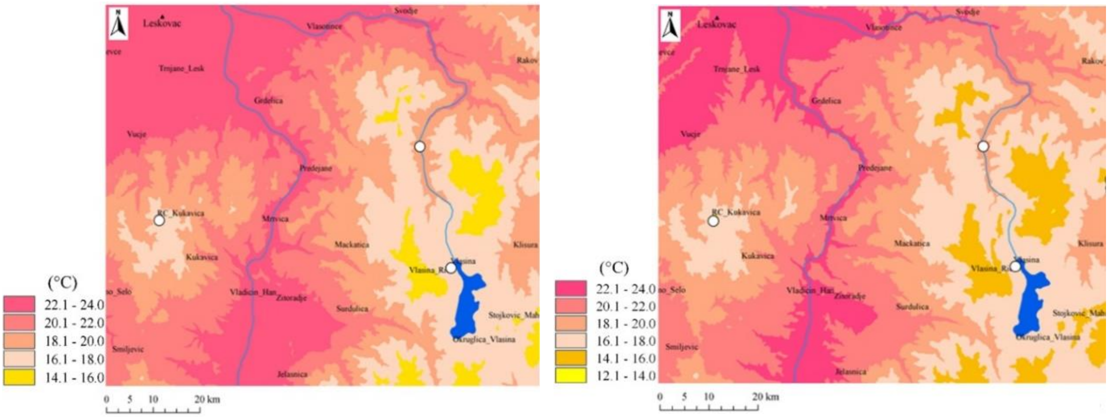

***Figure 6.** The spatial distribution of the mean monthly air temperatures in (ºC), for July (left) and August (right) 2022, in the research area*

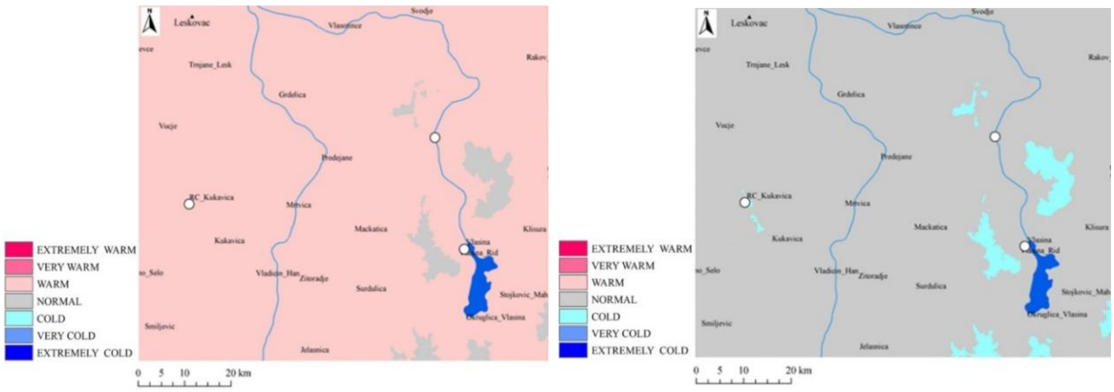

***Figure 7.** The spatial distribution of mean monthly temperatures based on the percentile method for July (left) and August (right) 2022, in the research area*

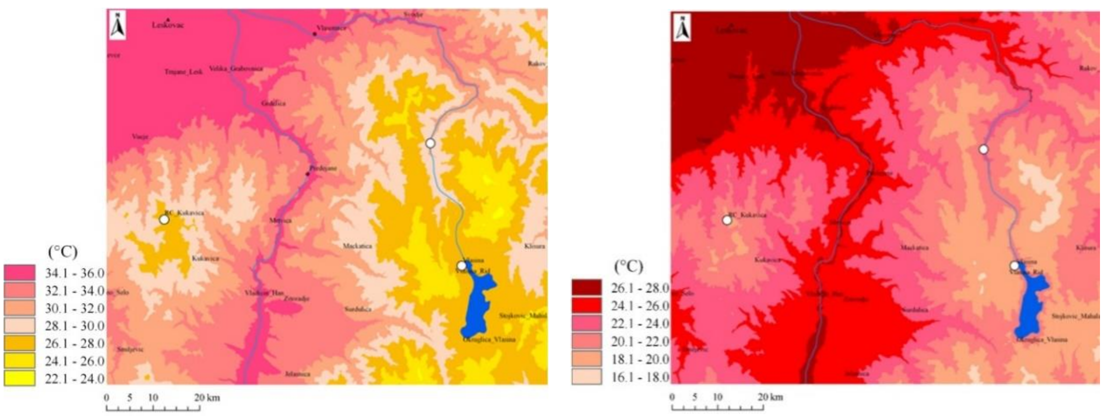

***Figure 8.** The spatial distribution of mean (left) and of maximum (right) daily air temperatures in (ºC), for July 29th, 2022, in the research area*

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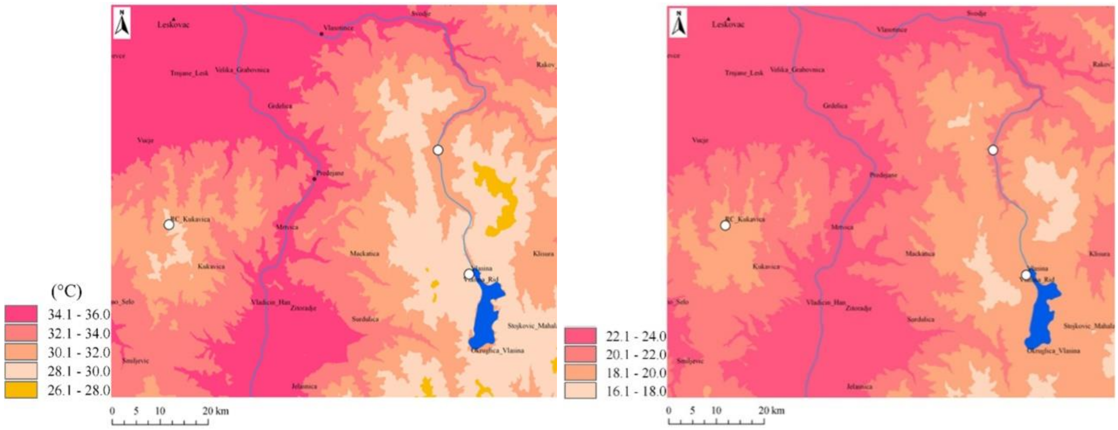

Figure 9. *The spatial distribution of mean (left) and of maximum (right) daily air temperatures in (ºC), for July 30th, 2022, in the research area*

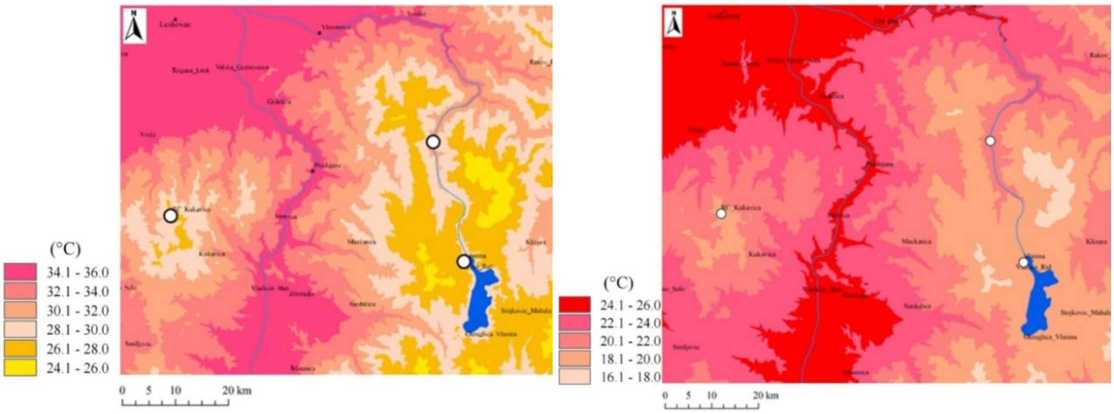

Figure 10. *The spatial distribution of mean (left) and of maximum (right) daily air temperatures in (ºC), for August 18th, 2022, in the research area*

Mean maximum monthly air temperature in the research area in July 2022 was 27.4ºC, and in August 26.8ºC. The deviations of the maximum daily temperatures for 2022 compared to the normal average maximum temperatures for July were positive, that is, the temperatures were higher by 4.5ºC (July 29th) and 6.3ºC (July 30th); and in relation to the norm of mean maximum temperatures in August, the temperature was higher by 4.5ºC (August 18th). The deviation of the maximum daily temperature for 2022 in relation to the normal mean maximum temperatures for July 30th was positive, i.e., the temperature was higher by 5.6ºC, while the deviation for August 18th was identical to July 29th (4.0ºC). Mean maximum monthly air temperatures based on the percentile method in July 2022 were in the "very warm" category, and in August 2022 in the „normal" category (*Figs. 11, 12*).

During the data collection, on the days and time of TIR imaging, the air temperature on three control instruments was in the range 25ºC to 27ºC.

Air temperatures in climatological terms, according to local time at 8 am, 3 pm, and 10 pm (UTC 6 am, 1 pm, and 2 pm), based on the interpolation method for the research days in 2022 are shown in *Figure 13*. Mean daily temperatures were 22.4ºC (July 29th), 20.9ºC (July 30th), and 21.5ºC (August 18th). The deviation of mean daily temperatures in

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2022 from normal mean daily temperatures for the referential period was positive, i.e., temperatures were higher by 3.1°C (July 29th), 1.4°C (July 30th), and 2.5°C (August 18th).

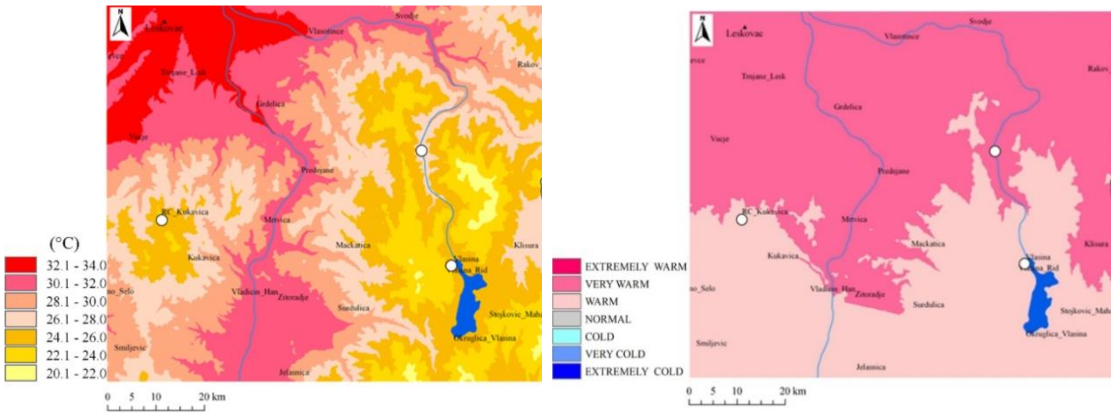

***Figure 11.** The spatial distribution of mean maximums monthly air temperatures in (°C) for July (left) and based on the percentile method (right) 2022, in the research area*

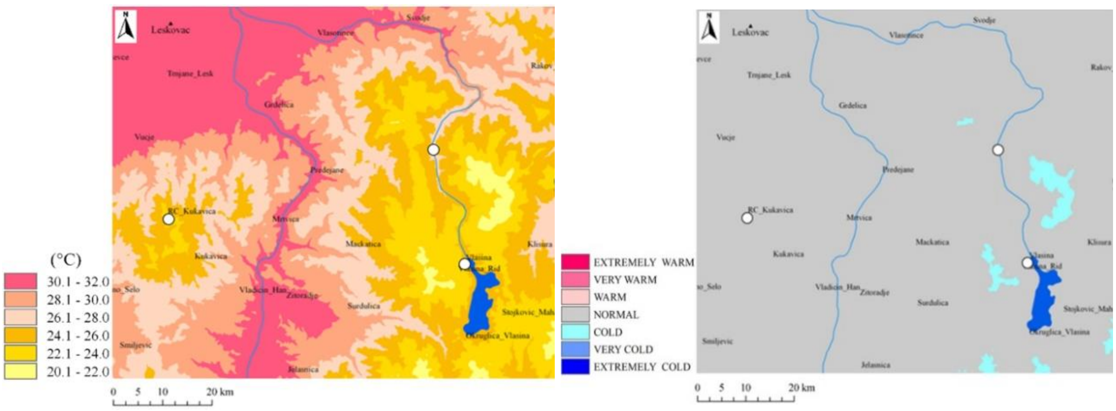

***Figure 12.** The spatial distribution of mean maximums monthly air temperatures in (°C) for August (left) and based on the percentile method (right) 2022, in the research area*

On all days, the maximum daily air temperatures were in the hours that followed the TIR recording: 30.2°C (July 29th), 32.0°C (July 30th), and 30.8°C (August 18th).

Cloud Cover and Wind Speed

Given that for TIR recording, it is necessary that the days are clear (by definition, these are days with cloud cover less than 2/10), and that the wind speed does not exceed 2 ms^{-1}, because a higher wind speed lowers the temperature on the leaf surface the values for the mentioned variables in terms of research are shown in *Table 2*.

During the data collection of TIR imaging, the cloud cover was 0 or 1/10, which confirms that the specified hours were in the clear category. The wind speed, depending on the term, varied from 1.4 to 1.9 ms^{-1}, so it could not affect the lowering of the leaf surface temperature, because it was lower than 2 ms^{-1}.

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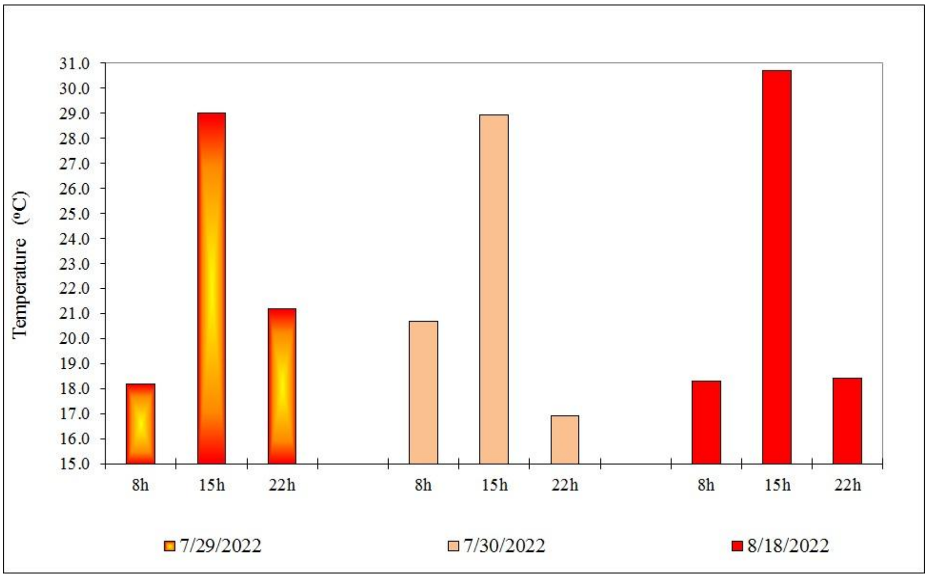

Figure 13. *Air temperatures in climatological terms, on the days of the research*

Table 2. *Cloud cover (1/10) and wind speed (ms^{-1}) by research days and time in 2022*

Parameter	Appointment	July 29th, 2022	July 30th, 2022	August 18th, 2022
Cloud cover (1/10)	12 pm	1/10	1/10	0/10
	1 pm	1/10	1/10	0/10
	2 pm	1/10	1/10	0/10
Wind speed (ms^{-1})	12 pm	1.8	1.9	1.5
	1 pm	1.4	1.5	1.9
	2 pm	1.9	1.8	1.9

Chronology of TIR Imaging of Norway Spruce Leaves and Control Surfaces

Table 3 shows the mean values of surface temperatures from 4 repetitions in the observation period, and the mean values for all research days, as well as the air temperature in specific hour of observation. By comparing TIR images of different surfaces, an ascending trend was found for all temperatures in the interval from 12 pm to 2 pm (*Fig. 14*). The mean temperature of Norway spruce leaves in the sun in days of the research, was July 29th, 2022: 31.0°C (tree 1), 31.3°C (tree 2), and 31.2°C (tree 3); July 30th, 2022: 31.0°C (tree 1), 31.1°C (tree 2), and 31.3°C (tree 3); and August 18th, 2022: 31.0°C (tree 1), 31.3°C (tree 2) and 31.2° C (tree 3). The mean temperature of leaves in the sun, for all research days, by tree was: 30.4°C (tree 1), 30.6°C (tree 2), and 31.0°C (tree 3). The average growth trend of leaf temperature in the sun in days of TIR imaging was 3.9°C (for tree 1 - 3.7°C, tree 2 - 3.9°C, and for tree 3 - 4°C). The mean temperature of Norway spruce leaves in the shade, during the days of the research was July 29th, 2022: 26.2°C (tree 1), 26.3°C (tree 2), and 26.4°C (tree 3); July 30th, 2022: 26.1°C (tree 1), 26.1°C (tree 2), and 26.4°C (tree 3); and August 18th, 2022: 25.9°C (tree 1), 26.1°C (tree 2) and 26.1°C (tree 3). The mean temperature of leaves in the shade, on all the days of the research by tree, was: 26.1°C (tree 1), 26.2°C (tree 2), and 26.3°C (tree 3). The average growing trend of leaf temperature in the shade during the TIR imaging was 0.5°C

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(for tree 1 and 2 - 0.5°C; and for tree 3 - 0.6°C). Temperature scaling of TIR images of leaves and control surfaces is shown in *Figure 14*. The mean temperature of leaves in the sun at 12 pm, for all trees on all days of the research, was 28.7°C, which is 2.8°C higher than the temperature of leaves in the shade in the same month at the time of TIR imaging. The difference between the mean values of leaf temperatures in the sun and in the shade in the period of TIR imaging at 2 pm, was 6.2°C. Comparative analysis showed differences between all TIR recorded surfaces. The bark of the trunk, whose mean temperatures on all days of the research, were 21.7°C (term 12 pm), 21.9°C (term 1 pm), and 22.6°C (term 2 pm), was distinguished as the surface that heated up the least. The temperature of the bark of the trunk was lower than the temperature of the leaves in the sun by: 7°C, 9.7°C, and 10°C at the same time of the TIR imaging. The lowest recorded temperature of the bark of the trunk was 18.2°C (August 18th, 2022, at 12 pm, tree 1), and the highest was 24.9°C (July 30th at 2:15 pm, tree 3). The mean temperature of leaves in the shade for all research days and all trees was higher than the average temperature of the bark of the trunk (which ranged from 3.8°C to 4.2°C).

Table 3. *Temperatures (°C) of researched parameters and air by research days and times in 2022*

Parameter	Appointment	July 29th, 2022	July 30th, 2022	August 18th, 2022	Mean value
Leaves in the sun	12 pm	28.8	28.8	28.6	28.7
	1 pm	31.8	31.7	31.4	31.6
	2 pm	32.9	32.8	32	32.6
Leaves in the shade	12 pm	25.9	25.9	25.8	25.9
	1 pm	26.4	26.3	26.1	26.3
	2 pm	26.5	26.4	26.2	26.4
The bark of the Norway spruce trunk	12 pm	21.8	21.7	21.6	21.7
	1 pm	22.1	21.9	21.8	21.9
	2 pm	22.7	22.6	22.5	22.6
Dry grass	12 pm	39.5	39.6	38.9	39.3
	1 pm	42.7	42.7	42.0	42.5
	2 pm	43.7	43.7	43.1	43.5
Macadam - dry land	12 pm	34.9	34.8	34.6	34.8
	1 pm	37.9	37.9	37.6	37.8
	2 pm	39.5	39.5	39.1	39.4
Concrete - mortar	12 pm	27.8	27.7	27.4	27.6
	1 pm	31.4	31.3	31	31.2
	2 pm	32.8	32.8	32.6	32.7
Asphalt	12 pm	42.5	42.5	42.4	42.5
	1 pm	44.1	44	43.8	44.0
	2 pm	47.5	47.3	46.9	47.2
Air temperature	12 pm	24.7	26.5	26.0	25.73
	1 pm	26.4	26.7	26.3	26.47
	2 pm	27.0	26.9	27.0	26.97

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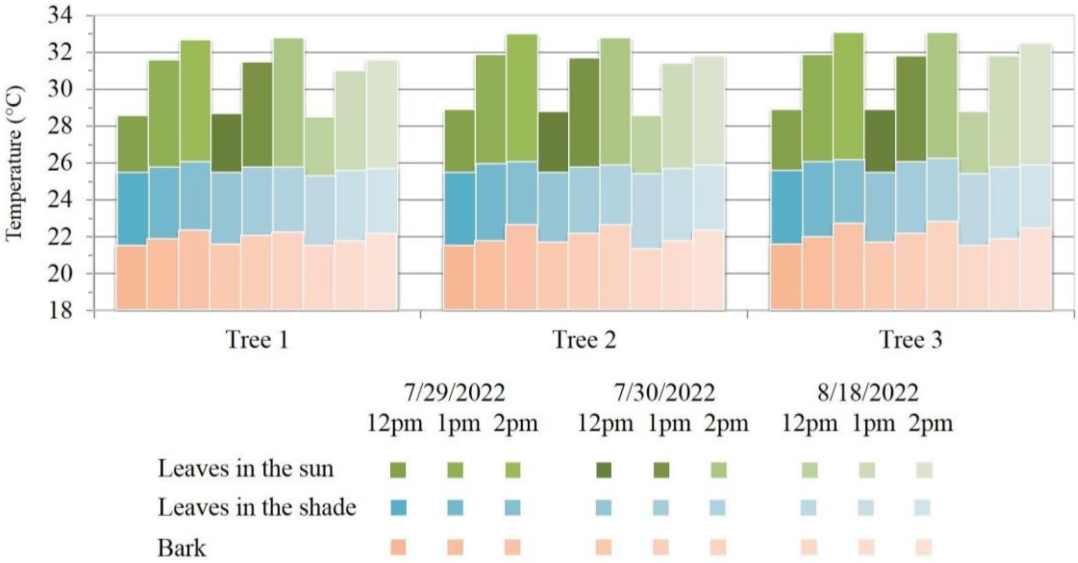

Figure 14. *Trend of TIR temperature (°C) of leaves and bark of Norway spruce trunks, for selected trees, by days and time of research in 2022*

It was found that the dry grass had very high temperatures. The mean values were from 39.3°C to 43.7°C (in the interval from 12 pm to 2 pm), which is 10.6°C to 10.9°C higher than the mean temperature of leaves in the sun.

Out of all the researched inert materials, concrete had the lowest mean temperatures on all the days of the research, from 27.6°C to 32.7°C (in the interval from 12 pm to 2 pm), while asphalt stood out as a material whose mean temperatures on all the days of the research had the highest values from 42.5°C (at 12 pm) to 47.2°C (at 2 pm). TIR images confirm a significant difference between the temperatures of inert surfaces compared to the leaves in the sun. The mean temperature of leaves in the sun, for all trees, was lower than the temperature of the asphalt by 12.4°C (at 12 pm) to 14.6°C (at 2 pm). Mean asphalt temperature values were higher by 14.5°C (at 2 pm) to 14.9°C (at 12 pm) than the concrete surface. The absolute maximum recorded asphalt temperature was 48.2°C (July 29th, 2022, at 2 pm).

The mean temperature values of dry soil (macadam) were higher than leaves in the sun by 6.1°C (at 12 pm). TIR images of concrete surfaces at 2 pm (32.7°C) and leaves in the sun (average value for all trees and days - 32.6°C) indicate that the temperature of the leaf surface was lower by 0.1°C, but concrete heated up faster and more intensively, which confirms the increase in concrete temperature by 4.7°C in the third period of observation compared to the first.

Analyzing the TIR images by research days (*Fig. 15*), August 18th, 2022, stands out as the day in which temperatures lower than 0.1°C were recorded for all surfaces (for leaves in the shade, as well as asphalt at 12 pm, compared to measurement days in July) up to 0.9°C (for leaves in the sun at 2 pm, compared to July 29th, 2022). The smallest differences occur between August 18th, 2022 and July 30th, 2022 for the temperatures of the leaves in the shade (0.1°C at 12 pm, 0.2°C at 1 pm, 0.2°C at 2 pm) and the bark of the trunk (0.1°C at 12 pm, 0.1°C at 1 pm, 0.1°C at 2 pm), while for the dry grass the differences compared to July 29th, 2022, were 0.6°C, 0.7°C and 0.6°C (at 12 pm, 1 pm and 2 pm) and 0.7°C, 0.7°C and 0.6°C (at 12 pm, 1 pm and 2 pm) compared to July 30th,

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2022. The average temperature of the leaf surface in the sun for all trees, was: July 29th, 2022 - 31.2°C, July 30th, 2022 - 31.1°C, and August 18th, 2022 - 30.7°C, for leaves in the shade 26.3°C (July 29th, 2022), 26.2°C (July 30th, 2022), and 26.0°C (August 18th, 2022), while for the bark of the trunk it was 22.2°C (July 29th, 2022), 22.4°C (July 30th, 2022), and 22.1°C (August 18th, 2022).

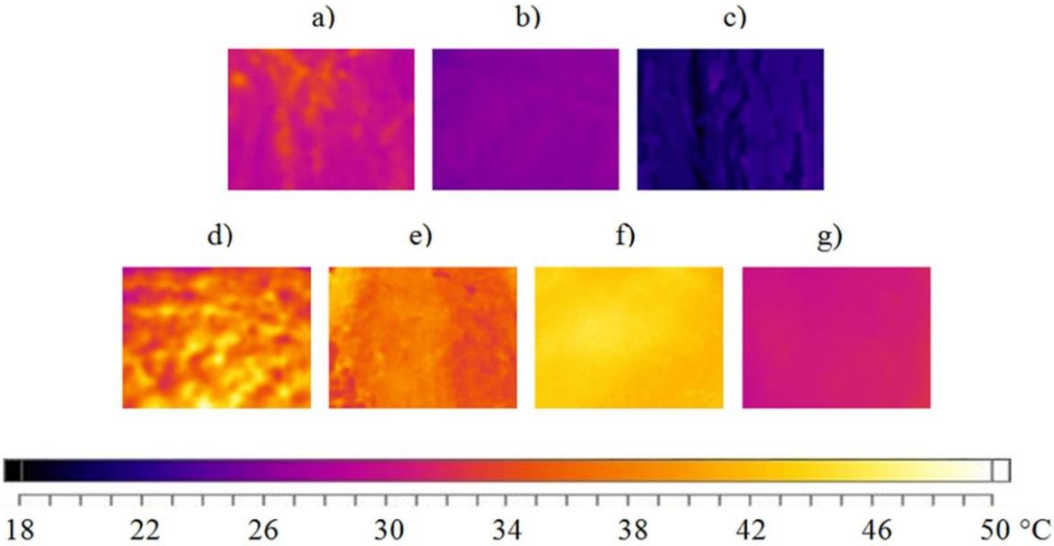

***Figure 15.** Infrared images (TIR) from August 18th, 2022, with temperature distribution: a) leaves in the sun, b) leaves in the shade, c) trunk bark in the shade, d) dry grass in the sun, e) dry soil in the sun, f) asphalt in the sun and g) concrete in the sun*

Of all the selected Norway spruce tree, tree 1 stands out, which, on all days of the research, had the lowest surface temperatures (leaves in the sun, leaves and the bark in the shade). The smallest difference was recorded in the leaves in the shade and the bark of the trunk. The mean values, for all days, differed by 0.2°C (from tree 2) and 0.4°C (from tree 3) for leaves in the sun, 0.1°C (from tree 2) and 0.2°C (from tree 3) for leaves in the shade, and 1.1°C (from tree 2) and 1.2°C (from tree 3) for the bark of the trunk in the shade. In the days of TIR imaging (July 29th, 2022, July 30th, 2022, and August 18th, 2022), the mean temperature of leaves in the sun of tree 1 was the lowest at all times (31.0°C, 31.0°C, and 30.4°C), while for tree 2 recorded values were: 31.3°C, 31.1°C, and 30.6°C; and for tree 3: 31.3°C, 31.3°C and 31.0°C. Tree 1 stands out in medium temperatures of leaves in the shade with the lowest average temperature during imaging (26.2°C, 26.1°C, and 25.9°C), while the values for other trees were: tree 2 - 26.3°C, 26.1°C and 26.1°C; and for tree 3 - 26.4°C, 26.4°C and 26.1°C. Also, the mean temperature of the bark surface had the lowest values in tree 1, and the highest in tree 3. The mean bark temperatures of tree 1, at all times, were: 22.1°C, 22.2°C, and 22.0°C, while in tree 2 were: 22.2°C, 22.4°C, and 22.0°C; and for tree 3: 22.3°C, 22.5°C, and 22.2°C. In tree 3, on July 29th, 2022, at 2 pm and July 30th, 2022, at 2 pm the highest temperature of leaves in the sun were recorded (33.1°C); on July 30th, 2022, the highest temperature of the leaves in the shade (26.7°C at 2 pm), as well as the highest temperature of the bark of the trunk at 2 pm (23.1°C) were recorded. Tree 3 stands in higher mean leaf temperatures in the sun on all days of the research (31.2°C) compared to tree 1 (30.8°C) and tree 2 (31.0°C); as well as for the leaves in the shade (26.3°C) compared to tree 1

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(26.1°C) and tree 2 (26.2°C), and trunk bark (22.3°C) compared to tree 1 (21.1°C) and tree 2 (22.2°C), which implies that the difference is caused by the position of the trees.

Analysis of TIR images at different times showed that for all surfaces, all trees, and on all the research days, the temperature had an increasing trend in the interval from 12 pm to 2 pm. The trend of temperature growth ranged from: 0.5°C for the leaves in the shade, over 0.9°C trunk bark in the shade, 3.9°C for leaves in the sun, 4.2°C for dry grass, 4.6°C dry soil (macadam), 4.7°C asphalt to 5.1°C for concrete. The highest increase was recorded for concrete temperatures and the lowest was for leaves in the shade.

The air temperature recorded on the control instruments was 3.7°C to 5.6°C lower than the temperature of the leaves in the sun and was close to the temperature values of leaves in the shade.

Discussion

Fluctuation of Climatic Variables: Mean and Maximum Air Temperature

Considering the period of research implementation, it is important to state that July 2022 was the fifth warmest July in Serbia for the period 1951-2022, with two heat waves and recorded summer and tropical days (Monthly Bulletin for July 2022, RHMZ). According to the Monthly Bulletin for August 2022 (RHMZ), depending on the region, August 2022 was very warm and warm without heat waves (based on the percentile method, the period during which the maximum daily air temperature was in the category “very warm” and “extremely warm” lasted for 5 or more consecutive days). In Serbia, summer days were registered (those are by definition days with a maximum daily air temperature of 25°C and above), as well as tropical days (by definition days with a maximum daily air temperature of 30°C and above). In the location where the Norway spruce monoculture is, all days during the research were tropical with a temperature higher than 30°C.

Comparative analysis of the mean monthly and the mean maximum monthly air temperatures to the referential period and to the yearly averages, the increase was registered in mean monthly values by 0.1ºC (August) to 0.6ºC (July); while in the mean maximum temperatures, the increase was in the interval of 0.5ºC (August) to 1.7ºC (July). The increase in mean daily temperatures on the days of the research for referential period, compared to the mean monthly temperatures for July and August for the same referential period, was significant. Temperatures were higher by 0.6ºC (July 29th, 2022), 0.8ºC (July 30th, 2022), and 0.1ºC (August 18th, 2022). An increase in the maximum daily temperatures on the days of the research for referential period was evident, compared to the mean maximum monthly temperatures for July and August of the same referential period by 0.5ºC (July 29th and August 18th) and 0.7ºC (July 30th). Our research confirms the findings from the Second National Report of the Republic of Serbia to the Framework of the United Nations Convention on Climate Change (2016), according to which there is a visible growth in mean, maximum and minimum daily temperatures, as well as that the growth of temperatures in Serbia is faster than average growth of annual temperatures on a global scale. The scenarios predict a further increase in the concentration of gases with a greenhouse effect in the atmosphere which would be close to the growth trends observed in the past years, so further increase in mean annual, mean monthly, and mean maximum monthly temperatures in Serbia can be expected by the end of this century (EPA, 2005).

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The fluctuation of the analyzed climate variables is in accordance with the IPCC (2012) which states that significant changes have occurred in the past decades in the frequency and intensity of extreme events, especially those caused by high temperatures.

For monitoring of changes in biodiversity and the impact of local climate changes on Norway spruce resilience, it is necessary to establish a standardized monitoring system. Changes in natural systems that occurred as a result of local climate changes have been confirmed by many studies (IPCC, 2007). Longitudinal shifts in the range of some species and changes in their altitude distribution, changes in phenophases, changes in migrations, and duration of the vegetation period were recorded. Research by Pauli et al. (2012) confirms the impact of climate change on the distribution of plants on high mountain peaks in Europe, especially in Southeastern Europe. Nevertheless, biodiversity monitoring in Serbia is carried out on a small number of species and habitats, and it is expected that the areal for some species will shift in latitude and altitude, that the retreat of certain forest communities might appear, and changes in the composition of plant communities are expected, as well as changes in tolerance of some species to light (Medarević et al., 2007). In this regard, it is important to note that the southernmost part of the Norway spruce areal is located on the Balkan Peninsula, which has the form of a peripheral or disjoint area, and that the analyzed trees were introduced to the Brod locality, where Norway spruce is not indigenous. Given that Lagercrantz and Ryman (1990) state that Norway spruce is in a constant process of genetic differentiation and adaptation, and that gene flow occurring today contributes to genetic variability, ways of using reproductive material require an understanding of intraspecific variation in relation to climate, which can only be realized through adequate testing of environmental conditions (Konnert et al., 2015). In this sense, this study's importance is in the testing of selected trees of Norway spruce at the age of 97, in conditions of air temperature fluctuations and evaluation and confirmation of their resilience to the aforementioned climatic variables.

Comparison of Temperatures from TIR Images

Considering that the survival and growth of Norway spruce are dependant on edaphic and climatic conditions, and that climate changes will directly affect the resilience and the spatial distribution of the species, the paper develops a method of detecting and monitoring Norway spruce stress as a key factor for protecting existing and planning future population (Šagát et al., 2021). We applied thermography as a technique which can be used to monitor changes in the state of plants, which has not been widely tested or used in forestry and landscape architecture practice.

The study confirmed the correlation between the TIR images of leaves in the shade and the recorded control air temperatures in the shade, as well as that the bark temperature of the trunk is the lowest. The obtained results are in accordance with the findings of Martin et al. (1999) that TIR images of canopy leaves of evergreen plants have significantly lower temperatures than broad-leaved ones. The same authors link the lower temperatures in conifers with the dimensions of the leaves, that is, they indicate that the smaller leaves of conifers are more tightly related to the surrounding air. The narrow distribution of TIR images between leaves in the shade and in the sun could be related to the position of the stomata, which are common in conifers and distributed in 1 up to 4 lines on each side of the leaves (Kouwenberg et al., 2003).

Experiments with tree seedlings and TIR imaging of adult trees proved the existence of different values between species, especially between conifers and deciduous trees. The

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above illustrates the potential influence of the species on surface temperatures. The composition of the forest or green areas has an important impact on the local climate because it affects the amount of light that reaches the soil, but also the exchange of gases (Ellison et al., 2017). A study by Renaud and Rebetez (2009), in which species with larger leaves are analyzed, confirmed that they have a stronger impact on regional cooling (lowering air temperature) than conifers, and a similar effect was shown in studies in the temperate zone (Naudts et al., 2016). Differences in leaf scale translate into tree scale and its impact on balance and microclimatic conditions (Klein et al., 2013).

TIR images of the bark of the trunk are in accordance with the statements of Sedmáková et al. (2019) that tree canopies affect changes in microclimate conditions by lowering air temperature during the summer months. The mean daily temperature of the trunk bark of the selected trees, at the time of the imaging, was 21.7°C, 21.9°C, and 22.6°C, which compared to the mean daily temperature of leaves in the sun was lower by 7.0ºC (12 pm), 9.7ºC (1 pm), and 11.1ºC (2 pm). Trees and climate change are in a specific relationship in which local climate change threatens to destroy it by increasing the air temperature while trees, especially forests, mitigate the effects of climate change. Local climate changes can cause the disappearance or retreat of species such as Norway spruce, which is important for the functioning of mountain ecosystems. Ecosystems can tolerate a certain level of climate change, i.e., their natural adaptability is the extent of disturbance that the ecosystem can withstand before it goes into an unstable state (Park Williams et al., 2013).

The research confirmed the hypothesis published in the studies of Ocokoljić and Milenković (2002) and Babić et al. (2012) that inert surfaces heat up more compared to plants (leaves in the sun, and leaves and trunk bark in the shade). A comparative analysis of the mean daily temperatures of concrete, at the time of the imaging, found that they were lower compared to the mean daily temperatures of asphalt. The absolute maximum temperatures of asphalt and concrete were: 47.5°C (July 29th) and 32.8°C (July 29th and July 30th). The hypothesis was not confirmed in dry grass where significantly higher average temperatures were recorded compared to the mentioned variables. Based on the data of TIR images, it was determined that the temperature of dry grass was higher than the temperature of leaves in the sun by 10.6ºC to 10.9ºC, and higher compared to the temperature of concrete by 10.8ºC to 11.7ºC.

The study confirmed that due to the increase in air temperature, a longer vegetation period, and variable amounts of precipitation, meadows and pastures in Serbia are increasingly left without enough water for regeneration. It was planned to record the natural grassland by TIR during the field experiments, but due to the lack of precipitation, the vegetation of the meadows has been exposed to drought since the end of May, which is why the TIR of dry grass was recorded. Namely, data from the Department for Climate Monitoring and Climate Change forecasts RHMZ (http://www.hidmet.gov.rs) for the period May to August 2022 confirm that the research region is characterized as very warm and warm (91-98 percentiles and 76-90 percentiles) and extremely dry to dry (< 2 percentile or 10-24 percentile). The research confirmed the findings from the studies of McDowell et al. (2011) and Stričević et al. (2021) that the increase in water deficit, extreme temperatures, and the length of the dry period will lead to changes in the ecosystem, which is why the primary task in the coming period will be how to adjust the use of natural grasslands and preserve their floristic composition.

In studies that are carried out under conditions of climate change, albedo has a great importance in the energy balance of the surface. Namely, part of the reflected solar

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radiation is absorbed by the soil or vegetation, which affects the increase in temperature or the rate of evapotranspiration (Wang et al., 2022). Part of the absorbed energy is transformed into heat that is re-radiated. The albedo value varies daily and seasonally due to the change in the angle of solar radiation (Jones, 1992), and in our study TIR recordings were performed during the summer, in the hours when the angle is the largest. It is particularly noteworthy that the study confirmed that all research days were tropical days by definition, and that the maximum daily air temperatures according to the percentile method on July 29th and August 18th were in the "warm" category, while July 30th was in the "very warm" category. The deviation from the "normal" category is evident and confirms the high intensity of the Sun's radiation. In this regard, the culture of Norway spruce at an age of about 50 years, near the selected trees, is multi-layered and has a low albedo because the radiation penetrates into the lower layers, reflecting between the branches and leaves in the canopy (Matthews, 1984). The focus of our study and the TIR imaging are related to selected Norway spruce trees that are isolated in a sunny location. Despite the fact that Norway spruce is a sciophilic species (Cvjetićanin et al., 2016), the selected "plus" trees reached the age of 97 years, heights from 50.94 to 53.1 m, have maximum vitality, without diseases and damage, with distinct aesthetic values and the crown that is formed right from the soil. Given that surface roughness affects reflection: shiny and smooth surfaces such as plant leaves have a high albedo even for smaller angles of solar radiation (Matthews, 1984), the result of this research is significant because TIR images of leaves in the sun were made on isolated trees, on leaves with highest angle of sun's radiation. Namely, the average growth trend of leaf temperature in the sun was 3.9°C, and in the shade 0.5°C. Surfaces with a rougher texture (such as the bark of the trunk) have lower albedo values, especially when the solar radiation is at a small angle, and also go through between branches and leaves (Dobos, 2003), which is in accordance with the results of our study. Depending on the selected tree, the bark temperature ranged from a minimum of 18.2°C (tree 1) to a maximum of 24.9°C (tree 3). For the surfaces that were compared, their texture is important, because fine-textured dry soil has a high albedo due to a relatively smooth surface, while moist clay soils have a lower albedo due to the absorption of incoming radiation. The content of organic matter increases soil absorption, so the albedo is lower with an increase of organic matter. But the presence of salt on the surface drastically increases albedo (Matthews, 1984), which could be the cause of high values during TIR imaging of dry grass. All TIR imaging in this study were performed with a thermal imaging camera with correction factor, in order to obtain adequate data and taking albedo into account.

Our study confirms the importance of using TIR images in determination of the differences in the natural environment. Special attention should be paid to the differences in the biological properties of the species (size and shape of the leaf), as well as to the properties of inert materials. Understanding the behavioral patterns of trees is the key to management and planning in the face of local climate change. The obtained results confirm the necessity of conducting permanent experimental research on the influence of heat waves and extreme temperatures on resilience, and therefore on the distribution of Norway spruce (Popa et al., 2022).

Further Research Suggestions

Despite using several methods to determine the air temperature in the paper, we believe that for future, long-term, research it would be beneficial to set up an automatic meteorological station in the town of Brod.

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Nevertheless, the applied methods are adequate and provide an update of the data that can be used and presented as a reflection of local climate changes and the resilience of the selected trees, as they refer to the period 1991-2020, as well as 2022 when the research was carried out. For future research on climatic elements, precipitation should be analyzed, because some authors report a significant mixed effect of precipitation and air temperature on the growth and development of Norway spruce (Vitali et al., 2018). Therefore, the subject of further research would be the assessment of Norway spruce resilience using the aforementioned mixed variable. Other factors also affect the survival of Norway spruce: anthropogenic pollution (Altman et al., 2017) as well as an increase in ozone concentration (Jurán et al., 2021), water status, transpiration intensity, etc. (Klimešová et al., 2021). The assessment of Norway spruce resilience should include all climatic elements and the mentioned variables in future studies, which should be carried out in other stands and cultures, especially "plus" trees selected in Southeast Europe.

Our study, although it was not its primary task, confirmed that the variable amount of precipitation causes a water deficit, and extreme temperatures and the length of the dry period lead to changes in the ecosystem, which is why we propose to carry out studies in the future that would be the basis for the use of natural lawns and preservation of their floristic composition.

Conclusion

In this research, Norway spruce leaf temperatures were analyzed as indicators of the resilience of the species as well as the air temperatures as climate variables, as indicators in the context of local climate changes, in the period 1991-2020. A comparison was made of mean monthly, mean daily, maximum monthly, maximum daily, and daily trends in the air temperatures in the year 2022, compared to the period 1991-2020. for the Brod location, in Southeastern Europe. An increase in all climate variables was recorded in the interval 0.1ºC to 1.7ºC, which confirmed previous findings that the growth of temperatures in Serbia is faster than the average growth of the annual temperatures at the global scale.

A comparison was made between the surface temperatures of leaves and different surfaces through TIR images. Temperatures of leaves in direct sunlight compared to the temperatures of the leaves in the shade were higher by 2.8°C (at 12 pm), and at 2 pm by 6.2°C. But the research clearly showed that Norway spruce leaves in the sun have approximately the same values as concrete, while asphalt had higher temperatures by 12.4°C (at 12 pm) to 14.6°C (at 2 pm). The bark of the trunk was the surface that warmed the least, with a temperature lower by 10°C at 2 pm compared to the temperature of the leaves in the sun. All analyzed surfaces had a trend of increasing temperatures during the day from 12 pm to 2 pm, which is expected considering the daily course of air temperature and insolation.

Obtained results are applicable mainly in forestry and landscape architecture. They can contribute to the understanding of local impacts of climate change, i.e., increase of the air temperatures, on the resilience of Norway spruce trees, which enables managers, planners, and designers to make decisions. They are also the basis for further research of thermal data in rural areas, as well as their comparison with the urban climate. Local climate change affects the changes in the species' habitat and the distribution of species, so the data obtained by TIR technology facilitate the study of thermal variations and indicate the resilience of the selected Norway spruce trees, which further indicates the

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same response to fluctuations of the analyzed climatic variables as it would have been in the case of climate change. Namely, all selected trees are 97 years old and of maximum vitality.

In conclusion, the research implies the necessity of broader research of TIR imaging on other mountains of Serbia in stands and plantations of Norway spruce, and especially on individual level to confirm the resilience to summer temperatures due to the specificity of the local climate.

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