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WYBRANE ZAGADNIENIA Z BIOKLIMATU TATR – ASPEKTY BIOKLIMATU ROŚLIN I BIOKLIMATU CZŁOWIEKA

SELECTED ASPECTS OF THE TATRA MTS. BIOCLIMATE – LOCAL (PLANTS) AND REGIONAL (HUMANS) PERSPECTIVES

1. Introduction

According to definition of the International Society of Biometeorology: "Biometeorology is an interdisciplinary science studying the interactions between atmospheric processes and living organisms – plants, animals and humans. The most important question that biometeorology answers is: *How does weather and climate impact the well-being of all living creatures?*" Biometeorological and bioclimatic research are carried out on different spatial and temporal scales, i.e. from micro to global and from momentary to multiannual.

The main feature of mountain areas is altitudinal zonality of atmospheric processes and climate. Firstly, it is the effect of the gradient of the air temperature, linked with the increase of altitude. This is considered as a background to establish climate zonality in mountain areas using the Köppen-Geiger scheme of global climate classification (Rubel et al. 2017). Altitudinal gradients are also observed at other elements and indicators of climate (e.g. solar radiation, length of vegetation period, precipitation, snow cover; Błażejczyk et al 2013; Błażejczyk 2019; Błażejczyk, Skrynyk 2019). This regularity, typical for the mountains of

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every latitude, has been a subject of interest for the explorers and scientists since von Humboldt's time (Löve 1970). Altitudinal gradients of climate variable cause zonation of the vegetation which determine of the climatic-vegetation. Among the mountains of Europe the Tatra Mts. are one of the areas where, similarly as in the Alps, the climatic and geobotanical studies have been conducted since the beginning of the 20^{th} century and brought numerous synthetic accounts on both climate (e.g. for Alps – Fliri 1975; Franz 1979; for Tatra Mts. – Konček 1974; Niedźwiedź 1992) and vegetation (Alps – Ozenda 1988; Ellenberg 1996; Tatra Mts. – Hadač 1962; Pawłowski 1972; Mirek, Piękoś-Mirkowa 1992a, b).

In general, the method used for the distinction of vegetation belts in the Tatra Mts. is constituted by the floristic differences and the so-called guide-associations, that is – the dominating associations, characteristic for a given altitude belt (Pawłowski 1927, 1972; Piękoś 1968). The climatic belts in the Tatra Mts., distinguished by Hess (1965, 1966), represent the 2-degree changes in mean annual air temperature in the altitudinal profile from –4°C (cold) to +6°C (temperate cool). They have counterparts in the vegetation belts (Pawłowski 1927, 1972; Mirek, Piękoś-Mirkowa 1992a, b; Piękoś-Mirkowa, Mirek 1996). The altitude limits of the climatic and vegetation belts coincide in the majority of cases (Table 1). The differences in the limit altitudes of the belts, determined according to the climatic and geobotanical criteria, are sufficiently small for associating these two phenomena and for speaking of the climatic-vegetation altitude belts, and, considering the activity of the contemporary morphogenetic processes and the relief forms, of the geoecological belts (Kotarba 1976). The specificity and intensity of landforming processes are a consequence of the complex geological structure of the Sucha Woda Valley. Its northern part is composed of sedimentary rocks of the peak and montane series. The southern part, on the other hand, is adjacent to the crystalline core of the Tatras and belongs to the so-called Goryczkowa crystal island with quartzite sandstones, on which non-carbonate soils are developed (Długosz 2013). Specific acidophilous vegetation has developed on them (Kozłowska 2013).

In the research on plant bioclimate, interactions between the vegetation cover developed in a given area and other environmental factors are very important. They shape specific features of the radiation balance and heat balance (Paszyński et al. 1995; 1999). In the Tatra Mts., preliminary research in this area was conducted by Baranowski (2004), who proved that the microclimate of the near ground air layer is the effect of the impact of the vegetation cover on the amount of absorbed solar radiation and long wave radiation from the ground.

Table 1. Climatic and vegetation belts in the Polish Tatra Mts. Compiled from Hess (1965), Mirek and Piękoś-Mirkowa (1992b). Actual vegetation after Kozłowska (2006).

Climatic belt	Average annual temperature (°C)	Altitude m a.s.l.	Vegetation belt	Altitude m a.s.l.	Plant formation	Actual vegetation
cold	between –4 and –2	2200-2663	subnivale	above (2250)2300-1800	cushion plants	cusion plants, moss and lichen communities
temperate cold	between 24 and 0	1850-2200	alpine	(2250)2300	alpine swards	alpine swards, snow-bed communities
very cool	between 0 and 2	1550-1850	subalpine	1550-1800	dwarf pine scrub	dwarf pine scrub, tall herbs, bilberry heath, post-grazing meadows
cook	between 2 and 4	1200-1550	upper montane	1200(1250)-1550	coniferous forest	spruce forest, pastures
temperate cool	between 4 and 6	900-1200	lower montane	900-1200(1250)	deciduous and mixed forests	spruce monoculture, beech-fir forests, manured and mown meadows and pastures

The altitude of the limits of particular belts changes locally depending upon the terrain relief, exposure, dominating wind directions, nature of parent rock, or the intensity of the biotic and anthropogenic factors. The influence of exposure or of the dominating wind directions on the course of limits of altitude belts in the Tatra Mts. is relatively well recognised (Hess 1965; Končok 1974; Błażejczyk et al. 2013). The respective relations have also been established in other mountainous areas (Geiger 1969; Barry, Van Wie 1974; Yoshino 1975, 1984; Rapetti, Vittorini 1988; Barry 1992; Rubel et al. 2017; Błażejczyk 2019). Modifications of the general regularities concerning altitude zonality of vegetation under the influence of terrain relief, including the large, primary relief forms (mountain ridge, main valley), the meso-forms (slope, valley-side), or the micro-forms (gully, niche), and under the influence of micro-climate are much less known for the Tatra Mts., like, anyway, also for other mountains, and much rarely studied (Jeník 1961, 1997; Migała 2005; Jodłowski 2007; Treml, Banaš 2008).

Altitudinal zonality of particular climate elements influence human bioclimate conditions. In the last decades several bioclimatic research were made for the Carpathians and other European mountain systems (Błażejczyk et al. 2021b). The altitudinal bioclimatic gradients were also studied for Mt. Everest (Szymczak, Błażejczyk 2021). The results of research indicated that the features of human bioclimate strongly not only depend on altitude but also on other climate variables, as wind speed, income of solar radiation and air humidity. While the mountains are a barriers for air masses the location of particular parts of mountains in relation to direction of air transition play significant role (Błażejczyk et al. 2020). When comparing bioclimatic features in different European mountain systems the regional impacts (e.g. continentality, longitude, latitude) are also observed (Błażejczyk et al. 2021a).

The present paper aims to discuss two aspects of mountain bioclimate on the example of Tatry Mts.: i) plant bioclimate, namely the functioning of acidophil vegetation, under the influence of local relief and microclimate features (which modify the altitudinal zonality) on the example of Suchej Wody Valey, and ii) human bioclimate, namely to show how local and regional geographical factors influence thermal stress in the Tatra Mts. The research deals with different spatial (micro and regional) and temporal (short term and multiannual) scales.

2. Study area

Tatra Mts. are the highest mountain group within the Carpathians (Gerlach Mt., 2655 m a.s.l.), situated along the border between Poland and Slovakia. The relief of these mountains is alpine. The plant bioclimate study was carried out in the upper part of the Sucha Woda Valley (Fig. 1) in the subalpine and the alpine belts, on the slopes developed on the granite and granodiorite substrates. The soils are therefore very similar throughout, rankers and tangel rankers. Degórski (1999) and Komornicki and Skiba (1996) give the acidophil soil characteristics of the study area.

The entire area, shown in Figure 1, was subject to solar energy, vegetation and relief mapping. The detailed studies have been conducted on two study plots: study plot A, situated on the SE slope of Uhrocie Kasprowe Mt. and study plot B – the nival gully located on the NE slope of Beskid Mt. For human bioclimate research the whole Tatra region was considered and meteorological stations selected for research represent various altitudes and location in relation to Tatra ridge.

3. Material and methods

The research and analysis methods used in the studies are different for plant bioclimatology and human bioclimatology. Their common goal is to study the

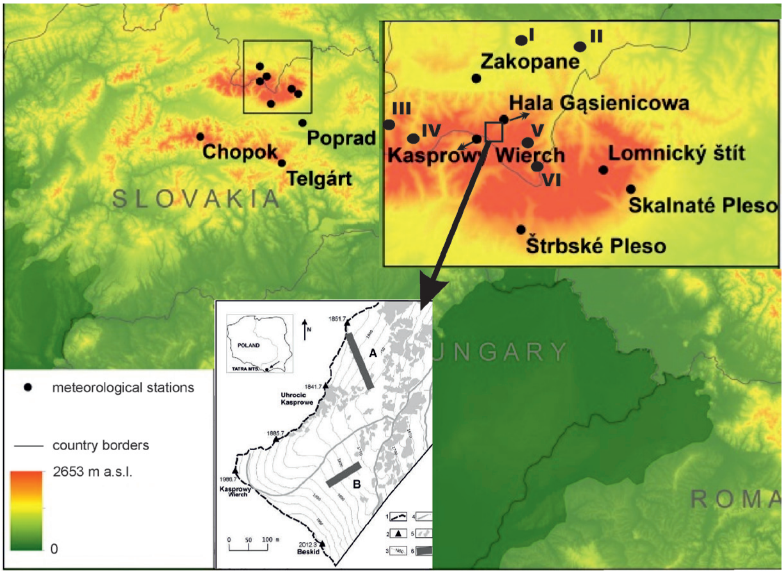

Fig. 1. The areas under study. Stations: I – Poronin, II – Bukowina Tatrzańska, III – Dolina Chochołowska, IV – Hala Ornak, V – Dolina Pięciu Stawów, VI – Morskie Oko. A – Uhrocie Kasprowe study area, B – Beskid study area 1 – ridges; 2 – summits; 3 – contour lines; 4 – tourist trails, 5 – *Pinus mugo* scrubs, 6 – study areas.

relationships between meteorological factors and living organisms, both plant and humans. In mountainous areas, the leading feature of these interactions is the altitudinal variability of meteorological conditions and abiotic features of the environment. This altitude variability is considered in our studies at various spatial and temporal scales.

3.1. Plant bioclimate research

The research were carried out in upper part of Suchej Wody Valley, close to Kasprowy Wierch and Beskid summits. Three elements of ecological system were analysed: local climate, vegetation and relief (Fig. 2).

In case of the climate two components were analysed: solar radiation and air temperature. To recognise amount of solar energy the map of potential totals of direct solar radiation (Kpot) reaching inclined surface were developed (Baranowski 2003a). These totals were calculated with the assumption of the cloudless sky, for the one-hour interval of 11 a.m. – 12 a.m. and the unit fields of 50 m x 50 m (Baranowski 1999). The energy potential was determined by

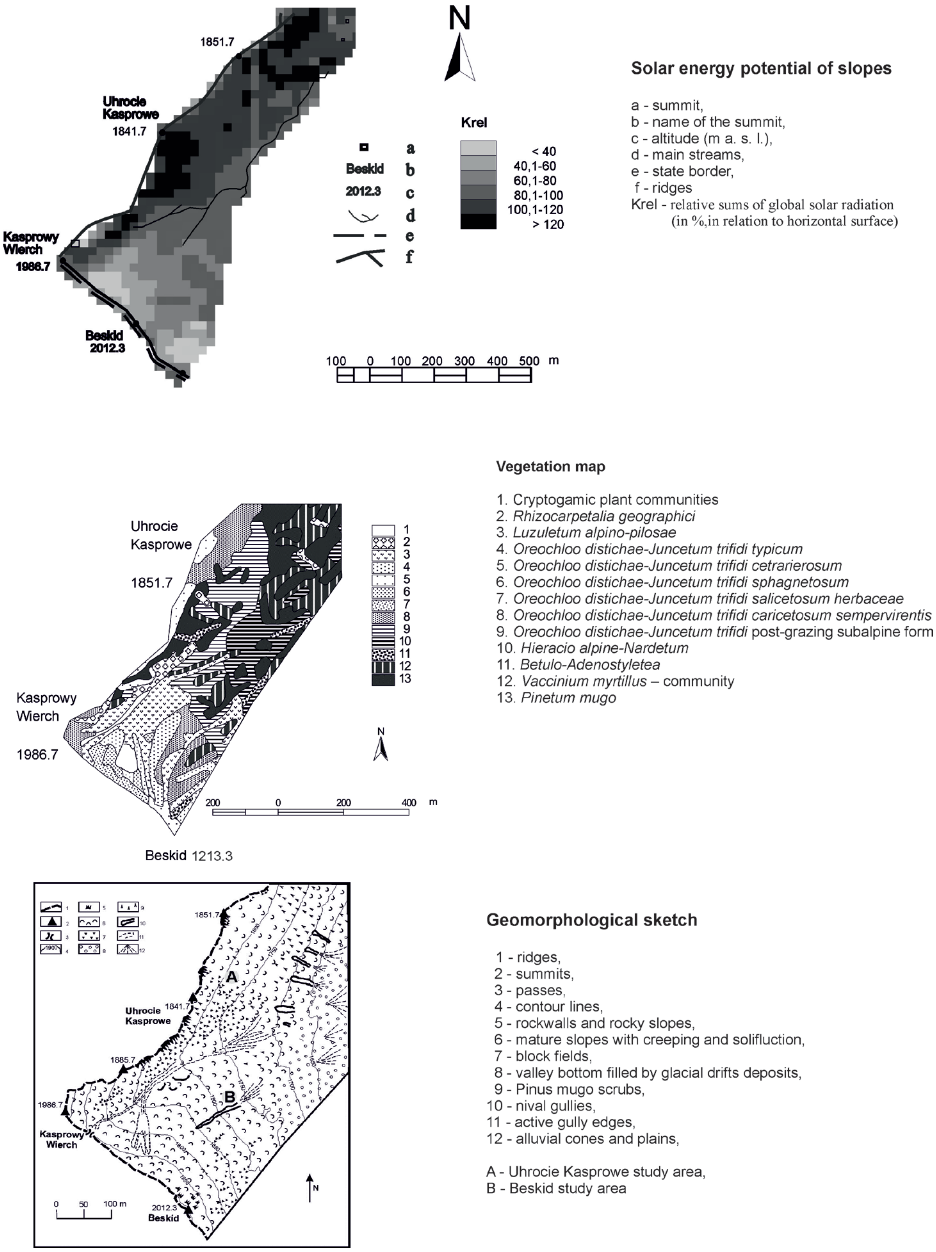

Fig. 2. Distribution of three essential components of the ecological system of the upper part of Suchej Wody Valley in the Tatra Mts.

relating the radiation totals of the particular fragments of the area (with the use of general principles of solar geometry) to the radiation reaching in the same time the horizontal surface (Krel).

In order to obtain the image of spatial distribution of air temperature it was measured during three field campaigns (in the years 2001-2003) in the selected points of the study area. The digital mini data loggers HOBO Pro were used in this purpose. The measurements were taken during vegetation periods starting from beginning of June up to end of August. The temperature and RH sensors were located in the ground adjacent layer, under radiation shields, at the height of 10 cm above ground with time resolution of 5 minuts. Up to 7 sensors were located in linear, altitudinal profiles. In study plot A it starts from the foot of the slope (1720 m a.s.l.) up to the summit of Uhrocie Kasprowe (1840 m a.s.l.). In study plot B the loggers were placed along the axis and the edge of the gully, at the altitude from 1760 to 1840 m a.s.l. For the statistical analysis we have selected highest (Tmax) and lowest (Tmin) registered air temperature and calculated its average values (Tavg) from the whole study periods.

The vegetation map of the Tatra Mts. on the scale of 1:10000 (Kozłowska 2006, 2013) was the background for general characteristic of vegetation. The geobotanical data of selected plant species had been taken from published phytosociological relevés and unpublished collected in the database (Kozłowska 2001 2013; Kozłowska – unpubl.). The chosen phytosociological relevés were located along the profiles A and B, parallel in the same points where air temperature was measured (see Fig. 1). Plant species as indicators of altitudinal differentiation of vegetation belonging to different phytosociological classes (*Nardo-Callunetea* and *Vaccinio-Piceetea* - for subalpine, *Caricetea curvulae* and *Salicetea herbaceae* - for alpine belts) were used in the presented analysis in local scale. In the microscale of selected relief form (nival gully) the indicative plant species were chosen on the basis of the paper of Kozłowska and Rączkowska (2006).

The geomorphological map was elaborated by Rączkowska on the basis of the field mapping and aerial photograph on the scale of 1:10000. The data concerning the disappearance of snow cover and snow patch (at study site B) were collected during field mapping and measurements of snow patches size, few times during each melting season. The relief of Suchej Wody Valley is described by Kotarba (2013).

3.2. Human bioclimate research

To analyse the features of human bioclimate of the Tatras region daily meteorological data (air temperature, relative humidity, total cloud cover and wind speed for 12 UTC) from 15 stations of national weather networks of Poland and Slovakia for the period 1991-2015 were used (Fig. 1, Table 2).Taking into account orographic, geological and climatic features they represent two physiographical groups: 1) montane, with elevation of 500-1400 m a.s.l. and mid-mountain landscape, 2) alpine, with elevation >1400 m a.s.l., represented alpine relief (Błażejczyk 2021a).

Majority of stations are located in the main body of the Tatry Mts. However, for better representation of Slovak Tatras region we have included to our considerations stations at more southern locations in the Low Tatra ridge, Chopok in alpine belt and Telgart in montane belt. The research by Błażejczyk et al (2020, 2021a) show general bioclimatic features of these two stations are similar to those located in the main body of Tatry Mts.

Meteorological data were used to calculate the Universal Thermal Climate Index – UTCI as a measure of bioclimatic thermal stress (Błażejczyk et al. 2012;

Table 2. Geographical information of studied meteorological stations (source: own elaboration).

Name of station	Elevation above sea level (Hs, m a.s.l.)	Physiographical type	Location
Poronin	770	montane	northward
Zakopane	857	montane	northward
Bukowina Tatrzańska	905	montane	northward
Hala Ornak	1090	montane	northward
Dolina Chochołowska	1150	montane	northward
Morskie Oko	1395	montane	northward
Hala Gąsienicowa	1520	alpine	northward
Dolina Pięciu Stawów	1670	alpine	northward
Kasprowy Wierch	1990	alpine	summit
Poprad	694	montane	southward
Telgart	901	montane	southward
Štrbské Pleso	1322	montane	southward
Skalnaté Pleso	1778	alpine	southward
Chopok	2005	alpine	summit
Lomnicky Štít	2635	alpine	summit

Bröde et al. 2012). For the calculations of UTCI the BioKlima©2.6 software package was used[1]. The Universal Thermal Climate Index (UTCI) is derived from the UTCI-Fiala model and is defined as the equivalent air temperature of reference condition causing the same model response (in sweat production, shivering, skin wettedness, skin blood flow as well as in rectal, face and mean skin temperatures) as the actual conditions (of air temperature and humidity, wind speed and mean radiant temperature). In the present research the UTCI values were categorised in 3 classes: no thermal stress (NT, UTCI = 9.1-26.0°C), cold stress (CS, UTCI ≤ –13°C) and heat stress (HS, UTCI > 32°C).

Statgraphics Centurion XVI software package was applied to calculate statistical analysis of observational data.

4. Results

4.1. Plant bioclimate

The slopes, on which the study plots were situated, have a similar relief. These slopes are mature and smooth, with the longitudinal profile evened out. Their inclination is 20-25°. The slopes are formed by the slow mass movements, mainly creeping and solifluction, as well as nivation and erosion.

The slopes under study differ, however, in two respects. There are no blockfields, devoid of plant and soil cover, on the slope of Beskid Mt. (B), while they are encountered on the slope of Uhrocie Kasprowe at the altitude of 1700-1850 m a.s.l. On the other hand, the slope of Uhrocie Kasprowe (A) has no distinct micro-forms of relief, such as nival niche, which is an object of study on the Beskid Mt. (B). This niche stretches between 1760 and 1860 m a.s.l. over the length of some 250 m. Its width varies from 20 m at the altitude of 1760 m a.s.l., through 35 m in the middle part (at the altitude of 1780 m a.s.l.) to 10-12 m in the upper part, at the altitude of 1850 m a.s.l. The depth of the niche varies from 2.5-3 m in the lower part, through 1.5-2.0 m in the middle part, to less than 1 m in the upper part. The niche has a slightly winding course. The nival gully is usually filled with snow in patches since the beginning of May until the end of June.

The studied area is characterised by the domination of slopes with eastern exposure. The slope of Uhrocie Kasprowe (site A) has predominantly ESE exposure, while the slope of Beskid (site B) has mainly NE exposure. The small differ-

[1] https://www.igipz.pan.pl/bioklima.html

ences in the exposure direction of the slopes influence the length of persistence of the snow patches. The snow cover disappears first from the slope of Uhrocie Kasprowe, with the patches remaining for a shorter time until the end of May.

At the studied area the Kpot on horizontal surface varied from about 0.9 MJ m^{-2} at winter solstice to 3.3 MJ m^{-2} at summer solstice. The various orientation and inclination of the slopes cause that the energy potential of the particular parts of the study area is differentiated. The relative totals of solar radiation fluctuate between less than 40% and more than 120% of radiation reaching horizontal surface. Fragments of slopes of Uhrocie Kasprowe are privileged in terms of insolation, while the lowest energy potential characterises the upper parts of the slopes of Beskid and Kasprowy Wierch Mt (Fig. 2).

The plant cover of the study area is typical for the subalpine and alpine belts developed on acidophil soils (Fig. 2). The grassland communities dominate, belonging to various syntaxonomic units (mainly *Oreochloo distichae – Juncetum trifidi* and also *Hieracio* (*alpini*)-*Nardetum*, accompanied by the dwarf scrub communities with bilberry (*Vaccinium myrtillus* L.) and dwarf mountain pine shrubs (*Pinetum mugo carpaticum*). The areas influenced by erosion processes are almost vegetation-less or partly covered with pioneer cryptogamic plant communities. The blockfields are overgrown with lichen plant communities (*Rhizocarpetalia geographici*). In the cool and wet places the snow-bed communities with *Luzula alpino-pilosa* appear. The habitats supplied with water are covered by tall herb communities and avalanche meadows from the *Betulo-Adenostyletea* class.

The mountain pine shrub (*Pinetum mugo*) is the natural climax community in the subalpine belt. Before the creation of the Tatras National Park these areas were grazed by the sheep and the part of mountain pine shrubs was cut out and the dwarf scrub communities with *Vaccinium myrtillus* or post-grazing grasslands dominate nowadays. In the alpine belt the alpine sward (*Oreochloo distichae – Juncetum trifidi*) is the natural climax community with different number of subassociations in accordance to the habitat conditions (Balcerkiewicz 1984).

Plant cover reflects both the climatic gradient, linked with the altitude, and the climatic differences depending upon exposure. It is possible to track on the basis of the vegetation map the ecoclinal transition of plant communities from the lowest *Pinetum mugo* and *Hieracio alpini-Nardetum* through the subalpine form of the alpine sward *Oreochloo distichae-Juncetum trifidi*, then through the similarly associated with the grazing places sward *Oreochloo distichae-Juncetum trifidi caricetosum sempervirentis*, up to the typical alpine belt sward *Oreochloo distichae-Juncetum trifidi typicum*. The slopes of Beskid with northern exposure are characterised by a high share of the snow-bed and scree communities (*Luzuletum alpino-pilosae, Oreochloo distichae-Juncetum trifidi salicetosum herbaceae*, cryptogamic plant communities). The slopes of Beskid, with SE exposure, are covered by the subalpine and alpine swards with the clumps of *Pinus mugo*.

4.2. Interrelations between vegetation, relief and microclimate features

4.2.1. The slope of Uhrocie Kasprowe (study plot A)

The mean, minimum and maximum values of air temperature in the ground adjacent layer, calculated for the studied period, change on the smoothed slope of Uhrocie Kasprowe along with the altitude a.s.l. according to various patterns (Fig. 3).

The mean temperature (Tavg) decreases linearly with the altitude a.s.l. The changes of altitude explain as much as 87% of the variability of temperature. For the difference in altitude of 110 m (between lower and upper measurement points) the difference of mean temperature amount to 0.62°C (0.56°C/100 m). This gradient is similar to the one given by Hess (1965) for Polish Carpathians.

The relations between altitude a.s.l. as well as maximum (Tmax) and minimum (Tmin) temperature is approximated with a quadratic equation. The changes of Tmax and Tmin are much less dependent upon the altitude a.s.l. (r # 0.55) and they are typical for the slopes with smoothed longitudinal and transversal profile, without rock walls nor cuts formed by gullies or bowls (Hess 1965).

A significant increase of Tmax observed at the altitude of about 1770 m a.s.l. is probably associated with specific structure of slope cover. It is built from rocky blocks cover, with very weak soil and plant cover, within which an intensive drainage of soil water takes place (Fig. 2). After a couple of days without precipitation a significant drying of the surface layer of the ground is observed. This cause strong heating of ground surface which is reflected through a significant increase of the maximum near-ground temperature. At the points located below and above the blockfield the ground is more humid and heats up less strongly. On the other hand, the minimum temperature distinctly decreases with altitude up to around 1820 m a.s.l., after which it increases. This observation could be assigned to the vertical reach of the thermal inversion in the upper part of the Suchej Wody Valley. Above the limit mentioned somewhat higher values of minimum air temperature are observed than in the middle part of the slope. Inversion processes are mostly observed in the night and morning hours. Thus, they influence mainly minimum and not maximum air temperature.

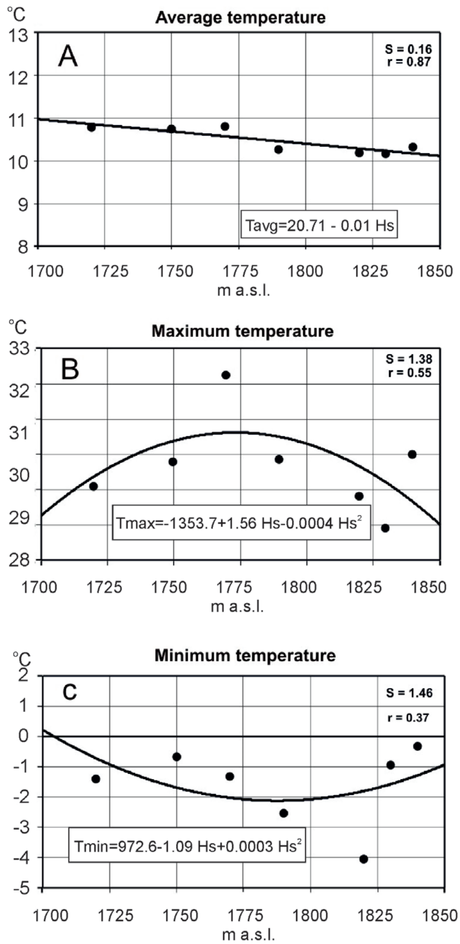

Fig. 3. Relationships between altitude above sea level (Hs, independent variable) and air temperature (dependent variables) on Uhrocie Kasprowe (study area A). Source: own elaboration.

The dependence of the number of species of the subalpine and alpine grasslands upon the altitude a.s.l. is not linear (Fig. 4). The changes of the number of species of the subalpine and alpine swards with the increase of the altitude a.s.l. are approximated with the quadratic equation (r = 0.83 and r = 0.95 respectively). Worth to know, that the above pattern of changes correspond to the changes of maximum and minimum temperature values (Fig. 3) Above the altitude of about 1770 m a.s.l. the number of alpine species starts to grow, reaching increasingly high values.

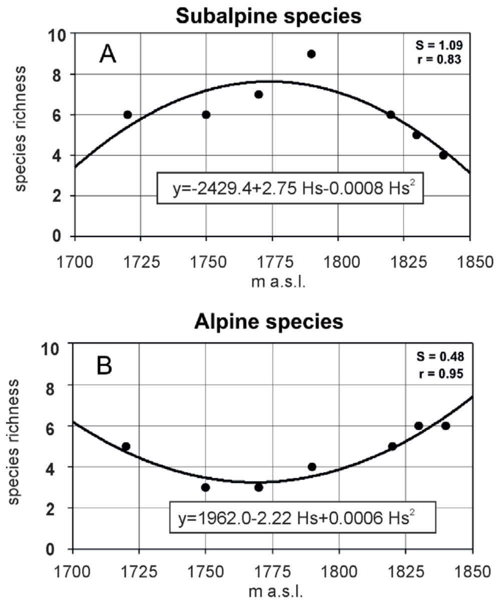

Fig. 4. Relationships between the richness of plant species (dependent variable) and altitude above sea level (Hs, independent variables) on Uhrocie Kasprowe (study area A). Source: own elaboration.

4.2.2. The slope of Beskid (study plot B)

Two factors distinctly influence the variation of air temperature on the northern slopes of Beskid (Fig. 5): altitude a.s.l., location inside the nival gully or at its edge. The vegetation appearing there clearly differs as to the species composition between the gully edge and the gully centre. Former studies have showed that the snow patch, which persists in the gully, constitutes an important factor determining the differentiation of vegetation (Kozłowska, Rączkowska 2006). The edge of the gully runs along a slope that is similar in geomorphological terms to the one of Uhrocie Kasprowe.

On the northern slope of Beskid the changes of the mean air temperature, associated with the difference of altitude a.s.l., undergoes modification linked with the presence of the gully. The difference of the mean air temperature between the lower and upper measurement sites at the gully edge (Fig. 5A) amounts to 0.85°C (about 1°C/100 m). This value is close to the value of the dry adiabatic gradient (International meteorological vocabulary, 1992).

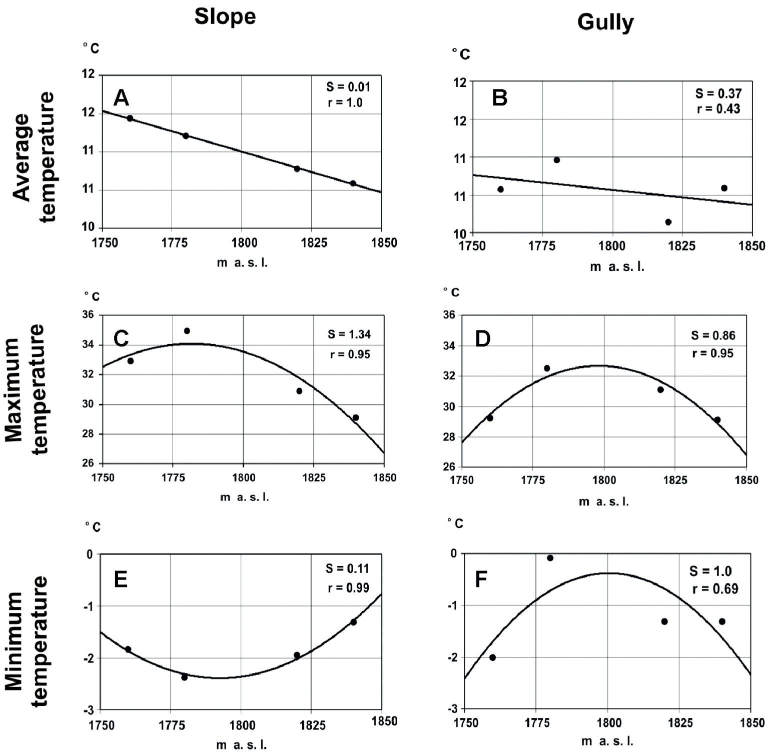

Fig. 5. Relationships between altitude above sea level (Hs, m a.s.l., independent variable) and air temperature (measured with the use of HOBO) as dependent variables on Beskid (study area B); Functions according to the models: A. Average air temperature versus altitude a.s.l. on the slope. y = 30.21 – 0.01·Hs; B. Average air temperature versus altitude a.s.l. in the gully. y = 17.64 – 0.004·Hs; C. Maximum air temperature versus altitude a.s.l. on the slope. y = –4964.9 + 5.62·Hs – 0.002·Hs^2; D. Maximum air temperature versus altitude a.s.l. in the gully. y = –7013.3 + 7.84·Hs – 0.002 Hs^2; E. Minimum air temperature versus altitude a.s.l. on the slope. y = –1577.3 – 1.76 Hs + 0.0005·Hs^2; F. Minimum air temperature versus altitude a.s.l. in the gully. y = –2593.7 + 2.88·Hs – 0.0008·Hs^2. Source: own elaboration.

The observed difference in mean air temperature is accompanied by the differentiation of vegetation at the edge of the gully (Fig. 6). There is a significantly high share of dwarf shrubs: *Vaccinium gaultherioides* and *V. myrtillus*, decreasing with the altitude a.s.l. The highest measurement site is characterised by the abundant appearance of *Juncus trifidus*, low share of *Luzula alpino-pilosa* and lack of *Vaccinium gaultherioides*. These species are the indicators for the habitats changing with the altitude a.s.l. At the edge of the gully in its upper part the climax vegetation of the alpine belt appears, similarly as on Uhrocie Kasprowe, giving transition below to the post-grazing subalpine grasslands and dwarf scrub

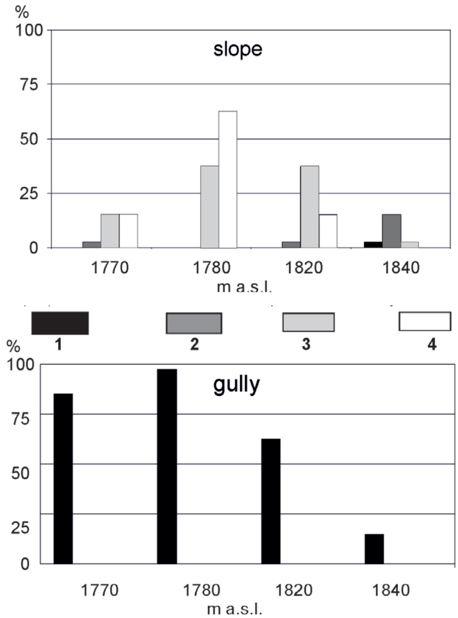

Fig. 6. Beskid study area – cover (%) of characteristic and dominant plant species at various altitudes. 1 – *Luzula alpino-pilosa*. 2 – *Juncus trifidus*, 3 – *Vaccinium myrtillus*, 4 - *Vaccinium gaultherioides*. Source: own elaboration.

communities. In particular, in the lower part we deal with dry dwarf scrub communities (*Empetro-Vaccinietum*), whose presence justifies the existence of the dry adiabatic gradient.

The distribution of the mean temperature values in the gully has another character (Fig. 5, right panel). The difference between the lowest and the highest sites amounts merely to 0.02°C. The linear trend of change calculated equals roughly 0.4°C/100 m. This gradient is similar to the humid adiabatic gradient. This fact is associated with the increased humidity of the air along the gully, as indicated by the domination of *Luzula alpino-pilosa*, growing in the middle of the gully, other species not playing any significant role, and the differentiation of vegetation belts not being observed inside the gully (Fig. 6).

The changes of the maximum temperature take place in a similar manner along the axis of the gully and at the edge (Fig. 5 C, D). In both locations the highest maximum temperature is observed at the altitude of approximately 1780 m a.s.l. Relatively high totals of solar radiation are observed in this part of the slope (see Fig. 2), bringing an increase of temperature during the day (Baranowski 2003b).

The minimum temperature attains its lowest values at the edge of the gully at the altitude of around 1780 m a.s.l. (Fig. 5E). Similarly as in the case of Uhrocie Kasprowe, this is associated with the vertical reach of the thermal inversion in this part of the Tatra Mts. Simultaneously, at this altitude a surprisingly high minimum temperature on the axis of the gully is observed (Fig. 5F). This is most probably linked with the abundant *Luzula alpino-pilosa* cover, which grows there and effectively hampers during the night the radiation of the heat from the ground to the atmosphere.

4.3. Human bioclimate features

When analysing annual values of UTCI one can find that most intensive heat stress occurs in Poronin (northward station). There is noted highest yearly UTCI-mean (10.1°C), UTCImax 38.1°C and occurrence of HS conditions (1.3% of days yearly). UTCImax >35°C was also registered at Dolina Chochołowska, Bukowina Tatrzańska, Zakopane and Poprad (montane stations). Lowest values of UTCI are observed at most elevated summit stations (Kasprowy Wierch, Chopok, Lomnicky Štit). More than 45% of CS yearly are very frequent at all elevated alpine stations. HS days occur occasionally mostly at low located stations (Table 3).

4.3.1. Annual cycle of UTCI

In general, annual course of UTCI at all stations is parallel each other. Phases of visible UTCI decreasing and increasing occurred at similar periods, e.g. warming phase in third decade of January, cooling periods in first decade of April and between 5 and 13 May. At similar days are also observed annual maximum of UTCI (30 JUL – 3 AUG). Stations with various elevation differ the UTCI values – the highest are at the stations located at the bottom of chain (e.g. Zakopane) and the lowest at most elevated stations (e.g. Lomnicky Štit) as seen on Figure 7.

4.3.2. Physiographical location and thermal stress

While mountains are a barrier for air masses flowing across the main ridge we have verified if gradients of thermal stress at northward and southward parts

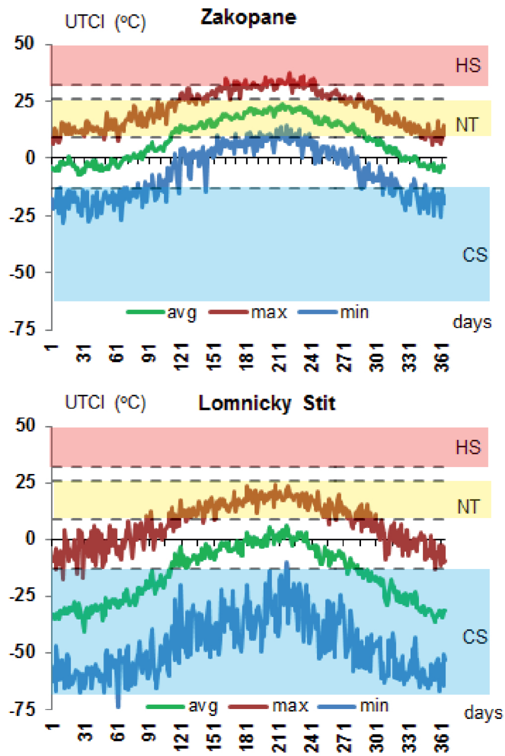

Fig. 7. Examples of the annual cycles of average (avg), maximum (max) and minimum (min) UTCI values at selected stations. Source: own elaboration.

of the Tatry Mts. differ. When considering annual characteristics of UTCI we can see that northward gradients of UTCI values and frequencies of particular UTCI categories are greater in the northern part of Tatras (Fig. 8). The biggest gradients are observed in case of minimum UTCI values (–2.01°C/100 m for northward and –1.32°C/100 m for southward slopes). For UTCI max altitudinal gradients are the lowest (–0.86 and –0.65°C/100 m). For the most of UTCI measures the gradients are statistically significant at p = 0.05 level (Tab. 4)

Considering altitudinal gradients in frequencies of particular UTCI categories one can see that for heat stress days the changes are statistically insignificant due to very rare occurrence of such situations. At both locations the gradients are similar each other (Fig. 9). Number of cold stress days increase according to altitude and CS gradients are 2.59 days/100 m for northward stations and 2.43 days/100 m for southward locations. Number of no thermal stress days decrease due to altitude with the rates of –2.07 and –1.91 days per 100 m (Tab. 4).

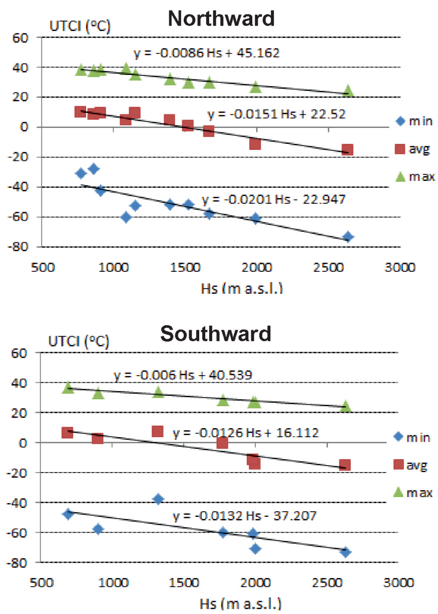

Fig. 8. Changes of particular UTCI measures (avg, min, max) due to altitude (Hs) increase at northward and southward meteorological stations. Source: own elaboration.

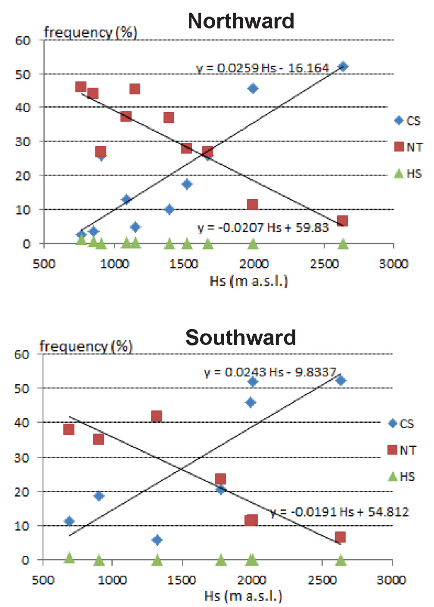

Fig. 9. Changes of the frequency of particular UTCI categories (CS, NT, HS) due to altitude (Hs) increase at northward and southward meteorological stations. Source: own elaboration.

Table 3. Mean, maximum (max) and minimum (min) annual UTCI values as well as yearly frequency of selected UTCI categories, 1986-2015. Source: own elaboration.

Station	UTCI values (°C)			Frequency of UTCI categories (%)		
	min	avg	max	CS	NT	HS
Poronin	–31.2	10.1	38.1	2.5	46.0	1.3
Zakopane	–28.2	8.4	37.2	3.6	43.9	0.6
Bukowina Tatrzańska	–42.2	8.8	38.1	25.8	26.9	.
Hala Ornak	–47.5	8.2	32.2	3.2	44.6	.
Dolina Chochołowska	–52.9	8.8	35.3	2.4	45.2	0.4
Morskie Oko	–51.8	7.6	32.7	7.4	4.5	0.1
Hala Gąsienicowa	–52.1	0.3	30.1	17.5	28.0	.
Dolina Pięciu Stawów	–58.2	–2.9	29.5	25.8	26.9	.
Kasprowy Wierch	–60.8	–12.1	26.8	45.7	11.4	.
Poprad	–48.1	5.7	36.6	11.3	38.0	0.7
Telgart	–58.2	2.2	33.3	18.5	35.0	0.1
Štrbské Pleso	–38.2	6.6	34.1	5.8	41.7	0.2
Skalnaté Pleso	–60.3	–1.3	28.2	20.7	23.6	.
Chopok	–71.0	–14.8	26.8	51.8	11.6	.
Lomnicky Štit	–73.5	–15.7	24.2	52.2	6.4	.

Table 4. Statistical characteristics of UTCI measures and frequencies of UTCI categories due to various locations of station in the Tatry Mts. Source: own elaboration.

	UTCI min	UTCI avg	UTCI max	CS	NT	HS
Northward						
gradient (per100 m)	**–2.01°C**	**–1.51°C**	**–0.86°C**	**2.59%**	**–2.07%**	*–0.05%*
p-value	**0.0021**	**0**	**0**	**0.0011**	**0.0008**	*0.0569*
correlation coefficient	**–0.85**	**–0.97**	**-0.95**	**0.87**	**–0.88**	*–0.62*
Southward						
gradient (per 100 m)	*–1.32°C*	**–1.26°C**	**-0.65°C**	**2.43%**	**–1.91%**	*–0.03%*
p-value	*0.0606*	**0.009**	**0.0005**	**0.0193**	**0.0054**	*0.0624*
correlation coefficient	*–0.73*	**-0.88**	**-0.96**	**0.84**	**–0.90**	*–0.73*

Relations **statistically significant marked in bold** and *statistically insignificant relations are marked in italic.*

5. Discussion and conclusions

The results of the climatic study brought the confirmation of the thermal gradient defined by Hess (1965) for the Carpathians, but also demonstrated its modification caused by the local habitat factors. Vegetation, conditioned by the abiotic factors, reflects well the changes of continuous character (Kozłowska 2008), and is also a good indicator of the local modifications (disturbances). On the open slope, including the edge of the gully, linear changes in the mean air temperature are noted even for not too pronounced altitude differences, with the plant species reacting to these differences in terms of gradual (ecoclinal) changing. In the present study this applies to the gradual transition from the subalpine to the alpine belt. It is also possible to render cartographically the gradual transition of the anthropogenic subalpine grasslands into the alpine swards.

The modifications of the thermal conditions by the local factors are expressed through the influence exerted by the vertical limit of the thermal inversion, resulting in the somewhat lower minimal values of the air temperature at the foot of the slope, and higher in the culmination part (Błażejczyk et al. 2013). Similar courses of the curve of air temperature changes along altitude above the valley bottom are also reported by T. Niedźwiedź (personal communication) for the Carpathian and Alpine valleys. In both cases the change of direction of the thermal gradient takes place at the altitude of some 300 m above the valley bottom, which is explained by the vertical limit of the thermal inversions in the mountain valleys.

Likewise, the local habitat factors, linked with relief (exposure, presence of blockfields, gullies), modify the altitude gradient of mean air temperature. On the slope with smoothed profile and well developed plant cover (Uhrocie Kasprowe) this gradient is equal 0.56°C/100 m and corresponds to the mean gradient reported for the Carpathians by Hess. In the present study the gradients represent microclimatic conditions of 10 cm near ground air layer. However, the research of Hess based on standard measurements carried out at meteorological stations at 2 m above ground. The results suggest that thermal gradients are mostly influenced by altitude. Local factors, as vegetation cover morphological features of slopes play secondary role. On the relatively dry edge of gully in the slope of Beskid Mt. altitudinal thermal gradient attains the value of approximately 1°C/100 m and is close to the dry adiabatic one. On the other hand, in the bottom of the gully, due to increased humidity of the air, correlated with the appearance of *Luzula alpino-pilosa*, altitude thermal gradient is about 0.4°C/100 m, which corresponds to the humid adiabatic gradient. These relations can be represented in the form of the scheme.

Further, the influence of microclimate on plants and the action of the limiting factors got uncovered. The middle part of Uhrocie Kasprowe provides appropriate conditions for the development of plants of the subalpine belt and some species of the alpine belt. Yet, the species of the alpine zone avoid in the subalpine belt the warmer places, although it cannot be unambiguously stated on the basis of the studies to date what is the limiting factor for them – higher temperature or the sharper competition from the other species, like, e.g., *Nardus stricta*, for which these conditions are more advantageous.

The snow patch, conditioned by the relief, modifies the thermal gradient in the altitude profile. It is accompanied by the vegetation, which is uniform in terms of the dominating species, constituted by *Luzula alpino-pilosa* (Kozłowska, Rączkowska 2006). The study reported demonstrates also the association between the appearance of *Luzula alpino-pilosa* and the weak altitude gradient of the mean air temperature. Simultaneously, a gradual zonation change of the dominating species of plants and their coverage is observed.

The study showed the impact of the elements of topoclimate (solar radiation, air temperature) on the distribution of plant species, representing plant communities typical for a given area. The slopes with high energy potential are not characterised by the thermophilous species or communities (because it is not feasible in the conditions of mountain climate), but rather by the lack of species and communities as indicators of cold, like, e.g. snow-bed communities. Then, on the slopes with low energy potential, appearance is observed – especially in the upper locations – of the snow-bed communities (*Luzuletum alpino-pilosae, Oreochloo distichae – Juncetum trifidi salicetosum herbaceae*) and the snow-bed species (like, for instance, *Luzula alpino-pilosa*).

A schematic image of the plant belts in the Tatra Mts. differs from the actual differentiation of vegetation (see Table 1), which was influenced by the shepherding economy, typical for high mountains, and human activity played the role of one of the ecological factors. The effects thereof could also be seen on the study area within the subalpine belt, from where the dwarf mountain pine was cut down. Formation of clearings in the forests or lowering of the upper limit of mountain pine exerts an influence on the properties of local climate, since relations between vegetation and climate are characterised by a clear feedback, as demonstrated in the present study. It was concluded in the previous studies that both the radiation balance and air temperature take a different courses at the same altitudes a.s.l. within the patches of dwarf mountain pine and the grasslands (Baranowski 2003a). This would imply that our results could have different numerical values if mountain pine shrubs were accounted for in place of the subalpine acidophil grasslands. Still, one should not expect that such a change could have an impact on the general conclusions concerning altitudinal zonality, phenomena of continuous character and their modifications associated with the relief forms.

Human bioclimate of mountain areas is rarely studied. Most of studies concern the long-term and seasonal variability of the perceived climate of individual meteorological stations (Gajic-Capka, Zaninovic 1997; Mateeva, Filipov 2003; Endler, Matzarakis 2011, Matzarakis et al. 2012; Pecelji et al. 2017). For the northern Carpathian area, Błażejczyk and his team (Błażejczyk at al. 2013, 2020, 2021a) examined various aspects of the diversity of thermal stress conditions. They paid attention to the influence of atmospheric circulation and location of station in relation to the main mountain range.

Altitudinal gradients in some mountain ranges of central and southern Europe were analyzed by Błażejczyk et al. (2021b). For the Tatra Mts. area, these gradients were determined only on the basis of Polish stations and therefore were similar to those determined in the current research for the northward station (for UTCIavg 2.0°C/100 m). Among other mountain ranges, similar UTCI gradients were determined for the Dinaric Alps and the Southern Alps (1.9°C/100 m). Current investigations have shown that when studying mountain ranges, the position of the station in relation to the course of the main range should be taken into account. In the Tatra Mts., the gradients on the southward slopes are significantly lower than on the northward ones.

It should also be emphasized that altitudinal gradients in UTCI values are greater than that observed for air temperature (Hess 1965; Błażejczyk 2019). This is the result of the fact that UTCI values are largely influenced not only by air temperature, but also by other climate elements (solar radiation, wind speed and air humidity). Błażejczyk's research (2019) proved that each of these elements changes in different manner with the height above sea level. In the context of UTCI, it is important that both, the altitudinal temperature drop and the increase in wind speed significantly affect the decrease in the UTCI value.

References

Balcerkiewicz S., 1984, Roślinność wysokogórska Doliny Pięciu Stawów Polskich w Tatrach i jej przemiany antropogeniczne. Seria: Biologia – Uniwersytet im. Adama Mickiewicza, 25, 191 pp.

Baranowski J., 1999, Wpływ różnych elementów środowiska przyrodniczego na dopływ promieniowania słonecznego, research report, Institute of Geography and Spatial Organization PAS, Warszawa.

Baranowski J., 2003a, Lokalne zróżnicowanie warunków solarnych w Tatrach i jego związki z rzeźbą terenu i szatą roślinną (na przykładzie Hali Gąsienicowej), PhD thesis, Institute of Geography and Spatial Organization PAS, Warszawa.

Baranowski J., 2003b, Pochłonięte promieniowanie słoneczne w Tatrach w otoczeniu Hali Gąsienicowej, Prace Geograficzne IGiPZ PAN, 188, 131-144.

Baranowski J., 2004, Energy exchange in an active layer in the Kocioł Kasprowy (Tatra Mountains), Geographia Polonica, 77 (1), 35-44.

Barry R.G., 1992, Mountain Weather and Climate, Routledge, London, 410 pp.

Barry R.G., Van Wie C.C., 1974, Topo- and microclimatology in alpine areas, [in:] Arctic and Alpine Environments, J.D. Ives, R.G. Barry (eds.), Methuen, London, 73-83.

Błażejczyk K., 2019, Sezonowa i wieloletnia zmienność niektórych elementów klimatu w Tatrach i Karkonoszach w latach 1951-2015, Przegląd Geograficzny, 91 (1), 59-80.

Błażejczyk K., Baranowski J., Błażejczyk A., Szmyd J., 2013, Klimat i bioklimat Hali Gąsienicowej, [in:] Dolina Suchej Wody w Tatrach. Środowisko i jego współczesne przemiany, Z. Rączkowska, A. Kotarba (eds.), Prace Geograficzne IGiPZ PAN, 239, 67-95.

Błażejczyk K., Nejedlik P., Skrynyk O., Halaś A., Skrynyk O., Baranowski J., Mikulova K., 2020, Thermal stress in northern Carpathians and air circulation, Miscellanea Geographica, 24 (3), 147-160, DOI: 10.2478/mgrsd-2020-0022.

Błażejczyk K., Nejedlik P., Skrynyk O., Halaś., Skrynyk O., Błażejczyk A., Mikulova K. 2021a, Influence of geographical factors on thermal stress in northern Carpathians, International Journal of Biometeorology, 65, 1553-1566, DOI: 10.1007/s00484-020-02011-x.

Błażejczyk K., Pecelj M., Nejedlik P., Skrynyk O., Mikulova K., 2021b, Thermal stress in selected mountain systems in central and eastern Europe – initial research based on UTCI Characteristics, Geographia Polonica, 94 (2), 223-236, DOI: 10.7163/GPol.0202.

Błażejczyk K., Skrynyk O., 2019, Wieloletnie zmiany temperatury powietrza, opadów i pokrywy śnieżnej w trzech pasmach górskich Europy Środkowej, [in:] Zmienność klimatu Polski i Europy oraz jej cyrkulacyjne uwarunkowania, L. Kolendowicz, E. Bednorz, A.M. Tomczyk (eds.), Bogucki Wyd. Naukowe, Poznań, 53-70.

Bröde P., Fiala D., Błażejczyk K., Holmér I., Jendritzky G., Kampmann B., Tinz B., Havenith G., 2012, Deriving the operational procedure for the Universal Thermal Climate Index (UTCI), International Journal of Biometeorology, 56 (3), 481-494, DOI: 10.1007/s00484-011-0454-1.

Degórski M., 1999, Zróżnicowanie pokrywy glebowej pięter wysokogórskich w bezwęglanowych rejonach Tatr Polskich, Prace Geograficzne IG i PZ PAN, 174, 25-36.

Długosz M., 2013, Budowa geologiczna, [in]: Dolina Suchej Wody w Tatrach. Środowisko i jego współczesne przemiany, Z. Rączkowska, A. Kotarba (eds.), Prace Geograficzne IGiPZ PAN, 239, 11-14.

Ellenberg H., 1996, Vegetation Mitteleuropas mit den Alpen. In ökologischer, dynamischer und historischer Sicht, Verlag Eugen Ulmer, Stuttgart, 1095 pp.

Endler Ch., Matzarakis A., 2011, Climatic potential for tourism in the Black Forest, Germany – winter season, International Journal of Biometeorology, 55, 339-351, DOI: 10.1007/s00484-010-0342-0.

Fliri F., 1975, Das Klima der Alpen im Raum von Tirol, Monographien zur Landeskunde Tirols, 1, Universitätsverlag Wagner, Innsbruck-München, 454 pp.

Franz H., 1979, Ökologie der Hochgebirge, Verlag Eugen Ulmer, Stuttgart, 495 pp.

Gajic-Čapka M., Zaninović K., 1997, Changes in temperature extremes and their possible causes at the SE boundary of the Alps, Theoretical and Applied Climatology, 57, 89-94, DOI: 10.1007/BF00867979.

Geiger R., 1969, Topoclimates, [in:] General Climatology, 2, World Survey of Climatology, 2, H. Flohn (ed), Elsevier, Amsterdam-London-New York, 105-138.

Hadač E., 1962, Übersicht der höheren Vegetationseinheiten des Tatragebirges, Vegetatio, 11, 46-54.

Hess M., 1965, Piętra klimatyczne w polskich Karpatach Zachodnich, Zeszyty Naukowe UJ, Prace Geograficzne, 11 (33), 267 pp.

Hess M., 1966, Znaczenie średniej temperatury roku dla poznania warunków klimatycznych, Przegląd Geograficzny, 38 (1), 17-40.

WMO, 1992, International meteorological vocabulary, 1992, WMO/OMM/BMO – No. 182.

Jeník J., 1961, Alpinská vegetace Krkonoš, Králického Sněžníku a Hrubého Jeseníku, Teorie anemoorografických systémů, ČSAV, Praha.

Jeník J., 1997, Anemo-orographic systems in the Hercynian Mts. and their effects on biodiversity, [in:] Climatological Aspects of Environmental Protection in Mountain Areas, K. Migała, J. Pereyma (eds.), Acta Univ. Wratislav., 1950, 9-22.

Jodłowski M., 2007, Górna granica kosodrzewiny w Tatrach, na Babiej Górze i w Karkonoszach. Struktura i dynamika ekotonu, Instytut Geografii i Gospodarki Przestrzennej UJ, Kraków, 188 pp.

Komornicki T., Skiba S., 1996, Gleby, [in:] Przyroda Tatrzańskiego Parku Narodowego, Z. Mirek (ed.), Kraków-Zakopane, 215-226.

Konček M. (ed.), 1974, Klima Tatier, Vyd. Slovenskoj Akad, Vied., Bratislava.

Kotarba A., 1976, Współczesne modelowanie węglanowych stoków wysokogórskich na przykładzie Czerwonych Wierchów w Tatrach Zachodnich, Prace Geograficzne IGiPZ PAN, 120, 128 pp.

Kotarba A., 2013, Rzeźba system dolinnego Suchej Wody i Pańszczycy, [in]: Dolina Suchej Wody w Tatrach. Środowisko i jego współczesne przemiany, Z. Rączkowska, A. Kotarba (eds.), Prace Geograficzne IGiPZ PAN, 239, 15-33.

Kozłowska A., 2001, Roślinność strefy przejścia między piętrem subalpejskim a alpejskim (na przykładzie wybranych obiektów w Dolinie Gąsienicowej), [in:] Między geografią i biologią – badania nad przemianami środowiska przyrodniczego, E. Roo-Zielińska, J. Solon (eds.), Prace Geograficzne IGiPZ PAN, 179, 219-252.

Kozłowska A., 2006, Detailed mapping of high-mountain vegetation in the Tatra Mts., Polish Botanical Studies, 22, 333-341.

Kozłowska A., 2008, Strefy przejścia między układami roślinnymi – analiza wieloskalowa (na przykładzie roślinności górskiej), Prace Geograficzne IGiPZ PAN, 215, 152 pp.

Kozłowska A., 2013, Roślinność Doliny Suchej Wody, [in:] Dolina Suchej Wody w Tatrach. Środowisko i jego współczesne przemiany, Z. Rączkowska, A. Kotarba (eds.), Prace Geograficzne IGiPZ PAN, 239, 127-136.

Kozłowska A., Rączkowska Z., 2006, Effect of snow patches on vegetation in the high-mountain nival gullies (Tatra Mts., Poland), Polish Journal of Ecology, 54 (1), 69-90.

Löve D., 1970, Subarctic and subalpine: where and what?, Arctic and Alpine Research, 2 (1), 63-73, DOI: 10.2307/1550141.

Mateeva Z., Filipov A., 2003, Bioclimatic distance index in the Rila-and-Rhodopy area of Bulgaria, [in:] Postępy w badaniach klimatycznych i bioklimatycznych, K. Błażejczyk, B. Krawczyk, M. Kuchcik (eds.), Prace Geograficzne, 188, 295-302.

Matzarakis A., Hämmerle M., Koch E., Rudel E., 2012, The climate tourism potential of Alpine destinations using the example of Sonnblick, Rauris and Salzburg, Theoretical and Applied Climatology, 110, 645-658, DOI: 10.1007/s00704-012-0686-y.

Migała K., 2005, Piętra klimatyczne w górach Europy a problem zmian globalnych, Acta Universitatis Wratislaviensis, 2718, Studia Geograficzne, 78, 149 pp.

Mirek Z., Piękoś-Mirkowa H., 1992a, Flora and vegetation of the Polish Tatra Mountains, Mountain Research and Development, 12 (2), 147-173.

Mirek Z., Piękoś-Mirkowa H., 1992b, Plant cover of the Western Carpathians (S Poland), Veröff. Geobot. Inst. ETH, Stiftung Rübel, Zürich, 107 (2), 116-150.

Mirek Z., Piękoś-Mirkowa H., Zając A., Zając M., 2002, Flowering plants and pteridophytes of Poland. A checklist, Biodiversity of Poland, 1, 442 pp.

Niedźwiedź T., 1992, Climate of the Tatra Mountains, Mountain Research and Development, 12 (2), 131-146.

Ozenda P., 1988, Die Vegetation der Alpen im europäischen Gebirgsraum, G. Fischer Verlag, Stuttgart, New York, 353 pp.

Paszyński J., Kędziora A., Tuchołka S., Kapuściński J., Olejnik J., 1995, Wpływ rodzaju powierzchni czynnej na strukturę bilansu cieplnego, [in:] Współczesne badania klimatologów Polskich w kraju i za granicą, Conference Papers, 23, 69-92.

Paszyński J., Miara K., Skoczek J., 1999, Wymiana energii między atmosferą a podłożem jako podstawa kartowania topoklimatycznego, Dokumentacja Geograficzna, 14, 127 pp.

Pawłowski B., 1927, Podstawy wydzielenia pięter roślinności w Tatrach i Beskidach Zachodnich, II Zjazd Słow. Geogr. i Etnogr. w Polsce, Sectio 3, 1-3.

Pawłowski B., 1972, Szata roślinna gór polskich, [in:] Szata roślinna Polski, W. Szafer, K. Zarzycki (eds.), PWN, Warszawa, 1, 89-252.

Pecelj M., Dordević D., Pecelj M.R., Pecelj-Purković J., Filipović D., Šećerov V., 2017, Biothermal conditions on Mt. Zlatibor based on thermophysiological indices, Archives of Biological Sciences, 69 (3), 455-461, DOI: 10.2298/ABS151223120P.

Piękoś H., 1968, Rozmieszczenie roślin regla dolnego i górnego na Sarniej Skale, Krokwi i Łysankach w Tatrach, Fragmenta Floristica et Geobotanica, 14 (3), 317-393.

Piękoś-Mirkowa H., Mirek Z., 1996, Zbiorowiska roślinne, [in:] Przyroda Tatrzańskiego Parku Narodowego, Z. Mirek (ed.), Kraków-Zakopane, 237-274.

Rapetti F., Vittorini S., 1988, Differenze termiche tra i versanti tirrenico ed adriatico dell'Appennino Settentrionale, lungo l'allineamento, Livorno – Modena, 20th International Conference on Alpine Meteorology, Sestola.

Rubel F., Brugger K., Haslinger K., Auer I., 2017, The climate of the European Alps: Shift of very high resolution Köppen-Geiger climate zones 1800-2100, Meteorologische Zeitschrift, 26 (2), 115-125, DOI: 10.1127/metz/2016/0816.

Skrynyk O., Błażejczyk K., 2021, Wpływ cyrkulacji atmosferycznej na opady w Tatrach oraz Czarnohorze, Przegląd Geograficzny, 93 (1), 43-58, DOI: 10.7163/PrzG.2021.1.3.

Szymczak R.K., Błażejczyk K., 2021, Heat balance when climbing Mount Everest, Frontiers in Physiology, 12, DOI: 10.3389/fphys.2021.765631.

Treml V., Banaš M., 2008, The effect of exposure on alpine treeline position: a case study from the High Sudetes, Czech Republic, Arctic, Antarctic and Alpine Research, 40 (4), 751-760.

Yoshino M.M., 1975, Climate in a small area. An introduction to local meteorology, University of Tokio Press, 549 pp.

Yoshino M.M., 1984, Thermal belt and cold air drainage on the mountain slope and cold air lakes in the basin at quiet, clear night, GeoJournal, 8 (3), 230-250, DOI: 10.1007/BF00446473.

Streszczenie

Obszary górskie, w tym Tatry, są ważnym elementem krajobrazu. Ich wyróżniającą się cechą jest strefowość wysokościowa wszystkich elementów środowiska: rzeźby terenu, pokrywy glebowej, szaty roślinnej i klimatu. Celem artykułu przedstawienie dwóch aspektów bioklimatu obszaru Tatr: i) bioklimatu roślin, a mianowicie interakcji zachodzących pomiędzy roślinnością acidofilną a lo-

kalnymi cechami rzeźby i mokroklimatu w piętrze subalpejskim i alpejskim Doliny Suchej Wody, oraz ii) bioklimatu człowieka, a mianowicie pokazanie, w jaki sposób lokalne i regionalne czynniki geograficzne wpływają na stres termiczny w Tatrach. Badania dotyczą różnych skal przestrzennych (mikro- i regionalnych) i czasowych (krótkoterminowych i wieloletnich).
Terenowe badania klimatyczno-roślinne prowadzono w górnej części Doliny Suchej Wody na zboczach Beskidu i Uhrocia Kasprowego, porośniętych naturalną roślinnością acidofilną, typową dla strefy alpejskiej i antropogeniczną (po wypasie) w strefie subalpejskiej. Interakcje pomiędzy cechami mikroklimatu, będące efektem specyficznych cech bilansu radiacyjnego, a istniejącą pokrywą roślinną kształtowały gradienty temperatury powietrza przy powierzchni gruntu, które były istotnie modyfikowane przez ekspozycję zboczy i lokalne czynniki siedliskowe związane z rzeźbą terenu (obecność bloków skalnych, zagłębień i płatów śniegu). Gradientom temperatury towarzyszyło stopniowe przechodzenie roślinności strefowej, typowej dla pasów subalpejskiego i alpejskiego. Badania bioklimatu człowieka uwzględniają regionalną zmienność stresu termicznego, określonego za pomocą wskaźnika UTCI, w północnej i południowej części Tatr. Wysokościowa strefowość obciążeń termicznych jest modyfikowana przez położenie w stosunku do głównego grzbietu. Gradienty UTCI są wyższe niż gradienty temperatury, szczególnie w obszarze północnym. Na północnych skłonach Tatr są one znacząco większe niż na skłonach południowych.

Słowa kluczowe: Tatry, bioklimat roślin, interakcje czynników środowiskowych, bioklimat człowieka, gradienty stresu cieplnego.

A b s t r a c t

Biometeorology is an interdisciplinary science dealing with research of the interactions between atmospheric processes and living organisms – humans, plants and animals. In the present paper we aim to discuss the influence of local and regional features of mountainous climate on the functioning of plant cover and on human organisms on the example of the Tatry Mts. The local scale perspective bases on experimental climate-vegetation studies were carried out in the upper part of Suchej Wody Valley on the slopes of Beskid Mt. and Uhrocie Kasprowe Mt. The slopes are covered with grassland vegetation, natural for the alpine belt, and anthropogenic (post-grazing) vegetation within the subalpine belt. The observed zonality of vegetation is an effect of interactions between the near ground gradients of air temperature modified by slope exposure and the local habitat factors associated with relief (exposure, presence of blockfields, gullies, and snow patches). The research of regional scale perspective deal with the human bioclimate by considering variability of the thermal stress, defined by UTCI, in northward and southwards parts of the Tatras and in their closer (Podtatrze, Spisko-Gubałowskie foothill) and more distant (Popradzka Valley, Low Tatras) surroundings. The spatial variability of thermal stress is an effect of climate altitudinal zonality modified by location in relation to main ridge. It causes that northward UTCI gradients are significantly higher than southward ones.

Key words: Tatra Mts., plant bioclimate, environmental factors interactions, human bioclimate features, thermal stress gradients.