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The effect of humidity and temperature on human well-being in the forest and on open terrain

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Abstract. Between 01.01.2010 and 31.12.2011, we conducted measurements of air temperature and relative humidity at points located deep within forest area, along the edge of the forest in the immediate vicinity of a lake and in open terrain. The thermal and humidity conditions that have a stimulating effect on human well-beeing were determined for the selected locations by calculating the number of hot ($t_{max} \geq 25°C$) and very hot days ($t_{max} \geq 30°C$) as well as the number of frosty ($t_{max} < 0°C$) and very frosty days ($t_{min} \leq -10°C$). The range of the stimulatory effect on human well-being by temperature was determined based on changes in the average night temperature and the amplitude of the daily air temperature. Stimulating humidity conditions were determined by comparing the the relative humidity to a reference value associated with a moist feeling and calculating the number of humid days ($s \geq 18.8$ mbar).

Keywords: thermo-humidity stimulus, forest, open terrain

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1. Introduction

Recreational and touristic use of forest areas gain more and more significance amongst the non-productive forest functions (Paschalis-Jakubowicz 2009). Forest sites became very popular and attractive places for satisfying the needs for rest of humans (Kikulski 2009; Referowska-Chodak 2015), which is largely linked to therapeutic and recreational characteristics of vegetative cover (Krzymowska-Kostrowicka 1997). A growing social need for touristic and recreational forest use results not only in larger pressure on forest ecosystems, which often leads to their degradation, but also in conflict with productive and environmental forest functions, which presents a certain challenge for the management practices of the State Forests (Tracz, Mazur 2003; Paschalis-Jakubowicz 2009; Kikulski 2011; Referowska-Chodak 2010, 2015).

A group of geographic and meteorological factors have an influence on the development of proper characteristics of bioclimate (Kozłowska-Szczęsna et al. 1997; Krzymowska-Kostrowicka 1997), which affects touristic and recreational attractiveness of a region (Błażejczyk 2004; Matzarakis 2006). Bioclimatic stimulators affect human body by triggering certain responses whilst their intensity changes through time and space. Air temperature and humidity, which belong to the group of thermal and humidity incentives, have a largest influence on human ability to feel the thermal conditions. Forest environment creates climatic conditions that differs from the conditions of open area (Drużkowski 1987; Santorski 2004; Wilczyński, Durło 2003, 2005; Ożga 2011). Defining the stimulating effect of thermal and humidity conditions in forests is part of the evaluation of forest bioclimatic potential.

The research hypothesis states that compared to open area, forest environment also changes its bioclimate by modifying climatic conditions.

The goal of current work was to compare stimulating effects of thermal and humidity conditions of forest site, open area as well as area located along the edge of the forest in the immediate vicinity of a lake.

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2. Research methods

In order to define the stimulating effect of thermal and humidity conditions, the field experiment was conducted within forest (L), open area (OT) as well as the area located along forest edge (GL) in the immediate vicinity of a lake (Fig. 1a). Selected research sites are located in the north-eastern Poland (Table 1) 25 km south east from Olsztyn (Fig. 1b) and lie within the Olsztyn Forest District, Nowa Wieś forest sub-district as well as in the Jedwabno Forest District, Łowne Jezioro forest sub-district in Bałdzki Piec. Continental midland pine forests including fresh pine forests *Peucedano-Pinetum* and moist pine forests *Molinio-Pinetum* as well as continental mixed forest *Pino-Quercetum* dominate the study area (Matuszkiewicz 2008a). According to the geobotanical division of Polish lands, the study area is located within the region marked as F.1a.2a and F.1a.2b, which positions it within the Northern Mazursko-Białoruski Division (F), Mazurska Province (1), Zachodniomazurska Sub-Province (a), District of Puszcza Napiwodzka (2), Sub-districts Maruzko-Kośniański (a) and Stawigudzko-Butryński (b) (Matuszkiewicz 2008b).

The research plots L and GL were set up in an even-aged pine stand without undergrowth; with patches of birch, buckthorn and juniper understory; and with ground cover consisted mainly of blackberry shrubs with the height of 30 cm and closure of 10. The measurement point L was positioned within the Kośno Lake Nature Reserve, which includes the natural water reservoir with eutrophic characteristics, the area of 551.9 ha and maximum depth of 44.6 m (about 13 m, on an average) as well as a narrow strip of forest around the lake (Jańczak 2006). The measurement point in an open area was set up 800 m away from forest in the permanently green area.

Air temperature and relative air humidity were measured in the established measurement points from 01.01.2010 to 31.12.2011 during the consecutive days at 0:00, 3:00, 6:00, 9:00, 12:00, 15:00, 18:00 and 21:00 o'clock (for every 3 h). The measurements were done using the iButton® loggers (Hygrochron Temperature and Humidity Logger iButton® with 8KB Data-Log Memory) manufactured by Maxim Dallas (Fig. 2).

The loggers were placed within the radiation protection covers Onset and mounted on trees (L and GL measurement points) and on poles (OT measurement point) on their nor-

a) b)

Figure 1. Location of measurement points (a) and area of investigation (b); L – forest, GL – eadge of forest, OT – open terrain

Table 1. Geographical coordinates of measurement points

Location	Latitude ϕ [°]	Longitude λ [°]	Height asl [m]	Distance from the Kosno lake [m]
L	53.6066	20.6585	138	1541
GL	53.6354	20.6755	124	9
OT	53.5997	20.6032	148	3996

L – forest, GL – eadge of forest, OT – open terrain

a) b)

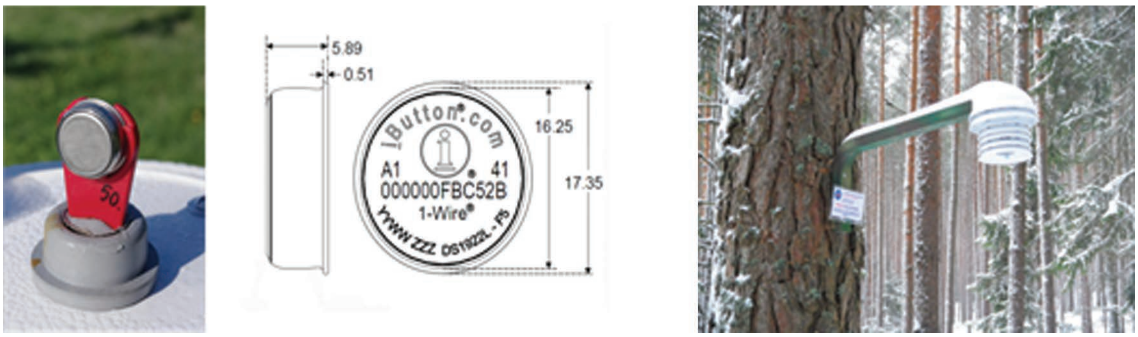

Figure 2. The Maxim Dallas sensor and it's dimensions (in mm) of the handle (a) and an example of fixing the sensor in the study area (b)

thern side at the standard height of 2 m above ground. Selection of loggers was dictated by their small size as well as their energy self-sufficiency, which was extremely important because of very long measurement period and location of loggers within forest interior.

The collected data were used for defining stimulating effects of thermal and humidity conditions on a seasonal bases meaning spring (March to May), summer (June to August), fall (September to November) and winter (December to February). The frequency of days when maximum and minimum temperature was outside the stated numerical boundaries was established, which presented the so-called number of specific days (Błażejczyk, Kunert 2011):

- number of hot days with maximum temperature of ≥ 25°C,
- number of very hot days with maximum temperature of ≥ 30°C,
- number of very cold days with minimum temperature of ≤ −10°C,
- number of cold days with maximum temperature of < 0°C.

Stimulating effect of thermal factors was established based on the day-to-day changes in the mean air temperature (Δt) as well as the changes in the value of daily amplitude of air temperature (*dt*), comparing them to the scale of criteria presented below (Table 2) (Błażejczyk 2004).

Stimulating effect of humidity factors was defined by comparing the value of relative humidity measured at 12 o'clock UTC with the scale of humidity perception (Table 3). The number of sultry days was estimated. A sultry day was described as a day when the value of actual pressure of water vapour at 12 o'clock UTC reached minimum 18.8 hPa (Kozłowska-Szczęsna et al. 1997). The value of actual water vapour pressure was stabled based on the air temperature and relative humidity at 12 o'clock UTC using the dependencies between those parameters (Kędziora 1995).

3. Results and discussion

Monthly measurements as well as annual value of the mean air temperature at the measurement point located within the forest site (L) were lower than those measured along the forest edge or in the open terrain. When comparing forest and open terrain, the differences were from 0.1°C in December to 1.0°C in June. For the mean annual temperature, the difference was 0.6°C. The results were similar to the data obtained by Drużkowski (1987). The differences between air temperature measured within the forest (L) and along the forest edge (GL) were slightly lower and reached from 0.2°C in February and March to 0.9°C in October. The mean air temperature in the forest was 0.5°C lower than that along its edge. The differences in temperature values obtained at the measurement points located in the immediate vicinity of the lake and open terrain were the lowest. Distinct meteorological conditions

Table 2. The scale of thermal incentives according to Bajbakova

Δt(°C)	Thermal incentives
≤ 2.0	neutral
2.1–4.0	felt
4.1–6.0	significant
≥ 6.1	sharp
dt	thermal incentives
< 4.0	neutral
4.0–7.9	weakly felt
8.0–-11.9	strongly felt
≥ 12.0	sharp

Source: Błażejczyk 2004
Δt is the day-to-day changes in the mean air temperature; *dt* is the daily amplitude of air temperature.

Table 3. The scale of humidity incentives according to Bokša, Boguckij

Relative air humidity *f* [%]	Humidity incentives
≤ 55.0	dry air
56.0–70.0	moderate dry air
71.0–85.0	humid air
> 85.0	very humid air

Source: Błażejczyk, Kunert 2011

within forest and in open terrain were noted by Santorski (2003). Whilst comparing air temperature in 1991–1995 measured at the Forest Meteorological Stations and coinciding by location meteorological posts of the Institute of Meteorology and Water Management (IMGW), which were representing the same environmental and forest districts, it was noted that in winter (from January to March) and autumn (October and November), the mean air temperature was higher at the forest stations compare to the posts of the IMGW.

Relative air humidity was the lowest in the open terrain, whilst its values at the remaining measurement points were similar (Table 4). The largest differences in relative air humidity between open terrain and forest sites were observed in summer, which agrees with the results received by Drużkowski (1987).

The number of days with distinctive temperature values serves as an important indicator of the stimulatory effect linked to thermal conditions (Fig. 3). The lowest number of hot and very hot days during summer as well as cold and very cold days during winter was noted within the forest edge, which could probably be related to a direct proximity of water reservoir and its mitigating effect on thermal extremes. The number of distinctive days within forest and in the open terrain was similar.

Evaluation of the degree of stimulating effect related to thermal conditions based on the day-to-day changes in the mean daily air temperature values (Fig. 4) indicated that on an average, 60% of all the days throughout the year were 'neutral' or those affecting the human activity at the lowest degree. Such days were more often registered in summer from 63% (in open terrain) to 70% (within forest). In spring and autumn, the share of neutral incentives was similar in all the analysed locations (about 62% in summer and 65% in autumn), whilst during winter, their share was the lowest and equal to about 54%. The day-to-day changes in temperature described as 'noticeable' had a very low differentiation amongst the seasons. They remained at the comparable level at all measurement points, being about 28% annually.

The changes in average daily temperature, which could have a negative or disturbing effect on human well-being described, respectively, as significant or severe incentives were more commonly noted in witner time. In autumn, in

Table 4. The average monthly air temperature (°C) and relative humidity (%) at measuring points in 2010–2011

Mounth	Temperature of air			Relative air humidity		
	L	GL	OT	L	GL	OT
I	-5.9	-5.6	-5.7	97	96	92
II	-5.0	-4.8	-4.7	93	92	87
III	1.2	1.4	1.7	83	82	79
IV	7.8	8.3	8.5	74	72	69
V	12.0	12.3	12.7	80	79	74
VI	15.9	16.5	16.9	76	75	71
VII	18.5	19.0	19.3	82	81	74
VIII	17.3	18.0	18.0	83	81	73
IX	12.2	12.9	12.7	87	86	79
X	5.7	6.6	6.2	89	87	83
XI	2.9	3.4	3.3	97	97	86
XII	-2.6	-2.3	-2.5	94	97	92
Annual average	7.5	8.0	8.1	86	85	79

L,GL, OT – as in Table 1

the open terrain and within forest edge, there were no severe incentives. They occasionally occured only within forest.

Thermal incentives established based on the daily amplitudes of temperature were showing high seasonal variability (Fig. 5). Neutral incentives were more commonly noted in winter, from 47% in open terrain to 53% at the forest edge. In autumn, their share was within 24–29%, whilst in spring and summer, they occured very rarely or at the level of 8–10%. Weakly felt thermal incenitives were more commonly noted in autumn, whilst during the other seasons, they had a simi-

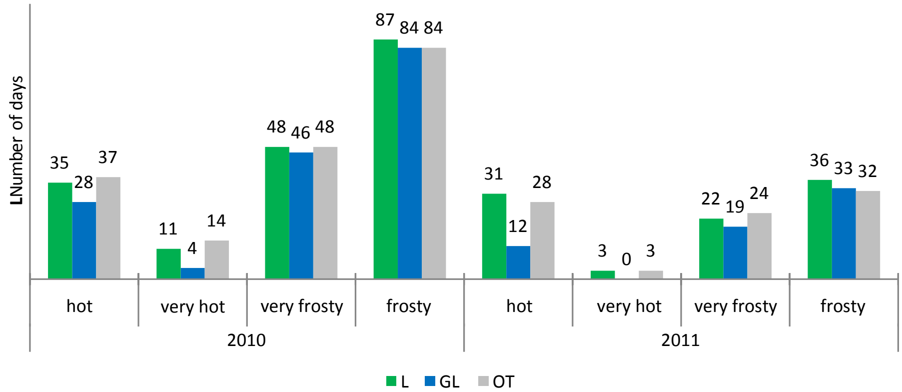

Figure 3. The number of specific days in 2010–2011; L,GL, OT – as in Figure 1

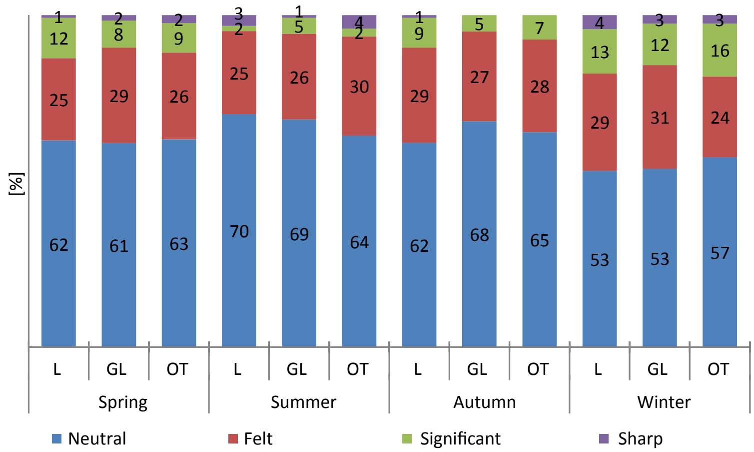

Figure 4. Occurrence frequency [%] of thermal incentives calculated based on day to day changes of the average daily air temperature in 2010–2011; L, GL, OT – as in Figure 1

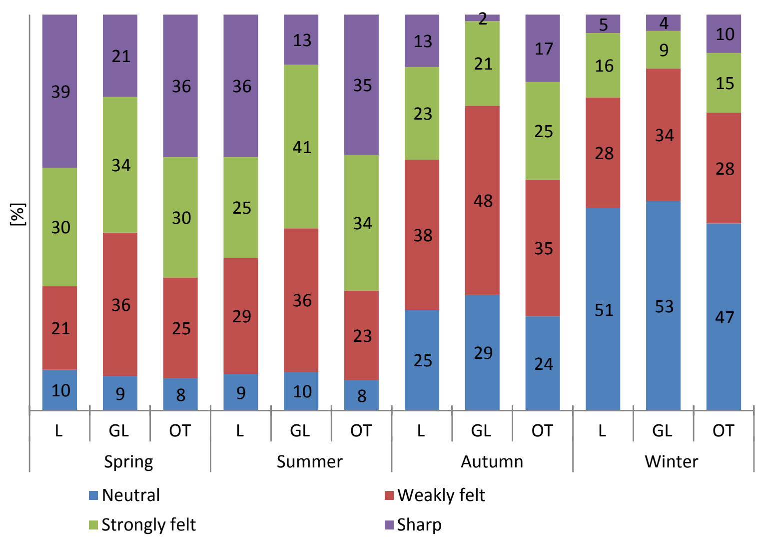

Figure 5. Occurrence frequency [%] of thermal incentives calculated based on differences of daily maximal and minimal air temperature in 2010–2011; L, GL, OT – as in Figure 1.

lar frequency of occurrence. Owing to the frequency of strongly felt and severe incentives, spring and summer could be characterised as less beneficial. In that respect, the winter could be evaluated as relatively beneficial, when severe variations in daily amplitudes of air temperature were occuring the least often and presented from 4% to 10% of situations.

Seasonal analysis of frequency of occurrence of the thermal incentives in the studied locations allowed to state that the share of specific incentives within forest and at open terrain was at the similar level. With a frequency significantly lower than that in two other measurement points, situations described as severe were noted at the forest edge with the nearby location of the lake during all the seasons. That area also had a significantly higher share of neutral and weakly felt incentives.

The frequency of occurrence of specific perception of humidity within forest and at forest edge was at the similar level during all the seasons. In those locations, in spring and summer, perception of dry and relatevely dry air reached 60% of the noted humidity perceptions. In autumn, very humid air was felt with the frequency of 59%, whilst in winter, such perception of humidity was dominating, being during 85% of days within forest and 79% of days at forest edge. In autumn and winter, perception of dry air was rarely observed. In the open terrain, dry air was noted more commonly, whilst wet air was more rare (Fig. 6).

Sultry days were noted from June to August whilst significantly higher number of such days occurred in 2010 (Fig. 7). The largest number of sultry days was observed at the measurement point located at the forest edge in the close proximity of the lake, which was linked to higher actual pressure of water vapour in the area surrounding water reservoir.

4. Conclusions

Forest environment changes thermal and humidity conditions of the local climate. The current work studied the bioclimatic relations between forest area and open terrain from the point of view of recreational forest function. The research conducted within forest areas and in the open terrain in 2010–2011 in the Olsztyn and Jedwabno Forest Districts allowed to formulate the following conclusions:

Mean monthly air temperature during all months of the year was the lowest in the forest compared to open terrain. The average annual air temperature in the forest was 7.5°C,

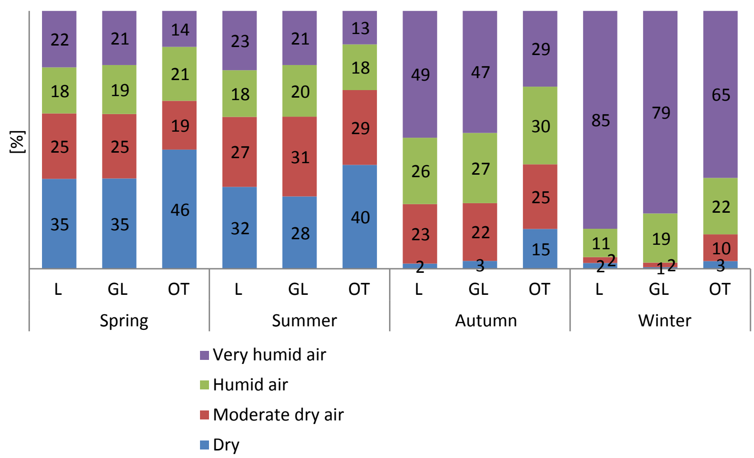

Figure 6. Occurrence frequency [%] of humidity incentives calculated based on relative humidity of air in 2010–2011; L, GL, OT – as in Figure 1

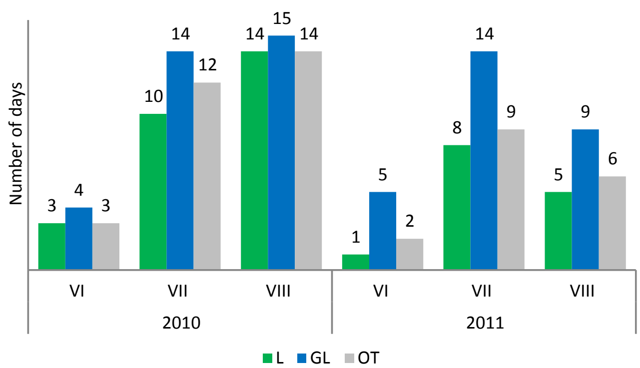

Figure 7. The number of sultry days in 2010–2011; L, GL, OT – as in Figure 1

which was 0.6°C lower than that in the open terrain. The average monthly and the average annual relative air humidity were higher in the forest than those in other locations.

The lowest number of cold, very cold, hot and sultry days were noted at the forest edge with the close proximity of water reservoir, whilst the highest number of such days was observed at the open terrain. Sultry days were more commonly noticed in the close proximity of the lake and less often in the forest.

Stimulating effect of thermal conditions evaluated based on the day-to-day changes in the mean daily air temperature (Δt) as well as the amplitude of the air temperature values (dt) was highly varied in the number of incentives throughout different seasons both at the open terrain as well as within forest areas. Thermal incentives of forest area, forest edge and open terrain showed only small differentiation.

Perception of humidity evaluated based on the relative air humidity values was highly differentiated during different seasons. In spring and summer, dry and relatively dry air was dominating, whilst in winter, it was noted only occasionally. Dry air was more common in spring in the open areas (46%) compared to forest area (35%), whilst in summer, those numbers varied at the level of 32–40%. In winter ,very wet air was dominating, being 85% of the time in forest and only 65% of the time in the open terrain.

Conflict of interests

The authors declare the lack of potential conflicts.

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Author's contribution

E.D. – study conception and preparation, interpretation of the results; M.P. – study conception and field research; Z.Sz. – literatury review, creating and editing graphs.

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