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EFFECTS OF HURRICANE-DRIVEN DEFORESTATION AND REFORESTATION ON DIURNAL SOIL TEMPERATURE CHANGES IN THE TATRA MOUNTAINS IN SOUTHERN POLAND

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ABSTRACT

Aim of the study

The aim of the study was to investigate the effect of hurricane-driven deforestation and reforestation on diurnal changes in soil temperatures in the Tatra Mountains (Poland).

Material and methods

Soil temperature was measured at 0.20 m of depth in the mineral soil horizons on both north-facing and south-facing slopes in the deforested subcatchment and in the control woodland subcatchment. Soil temperature measurements were collected every 10 minutes in 2015–2020. The cross-correlation analysis was applied in order to determine the magnitude of the delay of soil temperature to air temperature changes at four studied sites during a day.

Results and conclusions

The effect of deforestation on diurnal changes in soil temperature manifested itself mainly via a larger range of diurnal soil temperatures during warmer part of the year. In the summer months the diurnal soil temperature range for deforested slopes was 1 to 3°C higher than that for wooded slopes. Diurnal soil temperature ranges were found to strongly decline with reforestation. Deforested slopes were characterized by a more rapid soil temperature reaction to changes in air temperature over the course of the day. Cross-correlation revealed that soil temperature changes on a deforested, south-facing slope occurred 4 to 5 hours later relative to changes in air temperature, while the delay for a wooded slope facing the same direction was usually 7 to 8 hours. Soil temperatures in the summer, both during the day and at nighttime, were higher on deforested slopes than wooded slopes. This indicates that deforestation may significantly intensify soil warming caused by global climate warming.

Keywords: diurnal changes, deforestation, reforestation, soil temperature, Tatra Mountains

INTRODUCTION

Deforestation affects 0.13% to 0.20% of the Earth's surface every year (Chakravarty et al., 2012). One of the effects of deforestation is soil temperature change. According to Prevedello et al. (2019), deforestation caused surface temperature increases of 0.38°C and 0.16°C from 2000 to 2010 in tropical and temperate regions, respectively, while reforestation caused declines of –0.18 and –0.19°C in the same regions. Therefore, deforestation may significantly increase soil warming caused by global climate warming (Hu

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and Feng, 2003). Most studies suggest that deforestation triggers a very large increase in soil temperature in the warmer part of the year (Donnelly et al., 1991; Bhatti et al., 2000; Moroni et al., 2009; Hu et al., 2013) as well as small changes in the cooler part of the year (Donnelly et al., 1991; Hashimoto and Suzuki, 2004; Moroni et al., 2009). Ultimately deforestation may also lead to increased seasonality in soil temperature (Londo et al., 1999; Bhatti et al., 2000; Moroni et al., 2009).

Deforestation also affects soil temperature changes over each 24-hour period (diurnal changes). Diurnal soil temperature variation plays an important role in biogeochemical processes occurring in the soil. They are a very important factor shaping daily fluctuations in the concentration of labile soil phosphorus (Vandecar et al., 2009), methane emissions (Mikkela et al., 1995), and soil respiration – soil CO_2 efflux (Davidson et al., 1998; Subke et al., 2003, Uvarov et al., 2006; Tang et al., 2008). Hick Pries et al. (2017) noted an increase in CO_2 loss of 34% to 37% from the first meter of the top mineral soil horizon with a rise of 4°C in soil temperature. The diurnal soil temperature range also determines the composition of the microbial community and level of microbial activity (Uvarov et al., 2006; Vandecar et al., 2009). Despite this level of relevance of soil temperature in ecosystem functioning, soil temperature has not been analyzed as much as other environmental variables (Bai et al., 2014; Jungqvist et al., 2014; Oni et al., 2017).

The aim of the study was to identify the effects of deforestation triggered by hurricane-force winds in 2013 on diurnal soil temperature changes recorded on mountain slopes facing north and south in the Tatra Mountains in Poland. A windthrow event with the maximum hourly average wind velocity of 29 $m \cdot s^{-1}$ occurred on 25 December 2013 (Strzyżowski et al., 2016). Initial field research focused on soil temperature measurements on hillslopes in a deforested area in order to compare the results with those for an adjacent woodland subcatchment. However, a rare opportunity occurred in the course of the study – an opportunity to directly observe the effects of deforestation and reforestation on soil temperature in the same subcatchment. The studied woodland subcatchment was first affected by the bark beetle (Żelazny et al., 2018), which weakened spruce stands in 2018, and this was followed by very high winds in 2019 that toppled many of the trees (field observations). On the other hand, the deforested subcatchment was reforested. It also experienced gradual natural forest and bush succession.

STUDY AREA AND METEOROLOGIC BACKGROUND INFORMATION

The study was conducted in two small subcatchments of the Kościeliski Potok catchment: (1) Pośrednia Kopka, a hurricane-deforested subcatchment (area: 14.4 ha), (2) Kończysta Turnia, a woodland control subcatchment (area: 14.1 ha). Both subcatchments are located in the Western Tatra Mountains in southern Poland (see: Fig. 1). The woodland subcatchment is located at an elevation of 968 to 1,264 meters, while the deforested subcatchment is located at an elevation of 940 to 1,200 meters. The study area is underlain by sedimentary rocks: limestone, sandstone, conglomerates – these are covered with Rendzic Leptosols (Skeletic) and Haplic Cambisols (Eutric) (Skiba et al., 2015). The soils in the study area are most often 0.40 to 0.60 m deep. In the woodland subcatchment, the soils are characterized by the occurrence of the O horizon (0.01 to 0.05 m), while soils in the deforested subcatchment lack this horizon (Żelazny et al., 2018).

According to Hess (1965), the study area is located in a temperate climate zone. During the study period (2015–2020) the warmest months of the year were June, July, and August, with the mean monthly air temperature exceeding 10°C (see: Fig. 2). The coolest months of the year were usually December, January, and February, with the mean monthly air temperature decreasing below 0°C. The summer months were characterized by the highest atmospheric precipitation totals of the year (see: Fig. 2). Snow cover usually occurred from October or November to April or May. The average monthly snow depth reached usually 300 to 400 mm, with as much as 800 mm, noted in December, January, and February. Exceptionally low snow cover depths were noted in the winter of 2015/2016 (see: Fig. 2).

Until December of 2013 the study area was covered with an 85 to 150 year old fir and spruce forest. For-

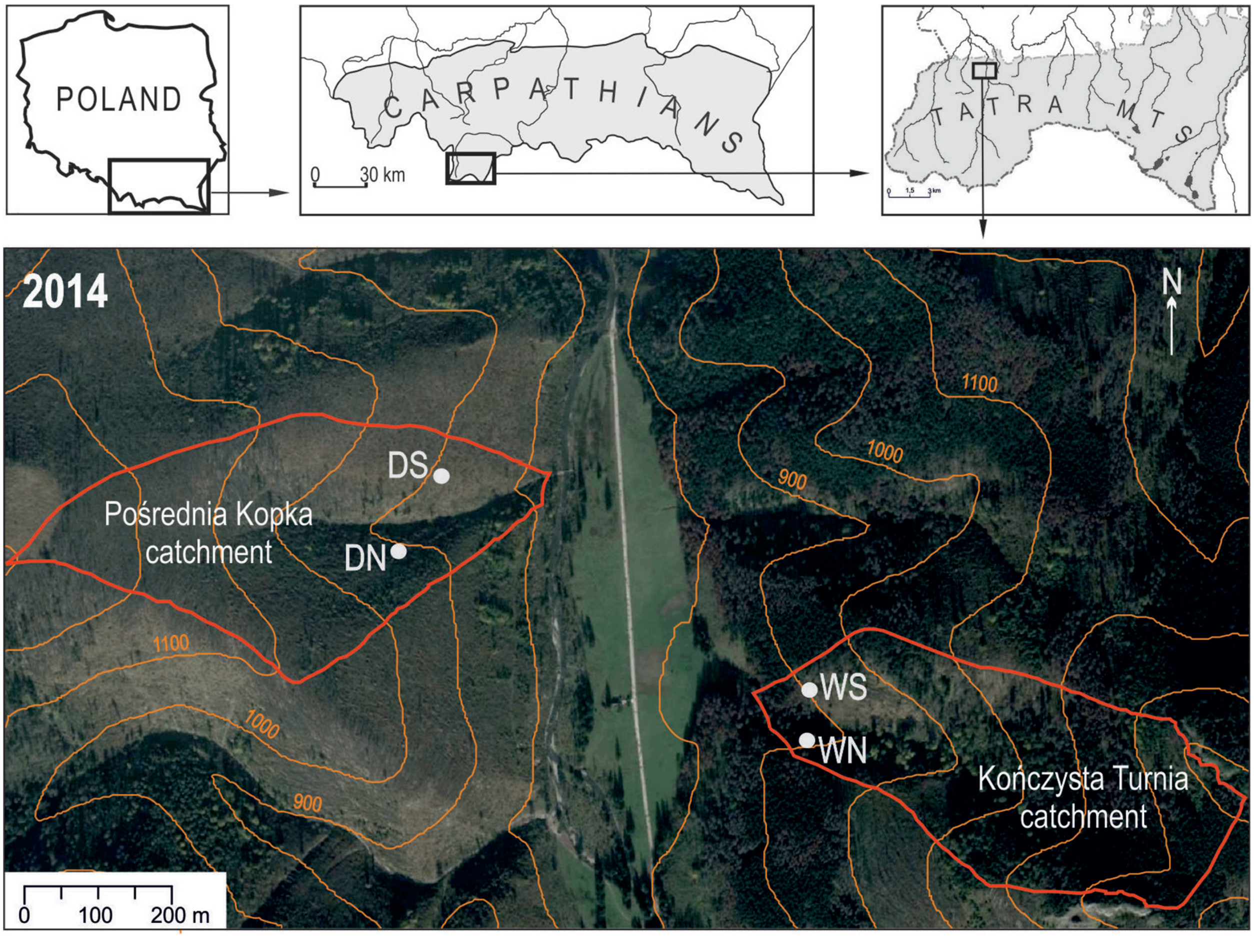

Fig. 1. Study area one year after deforestation triggered by hurricane-force winds in 2013

est coverage was almost 100% in the Pośrednia Kopka subcatchment and about 93% in the Kończysta Turnia subcatchment. In December 2013 hurricane-force winds felled 97% of tree stands in the Pośrednia Kopka subcatchment while in the Kończysta Turnia subcatchment only 13% (Żelazny et al., 2018). Some of the fallen trees were removed in 2014–2015 in the Pośrednia Kopka subcatchment. Fir and beech seedlings were planted in a lower and middle part of this subcatchment in 2015. According to Żelazny et al. (2018), 23% of the deforested area of the Pośrednia Kopka subcatchment experienced an invasion of bush vegetation and juvenile trees in 2018, while almost 50% of the forested area in the Kończysta Turnia subcatchment experienced an attack by the bark beetle. A large percentage of trees on the south-facing slope of the Kończysta Turnia subcatchment fell down by high winds in 2019.

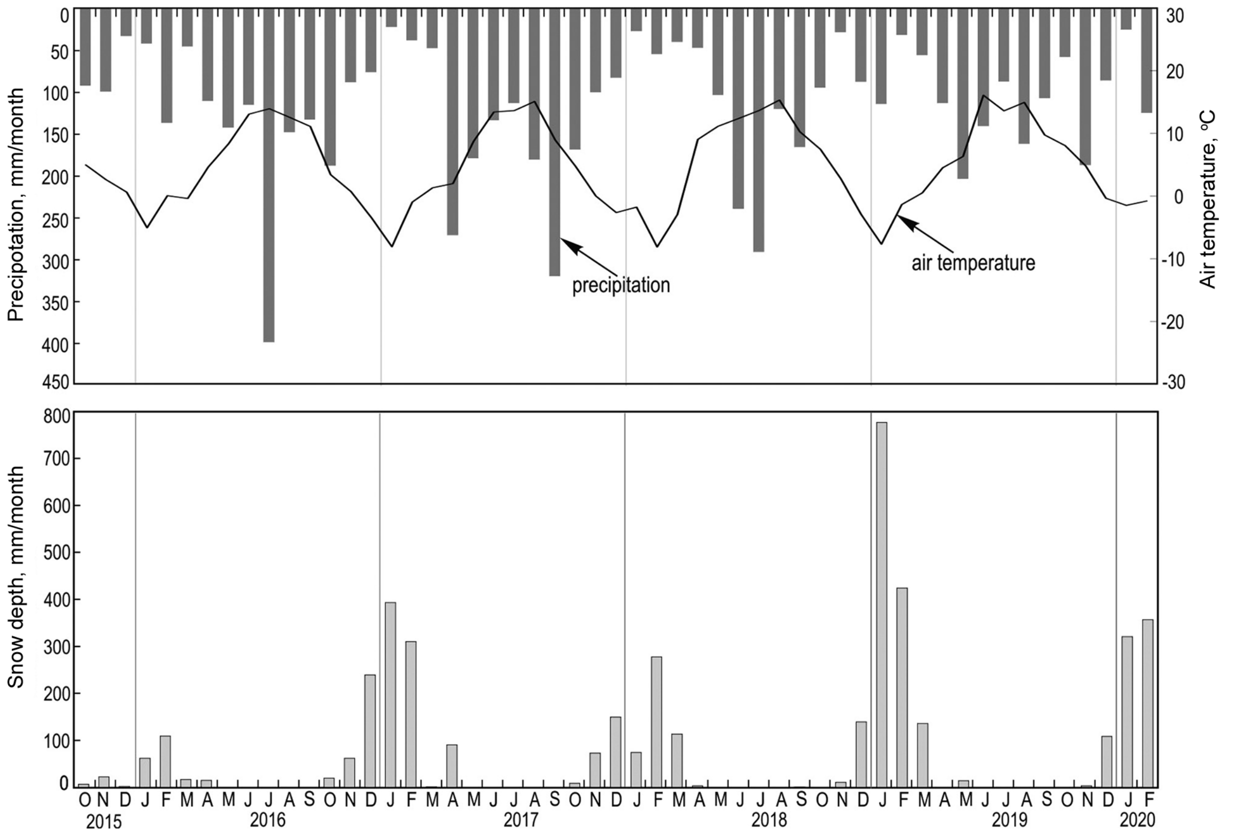

Fig. 2. Meteorological characteristics of study period (2015–2020): monthly precipitation totals, mean monthly air temperature, and mean monthly snow depth

MATERIALS AND METHODS

Field measurements

Decagon ECH2O 5TM sensors measuring soil temperature were placed at a depth of 0.20 m in the mineral soil horizons of four sites – on north-facing and south-facing deforested slopes (DN and DS sites) in the Pośrednia Kopka subcatchment and on north-facing and south-facing woodland slopes (WN and WS sites) in the control Kończysta Turnia subcatchment. The sensors were installed at an elevation of about 900 meters (see: Fig. 1). Soil temperature measurements were collected every 10 minutes. The first sensors were installed in October 2015 at the WN site and DS site. In April 2017 sensors were installed at the DN site, while in June 2017 at the WS site. The sensors failed several times, which explains gaps in the data set used in the study.

Meteorologic data were obtained from two weather stations located in the vicinity of the studied areas. The stations are run by the Institute of Meteorology and Water Management in Poland. Air temperature data measured at a height of two meters were obtained from the Polana Chochołowska weather station (1,147 m a.s.l.) located about 6 km away from the studied catchments, while atmospheric precipitation and snow cover data came from the Kiry-Kościelisko weather station (928 m a.s.l.) located about 1 km away from the studied catchments.

Statistical analysis

The diurnal soil and air temperature fluctuation range describes the difference between daily maximum temperature and daily minimum temperature. Box-and-whisker plots were used to show monthly median, quantiles and extreme values of the diurnal soil and air temperature fluctuation range (see: Fig. 3), and the

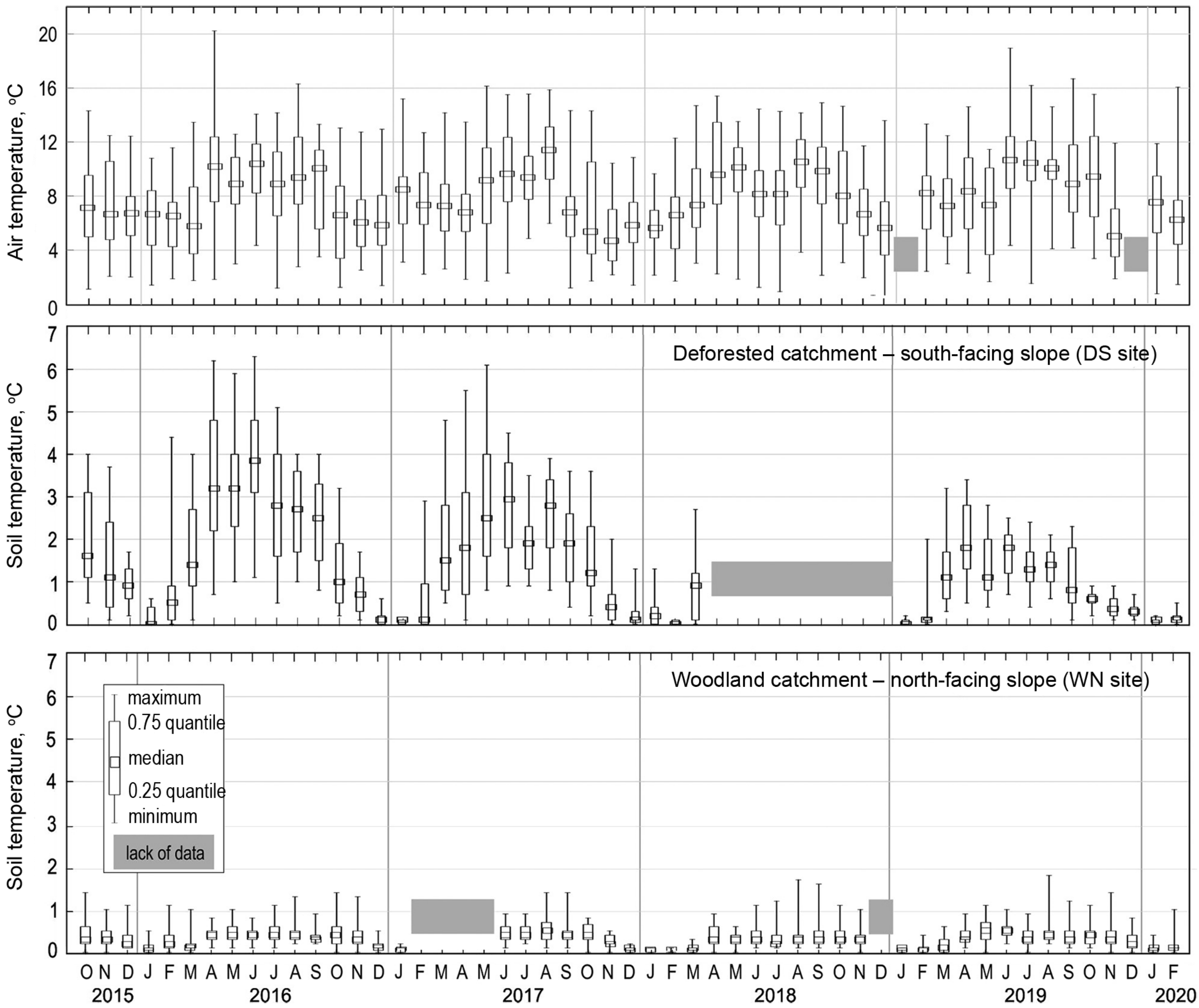

Fig. 3. Monthly changes of diurnal air and soil temperatures ranges at south-facing slope of the deforested subcatchment and at north-facing slope of the woodland subcatchment

soil moisture (see: Fig. 7). Soil temperature and air temperature data obtained every 10 minutes were used to calculate the coefficient of correlation for the two parameters for individual months using the formula (Shaw and Wheeler, 1997):

$$r = \frac{n\,\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{\left[n\,\Sigma X^2 - (\Sigma X)^2\right] \times \left[n\,\Sigma Y^2 - (\Sigma Y)^2\right]}} \quad (1)$$

where r is the correlation coefficient between air temperature time series X and soil temperature time series Y; N is the number of variables in the data set. A cross-correlation was also calculated for soil and air temperature time series. The cross-correlation coefficient (r_m) was computed using the formula (Davis, 2002):

$$r_m = \frac{n\,\Sigma X_i Y_{i+m} - (\Sigma X)(\Sigma Y)}{\sqrt{\left[n\,\Sigma X^2 - (\Sigma X)^2\right] \times \left[n\,\Sigma Y^2 - (\Sigma Y)^2\right]}} \quad (2)$$

where r_m is the cross-correlation coefficient at time lag m (m =1, 2, 3…12 hours) between air temperature time series X and soil temperature time series Y; N is the number of variables in the data set. The lag time for the maximum cross-correlation coefficient indicates the magnitude of the delay of soil temperature to air temperature changes during a given day. All statistical analyses were performed in Statistica 1.3 software (TIBCO Software Inc. 2020).

RESULTS

The largest diurnal fluctuations in soil temperature at depth of 0.20 m at all the studied sites were noted in spring and summer, while smaller fluctuations were noted in autumn and negligible fluctuations were noted in winter (see: Fig. 3). The largest diurnal soil fluctuation ranges were noted on a deforested slope facing south (DS site), while the smallest on a woodland slope facing north (WN site) (see: Fig. 3). During the period 2015–2020 a gradual contraction of the diurnal soil temperature fluctuation range was noted at the DS site – the range was much smaller towards the end of the study period relative to its beginning (see: Fig. 3). For example, in the summer when the soil temperature did not fall below 15°C (even at night), its diurnal fluctuation range in 2016 was most often found to be between 2.5°C and 4.0°C, reaching 6°C in some cases (see: Fig. 4). However, in 2017, the soil temperature range was 1.5°C to 3.0°C. By 2019 it had contracted further to an interval of 1°C to 2°C (see: Fig. 4). Over the same period, daily air temperature averages and diurnal air temperature ranges did not decrease (see: Figs. 2 and 3). Diurnal soil fluctuations ranges at the other studied sites (WS, WN and DN sites) were smaller than that at DS site – usually did not exceed 1.5°C, and did not change distinctly during this time – examples in Fig. 5. However, in 2019 an expansion of diurnal soil temperature ranges was noted for the WS site, which became comparable to those for the DS site, where they had become much smaller (see: Fig. 5).

In the summer months of 2016 and 2017 (no data for 2018), at very high soil temperatures (usually above 15°C), the lowest diurnal soil temperatures at the DS site were noted around 8:00 AM, while the highest between 2:00 and 3:00 PM (see: Figs. 4 and 5). In the months with lower soil temperatures (5°C to 15°C), the time of occurrence of the lowest and highest daily soil temperatures at the DS shifted to a later time. For

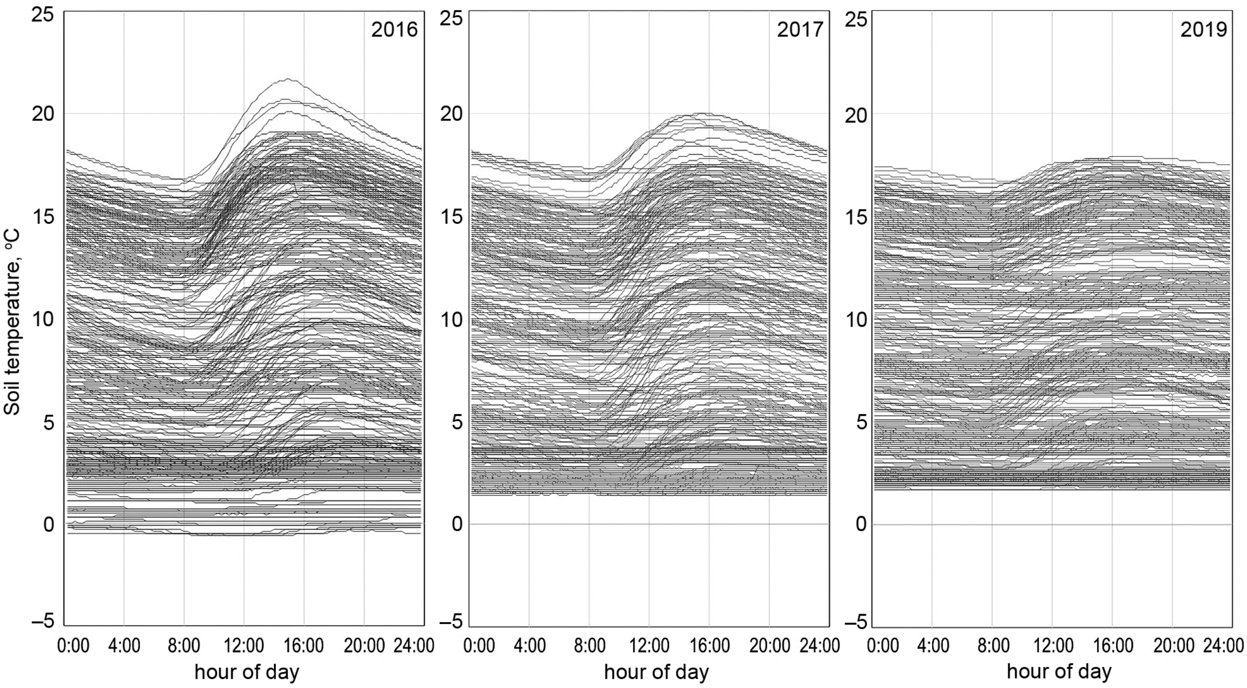

Fig. 4. Diurnal soil temperature changes at DS site in 2016, 2017, and 2019 – each line repersents one day of the year

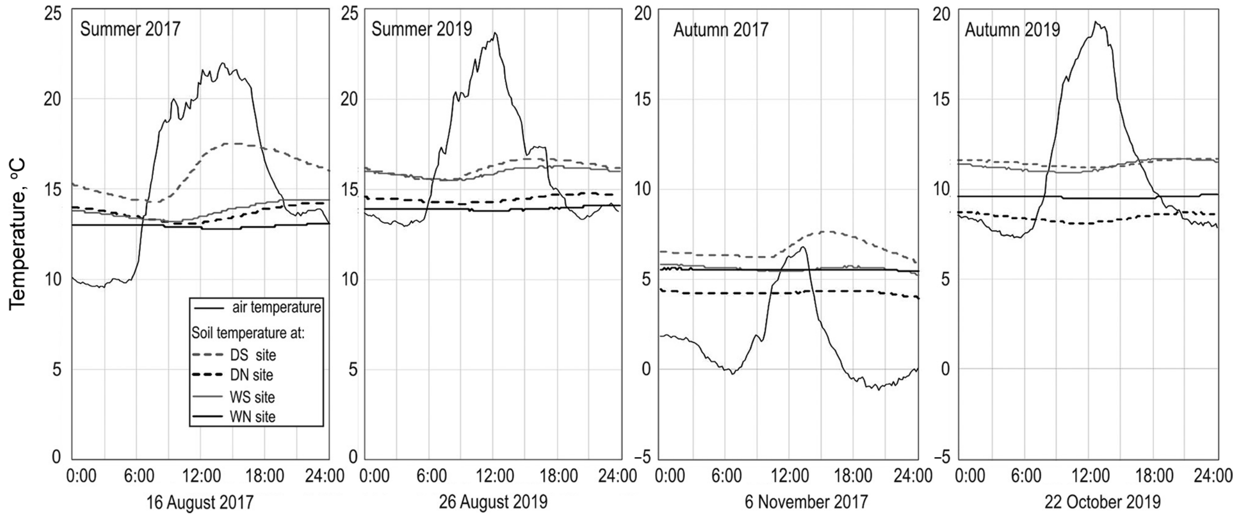

Fig. 5. Diurnal air and soil temperature changes at four studied sites – examples from summer and autumn 2017 and 2019

example, the lowest noted diurnal soil temperatures in late autumn occurred between 10:00 AM and 11:00 AM, while the highest between 4:00 PM and 5:00 PM (see: Fig. 5). In the same period (2016 and 2017), the lowest and highest diurnal soil temperatures in the warmer part of the year were noted later at WS site, WN site, and DN site relative to the DS site. The lowest temperatures were noted between 10:00 AM and 12:00 PM, and the highest between 10:00 PM and midnight (example in Fig. 5). In the summertime, soil temperatures both during the daytime and at nighttime were much higher on deforested slopes versus woodland slopes (facing in the same geographic direction). In 2019, when the diurnal soil temperature range had strongly contracted at the DS site, the daily change pattern at this site came to resemble that at the other studied sites (see: Figs. 4 and 5).

A large delay in soil temperature changes – relative to changes in air temperature over the course of the day – occurred at all the studied sites. In the years 2015–2017 the smallest delay occurred at the DS site, larger delay at the WS site, and the largest delay at the DN site and WN site (example in Fig. 5). The coefficient of correlation between soil temperature and air temperature in summer was highest for the DS site, lower at the WS sites, and the lowest at the WN and DN sites (see: Table 1). The cross-correlation coefficient for all the studied sites increased markedly after

Table 1. Coefficients of correlation between soil temperature and air temperature at four studied sites. Only correlation coefficients with a significance level $P \leq 0.05$ are shown

Year/month	DS	DN	WS	WN
2017/ June	0.61	0.28	0.62	0.40
2017/ July	0.64	0.32	0.58	0.32
2017/ August	0.75	0.42	0.58	0.37
2017/ September	0.70	0.49	0.60	0.48
2017/ November	0.49	0.42	0.59	0.42
2017/ December	–0.12	–0.35		–0.36
2018/ January	0.43	0.34	0.41	0.15
2018/ Fabruary	0.70	0.26	0.41	0.68
2018/ March	0.51	–0.26	0.14	–0.36
2019/ Fabruary	0.09	0.09	0.10	
2019/ March	0.47	0.16	0.36	
2019/ April	0.68	0.34	0.55	0.31
2019/ May	0.75	0.67	0.71	0.51
2019/ June	0.53	0.33	0.43	0.26
2019/ July	0.63	0.46	0.52	0.38
2019/ August	0.57	0.26	0.49	0.18
2019/ September	0.46	0.39	0.47	0.36
2019/ October	0.43	0.35	0.62	0.40
2019/ November	0.29	0.32	0.45	0.24
2020/ January	–0.14	–0.17	–0.21	–0.25
2020/ Fabruary	–0.32	0.17	0.17	–0.19

the temporal shift in air temperature value by a certain number of hours over the course of a 24-hour period. The highest cross-correlation coefficient for the DS site was noted for lag time of 4 to 5 hours while the highest cross-correlation coefficient for the WS site was usually noted for lag time of 7 to 8 hours (see: Fig. 6). During 2015–2019, the maximum values of the cross-correlation coefficient gradually decreased and the corresponding lag time increased at DS site (see: Fig. 6). For the DN and WN sites the lag times between soil temperature and air temperature changes equaled more than 10 hours (data not shown).

DISCUSSION

The results shown in this study suggest that deforestation leads to an increase in diurnal soil temperature ranges at a depth of 0.20 m. Diurnal soil temperature

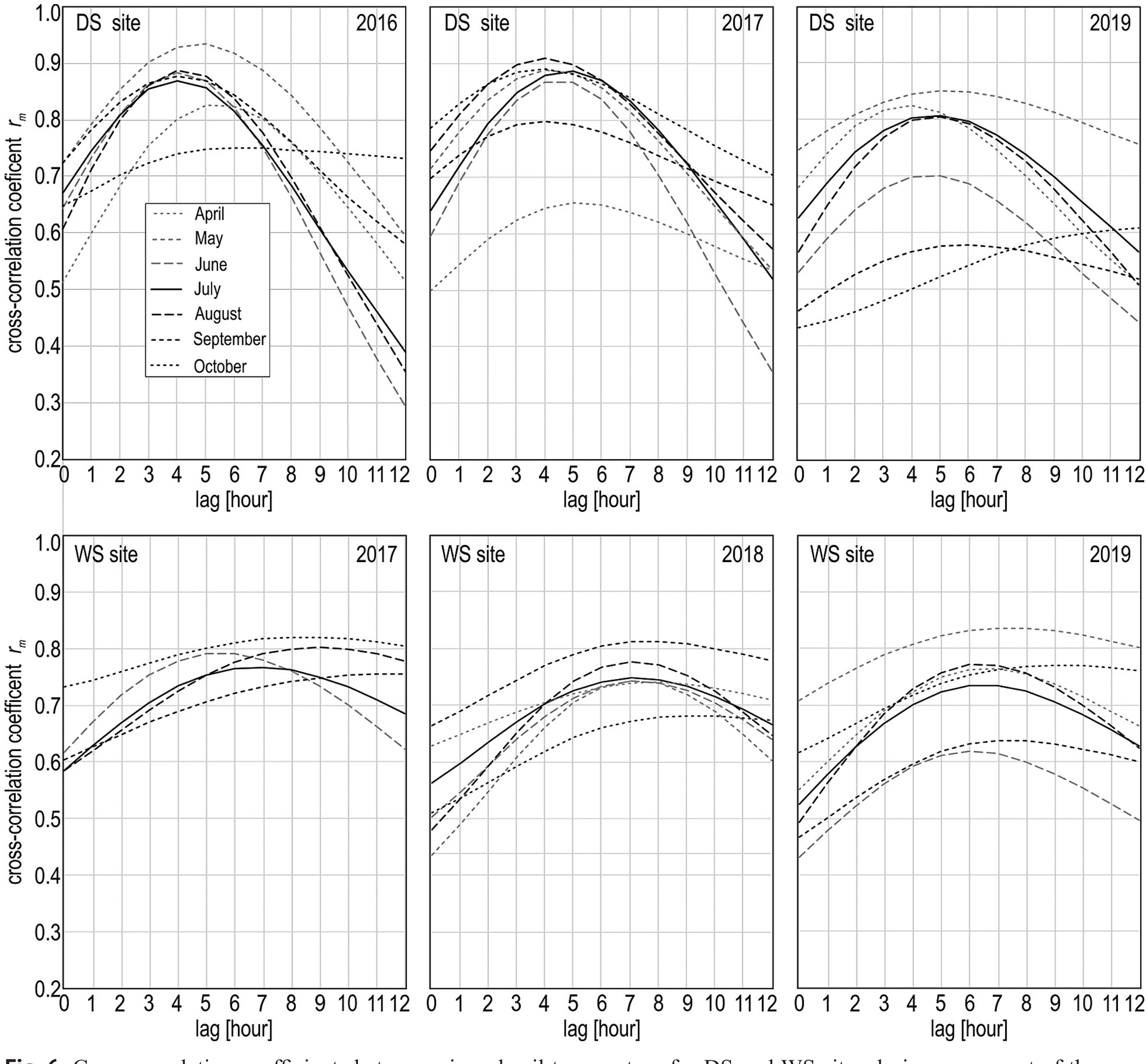

Fig. 6. Cross-correlation coefficients between air and soil temperature for DS and WS sites during warm part of the year (April-October). All correlation coefficients are at the significance level of $P \leq 0.05$

ranges noted in the summer for south-facing, deforested slopes are usually 1°C to 3°C higher than those noted for south-facing, woodland slopes. On slopes facing north the difference between woodland slopes and deforested slopes is smaller at about only a degree Celsius. A small increase in the diurnal soil temperature range was also noted after partial deforestation of a woodland slope in 2019. The rise in soil temperature fluctuations following deforestation is strongly linked with greater sensitivity of exposed surfaces to changes in air temperature. Absorbed solar radiation rises substantially during the daytime in areas without trees (Hashimoto and Suzuki, 2004). According to Ueno et al. (2015) the forest canopy is a relatively strong barrier to insulation and thermal downward radiation leading to smaller diurnal differences in the radiation balance. In addition to the lack of forest cover, a key factor in increases in the sensitivity of deforested areas to changes in air temperature consists of the small thickness or even complete absence of an organic O horizon across deforested slopes. According to Bhatti et al. (2000), this horizon functions as a thermal insulator. The high sensitivity of deforested areas to changes in air temperature is also shown by strong correlations between soil temperature and air temperature in the warmer part of the year across the forest-free hillslopes examined in this study, especially those facing the southern direction. According to Easterling et al. (1997) and Braganza et al. (2004), climate warming apart from deforestation is a factor that strongly affects diurnal changes in soil temperature today. However, this effect is different from the effect of deforestation, as climate warming leads to a decline in diurnal soil temperature fluctuations. This is a factor that can significantly reduce the diurnal changes in soil temperature today. For example, Braganza et al. (2004) showed a strong negative trend for the diurnal surface temperature range noted over land of about 0.4°C over a period of 50 years (1951–2000) triggered by climate warming. The cause of this is a meaningful increase in minimum soil temperatures and at the same time a small increase in maximum soil temperatures, which leads to a smaller difference in soil temperature over a 24-hour period.

In the cooler part of the year, correlations between soil temperature and air temperature were very weak at all the studied sites due to the buffer effect of snow on soil temperature. Despite the presence of discernible ranges of diurnal air temperature at this time, no discernible diurnal soil temperature ranges were observed at any of the studied sites. The reason for this is the high thermal insulation capability of snow. The thickness of snow cover during the study period reached sometimes as much as 800 mm (see: Fig. 2). Different results were obtained by Ueno et al. (2015) in their winter work in Japan, where they observed diurnal fluctuations in soil temperature at a depth of 0.05 m. They did, however, find that the fluctuations were much larger in deforested areas than woodland areas. It is likely that the reason behind this difference was much thinner snow cover in the Japan study versus that in the Western Tatras in Poland. In the Japan study, the thickness of snow cover did not exceed 200 mm, and temperature measurements were taken at a much smaller depth of 0.05 m (Ueno et al., 2015). According to Hejduk et al. (2019), the impact of air temperature on soil temperature decreases with soil depth.

The gradual encroachment of young forest across the studied deforested slope produced diurnal soil temperature ranges in the summer season in the Western Tatras that were much smaller. Diurnal soil temperature ranges noted for a south-facing, deforested slope decreased between roughly 1.5°C and 2.0°C over a period of four years of reforestation, with no corresponding changes in diurnal air temperature ranges and average daily air temperatures (see: Figs. 2 and 3). This shows just how important young tree stands are in the process of buffering diurnal changes in soil temperature.

The present study results indicate that the buffering role of forest is also manifested by a strongly delayed response of soil temperature on woodland slopes to diurnal changes in air temperature relative to deforested slopes. Cross-correlation revealed that the delay noted on a south-facing slope with trees in the summer was usually 7 to 8 hours, while on a slope without trees and facing in the same geographic direction, it was only 4 to 5 hours. The gradual overgrowing of the deforested slope (reforestation) resulted in a gradual increase in the delay. The absence of a buffer effect of forest on soil temperature is manifested in faster soil warming over the course of the day along with rising temperatures of the ambient air as well as by faster heat loss at nighttime with falling air temperatures. Faster soil warming in the daytime and faster heat loss at nighttime in deforested areas are also facilitated by the small thickness or even absence of an organic forest floor above the mineral soil. Zhou et al. (2007) showed that loss of vegetation would reduce the diurnal temperature range over semi-arid regions of drought and increase it over more humid regions. According to Schultz et al. (2017), deforestation results in strong warming during the day in tropical regions and large cooling at night at high latitudes. On the basis of global satellite data, Schultz et al. (2017) state that in temperate regions deforestation leads to some warming of the soil in the daytime and moderate cooling at nighttime. The present study from the Western Tatras based on field measurements does not confirm the findings of Schultz et al. (2017). Despite a rapid soil temperature response to diurnal changes in air temperature on the deforested slope facing in the southern direction, soil temperatures at night and during the day remained higher than those noted for a south-facing, woodland slope. Hence, the present study has shown that deforestation causes soil warming in the daytime and also at nighttime.

In the spring and autumn, the time of occurrence of the lowest and highest soil temperatures in the Western Tatras on south-facing, deforested slopes is delayed towards the later hours of the day relative to the summer season. The time shift of the lowest soil temperatures towards the later hours of the day was mostly associated with the time shift of increases in air temperature in the morning hours from around 5:00 AM in summer to around 7:00 AM in the spring and autumn. The time shift of the highest temperatures of the soil towards later hours in spring and autumn, despite an earlier onset of lower air temperatures, is associated most likely with increased soil moisture levels in spring and autumn relative to the summer season (see: Fig. 7). Holding a greater amount of moisture by the soil is also characterized by increased heat inertia: soil warms slower and cools slower. This effect was noted by Al-Kayssi et al. (1990) who found that an increase in the moisture level decreases the difference in soil temperatures between daytime and nighttime hours. Thus, soil moisture may also function as a buffer protecting the soil from rapid changes in temperature over the course of the day.

CONCLUSIONS

The presented research conducted in the Tatra Mountains (Poland) allows to draw the following conclusions:

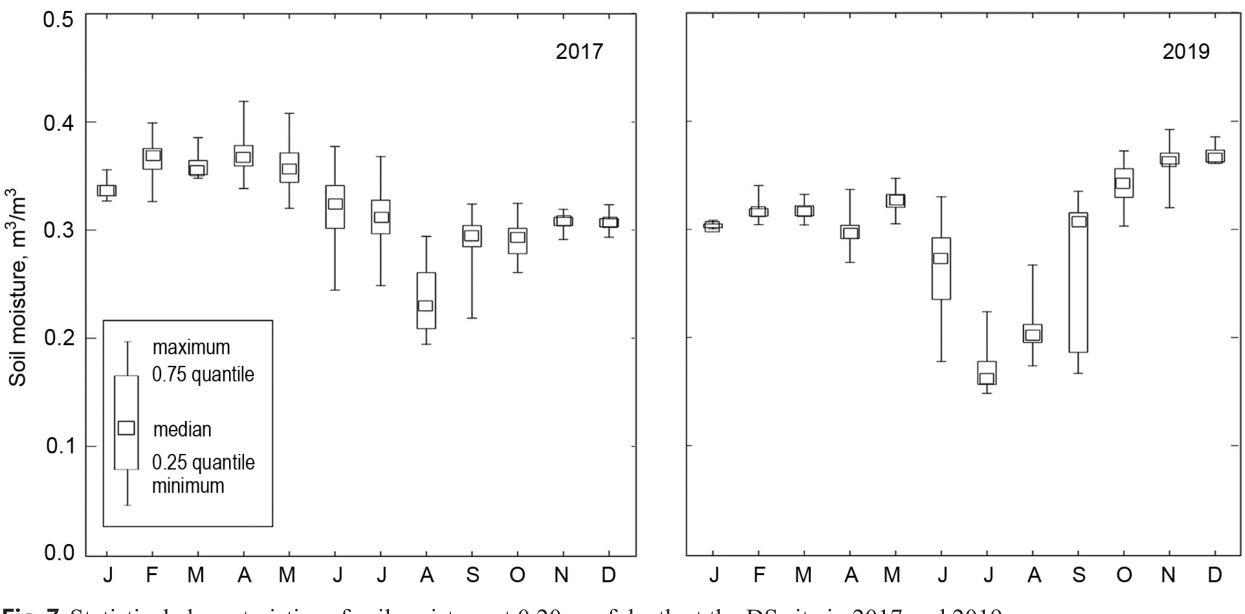

Fig. 7. Statistical characteristics of soil moisture at 0.20 m of depth at the DS site in 2017 and 2019

1. The effect of deforestation on diurnal soil temperature changes at a depth of 0.20 m, as measured in a mountain study sites, is manifested, first and foremost, by larger diurnal soil temperature ranges, which are 1°C to 3°C higher in the summer than those noted for woodland slopes. This effect is driven by the greater sensitivity of deforested areas to changes in ambient air temperature. Trees, even very small ones, and a characteristic of forests organic O horizon function as a buffer securing deeper-situated soil horizons from the effects of changes in air temperature.
2. The diurnal range of soil temperatures clearly declines along with increased reforestation with young trees.
3. Deforested hillslopes are characterized by a faster soil temperature response to changes in ambient air temperature over the course of the day. In the summer months, this response is usually three hours faster on forest-free slope facing in the southern direction relative to woodland slope facing in the same direction.
4. The response of the soil temperature on the deforested slope to diurnal changes in air temperature is strongly delayed in the spring and autumn. The most likely cause of this is increased soil moisture content during these two seasons – soils with more moisture content are characterized by greater heat inertia: slower warming and slower cooling.
5. Despite the fast soil temperature response on deforested slopes, facing the southern direction, to changes in air temperature over the course of the day, soil temperatures both during the daytime and nighttime on these slopes were higher than those on woodland slopes facing in the same geographic direction. Thus, the present study indicates that the process of deforestation leads to soil warming both during daytime and nighttime hours in mountain catchments in the temperate climate zone.

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WPŁYW DEFORESTACJI WYWOŁANEJ GWAŁTOWNYM PORYWEM WIATRU ORAZ REFORESTACJI NA DOBOWE ZMIANY TEMPERATURY GLEBY W TATRACH (POŁUDNIOWA POLSKA)

ABSTRAKT

Cel pracy

Celem pracy było określenie wpływu deforestacji i reforestacji na dobowe zmiany temperatury gleb w zachodniej części Tatrach Polskich.

Materiał i metody

Temperatura gleb mierzona była w latach 2015–2020 co 10 minut na głębokości 20 cm na stokach o ekspozycji północnej i południowej w zlewni wylesionej na skutek huraganowego porywu wiatru w 2013 r. oraz w zlewni kontrolnej (zalesionej). Obie badane małe zlewnie położone są w północnej części zlewni Kościeliskiego Potoku. W celu określenia wielkości opóźnienia zmian temperatury gleby w stosunku do zmian temperatury powietrza w ciągu doby wykonano korelację krzyżową (ang. *cross-correlation*).

Wyniki i wnioski

Wpływ deforestacji na dobowe zmiany temperatury gleby przejawiał się przede wszystkim większą dobową amplitudą temperatury gleby. W miesiącach letnich dobowe amplitudy temperatury gleby na stokach wylesionych były o 1–3ºC wyższe od amplitud na stokach zalesionych. Wraz z zarastaniem stoków wylesionych młodym lasem (reforestacja) dobowe amplitudy temperatury gleby wyraźnie malały. Latem na stoku wylesionym o ekspozycji południowej zmiany temperatury gleby następowały z opóźnieniem 4–5 godzin w stosunku do zmian temperatury powietrza, podczas gdy na stoku zalesionym o takiej samej ekspozycji opóźnienie to wynosiło aż 7–8 godzin. Pomimo dużej wrażliwości temperatury gleby na stokach wylesionych na zmiany temperatury powietrza, latem temperatura gleby, nie tylko w dzień, ale i w nocy była wyższa na stokach wylesionych niż na stokach zalesionych. Prezentowane wyniki wskazują, że deforestacja może znacząco nasilać proces ocieplania się gleb wywołany obecnie stopniowym ocieplaniem się klimatu.

Słowa kluczowe: Tatry, zmiany dobowe, deforestacja, reforestacja, temperatura gleb