

Effects of catchment area forestation on the temperature of river waters

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Abstract: The objective of this paper was to analyse the effects of catchment area forestation on the temperature of river waters. Two rivers, Czerna Wielka and Szprotawa, were covered in this research project and both are located in south-west Poland, running through the largest compact forest complex in the country, Bory Dolnośląskie. Both of the rivers are located within the same climatic region, and are similar in terms of their hydrology. Land use in the catchment area however is very diverse with 71.6% forest cover in the case of the Czerna Wielka River and direct contact of the forest with the river occurs over 68.3% of its length. For the Szprotawa River, the indices amount to only 39.3% and 21.6%, respectively. Data on the daily water temperatures for both of the rivers were obtained from the Hydrological Yearbooks of Surface Waters for the period 1969–1983. The mean annual water temperature in the analysed period in the case of the Czerna Wielka River amounted to 8.0°C, and in the case of the Szprotawa River it equalled 9.2°C. During the cooler half of the year (November–April), the mean water temperature for the entire examined period amounted to 3.8°C for Czerna Wielka, and 3.6°C for Szprotawa. Higher variability was recorded for the warmer seasons (May–October), where mean temperatures amounted to 12.1°C and 14.7°C, respectively. The obtained results concur with other similar research conducted around the world, and in the context of climate change are of practical value. The important role of forests in the moderation of thermal conditions is evidently unquestionable. Therefore, minimising the impact of unfavourable climatic changes on river ecosystems and their surroundings requires striving for appropriate forest management in the near-bank (buffer) zone along banks of both larger rivers and their tributaries

Keywords: water temperature, shade, forest catchment basin, Bory Dolnośląskie

1. Introduction

As a result of adaptation to ever-increasing human needs, the transformations of the natural environment through the centuries, radically changed its original components. Changes in the land use structure set in a series of responses, in relation to both biotic and abiotic factors. Despite significant transformations of the structure of forest areas, they still remain relatively natural. The presence of forests affects many elements of the natural environment, including soil temperature (Durło, Wilczyński 2003), soil freezing (Kuzniar 1952), snow cover rate (Felixsik et al., 2006), local climate thermal and moisture conditions (Dragańska et al. 2016), fish species composition (Rechulicz, Płaska 2016), and so on. The specificity of forest ecosystems, as compared to other ecosystems, inspired

the development of many comprehensive scientific disciplines associated with studies on forest ecosystem functioning. One of these is forest hydrology, which focuses on water circulation and related processes. Research on forest hydrology addresses various aspects and plays a prominent role in the efforts of the world's scientific community (Rowe, Taylor 1994, Wallace et al. 2009, Zhang et al. 2014). In Poland, forest hydrology has received much attention as well, which is reflected in the studies related to water resources retention (Frydel 2008, Ptak 2015), groundwater (Pawlik-Dobrowolski 1977, Liberacki 2004, Grajewski, Okoński 2007) and river water flow/outflow (Kostuch 2004, Stasik et al. 2007; Franczak 2017). However, studies on one of the basic features of water, i.e. its temperature, have been hitherto in short supply. This parameter determines a number of processes and pheno-

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mena taking place in water ecosystems. It affects water density, shapes the composition of flora and fauna species and plays a decisive role in gas dissolution (e.g. affects oxygen concentration – a prerequisite for endurance of hydrobiological elements and maintenance of water quality) and affects the duration of the ice season. Water temperature depends on a number of factors, such as climatic conditions, anthropopressure and groundwater replenishment, among others. The temperature of water exhibits particularly pronounced associations with climatic factors (Langan et al., 2001, Scheffer et al. 2001, Morrill et al. 2005); however, these dependencies may be modified by local conditions related to the catchment structure or the nearest water neighbourhood.

The aim of the present study was the analysis of water temperature in two rivers located in south-western Poland, whose catchment areas are characterized by different extents of forest cover (Figure 1).

2. Materials and methods

In the present study, data on daily temperatures of the surface layer waters in the rivers Czerna Wielka and Szprotawa were used. The selection of the rivers was driven by the differentiation of the share of forest area in their catchments, the similarity between climatic features prevailing in the catchments and also the similarity of hydrological parameters in the two rivers. Both rivers flow through the largest compact forest complex in Poland – Bory Dolnośląskie. Initially, fresh coniferous and mixed coniferous forests constituted habitat types in the complex, until

they were replaced by coniferous forests with dominant Scots pine *Pinus sylvestris* L. and sparsely occurring birch *Betula* L. and oak *Quercus* L. trees (www.bory-dolnoslaskie.eu). The forest cover in the Czerna Wielka and Szprotawa catchment areas are 71.6% and 39.3%, respectively. The proportion of the length of the main rivers in direct contact with forest areas is 68.3% for Czerna Wielka) and 21.6% for Szprotawa.

According to the division of Poland into the climatic regions (Woś 2010), the analysed catchments are situated within the Lower Silesian Western Region (No. 23). This region is characterised by the real sunshine duration of 1460 hours per year. In June, the average real sunshine duration is 6.5 hours, and in December it is 1.2 hours. The average annual air temperature in the region is 8.4°C. In the coldest month (January), it drops to –1.4°C, and in the warmest month (July), it rises to 18.1°C. The average annual cloud cover is 67%.

The analysis of the distribution and changes of water temperature in the Odra basin in the years 1969–1983 was performed using data available in the publication *Rocznik Hydrologiczny Wód Powierzchniowych (Annals of Surface Water Hydrology)* for the years 1969–1983. Further comparative analyses were not carried out, as complete data concerning the period after the year 1983 were not available. The data were compiled through the hydrological year, which runs from 1 November to 31 October of the subsequent year. River temperatures at the depth of 0.4 m were measured by gauging stations in the localities Żagań and Szprotawa at 7:00 a.m. daily. The analysed rivers were characterised by similar average annual water flows, which in the years 1971–1980 ranged

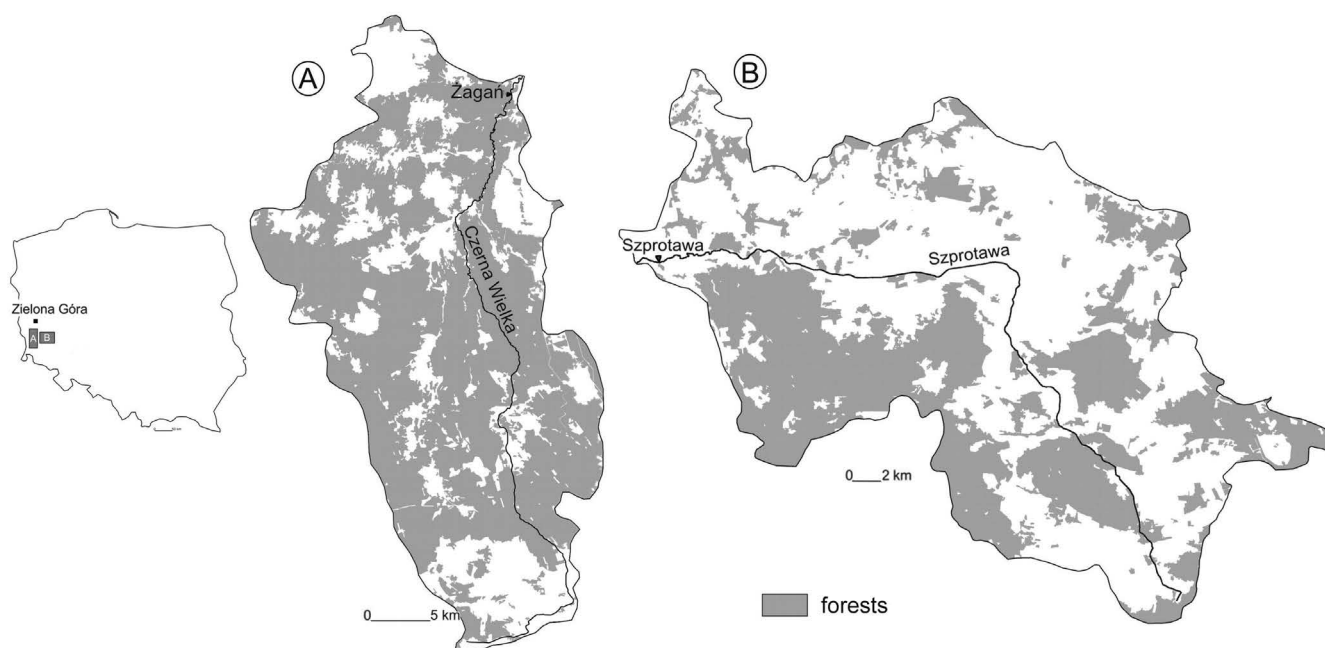


Figure 1. Location of the analysed catchments: A – Czerna Wielka River, B – Szprotawa River

from $3.4 \text{ m}^3 \cdot \text{s}^{-1}$ (Szprotawa) to $4.6 \text{ m}^3 \cdot \text{s}^{-1}$ (Czerna Wielka). In terms of water outflow, both rivers are characterised by a moderate nival regime, which means that the average outflow in the spring month is from 130% to 180% of the average annual outflow (Wrzesiński 2013). In both catchments, the lithology is dominated by formations with medium permeability (Mapa Hydrograficzna Polski 2001–2002; *Hydrographic Map of Poland 2001–2002*). Land use forms were determined using 1:50 000 topographic map, and calculations regarding the share of forest areas were made using QGIS software. In the present study, data on air temperature recorded by the weather station Zielona Góra (1969–1983), situated about 40 km away from the gauging stations in Żagań and Szprotawa, were also used. The relationship between water temperature and air temperature was determined using the Pearson correlation coefficient. The calculations were performed in Excel spreadsheet application (Microsoft Corp.).

3. Results and discussion

The results of the analysis performed showed diversification of thermal conditions in the studied rivers. The average annual water temperatures are summarised in Table 1.

In the analysed period, the average water temperature in the Czerna Wielka river was 8.0°C , and in the Szprotawa

river, it was 9.2°C . The average annual temperatures varied and ranged from 0.5°C in 1969 to 1.8°C in 1982. The average water temperature in the cold half-year (November–April), calculated for the entire observation period, was 3.8°C in the Czerna Wielka and in the Szprotawa, it was 3.6°C . Greater variation was observed in the warm half-year (May–October), when the average temperatures were 12.1°C and 14.7°C , respectively. In the 15-year period, the maximum temperature of water in the Czerna Wielka river was 19.9°C , and in the Szprotawa river, it was 24.3°C . A considerable difference in the average annual maximum temperatures between the rivers was observed, and the greatest difference of 6.4°C was observed in 1982. Under the climatic conditions of the region, in the coldest month (January) and in the warmest month (July), the differences between the average water temperatures of the rivers were 0.3°C and 3.5°C , respectively. The seasonal variation in the temperatures of both rivers is clearly visible in the course of daily water temperatures, as illustrated in Figure 2.

Significant differentiation of the thermal regime of the two closely located rivers (the distance between the measurement stations is only 17 km in a straight line) was particularly visible in the warm half-year, i.e. during the growing season. Then the ‘umbrella’ of the tree crowns limits solar radiation, which according to Caissie (2006) is the basic source of heat for rivers. Rutherford et al. (1997) emphasise that vegetation along river banks absorbs some of the shortwave radiation, which is principally evident during cloudless summer days. Taking into account relatively homogeneous climatic and hydrological conditions of the discussed rivers, the observed thermal differences between them may well be due to the diversified land use structure of their catchments related to forest cover.

Forest catchment areas have a characteristic thermal regime (Webb, Crisp 2006). Therefore, the relationship between river water temperatures and forest areas is routinely studied in forest hydrology research carried out in various parts of the world (Zwieniecki, Newton 1999, Wilkerson et al., 2006, Hannah et al. 2008, Rayne et al. 2008, Subehi et al. 2009, Bowler et al., 2012). Johnson (2004), studying the effect of artificial shading on the watercourse located in Oregon (USA) conducted in July, showed that the net energy flow in the non-shaded zone was $580 \text{ W} \cdot \text{m}^{-2}$, whereas in the shaded zone, it was significantly reduced by $149 \text{ W} \cdot \text{m}^{-2}$. This corresponds approximately to 1°C reduction in the maximum temperature. Dohet et al. (2015), based on water temperature measurements carried out in three streams in Luxembourg, found that near-bank forests clearly mitigated winter minima, summer peaks and thermal variations. Kristensen et al. (2015), who observed the temperature of five streams in Denmark, in the period from June 2010 to July 2011, found, among others, that even the shortest near-bank forest sections (100 m) reduced stream water temperature by

Table 1. The average annual temperatures of the analyzed rivers in 1969–1983

Years	Szprotawa [$^\circ\text{C}$]	Czerna Wielka [$^\circ\text{C}$]
1969	8.4	7.9
1970	8.3	7.3
1971	9.1	8.3
1972	9.2	8.2
1973	9.3	8.0
1974	9.1	8.0
1975	9.8	8.9
1976	9.0	7.5
1977	9.6	8.3
1978	9.1	7.9
1979	8.9	7.5
1980	8.7	7.3
1981	9.6	8.3
1982	9.6	7.8
1983	10.2	8.6

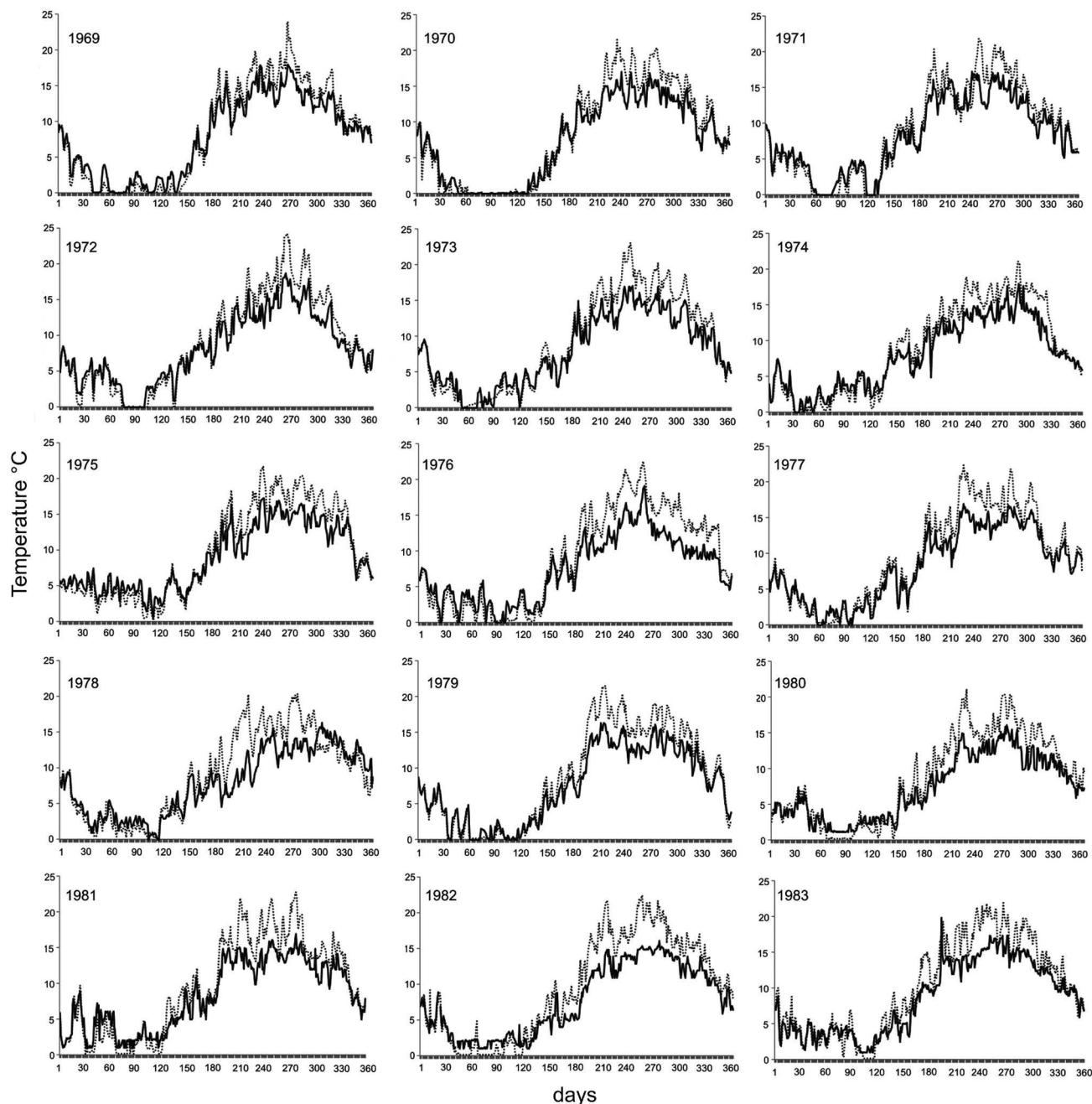


Figure 2. Course of water temperature in the Czerna Wielka and Szprotawa Rivers in the period 1969–1983 (continuous line – Czerna Wielka River, dotted line – Szprotawa River)

maximum of 1°C when compared to the temperature of one stream in open areas. A larger forest share (section up to 500 m) in the near-bank zone reduces temperature by approximately 2.5°C. Broadmeadow et al. (2011), when analysing the catchments of two rivers in England (in 2005–2007), noted lower water temperatures in places in shade or partial shade, as compared to those observed in open areas. The average temperature

of the summer period fluctuated, respectively, between 13.5°C and 16.8°C in relation to the range of 15.1–19.3 °C in the second case. Analogously, in the shaded zone, the maximum temperatures were in the range of 14.3–19.2°C, whereas in the zone without trees, the maximum temperatures ranged from 17.0°C to 23.1°C. It should be emphasised that forest cover within the entire catchment area is important. The temperature of flowing

waters in a given measurement profile (point) is not only due to the effect of the location of the measurement point, but also the effect of waters flowing from other parts of the sediment supply area. This fact is highlighted by Moore et al. (2005), who presented factors regulating river water temperature using a model concept. Thus, it is important to have information on the forest areas shading other, smaller watercourses – e.g. tributaries of the main river.

The results obtained in the present study correspond with other comparable observations carried out in the world, from which it is clear that the presence of forests affects the lowering of water temperature in the river. This is an extremely valuable observation in the context of climate change. Water temperature in the Szprotawa and Czerna Wielka rivers showed a very strong relationship with air temperature ($r = 0.94$ and $r = 0.91$, at $p = 0.05$, respectively). As clear from this dependence, air temperature is a key parameter determining the thermal regime of rivers. As indicated in the introduction part, water temperature is closely related to a number of processes and phenomena, both biotic and abiotic, ongoing in the river bed as well as in its surroundings. The rise in river temperature observed in many regions of the Northern Hemisphere (Kaushal et al 2010, Jurgelėnaitė et al. 2012, Žganec 2012, Ptak et al. 2016) will lead to significant transformations of the river ecosystems. Therefore, it becomes imperative to counteract this unfavourable situation. As postulated by Wilby et al. (2010), in the context of the protection of inland waters against the effects of global warming, the enhancement of shading effect is a key activity in this respect.

4. Conclusion

In Poland, the relationship of forest areas with thermal conditions in rivers has been an underestimated research task. The present study, by analysing changes in water temperature in the context of diversified forest cover of the two catchments, complements this gap and is a starting point to extend research of this type in the future, in relation to other areas (other rivers, other regions, etc.). The analysis undertaken is part of a wider stream of research conducted in Poland, the aim of which is to determine the role of forest in the functioning of many components of the natural environment. As a result of daily observations of water temperature over the course of 15 years, it was established that the Czerna Wielka river (with a larger share of forests in the catchment area) was characterised by lower water temperatures as compared to the Szprotawa river (with a smaller share of forests in the catchment). The largest temperature differences were observed in the warm half-year (May–October). The obtained results are confirmed in other analyses of this type conducted worldwide and may be of a practical use in the context of observed climate changes. One of the clear signs of global warming is an increase in temperature of surface wa-

ters, and this is often assumed to be the indisputable indicator of climate change. As it has been shown, the role of forest in mitigating thermal conditions is unquestionable. Therefore, in order to minimise the impact of unfavorable climate changes on river ecosystems and their surroundings, it is necessary to strive for proper forest management in the near-bank (buffer) zones along the banks of both main rivers and their tributaries.

Conflict of interest

The author declares no potential conflicts.

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