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APPLICABILITY OF DENDROCHRONOLOGY IN THE EVALUATION OF THE LONG-TERM IMPACT OF HIKING ON THE CONDITION OF STANDS ADJACENT TO HIKING TRAILS

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Abstract: Increased tourism activity may negatively affect cover adjacent to hiking trails in terms of land degradation, soil erosion, and destruction of vegetation. The aim of the research was to determine the effect of trampling on the annual growth of trees under pressure due to hiking. We decided to test the applicability of dendrochronology in evaluating the impact of hiking on the condition of forest stands through which hiking trails run. The research was carried out on a spruce stand adjacent to the hiking trail Polana Waksmundzka-Hala Gąsienicowa in the Polish Tatra Mountains. The trail was divided into five transects within which two areas were outlined: the area of destruction caused by trampling and the area not affected by tourism (control area). Drills were made in selected trees to extract samples for determining annual incremental growth. Then, dynamics of incremental growth in trees from the experimental and control areas were compared. The results revealed that the mean annual growth in trees adjacent to the hiking trail is lower than seen in the trees from the area not directly affected by tourism activity. This may prove that tourists transit on mountain trails has a negative effect on the radial growth of trees adjacent to these trails.
The research indicates that dendrochronology is a reliable method that can be applied in evaluating the effect of trampling on the conditions of stands under pressure due to hiking. Dendrochronology may also supplement research on the influence of hiking and biking on the conditions of ecosystems adjacent to tourist trails.

Keywords: tourism carrying capacity, dendrochronology, Tatra National Park

Tourism is often perceived as one of the most important elements of sustainable development (Kombol, 2000; Krnacova et al., 2001). This form of activity in a given area combines the possibility of economic growth with

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biodiversity conservation (Maikihuri et al., 2000; Neto, 2003). On the other hand, excessive or uneven tourist flow in a given region may result in environmental degradation (Hresko, Bugar, 2001; Gorczyca, Krzemień, 2002). The most spectacular examples of this phenomenon mostly concern the expansion of tourism infrastructure: mountain cabins, hotels, access roads, railroads, and ski lifts (Witkowski, 1996; Łajczak, 1996).

Less spectacular, but known from the literature on the subject, is the impact of mass tourism (hiking). During the interwar period, Klecka (1937) presented vertical stratification of vegetation adjacent to tourist trails. Later studies showed the erosion process on hiking trails caused by vegetation mat that was breached or worn away (Root, Kapnik, 1972; Kethledge et al., 1985; Li et al., 2005). In Poland, comprehensive studies on the impact of hiking on the natural environment in mountains were conducted mainly in Tatra National Park (Skawiński 1993) and the Pilsko range (Łajczak, 1996; Bandoła-Ciołczyk, Kurzyński, 1996; Mielnicka, 1996). Kostrowicki (1981) carried out experimental studies in this topic. The extensive work of Krzymowska-Kostrowicka (1997) is a compilation of theories concerning the relationship between tourism, recreation, and the natural environment.

Unfortunately, the impact of tourism is not limited to hiking trails, but also extends to adjacent areas. The results of research conducted in the Pilsko range (Łajczak, 1996) clearly demonstrated that due to deep erosion seen on stretches of trails, tourists tended to walk around the erosion and trample on adjacent vegetation cover, thus widening the trails. After some time, trails may be expanded up to a dozen or so meters. Other research showed that trail expansion may also result from, in addition to its condition, the type of habitat. Satchell and Marren (1976) proved that with the same tourist flow, trails running through open spaces are much wider that the trails in forests. Bayfield (1973) and Lance et al. (1989) reported that trails branch off and widen owing to tourists who walk around boggy and uneven ground. In addition, tourists tend to walk around stretches of trail that are steep, difficult, or dangerous (Ciapała et al., 2010).

Thus far, researchers (Kostrowicki, 1981; Bogucka and Marchlewski, 1982; Mielnicka, 1996; Pawlaczyk, 2002) have studied and described a theoretical tourism carrying capacity for different natural sites. Despite a large number of publications on this topic, there is little in-depth research into how the natural environment will respond once limitations have been exceeded. There are studies that describe the impact of hiking on the condition of the natural habitat. These papers present the relationship between the changes in the physiochemical properties of soil and structure of soil that lead to a decrease in water and air capacity, as well as to a disturbance

in thermal regimes (Guzikowa, 1982; Lei, 2004; Krzemień, Gorczyca, 2006). The studies mentioned above indicate that high tourism activity may lead to extensive mass transfer of soil causing microrelief: ruts, banks along the trails, niches, and talus fan (Krzymowska-Kostrowicka, 1997). There is little research that describes the impact of trampling on flora and fauna adjacent to hiking trails. In Poland, researchers who have conducted studies in this issue include Faliński (1973), who studied the impact of trampling on forest undergrowth; Holeksy and Holeksy (1981); and Pawlaczyk (2002), who carried out a broader analysis. Pawlaczyk observed that the majority of the developed methods may be adopted only to estimate the effect of tourism activity on the vegetation cover of the area in question, but only with respect to trampling the undergrowth.

The aim of the research was to verify whether or not increased numbers of hikers affect the condition of stands adjacent to hiking trails, taking a closer look at the mean annual increment (MAI). Furthermore, it is assessed whether dendrochronology is applicable in the evaluation of the degree to which tourist activity affects the conditions of trees. Research was conducted in Tatra National Park on the hiking trail that leads from Hala Gąsienicowa to Polana Waksmundzka. The trail runs through a spruce stand.

Method

The research utilized dendrochronology, which allows the age of trees to be determined based on the analysis of mean annual growth. The width of the tree rings depends on various conditions: wide rings are observed in favorable growing seasons, narrow rings appear in unfavorable seasons (Zielski & Krąpiec, 2004). Within the five stretches, 50-100 m transects were marked including a vertical stratification of the trail. Based on the perceptible destruction of soil and vegetation cover, two areas were defined: area of destruction and area not affected by tourism.

Trees selected for analysis had perceptible damage to roots. In each transect, a sample was taken from 10 trees: 5 trees with protruding roots and adjacent to the hiking trail; 5 trees that grew far away from the trail. Since an assumption was made that trampling only affects the annual growth of rings of trees adjacent to the trails, the research material was therefore chosen according to the following criteria:

- dendrochronological analysis had to be homogenic, i.e., all the drilled trees had to belong to the same family, had to belong to the same biosocial category, and had to grow in the same microhabitat conditions;
- trees from different zones grow the same climate conditions.

Two samples were extracted from each tree at the height of around 1.3 m. The samples were taped to a film, dried, and polished. Each sample was scanned and growth rings were marked through a CooRecorder program. The width of each ring was measured with a CDendro program, and data were recorded in a spreadsheet (Figure 1).

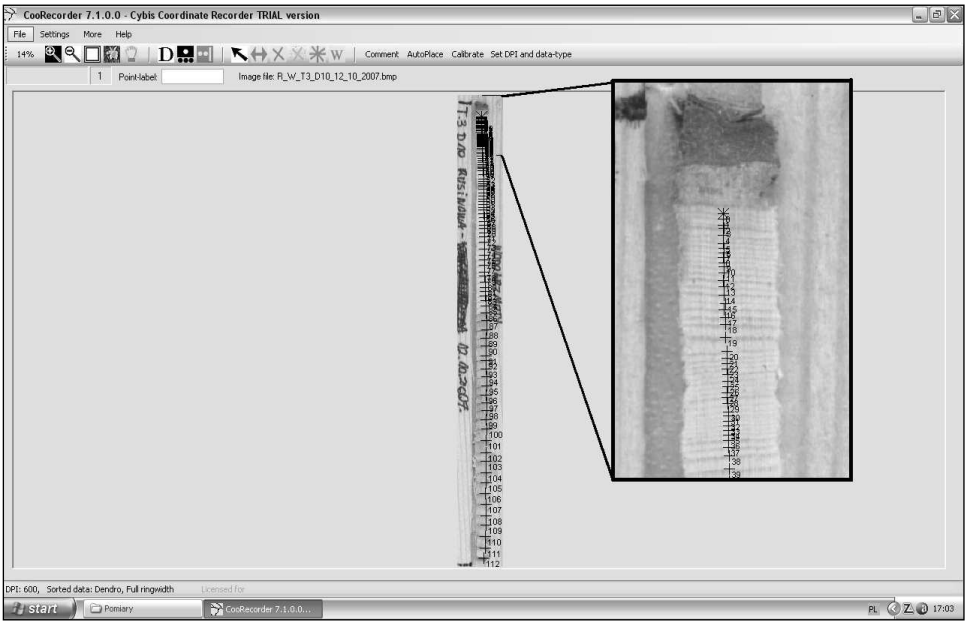

Figure 1. Interface of a CooRecorder program presenting an enlarged initial part of a sample

Tree-ring dating was conducted and related to calendar years based on visual synchronization of dendrochronological patterns and signature years. Afterwards, MAI was calculated for each year for the trees adjacent to the hiking trail and for the trees in the control area. Annual ring growth pattern in trees from different areas of destruction were compared, and the differences between them were measured. The MAI trend of the trees from the control area, i.e., the places with null tourism activity, was treated as a control trend. The MAI trends from the area of destruction were compared with the control trend. These comparisons were carried out for each year. The results were correlated with historical data for the intensity of and changes in tourism activity in Tatra National Park (Czochańki, 2002). Comparison of the increment differences resulting from trampling with historical data allowed the process of degradation in the researched areas to be reconstructed.

Results

The MAI of the trees from the five transects of the hiking trail from Hala Gąsienicwa to Polana Waksmundzka are presented on the graph below (Figure 2). The MAI in the trees adjacent to the trail is lower than in

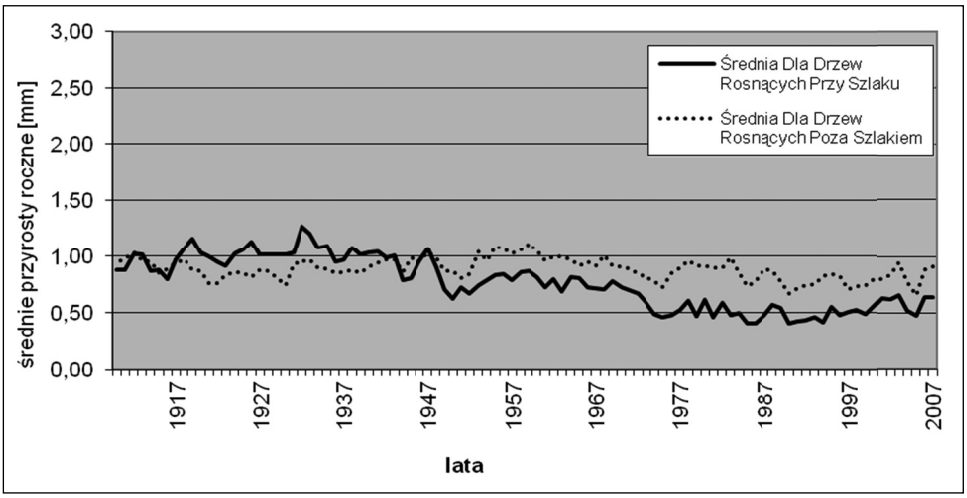

Figure 2. Mean annual increment of the trees adjacent to the trail Hala Gąsienicowa-Polana Waksmundzka

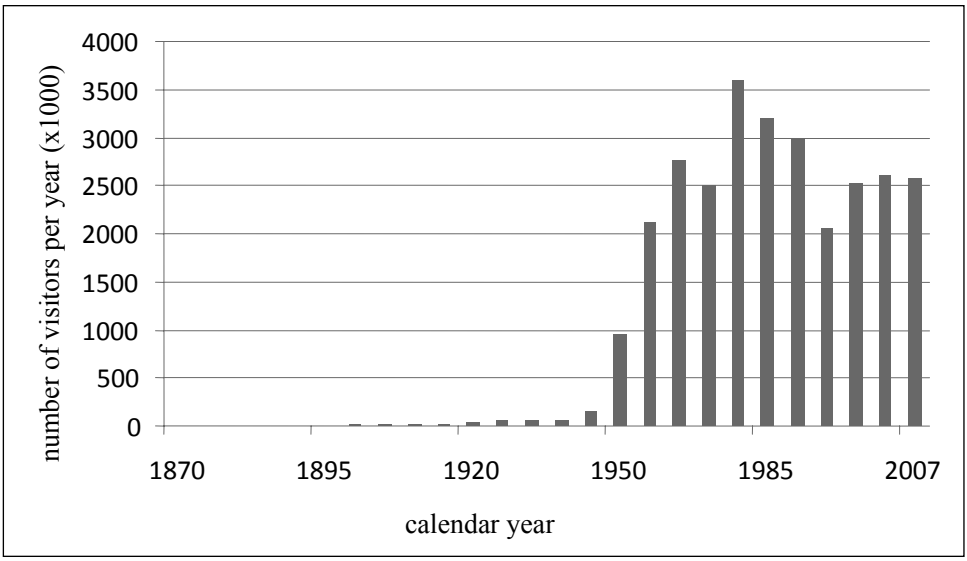

Figure 3. Number of tourists visiting Tatra National Park (based on Czochański, 2002)

the trees from the control area, except from 1916 to 1945. The MAI in this period was probably high due to better access to sunlight rather than due to the impact of tourism activity. After World War II, MAI in the trees adjacent to the trail decreased significantly in comparison to the trees not affected by tourism activity.

Correlations were calculated between MAI of trees adjacent to the hiking trail and from the control area and the intensity of tourism (data based on Czochański, 2002) in different years (Figure 3). The results demonstrated that in all analyzed cases of all five transects, significant negative correlations occurred. This means that as tourism activity increased, the MAI of the trees adjacent to the trails decreased in comparison with the trees from the control area (Table 1). The correlation between MAI measured for the whole trail and annual data on tourism activity in different years was -.92, $p<0,05$.

Table 1. Correlations between mean annual increment of the trees adjacent to the trail and from the control area and tourism activity in different years ($p<.05$)

Transect number	correlation
transect 1	- 0,789
transect 2	- 0,833
transect 3	- 0,398
transect 4	- 0,686
transect 5	- 0,911
entire trail	**- 0,919**

Conclusions

The growth of a tree is influenced by many factors, among which the most important is climate. The MAI of a tree depends on the temperature in summer, precipitation, insolation, and many other atmospheric phenomena. Spruce requires appropriate levels of humidity of soil and air. The influence of temperature on the MAI of spruce trees in the Tatra Mountains can be seen in the studies conducted in Dolina Strążyska (Zielski & Krąpiec, 2004, Zielonka et al., 2008). Other important stressors affecting MAI are: fire, change of habitat, defoliation, lack of natural light, cold or drought, extreme living conditions, and competition (Schweingruber 2007). Stressors resulting from the human impact on the environment, especially air pollu-

tion (dust and fuels), have a negative impact on MAI, or cause the disappearance of MAI, in all trees, but coniferous trees are particularly sensitive to these stressors (Zielski, Krąpiec, 2004). Human activity is of no less importance here. Due to mechanical damage to bark, roots and trunks, trees have a very low MAI, narrow in the late wood and with changes in the xylem (Schweingruber, 1996).

The results of this study prove the assumptions true concerning the negative impact of tourist activity (trampling) on MAI of the majority of trees adjacent to the examined trail stretches. Significant decreases of MAI of spruce trees in the entire examined area can be observed after 1948. In 1948 tourist flow into Tatra National Park was 150,000, which was twice as much as in 1938 (Czochański, 2002). Results from the analysis show that dendrochronology is applicable in the evaluation of the effect of tourism activity on stands adjacent to hiking trails.

Putting restrictions on tourism activity in Tatra National Park seems impossible, or even inadvisable, bearing in mind the growing importance of tourism in this region. As can be inferred from the observations, a certain portion of the damage caused to the trees could be avoided by hardening the mountain trails, constructing drainage systems along the trails, and implementing protection that will stop erosion processes. Moreover, it would be advisable to install wooden handrails along the steep stretches of the trail, widen the trails wherever possible, harden the stretches with non-skid material, and renovate the trail surface. These measures may prevent tourists from turning aside from difficult and dangerous stretches, and, along with that, decrease the risk of damaging the vegetation cover and tree roots (Ciapała et al., 2010).

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