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TREE RING ANALYSIS AS AN INDICATOR OF ENVIRONMENTAL CHANGES CAUSED BY TOURIST TRAMPLING – A POTENTIAL METHOD FOR THE ASSESSMENT OF THE IMPACT OF TOURISTS

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Abstract: This paper shows that tree-ring trends might be used for the assessment of the intensity of trampling along touristic tracks in the forests. The study aims at determining the effects of trampling, on the dynamics of annual increments in trees subject to pressure from hiking tourism. The studies were conducted at a spruce stand in the Tatra Mts., on sections of different trails. Within each trail, four transects were determined. Transects include the zones with damage from trampling and the unaffected areas, treated as a reference zones. Selected trees growing in both zones were sampled by coring and the core samples were used to develop sequences of annual increment widths. Next, the dynamics of increments in trees growing in the tourist zone and the reference zone were compared. The decrease in the annual increments was significantly more rapid in trees growing directly along the trail that those in trees deep in the forest stand in one locality. This finding may testify the adverse effects of hiking along tourist routes on the radial increments in trees in the neighbourhood of the trails. The results of the study indicate that the impact of trampling in the form of soil compaction and mechanical damage to root systems of trees may, to some extent, be compensated by better light access and lessened competition experienced by trees growing along the edges of hiking trails. Tree-ring analyses might be an efficient alternative for assessment of tourism intensity conducted by the other methods.

Keywords: dendrochronology, tourist impact, spruce forest, trampling.

1. INTRODUCTION

Tourism is fairly often perceived to be one of the more important components of sustainable development (Kombol, 2000; Krnacova *et al.*, 2001). This form of activity combines the prospects of economic growth with the preservation of high values of natural properties in a given area (Maikihuri *et al.*, 2000; Neto, 2003). On the other hand, the burden of excessive or uncontrolled tourism can lead to the degradation of nature in a given region (Hresko and Bugar, 2001). The most spectacular examples of this phenomenon concern chiefly the environmental impact of extensive tourist infrastructure, such as mountain hostels, hotels, access roads as well as ski lifts.

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Less spectacular are the effects of mass hiking, such as soil erosion initiated by the complete destruction of turf, on trails used by hikers (Root and Kapnik, 1972; Kethledge *et al.*, 1985; Li *et al.*, 2005). The impact exerted by hikers is not limited to trails alone but extends to the areas along them. The extent of this increased width is affected, apart from the state of the path, by the habitat which it crosses. Satchell and Marren (1976) proved that even with the same number of tourists, trails in open areas are significantly wider that those in forests. Next, studies by Bayfield (1973) and Lance *et al.* (1989) have demonstrated that the dividing and widening of trails are often caused by tourists' attempts to avoid boggy or more uneven fragments of trails. The scale of the impact of trampling also varies due to the vegetation type (Andersen, 1995). The main influence of trampling is related to changes in soil properties and subsequent erosion (de Gouvenain, 1996; Hammitt and Cole, 1998; Hill and Pickering, 2006; Olive and Marion, 2009; Kissling *et al.*, 2009; Cole 2004, 1995). Knowledge of the scale of the impact caused by tourists is very important during the planning of recreation trails, especially in national parks and other protected areas (Tomczyk and Ewertowski, 2013).

The objective of this study is to demonstrate how intensive hiking impacts the condition of spruces in the direct vicinity of tourist trails, with particular attention focused on the dynamics of annual increment rings in spruces. In this paper we propose that tree-ring reactions in trees growing in the trampling zone might be an effective indicator to assess the ecological impact of tourist movement on forest environments. Radial increment is determined by several factors including: climate, age of tree, and disturbances. Generally speaking, the dynamics of annual increments reflect environmental changes associated with any broadly defined environmental disturbances (Schweingruber, 1996). Damage to crowns, assimilation organs or root systems leads to the reduction of wood production and therefore, to a decrease in the width of annual increment rings. On the other hand, reduced competition resulting from the decreased density of the tree canopy will result in greater annual increments shown in broader bands (Lorimer and Frelich, 1989; Payette *et al.*, 1990; Zielonka *et al.*, 2008). Such changes may be caused by natural factors, e.g. windfalls, fires, insect gradations or the direct result of logging, thinning or other forms of forest use by humans. The dendrochronological analysis of such changes in increment trends associated with alterations in growth conditions, permits one to precisely identify the timing of the disturbance as well as determine the level of its intensity (Bergeron *et al.*, 2002; Schweingruber, 1996; Schweingruber, 1989). Our primary aim was to check whether tree-ring reactions in trees located along tourist trails can be used to determine the intensity of tourist traffic.

2. METHODS

Study area

The studies were conducted in the western part of the Polish Tatra National Park. This area includes the highest mountain range in Poland. The plant cover of the Park includes alpine meadows, mountain pine scrubs and spruce forest, natural as well as artificial, planted in the nineteenth century instead of native beech forest. Due to its outstanding natural values, the Tatra Mountains are one of the oldest and most popular tourist regions in Poland and suffer the greatest volume of tourist traffic per unit of any area in the country, although this has tended to fluctuate over the years. Its slow increase since the end of the nineteenth century, through the first great wave in the period between the World Wars, followed by the huge surge in mass tourism after 1950, reached its peak in the 1980s. At present, the volume of tourist traffic has stabilised (Czochański, 2002) and the most recent decade was the first where no major fluctuations or permanent increases were noted (Czochański, 2002). Three hiking trails were selected (**Fig. 1**), where the trampling phenomenon could be seen and where routes passed through spruce forest stands. These trails differ in their intensity of use by tourists, as well as in the manner of development of tourist-related infrastructure. Other differences include: the width of the trail trampled down by hikers, the method of preparing the ground surface, as well as the altitudinal zone in which the trail is situated.

Trail (A). Kuźnice – Nosal is a trail running through artificial spruce forest in the lower montane forest zone with fir and beech admixtures, which gently climbs up a rolling slope. The substrate is predominantly made up of Jurassic formations. The trail reaches an altitude of 1206 m a.s.l. at its end. The trail is well-prepared for hiking, with a hardened surface, wide path, footbridge and wooden steps. Trees are mostly situated along the

Fig. 1. *Location of the study plot in the Tatra National Park. a — Tatra NP border, b — study plots (A, B, C), c — mountain hostels.*

trail and have been circumvented on one side only, where the resulting devastation by trampling can be seen. In several places, the exposed root appears directly on the trail. There is only one steeply sloped place near Nosalowa pass and it is where the roots of trees passed by hikers are exposed on all sides. A ski trail also crosses the hiking trail at this point.

Route (B). Strążyska Valley – Grzybowiec pass is a trail running through the lower montane forest zone artificially afforested with common spruces. Initially, the trail leads up a gentle slope, before running along a stream and then climbing steeply. The substrate is predominantly made up of limestone and thick-bed dolomites. The trail reaches an altitude of 1311 m a.s.l. at its end. A stone path has been laid on the trail, with stone steps at places where the slope becomes steeper. Exposed tree roots are seen mostly on one side of the affected trees — where hikers have walked around them. In the section of the trail with a steeper incline, the deviation from the stone path is also marked by shortcuts trodden by hikers.

Trail (C). Mała Łąka valley – Miętusi pass is a trail running through the lower montane forest zone, afforested by artificial spruce stands. The substrate is predominantly comprised of limestone and thick-bed dolomites, whilst in the lower part it is covered with moraines. The trail is sharply inclined and at its end reaches an altitude of 1187 m a.s.l. The trail was prepared for hiking by laying a narrow path of stones. It is visibly too narrow and, as a result, trampled down tracks have appeared on both sides of the trail. Furthermore, the intensive use of this trail has caused many tree roots along large parts of the trail to become exposed. Some of the trees growing close to the main axis of the trail have been circumvented on all sides by tourists. Near the places with a particularly high inclination, tourists have created shortcuts.

Data collection and analyses

Four 50–100 m long transects, covering the crosswise profiles, were delineated on each of the selected trails. Based on a visual estimation of the destruction of soil cover and of the degree of vegetation coverage, two zones were distinguished: a) zone of destruction, and b) zone free of hikers' impact. Next, in each of the zones, tree ring samples were taken from selected trees with the use of a Pressler corer. In further analysis, the zone unaffected by the impact of hiking was treated as a background. The selection of trees to be sampled by coring was governed by the following criteria:

- the sample for dendrochronological analyses was as homogeneous as possible, *i.e.* all trees cored were of the same generation and the same biosocial position as well as growing in the same microhabitat conditions.
- the trees growing in all zones are affected by the same climatic conditions. It must, however, be taken into account that in places where soil degradation occurred, the additional factor of climatic stress showed in increments, could be greatly enhanced.

Trees were cored at a height of 1.3 m. The cores were then stuck to thin strips of wood, dried and polished. The next steps involved scanning each sample and marking the annual increments using CooRecorder software, and then measuring the widths of the annual increments using CDendro software (CDendro, 2013). The cross-dating procedure was controlled with the use of pointer years (Schweingruber *et al.*, 1990, Yamaguchi, 1991). The results of the measurements were finally checked with COFECHA, a standard procedure for the verification of time series in dendrochronology (Holmes, 1983). Then the ring-widths series were averaged for each transect and trail and zone. The growth curves obtained from different destruction zones were then compared with each other, as well as with the reference trend assumed as an averaged increment trend in trees growing in the zone free of tourism. The tree ring analyses were based on a total of 140 ring-widths series.

The analysis of tree-ring changes were done in two stages. First, the regression for tree-ring series and time were calculated for trees near the track and control sample separately, and the parallelism of the regression lines was controlled. If the regression lines were significantly unparallel, the dynamics of differences in their courses were analyzed. They were based on the analysis of the time dynamics of average differences between observed tree-ring widths of trees near the tourist track and the values expected based on a control sample. If the polynomial lines presented a better fit than the straight line then it meant that the differences in the tree-ring series between the analyzed samples had changed during the studied period. The breaking point of change was regarded as the point of osculation between the polynomial function and the straight line parallel to the linear function (Gottschalk and Dunn, 2005). The results obtained were compared with historical data on the volume and changes in tourist traffic in the Polish Tatra National Park.

3. RESULTS

Average increments in trees growing on trails or outside trails

The average annual increments in trees on the Kuźnice – Nosal trail (A) are presented on the graph (**Fig. 2**). Generally, in this area, the increments of trees under trampling pressure are wider ($t = 9.510644$; $p < 0.0001$). Since *ca.* 1980, the differences between the control group and trees under pressure have become progressively thinner, up to the year 2003 when increments of trees near the tourist trail have become higher than trees growing deeper in the forest.

The average annual increments in trees in Strążyska Valley – Grzybowiec Pass trail (B), are presented in **Fig. 3**. Throughout the years there is no obvious relationship between the size of annual increments and the situation of the trees, either on the trail or away from it ($t = 8.696691$; $p < 0.0001$). Since 1963, the trees growing immediately along the trail have begun to show much greater increments and it was only towards the end of 1990s that these differences started to gradually fade away. The average annual increments on the trail (C) between Mała Łąka Valley and Miętusi Pass are shown on the graph in

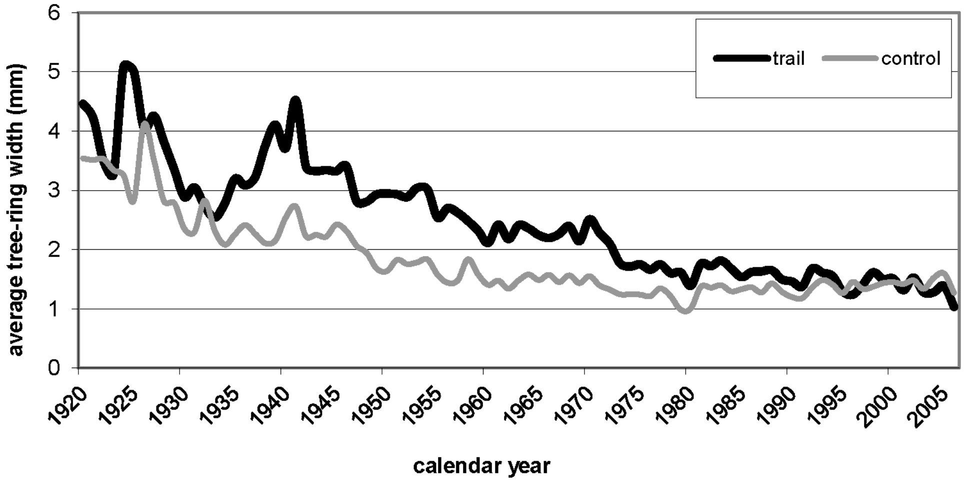

Fig. 2. The average annual tree-ring width series on the trail and outside the trail (A) the Kuźnice — Nosal trail.

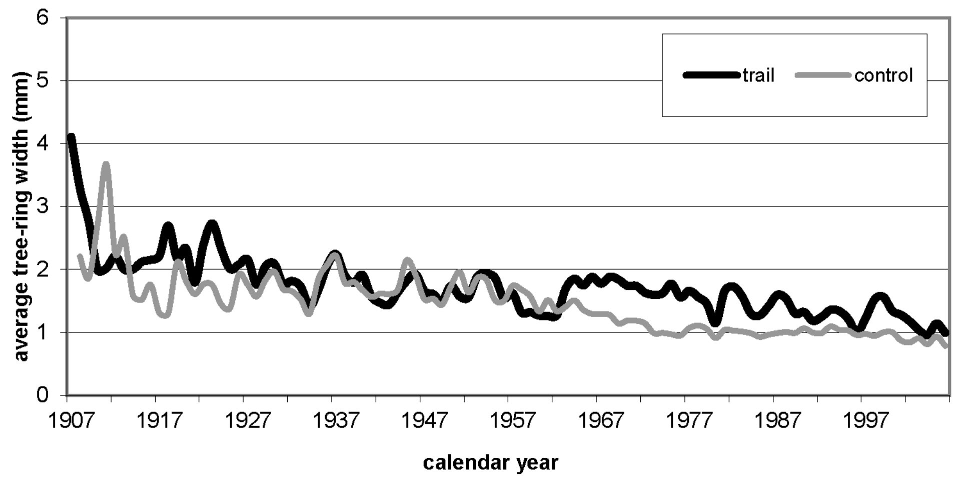

Fig. 3. The average annual tree-ring width series trees on the trail and outside the trail (B) Strążyska Valley — Grzybowiec Pass trail.

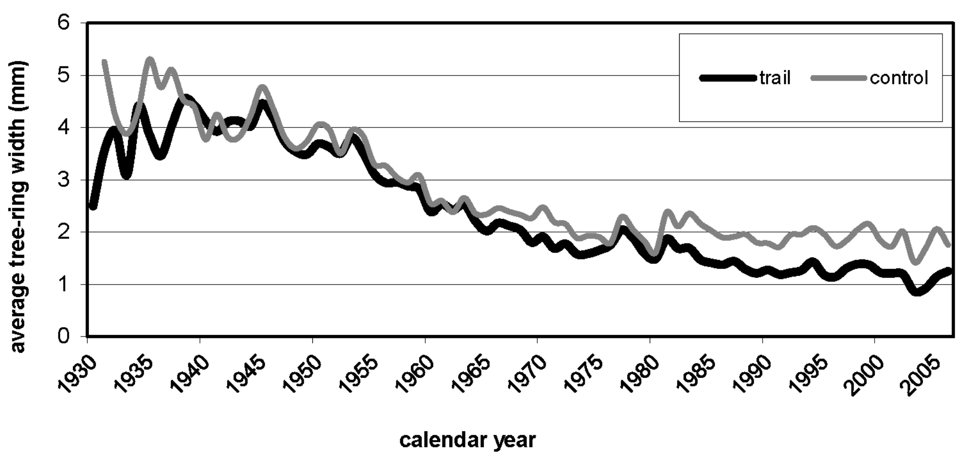

Fig. 4. The average annual tree-ring width series trees on the trail and outside the trail (C) Mała Łąka Valley.

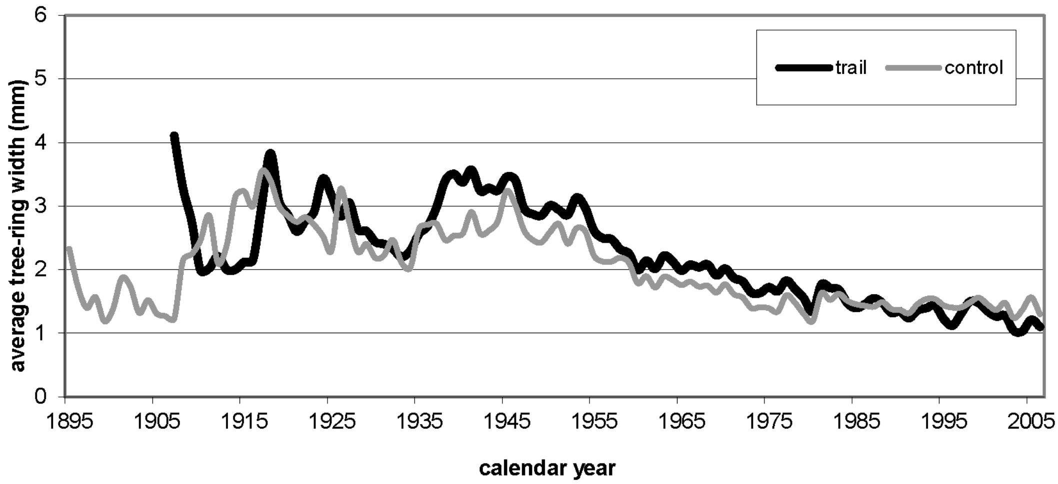

Fig. 5. *The average annual tree-ring width in trees on the trails and outside the trails. All series combined.*

Fig. 4. In all years, the increments in trees growing outside the trail exceeded the average increments in trees growing on the trail ($t = -6.90091$; $p < 0.0001$). The differences in increments between the trees growing inside the forest and those growing immediately along the trail increased markedly after 1980.

After the data from all trails were pooled, a graph showing the average increments in trees throughout the whole study area was obtained (**Fig. 5**). Pooling the data shows that the trees on the hiking trails grew better up to the beginning of the 1980s. Since that time, there has been a regression in the size of increments in trees exposed to the impact of hiking tourism, compared with trees in the depths of the forest.

The analysis of tendencies in tree-ring width showed that at study plots A and C the increments diminished significantly more rapidly on the tourist track than in the control group (**Fig. 6A**, **6C**). For the locality B there were no differences (**Fig. 6B**).

It is worth stressing that in the locality A tree-ring widths at the beginning of the study period were higher near the tourist trail than in the control samples and these differences continuously decreased. This decrease, however, was not a linear process. The analysis of the dynamics of residuals calculated from the expected data calculated based on the control sample data shows that until the 1970s this process was more rapid. The calculated breaking point was 1972, moreover there is no significant directional tendency after 1978 (**Fig. 7A**). At sitecality C both tree ring series in the trail and the control group were similar at the beginning of the studied period. However, the process of their diminishing was more rapid for trees on the tourist trail. The breaking point was 1968 (**Fig. 7B**).

Data on the touristic traffic clearly showed an increase in the second half of the twentieth century (**Fig. 8**). The analysis of these changes enabled the calculation of the time when the rapid intensification of tourist impact occurred (**Fig. 9**)

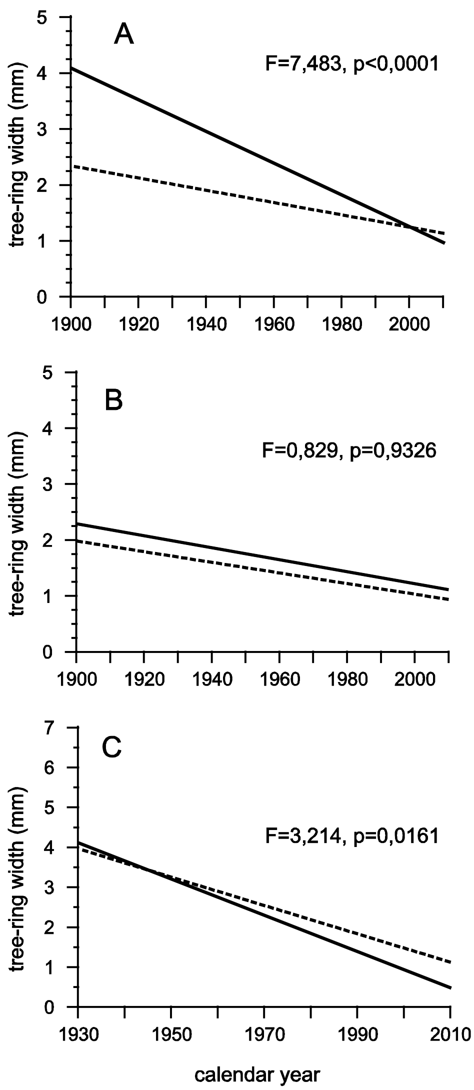

Fig. 6. *Parallelism analysis of diminishing in tree-ring series for analyzed localities: A, B and C. Solid lines represent tourist trails and dashed lines control samples.* F *denotes the calculus of parallelism test,* p *— obtained significance level.*

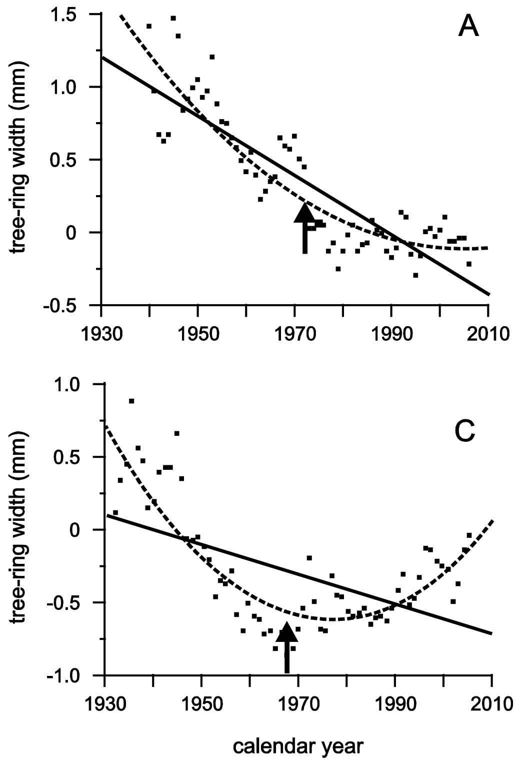

Fig. 7. *The dynamics of differences between observed average values of tree-ring series at the tourist trail and values expected based on the data from control sample for localities A and C. Positive values signify diminishing of tree-ring width higher than expected whereas negative values lower. The presented lines represent the best fitted linear (solid line) and polynomial (dashed lines) functions. Arrow indicates a point of osculation (a breaking point for tendency. Due to insignificant differences the analysis wasn't conducted for the locality B.*

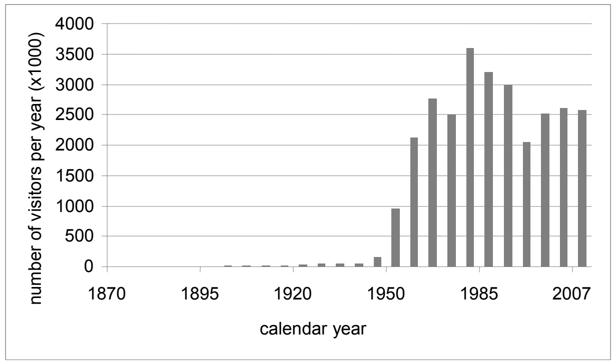

Fig. 8. *The volume of tourist traffic over time in the Tatra National Park.*

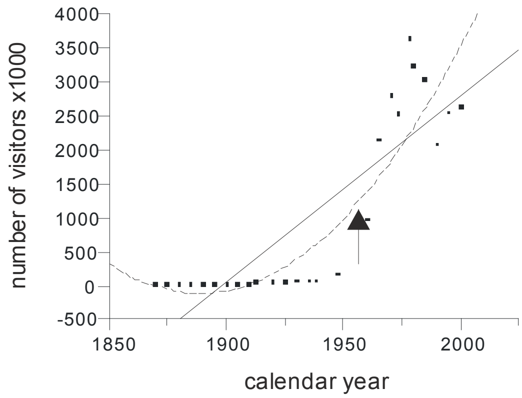

Fig. 9. *The intensity of tourism impact in the Tatra National Park. Arrow indicates the beginning of the rapid intensification of the traffic, calculated as point of osculation.*

4. DISCUSSION

The high intensity of tourist traffic in the Polish Tatra Mountains, is not neutral to trees growing directly on the trails. According to data for all tickets sold in 1996 in the Polish Tatra National Park, in those entry points closest to the trails under study, the highest number of tourists were recorded at: Strążyska Valley (B) — 155 650, Mała Łąka Valley (C) — 46 150, and Nosal (A) — 24 240 (Gorczyca and Krzemień, 2002). Nonetheless, the fact that these entry points enable access to several different trails makes it impossible to determine a more precise inference about the intensity of tourist movement on the sections of trails concerned in this study.

Both data from publications and the results of this study allow one to conclude that tourist traffic has a negative effect on the size of annual increments in trees. However, on some of the trails studied, radial increments in spruces could not be found. This phenomenon could be explained by the slightly different density of trees in the zone directly bordering the trail, compared with the density of trees deeper in the stand. In order to determine a suitable tourist traffic capacity, the trail is marked across the less dense fragments of forests. Additionally, the trees evidently obstructing the trail could have been removed in the past, particularly when permanent trails were stabilised. All these practices could provide better access of light to the crowns of trees growing along both sides of the trail and, consequently, result in their greater growth dynamics compared with trees deeper in the forest stand (Lorimer and Frelich, 1989; Payette *et al.*, 1990, Zielonka *et al.*, 2008). Although — in line with the methodology applied — the trees selected for examinations were growing in similar light conditions, it is difficult to exclude the effect of more light on the crowns of trees growing close to the trail. This effect may explain the higher average increments in trees growing along the trails in the majority of the trails studied (except for Przysłop Miętusi pass), during the period prior to the intensification of tourist traffic *i.e.* before 1980. It turned out, however, that even more light reaching the crowns of trees along trails, on trails with high intensity tourist traffic, could not compensate for the stress resulting from the damage caused by hikers. This process can be noted when the increment averages for all trails, are compared. As seen from data from 1980, progressive depressions in increments appear in trees growing along the trails when compared with the size of increments in trees from the depths of the forest.

As shown by results obtained for the majority of transects where spruces were cored, the increments in 1980 in trees growing directly on the trail, and therefore exposed to the pressure of tourism, are much lower than in those trees growing further away from the path. This process is clearly noticeable on the trail from Mała Łąka Valley to Przysłop Miętusi Pass (C). The samples from several damaged zones, particularly on the Strążyska valley to Grzybowiec Pass trail (B) indicate, however, exactly the reverse trend: that the increments in trees growing on the trail are much greater than those growing outside the trail. There could be a great many reasons for such a phenomenon, associated with the much stronger impact of factors other than pressure from tourism. It could be the different heights of particular trails and different elevations of their end points. The trail from Strążyska Valley to Grzybowiec Pass (B), is situated at a higher altitude than the other two trails. In addition it is the least trampled down, whilst the roots are exposed mostly on one side only and the damage to them is much less severe than, for example, on the trail leading to the Miętusi Pass. Similarly, in the case of the Kuźnice to Nosal trail (A), where the manner of outlining the trail may have a significant effect on the trees growing on it or close to it. It is a traverse path which does not climb straight up — as is the case of the Mała Łąka Valley to Przysłop Miętusi Pass (C) — but across the slope. As a result, some of water may flow down the trail, thus providing better access to water for the trees, which in turn will positively affect their annual increments. On the Kuźnice to Nosal trail (A), as well as on the Strążyska Valley to Grzybowiec Pass trail (B), tree roots are exposed only on one side. Perhaps these trees can still cope with the stress of pressure from tourists, unlike the trees whose roots are exposed on both sides, such as along the Mała Łąka Valley to Przysłop Miętusi Pass trail (C). This conjecture reflects the results of studies conducted and is based on the differences found between the results obtained for the trail on the Przysłop Miętusi pass and the other two trails.

Our data shows that a tourist trail may have a different influence on trees located nearby. Trees on a trail may grow better due to better light conditions (Lorimer and Frelich, 1989; Payette *et al.*, 1990, Zielonka *et al.*, 2008), which are an effect of the lower density of trees. The other reaction is when trees disturbed by trampling suffer from the deterioration of soil properties, wounds and impeded mycorrhiza (Cole, 2004; Kissling *et al.*, 2009; de Gouvenain, 1996) and the better light conditions do not compensate for the effects of trampling. As was shown in our study, the increase of tourist traffic might be recorded in tree-rings as an abrupt decrease in the growth dynamics.

5. CONCLUSION

We conclude that tree-ring trends might be used for the assessment of the intensity of trampling along tourist trails in forests. If trees growing along such trails bear signs of growth reduction compared with control trees, it may indicate that tourist traffic, as a factor, has begun to significantly influence the forest environment. Tree-ring analyses might be an efficient alternative for the assessment of tourist intensity conducted using other methods. Besides, the comparison of the growth of trees in pressure zones with those in a control zone gives the possibility to estimate the scale of the impact in a continuous way. A very important advantage of the method is that the tree-ring series gives the possibility of retrospective observations of tourist pressure. Continuous data on tree growth enables data on tourist traffic to be related with the scale of the impact and also enables predictions of future impacts to be made.

REFERENCES

Andersen UV, 1995. Resistance of Danish coastal vegetation types to human trampling. *Biological Conservation* 71(3): 223–230, DOI 10.1016/0006-3207(94)00031-K.

Bayfield NG, 1973. Use and deterioration of some Scottish hill paths. *Journal of Applied Ecology* 10(2): 635–644, DOI 10.2307/2402307.

Bergeron Y, Denneler B, Charron D and Girardin MP, 2002. Using dendrochronology to reconstruct disturbances and forest dynamics around Lake Duparquet, northwestern Quebec. *Dendrochronologia* 20(1–2): 175–189, DOI 10.1078/1125-7865-00015.

CDendro — http://www.cybis.se/forfun/dendro/index.htm (Accessed: 7 December 2013).

Cole DN, 1995. Experimental trampling of vegetation. I Relationship between trampling intensity and vegetation response. *Journal of Applied Ecology* 32(1): 203–214, DOI 10.2307/2404429.

Cole DN, 2004. Impacts of hiking and camping on soils and vegetation: a review. *Environmental Impacts of Ecotourism* (ed. R. Buckley), pp. 41–60. CABI Publishing, New York.

Czochański J, 2002. Ruch turystyczny w Tatrzańskim Parku Narodowym. *Użytkowanie turystyczne Parków Narodowych.* (Tourist traffic in the Tatra National Park. *Tourism in National Parks).* (ed. J. Partyka), pp. 385–404. Instytut Ochrony Przyrody Polskiej Akademii Nauk, Ojcowski Park Narodowy, Ojców. (in Polish).

Gorczyca E and Krzemień K, 2002. Wpływ ruchu turystycznego na rzeźbę Tatrzańskiego Parku Narodowego. *Przemiany środowiska przyrodniczego Tatr.* (Impact of tourism on the relief of the Tatra National Park. *Changes of the nature environment of the Tatra Mountains*). (eds. W. Borowiec, A. Kotarba, A. Kownacki, Z. Krzan, & Z. Mirek), pp. 389–394. Tatrzański Park Narodowy, Polskie Towarzystwo Przyjaciół Nauk o Ziemi, Oddział Kraków, Kraków – Zakopane. (in Polish).

Gottschalk PJ and Dunn JR, 2005. Measuring Paralelism, Linearity and Relative Potency in Bioassay and Immunoassay Data. *Journal of Biopharmaceutical Statistic* 15(3): 437–463, DOI 10.1081/BIP-200056532.

de Gouvenain RC, 1996. Indirect impacts of soil trampling on tree growth and plant succession in the North Cascade Mountains of Washington. *Biological Conservation* 75(3): 279–287, DOI 10.1016/0006-3207(95)00036-4.

Hammitt W and Cole D, 1998. *Wildland recreation: ecology and management, 2nd edition*. John Wiley. New York.

Hill W and Pickering CM, 2006. Vegetation associated with different walking track types in the Kosciuszko alpine area, Australia. *Jour-*

nal of Environmental Management 78(1): 24–34, DOI 10.1016/j.jenvman.2005.04.007.

Holmes RL, 1983. Computer assisted quality control in tree-ring dating and measurement. *Tree-Ring Bulletin* 43: 69–78.

Hresko J and Bugar G, 2001. Problems of natural hazard assessment and monitoring in the Tatra Mts. *Ekologia-Bratislava* 20(Suppl. 1): 96–100.

Kethledge EH, Leonard RE and Richards NA, 1985. *Rehabilitation of Alpine Vegetation in the Adirondack Mountains of New York State.* USDA Forest Service, Northestern Experiment Station Research Paper, NE-553, Bromall, Pensylvania.

Kissling M, Hegetschweiler KT, Rusterholz HP and Baur B, 2009. Short-term and long-term effects of human trampling on above-ground vegetation, soil density, soil organic matter and soil microbial processes in suburban beech forests. *Applied Soil Ecology* 42(3): 303–314, DOI 10.1016/j.apsoil.2009.05.008.

Kombol P, 2000. Rural tourism on the Croatian islands — Sustainable development and regenerative strategies. *Periodicum Biologorum* 102: 425–431.

Krnacova Z, Pavlickova K and Spisak P, 2001. Assumptions of the development of tourism in rural areas of Slovakia. *Ekologia-Bratislava* 20(Suppl. 3): 317–324.

Lance AN, Baugh ID and Love JA, 1989. Continued footpath widening in the Carrington Mountains, Scotland. *Biological Conservation* 49(3): 201–214, DOI 10.1016/0006-3207(89)90036-0.

Li W, Ge X and Liu Ch, 2005. Hiking trails and tourism impact assessment in protected area: Jiuzhaigou Biosphere Reserve, China. *Environmental monitoring and assessment* 108(1–3): 279–293, DOI 10.1007/s10661-005-4327-0.

Lorimer CG and Frelich LE, 1989. A methodology for estimating canopy disturbance frequency and intensity in dense temperate forests. *Canadian Journal of Forest Research* 19(5): 651–663, DOI 10.1139/x89-102.

Łajczak A, 1996. *Wpływ narciarstwa i turystyki pieszej na erozję gleby w obszarze podszczytowym Pilska.(Influence of skiing and hiking on soil erosion of the top of the Pilsko Massif)*. Studia Naturae 41: 131–159. (in Polish).

Maikhuri RK, Rana U, Rao KS, Nautiyal S and Saxena KG, 2000. Promoting ecotourism in the buffer zone areas of Nanda Devi Biosphere Reserve: an option to resolve people-policy conflict. *International Journal of Sustainable Development and World Ecology* 7(4): 333–342, DOI 10.1080/13504500009470052.

Neto F, 2003. A new approach to sustainable tourism development: Moving beyond environmental protection. *Natural Resources Forum* 27(3): 212–222, DOI 10.1111/1477-8947.00056.

Olive ND and Marion JL, 2009. The influence of userelated, environmental, and managerial factors on soil loss from recreational trails. *Journal of Environmental Management* 90(3): 1483–1493, DOI 10.1016/j.jenvman.2008.10.004.

Payette S, Filion L and Delwaide A, 1990. Disturbance regime of a cold temperate forest as deduced from treering patterns — the Tantare-ecological-reserve, Quebec. *Canadian Journal of Forest Research* 20(8): 1228–1241, DOI 10.1139/x90-162.

Root JD and Kapnik LJ, 1972. *Trail conditions along a portion of the Great Divide trail route, Alberta and British Columbia Mountains.* Research Council of Alberta, Edmonton Alberta

Satchell JE and Marren PR, 1976. *The effect of recreation of the ecology of natural landscapes.* Nature and environment series 11, Council of Europe, Strasbourg.

Schweingruber FH, 1989. *Tree Rings: basics and application of dendrochronology*. Kluver Academic Publisher.

Schweingruber FG, Eckstein D, Serre-Bachet F and Bräker OU, 1990. Identification, presentation, and interpretation of event years and pointer years in dendrochronology. *Dendrochronologia* 8: 9–37.

Schweingruber FH, 1996. *Tree Rings and Environment Dendroecology.* Paul Haupt Publisher, Berne Stuttgart Vienna.

Tomczyk AM and Ewertowski M, 2013. Planning of recreational trails in protected areas: Application of regression tree analysis and geographic information systems. *Applied Geography* 40: 129–139, DOI 10.1016/j.apgeog.2013.02.004.

Yamaguchi DK, 1991. A simple method for cross-dating increment cores from living trees. *Canadian Jornal of Forest Research* 21(3): 414–416, DOI 10.1139/x91-053.

Zielonka T, Holeksa J and Ciapała S, 2008. A reconstruction of flood events using scarred trees in the Tatra Mountains, Poland. *Dendrochronologia* 26(3) 173–183, DOI 10.1016/j.dendro.2008.06.003.