Needle traces as indicators of growing conditions in Scots pine (*Pinus sylvestris* L.)

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ABSTRACT: Needle retention (number of needle sets) and needle density (number of needle pairs per centimeter of shoot) were surveyed on Scots pines in five forest regions of Slovakia. The Needle Trace Method (NTM) was used to determine needle retention and needle density along the main stem retrospectively for the last four decades. In all forest regions, the values of these indicators varied from year to year. However, in Záhorská lowland, Vtáčnik, Krupinská plain, and High Tatras, the trends of both observed indicators were constant over the time series. The situation was different in the Levočské hills, where the needle retention displayed a decreasing trend and needle density an increasing trend. These trends probably reflected a long-term stress of air pollution on pines in this forest stand.

Keywords: needle retention; needle density; environmental and anthropogenic impacts

Most coniferous species of the boreal and temperate zones keep needles the whole year but the number of needle sets naturally differs between growing season and dormancy. Every year about one set of oldest needles shed at the end of growing season is replaced by a new one in the spring of the following year. A number of needle sets on conifers can be changing over time due to a variety of disturbances (JALKANEN 1995). Hence, development of the number of needle sets and especially its sudden decrease can indicate environmental and anthropogenic impacts on conifers.

Observations on defoliation together with discoloration have been carried out in most European countries and North America to monitor the health conditions of forest ecosystems (ANONYMOUS 1988). The terrestrial visual observation itself or in combination with aerial infrared photographs were used for the assessment. The main weaknesses of visual assessment are: certain subjectivity of each observer, acquirement of data only for current-year needle retention, and inadequate consideration of the natural variability of needle retention in this tree species (INNES 1998). KURKELA and JALKANEN (1990) invented the Needle Trace Method (NTM), which dissolved the above mentioned problems and enabled to survey needle retention (number of needle sets) retrospectively for almost the whole tree's life.

The NTM is based on the examination of the vascular bundles connecting the needles and shoot pith. According to studies of ELLIOT (1937), vascular bundles stop their elongation at the tree ring after the needle pairs are shed. Thus, needle longevity corresponds with the number of annual tree rings containing vascular bundles, i.e. needle traces. The needle traces are well recognizable by naked eye on *Pinus* species, since they have a different (darker) color from the surrounding wood tissues. The needle traces appear as dark-brown dots in the longitudinal wood surface. The NTM is applicable to the main stem rather than to the branches because of the irregularity and thinness of annual rings in the branches (AALTO, JALKANEN 1998a). In addition, needles along the stem are always more exposed to the prevailing light than the needles on the branches situated lower in the canopy (WOOD 1974). Consequently, the needles along the stem of dominant and co-dominant trees, in comparison with the needles on the branches, are negligibly influenced by tree competition for light.

The aim of this study was to examine long-term development of needle retention (number of needle sets) on Scots pines in five forest regions of Slovakia. A further aim was to test needle retention and needle density as indicators of growing conditions, especially environmental and anthropogenic stresses, in Scots pines.

MATERIALS AND METHODS

Fieldwork was performed in the summers of 2000 and 2001 in five forest regions of Slovakia: Záhorská lowland, Vtáčnik, Krupinská plain, High Tatras, and Levočské hills (Fig. 1). The altitudes of pine stands sampled were between 185 m a.s.l. (Záhorská lowland) and 1,050 m a.s.l. (High Tatras). The main characteristics of research plots are shown in Table 1.

In each forest stand, seven or eight co-dominant pines were felled and researched. The number of needle sets on

Table 1. The main characteristics of the research plots and Scots pines

Plot No.	Forest region	Forest vegetation zone	Altitude of plot (m a.s.l.)	Number of pines researched	Mean age of pines (years)	Mean height of pines (m)	Mean dbh of pines (cm)
1	Záhorská lowland	1	185	7	41	17.6	16.9
2	Vtáčnik	4	600	7	48	20.2	26.0
3	Krupinská plain	2	250	8	41	16.7	20.0
4	High Tatras	6	1,050	7	49	19.1	24.2
5	Levočské hills	5	580	7	50	23.1	22.8

branches was assessed visually whorl by whorl at a precision of 0.1 needle set (data for the current year 2000 or 2001). Then, the branches were cut from the main stem. Using a chain saw and a waterproof pen-marker, a linear mark was drawn onto the stem to indicate the east-facing side. The stems were cut into pieces respecting annual shoots (i.e. each piece represented a section between two neighboring whorls). The lengths of the annual shoots (height increments), starting from breast height to tree top, were measured and considered for further needle trace survey. Every shoot was shortened for a bolt approximately 15 cm long. Tree code and numerical order within the stem were marked on the bolts. The bolts with discs cut off at breast height were transported and dried at a room temperature for a few days.

The annual radial increments were measured from the breast-height discs. The bolts were longitudinally split with an axe to get their central parts and all the rings containing needle traces on the marked east-facing side. The ends of the bolts were polished with an electric grinding machine to make the rings easily distinguishable. Then, angles were drawn on both ends of the bolts delimiting the examined area. The precise length of every bolt was measured. The bolts were planed manually ring by ring, and the number of needle traces in each ring was recorded. The data on height increment, radial increment, angles α_1 and α_2, bolt length and number of needle traces in each ring were processed using the computer program NTMENG version 5.1 (AALTO, JALKANEN 1998b). The computer program calculates summer and winter retention (i.e. number of needle sets in growing season and in dormancy season), annual needle loss (differences between the number of needle sets in summer and in successive winter), needle density per cm of shoot, number of needle pairs in leading shoot and total number of needles on stem for every year of the tree's life. More detailed information on the procedure of the NTM, as well as the formulas to calculate the particular parameters, are in the manuals "The needle trace method" (AALTO, JALKANEN 1998a) and "NTM version 5.1" (AALTO, JALKANEN 1998b). The following part of this paper is focused mainly on summer needle retention issues.

All the needles that are born in the same calendar year make up a needle set. One full needle set (no needles are missing in the annual shoot) is expressed numerically as 1.0 or 100%. As needles normally live longer than one year, there can be for example four different needle age classes: the needles are born in the year n, $n - 1$, $n - 2$ and $n - 3$ in the branches and the main stem. If no needles in the shoots of the four years have shed, all original needles are intact, resulting in four full needle sets, expressed also that the number of needle sets is four. However, needles tend to die (shed) from older shoots. For instance, if there are 25, 50, and 75% of needles lost in the shoots of $n - 1$, $n - 2$, and $n - 3$, the amount of the remaining needles is

Fig. 1. Approximate allocation of the research plots

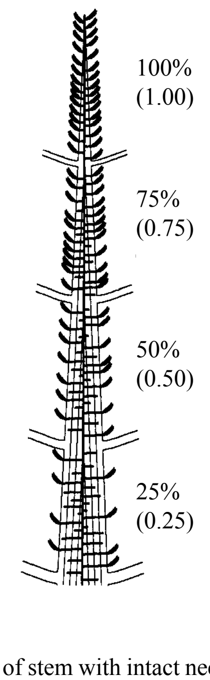

Fig. 2. Upper part of stem with intact needles and traces of shed needles. Number of needle sets in current year is 2.50

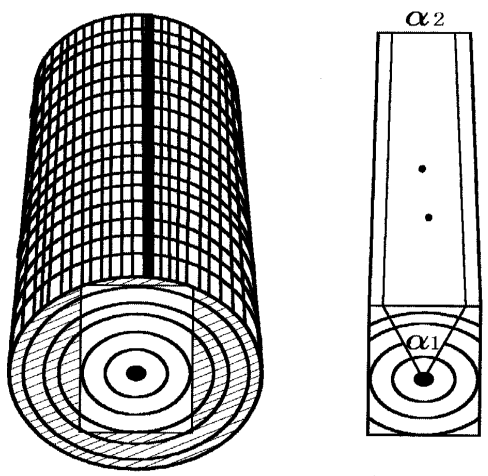

Fig. 3. Inventory of needle sets on the fifth tree ring (in this case there are two traces)

75, 50, and 25%, respectively, equaling 0.75, 0.50, and 0.25 needle sets left. Hence, the total number of needle sets is 1.0 + 0.75 + 0.50 + 0.25 = 2.50. This procedure is the same in both cases, whether the current situation is determined visually for tree top (Fig. 2), or the NTM is used to reveal the needle history to any particular year. Using the NTM, needle traces can easily be recognized on the planed surface of the innermost tree rings where they are assessed on an area delimited by angles α_1 and α_2 (Fig. 3).

RESULTS

In the years 2000 and 2001, the Scots pines on the particular research plots had between 16 and 25 "green" whorls (those with living needles). The values for the number of needle sets were variable between the plots, and also between the pines growing on the same plot. In Table 2, averages for "optimal" number of needle sets (highest value within the tree crown) are given for each plot. Position of the whorl bearing these needle sets as well as number of green whorls are shown. The table also gives minimum and maximum values for the number of needle sets situated on the above mentioned whorls of the particular pines. The highest value (3.30) for optimal number of needle sets was recorded on 8th–10th whorls of pines growing in the High Tatras and the lowest (2.60) on 4th–7th whorls of pines in Záhorská lowland. Differences in the values for optimal number of needle sets between the pines on the same plots were from 0.50 (Záhorská lowland and Krupinská plain) to 0.80 (High Tatras). The number of needle sets on branches increased from the first whorl to the upper third of the crown (between 4th and 10th whorl). Then, the number of needle sets decreased downward to the crown foot. An example of needle retention variability in the crowns of pines is illustrated in Fig. 4 (Záhorská lowland).

From the visual observations, current values for needle retention in the upper part of the main stem and optimal

Table 2. "Optimal" needle retention (number of needle sets – min., max., and average values between the particluar pines) and position of whorls having this retention

Plot No.	Number of needle sets			Position of whorl	Number of green whorls
	min.	max.	average		
1	2.50	3.00	2.60	4–7	16
2	2.60	3.20	2.80	6–8	25
3	2.60	3.10	2.70	6–7	16
4	2.90	3.70	3.30	8–10	21
5	2.70	3.30	2.90	6–10	21

Table 3. Long-term average values of needle retention (number of needle sets) along the main stem and its min. and max. values between the particular pines and years

Plot No.	Number of needle sets		
	min. and max. values between particular		long-term average
	pines	years	
1	2.50–3.09	2.11–3.02	2.68
2	2.54–3.16	2.59–3.14	2.85
3	2.49–2.97	2.28–3.01	2.62
4	2.96–3.64	2.92–3.50	3.20
5	2.75–3.37	2.61–3.64	3.02

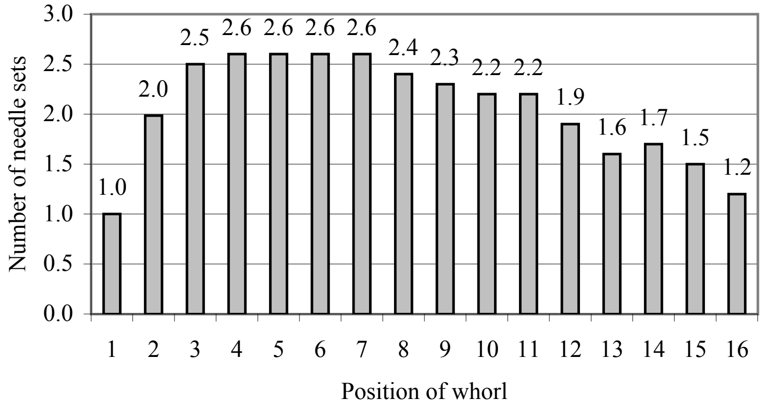

Fig. 4. The mean number of needle sets on the particular whorls of Scots pines (Záhorská lowland)

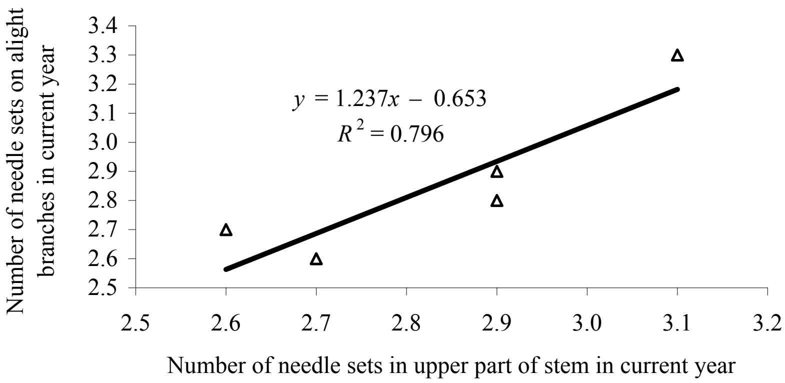

Fig. 5. Correlation between the needle retention in the upper part of stem and needle retention on alight branches (averages for five research plots)

needle retention on the branches were compared. The fact that these two characteristics had very similar values is evident from Fig. 5 – it shows correlations between the average values of needle retention in the upper part of the main stem and needle retention on the alight branches for the pines of five research plots.

The long-term mean needle retention on the main stem, determined by the NTM, in the particular forest regions was as follows: 2.68 needle pairs for Záhorská lowland, 2.85 for Vtáčnik, 2.62 for Krupinská plain, 3.20 for High Tatras, and 3.02 for Levočské hills. These values varied between the particular pines and also between the years (Table 3). For instance, in Záhorská lowland, the minimum value of long-term average for needle retention was 2.50 and the maximum one was 3.09. Thus, certain individual dispositions to needle retention of pines might be assumed. Even higher variability of needle retention is seen between the values recorded for the particular years. For example in Záhorská lowland, needle retention was between 2.11 (1967) and 3.02 (1975).

Only insignificant differences were found in the long-term averages of needle density (number of needle pairs per cm of shoot) between the particular forest regions. Their values were: 6.41 (Záhorská lowland), 6.49 (Vtáčnik), 6.43 (Krupinská plain), 6.61 (High Tatras), and 6.34 (Levočské hills).

As we have already mentioned above, high variability in the values of needle retention was observed between the particular years. These differences were from 0.58 (High Tatras) to 1.03 needle set (Levočské hills). Figs. 6–10 describe the trends of needle retention for the pines of five research plots. The longest time series of needle retention (output data from the NTM) was recorded for the research plot in Vtáčnik (1958–1999), the shortest one in Krupinská plain (1970–1999). The number of needle sets varied from year to year, nevertheless differences between two successive years did not exceed the value of 0.3.

On the research plots, the trends of needle retention and needle density (diagrams for needle density are not shown) were constant over the observed time series. As

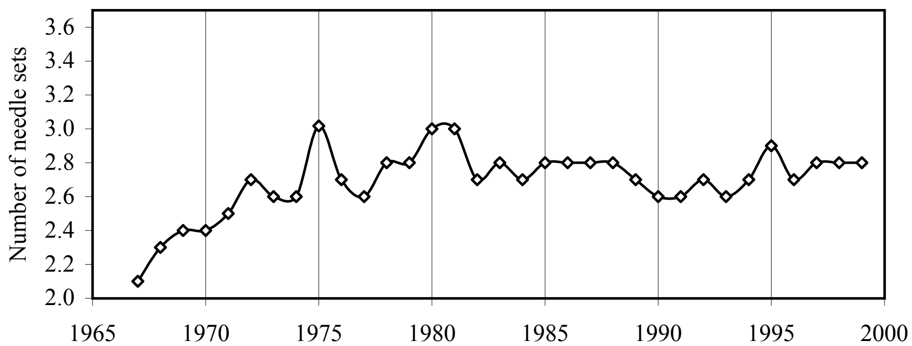

Fig. 6. The trend of needle retention in the years 1967–1999 (Záhorská lowland)

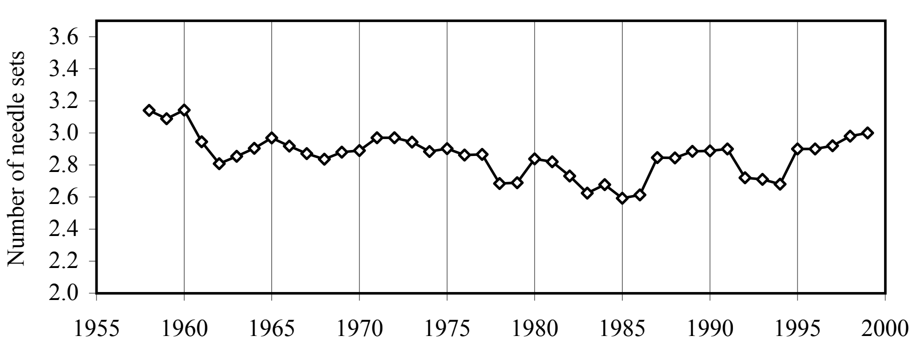

Fig. 7. The trend of needle retention in the years 1958–1999 (Vtáčnik)

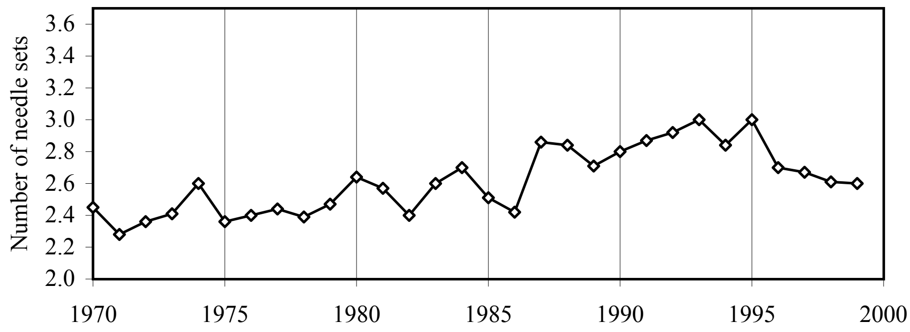

Fig. 8. The trend of needle retention in the years 1970–1999 (Krupinská plain)

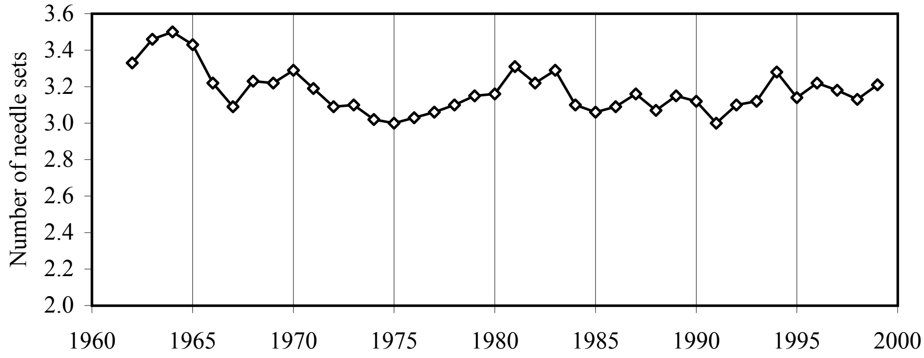

Fig. 9. The trend of needle retention in the years 1962–1999 (High Tatras)

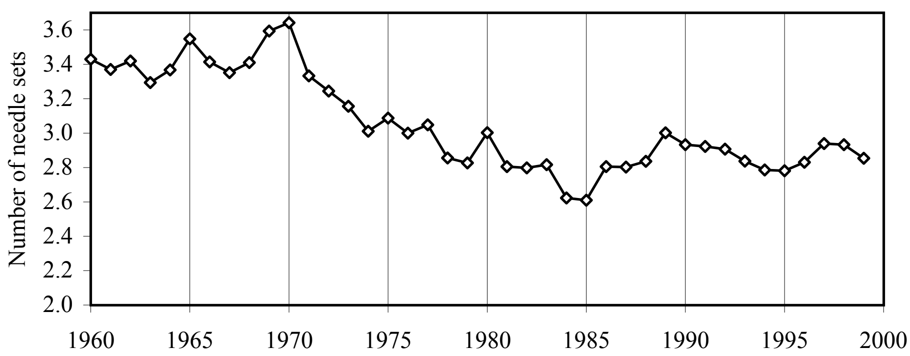

Fig. 10. The trend of needle retention in the years 1960–1999 (Levočské hills)

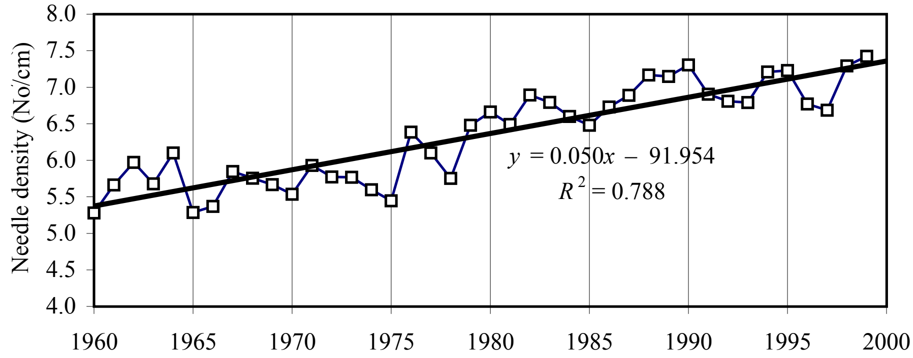

Fig. 11. The trend of needle density in the years 1960–1999 (Levočské hills)

for the needle retention it means that the long-term budget between newly born and annually shed needle sets was in equilibrium. The situation for pines in the Levočské hills was different. The trend of needle retention in this locality was decreasing and that of needle density increasing (Figs. 10 and 11). The trends in Levočské hills reflected the worsening health condition of pine stand. Relationships between needle retention and needle density were studied in the particular years for each research plot. The closest correlation was observed just for the pines in the Levočské hills (Fig. 12). It seems that both needle retention and needle density are sensitive indicators of growing conditions in pines. However, they react to unfavorable conditions in opposite ways (reverse trends of their values).

Besides the trends of needle retention and needle density, trends of radial and height increments were also investigated on the research plots. The results showed that trends of needle retention and both increments suggested certain

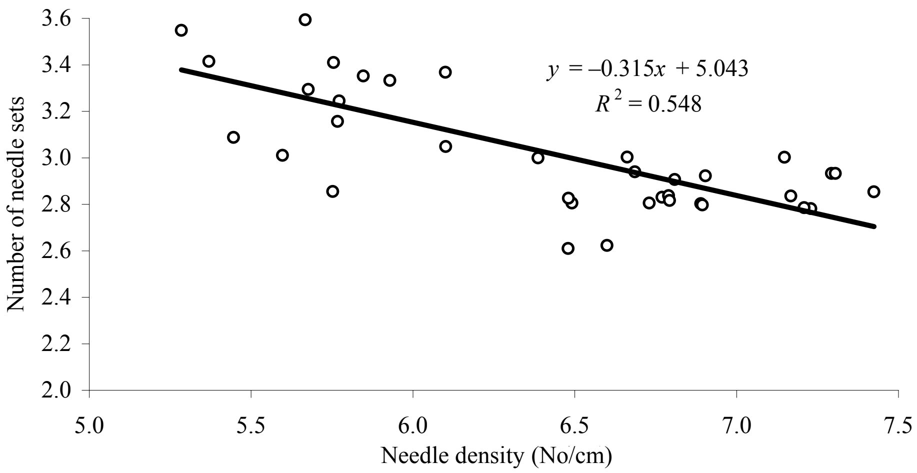

Fig. 12. Correlation between the needle density and needle retention (Levočské hills)

resemblance. Comparisons of the trends of needle retention, radial increment, and height increment were already analyzed in previous papers (KONÔPKA et al. 2000a,b), therefore these data are not shown in this paper.

Since the data on needle retention came from five research plots situated at different localities, altitude as a factor influencing the number of needle sets could be analyzed. A very close correlation for these two characteristics was proved ($r^2 = 0.8962$). The values for the number of needle sets grew linearly with altitude, expressed by the equation $y = 0.0007x + 2.5227$. From the linear model, the value of needle retention for the lowest location of Scots pine occurrence (150 m a.s.l.) would be 2.63 and for the highest one (1,400 m a.s.l.) 3.50 needle sets (Table 4).

Table 4. Needle retention (number of needle sets) with respect to altitude (linear model $y = 0.0007x + 2.5227$, $r^2 = 0.8962$)

Altitude (m a.s.l.)	Needle retention (needle sets)
150	2.63
200	2.66
300	2.73
400	2.80
500	2.87
600	2.94
700	3.01
800	3.08
900	3.15
1,000	3.22
1,100	3.29
1,200	3.36
1,300	3.43
1,400	3.50

DISCUSSION

The number of needle sets varied between whorls in the pine crowns significantly. The maximum value of needle sets was observed in the upper third of crowns (from 4th to 10th whorl – counted from the tree top). These whorls had very uniform needle retention (± 0.1 needle set) because they were negligibly influenced by suppression. Thus, a visual observation of the health status in pines should be focused on assessment of defoliation in these whorls. Needle retention in the upper part of the main stem and needle retention on the alight branches had very similar values. It proves that the investigation of needle retention on the main stem (visually for current year or retrospectively for time series) truly describes the situation of needle retention on branches. The whorls that were situated lower carried fewer needle sets due to sunlight reduction. This phenomenon is in agreement with the finding of MADGWICK (1983). On the other hand, some authors (e.g. MAILLETTE 1982) found that needles in lower canopy often lived longer. We observed this effect only on the research plot in the High Tatras that the oldest needles (as many as 6-year-old) were recorded in the lower half of crowns. The needles in the upper half of crowns, aged up to 5 years, made up more complete sets than those situated in the lower half.

The mean values of long-term needle retention in the pines were different between the particular research plots. The maximum value was found in the pines of High Tatras (3.20 needle sets), the minimum one in Krupinská plain (2.62). We assumed a certain relationship between the needle retention and altitude. The relationship was proved by a close linear correlation indicating that the needle retention grew with altitude. However, the increase in values for the number of needle sets was rather small. The linear model showed that the value of needle retention for the lowest location of Scots pine occurrence (150 m a.s.l.) would be 2.63 and for the highest one (1,400 m a.s.l.) 3.50 needle sets. Thus, the difference between the highest and lowest location of Scots pine occurrence was only 0.87 needle set. This result is in accordance with the knowledge of EWERS and SCHMID (1981), who found an increase in needle longevity of bristlecone pine (*Pinus longaeva* D.K. Bailey) with altitude in the USA. The same finding was also obtained by KONÔPKA et al. (2000a) for Japanese black pine (*Pinus* *thunbergii* Parl.) in Japan. The results from Sweden and Finland (ALBREKTSON 1988; JALKANEN 1995) showed the number of needle sets to increase with increase of latitude, i.e. from south to north. The increase in needle retention with both altitude and latitude can be explained by the thermal sum as a decisive factor governing the needle life span.

Surprisingly, rather large differences in the long-term needle retention were observed between the particular pines on the research plots. These differences can be explained by combination of individual genetic properties and growing conditions of the pines.

The distinct differences in needle retention (1.03) between the particular years in Levočské hills can be related to worsened growing conditions at this site. The Spiš region, where Levočské hills belong to, ranked among the most polluted areas in Slovakia. High concentrations of noxious matters were produced there mainly in the 70s and 80s. The deteriorated growing conditions were proved by the time series of needle retention and needle density. While needle retention showed a decreasing trend, needle density manifested a gradual rise. Certain stabilization of the values for both these indicators was observed in the last decade. This can be a positive consequence of reduced emission volume since the end of the 80s. Results similar to ours were also obtained by JALKANEN (1996), who proved a gradual decrease in needle retention over the last two decades in Scots pine stands near to a pollution source. The phenomenon that the number of needle sets decreases due to a variety of stresses is generally known and it is widely used for the monitoring of forest health. However, the needle density and its relationship to growing conditions of trees have been researched very rarely. JALKANEN et al. (1998) found that the needle density in Scots pine was highest in the years with abnormally cold growing season. The authors considered needle density as a sensitive indicator of temperature extremes, and even suggested it as a novel parameter for detection of climatic changes. Our results showed the long-term average value of needle density in Scots pine between 6.34 (Levočské hills) and 6.61 (High Tatras). JALKANEN et al. (1998) determined the value of average needle density in Northern Finland 10.5 pairs per centimeter of shoot.

The results showed a high variability in the values of needle retention between the particular years not only in Levočské hills but also in all other forest regions. The oscillations in the trends of needle retention in the pines could be caused by a variety of factors. In view of the importance of meteorological conditions for needle retention development, the averages of monthly temperatures and precipitation in the particular years were analyzed. The data were obtained from hydrometeorological stations situated as near as possible to the research plots. The analysis showed that the sum of precipitation in the first half of growing season (April–June) considerably influenced the needle retention in some years. For instance in Záhorská lowland, a depression in the needle retention trend was observed in 1977, when the sum of precipitation (118 mm) during the first half of growing season was extremely low. On the contrary, a peak of the needle retention trend in 1995 coincided with very high sum of precipitation (263 mm). The previous research showed that needle retention and needle density proved to be suitable indicators to monitor retrospectively the effect of not only abiotic harmful agents (mainly air pollution and temperature extremes) but also biotic ones, e.g. fungal diseases (JALKANEN et al. 1994) and leaf-eating insect (KONÔPKA et al. 2000a).

Interesting development (steep increase) of needle retention was recorded for the initial stage of pine growth in Záhorská lowland. From the trend (in 1967–1975) one can assume unfavorable growing conditions for the pines aged up to approximately 15 years (tree height of about 4–5 m). These stressful conditions could be caused by extremely high temperatures in summers that are typical of sandy sites in Záhorská lowland. Sandy soils create a layer of hot air above their surface that negatively affects the physiological status of young pines, which results in a reduction of needle sets. Later on, older pines (reaching height of about 4 m) build up the closed canopy that makes more favorable climatic conditions for their crowns. Certainly, many other factors also affected the variability of needle retention over the time on the research plots. Clarifying the sensitivity of needle retention and needle density to particular stresses further research should be done. In fact, site-specific records of the occurrence of harmful factors and meteorological data from previous decades would be necessary for making progress in the field.

So far, our research has shown that needle retention (partly also needle density) is a more suitable indicator of stresses in pines than radial increment and height increment. While the increments depend strongly on tree age, needle retention and needle density are relatively independent of growth stage.

CONCLUSIONS

The obtained results can be summarized as follows:

– maximum values for the number of needle sets occurred in the upper third of the "green" pine crown (for about 40- and 50-year-old pines approximately on the seventh whorl counting from the tree top). Special attention of the observer visually assessing the pine crown condition should be focused thereon,
– the number of needle sets in the upper part of the main stem manifested very similar values to the number of needle sets of branches situated on the alight part of pine crowns,
– differences in the number of needle sets between the particular years were considerable (up to 1.0 needle set). Worsening growth conditions cause a decrease in needle retention. An opposite situation was observed for the values of needle density that long-term deterioration of growth conditions increased the number of needle pairs per cm of shoot,

– the number of needle sets increased naturally with altitude. However, the increase in the values was rather small (0.35 needle set per 500 m).

References

AALTO T., JALKANEN R., 1998a. The needle trace method. Research Papers, Research Institute, Helsinki: 36.

AALTO T., JALKANE R., 1998b. Computation program for the needle trace method. NTMENG Version 5.1. Forest Research Institute, Helsinki: 12.

ALBREKTSON A., 1988. Needle litterfall in stand of *Pinus sylvestris* L. in Sweden, in relation to site quality, stand age and latitude. Scand. J. For. Res., *3*: 333–342.

ANONYMOUS, 1988. Manual of methodologies and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. UNEP/UN-ECE, Strasbourg: 228.

ELLIOT J.H., 1937. The development of the vascular system in evergreen leaves more than one year old. Ann. Bot., *1*: 107–127.

EWERS F.W., SCHMID R., 1981. Longevity of needle fascicles of *Pinus longaeva* (bristlecone pine) and other North American pines. Oecologia, *51*: 107–115.

INNES J., 1998. Forest health survey: problems in assessing observer objectivity. Can. J. For. Res., *18*: 560–565.

JALKANEN R., 1995. Needle Trace Method (NTM) for retrospective needle retention studies on Scots pine (*Pinus sylvestris* L.). Acta Univ. Ouluensis, Oulu: 84.

JALKANEN R., 1996. Needle retention chronology along a pollution gradient. In: Tree rings, environment and humanity. Radiocarbon: 419–426.

JALKANEN R., AALTO T., KURKELA T., 1994. The use of needle-trace method (NTM) in retrospectively detecting *Lophodermella* needle-cast epidemic. Eur. J. For. Path., *24*: 376–385.

JALKANEN R., AALTO T., KURKELA T., 1998. Revealing past needle density in *Pinus* spp. Scand. J. For. Res., *13*: 292–296.

KONÔPKA B., TSUKAHARA H., JALKANEN R., 2000a. A comparison of needle retention on Japanese black pine and Japanese red pine. J. For. Res., *5*: 175–180.

KONÔPKA B., TSUKAHARA H., NETSU A., 2000b. Development of needle retention in Japanese black pine (*Pinus thunbergii* Parl.) plantation in the years 1967–1997. Ekológia (Bratislava), *19*: 141–150.

KURKELA T., JALKANEN R., 1990. Revealing past needle retention in *Pinus* spp. Scand. J. For. Res., *4*: 481–485.

MADGWICK H.A.I., 1983. Seasonal changes in the biomass of a young *Pinus radiata* stand. N. Z. J. For. Sci., *13*: 26–36.

MAILLETTE L., 1982. Needle demography and growth pattern of Corsican pine. Can. J. Bot., *60*: 105–106.

WOOD G.B., 1974. Age distribution of needle fascicles in the crown of a radiate pine sapling. Aust. For. Res., *1*: 15–20.

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Stopy po ihličí ako indikátory rastových pomerov borovice sosny (*Pinus sylvestris* L.)

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ABSTRAKT: Retencia ihlíc (počet ročníkov ihlíc) a hustota nasadenia ihlíc (počet párov ihlíc na bežný centimeter kmeňa) sa sledovali na boroviciach v piatich lesných oblastiach Slovenska. Metóda stôp po ihličí (Needle Trace Method – NTM) sa použila na odvodenie počtu ročníkov ihlíc a hustoty ich nasadenia na kmeňoch retrospektívne pre ostatné štyri desaťročia. Vo všetkých lesných oblastiach hodnoty týchto indikátorov kolísali medzi jednotlivými rokmi. Avšak na Záhorskej nížine, Vtáčniku, vo Vysokých Tatrách a Krupinskej planine bola ich tendencia dlhodobo vyrovnaná. Odlišná situácia bola v Levočských vrchoch, kde retencia ihlíc mala klesajúcu a hustota nasadenia ihlíc rastúcu tendenciu. Tieto tendencie pravdepodobne odrážali dlhodobý stres znečistenia ovzdušia na boroviciach v sledovanom poraste.

Kľúčové slová: retencia ihlíc; hustota nasadenia ihlíc; environmentálne a antropogénne vplyvy

Najjednoduchšou metódou hodnotenia kondície drevín je vizuálne posúdenie stavu koruny, menovite straty asimilačných orgánov a ich žltnutia. Táto metóda má ale niekoľko nedostatkov. Výsledky vizuálneho hodnotenia sú zaťažené subjektívnou chybou hodnotiteľa. Ďalším problémom je adekvátne zohľadnenie rôznych faktorov (mimo škodlivých činiteľov) ovplyvňujúcich prirodzené olistenie drevín.

Pre zhodnotenie dlhodobej retencie ihlíc na boroviciach možno aplikovať metódu stôp po ihličí – NTM (Needle Trace Method), ktorú vyvinuli fínski odborníci začiatkom deväťdesiatych rokov (Kurkela, Jalkanen 1990). Metóda sa zakladá na zisťovaní počtu stôp, ktoré vytvárajú kanáliky spájajúce dreňovú časť kmeňa (alebo vetvy) a ihlice. Kanálik za vyvíja len dovtedy, kým sú na ňom pripojené ihlice. Ako náhle ihlice odpadnú, jeho rast sa zastavuje. Takže vek, ktorého sa dožila ihlica, možno zistiť podľa počtu letokruhov obsahujúcich tento kanálik (na pozdĺžnom reze kmeňa ide o stopy v podobe bodiek). Metóda sa dá ľahko uplatniť pri boroviciach, pretože stopy po ihličí možno pozorovať voľným okom. Predmetom sledovania sú spravidla ihlice na kmeni úrovňových a nadúrovňových borovíc. Životnosť týchto ihlíc je v porovnaní s ihlicami na zatienených vetvách len minimálne ovplyvnená zníženou intenzitou osvetlenia. NTM minimalizuje subjektívnu chybu hodnotiteľa.

Počas vegetačného obdobia rokov 2000 a 2001 sa výskum zameral na lesné oblasti Záhorská nížina, Vtáčnik, Krupinská planina, Vysoké Tatry a Levočské vrchy. V každej lesnej oblasti sa vybral jeden porast s prevahou borovíc piateho vekového stupňa (41–50 rokov). V sledovaných porastoch sa spílilo sedem až osem úrovňových borovíc. Išlo o lesné porasty nachádzajúce sa v nadmorských výškach od 185 do 1 050 m n. m.

Na spílených boroviciach sa zisťoval počet „zelených" praslenov (teda tých, čo mali ešte živé ihlice). Bolo ich od 16 (plochy na Záhorskej nížine a Krupinskej planine) po 25 (Vtáčnik). Vizuálny odhad počtu ročníkov ihlíc na spílených boroviciach poukázal na veľké rozdiely medzi jednotlivými praslenmi. Počet ročníkov ihlíc rástol od prvého praslena až po praslen nachádzajúci sa zhruba v hornej tretine koruny. Potom klesal smerom k báze koruny. Na nezaclonených vetvách borovíc bola hodnota počtu ročníkov ihlíc veľmi blízka počtu ročníkov ihlíc na vrcholci. Takže možno konštatovať, že údaje o počte ročníkov ihlíc vo vrcholci (získané pomocou NTM) dobre odzrkadľujú aj počet ročníkov ihlíc na nezatienených vetvách.

Prostredníctvom NTM sa sledovala dlhodobá retencia ihlíc a hustota ich nasadenia na kmeni borovíc. Dlhodobé priemery hodnôt retencie ihlíc boli na jednotlivých výskumných plochách takéto: Záhorská nížina 2,68, Vtáčnik 2,85, Krupinská planina 2,62, Vysoké Tatry 3,20 a Levočské vrchy 3,02 ročníka ihlíc. Pre hustotu nasadenia ihlíc sa zistili takéto dlhodobé priemery: Záhorská nížina 6,41, Vtáčnik 6,49, Krupinská planina 6,43, Vysoké Tatry 6,61 a Levočské vrchy 6,43 párov ihlíc na bežný centimeter kmeňa.

Medziročné rozdiely hodnôt sledovaných indikátorov pravdepodobne spôsobili prevažne rôzne klimatické podmienky v jednotlivých rokoch. Z tohto dôvodu sa získali meteorologické údaje, konkrétne úhrny zrážok a priemerné teploty z meteorologických staníc nachádzajúcich sa čo najbližšie k výskumným plochám. Zistilo sa, že nárast alebo pokles počtu ročníkov ihlíc často súvisel s úhrnom zrážok z prvej polovici vegetačného obdobia v danom roku. Pravdaže medziročné oscilácie hodnôt počtu ročníkov ihlíc spôsobujú aj ďalšie činitele.

Dlhodobá tendencia retencie ihlíc indikuje zmeny rastových podmienok borovíc. Najvýraznejšia dlhodobá zmena (trvalý pokles) sa zaznamenala v lesnom poraste nachádzajúcom sa v Levočských vrchoch. Zníženie retencie ihlíc, a teda aj pravdepodobné zhoršovanie rastových podmienok, sa tu pozoruje od začiatku sedemdesiatych rokov, mierne zlepšenie nastáva v deväťdesiatych rokoch. Tento stav možno najpravdepodobnejšie dať do súvisu s imisnou situáciou a s jej negatívnymi následkami na lesné porasty. V prípade tohto porastu bol zaujímavý aj vývoj hustoty nasadenia ihlíc. Tu sa zaznamenala opačná tendencia, t.j. nárast hustoty nasadenia ihlíc (v ostatných sledovaných porastoch bola táto tendencia vyrovnaná). Takže možno konštatovať, že ak zhoršujúce rastové podmienky skracujú retenciu ihlíc, drevina na toto reaguje ich hustejším nasadením. Zaujímavý bol rast počtu ročníkov ihlíc v lesnom poraste na Záhorí v rokoch 1967–1975. Z vývoja by sa mohli odvodiť zlé rastové pomery v týchto borinách asi do veku 15 rokov (do ich strednej výšky okolo 4–5 m). Tieto zhoršené rastové podmienky pravdepodobne súviseli s bioklimatickými pomermi na viatych pieskoch. V letnom období tu dochádza k extrémnemu prehrievaniu pôdneho povrchu, ktoré môže výrazne ovplyvniť kondíciu koruny. Situácia sa zlepšuje po odrastení jedincov do už uvedenej výšky, kedy sú porasty dostatočne zapojené a vytvárajú si vlastnú mikroklímu.

Zistili sa určité rozdiely hodnôt dlhodobej retencie ihlíc na boroviciach medzi jednotlivými výskumnými plochami, čo súviselo hlavne s ich nadmorskou výškou. Preto sa odvodil lineárny model pre vyjadrenie vzťahu medzi nadmorskou výškou a počtom ročníkov ihlíc na boroviciach. Z lineárneho modelu možno pre podmienky Slovenska konštatovať, že rozdiel v počte ročníkov ihlíc medzi najnižším výskytom borovice (150 m n. m.) a jej najvyšším výskytom (1 400 m n. m.) bol 0,87. Takže tieto rozdiely neboli veľmi výrazné. Dosiahnuté výsledky sú v zhode s údajmi ALBREKTSONA (1988) a JALKANENA (1995), ktorí vo Švédsku, resp. Fínsku zistili nárast počtu ročníkov ihlíc z nižších do vyšších nadmorských výšok a od juhu na sever. JALKANEN (1986) dokázal, že počet ročníkov ihlíc súvisí s dĺžkou vegetačného obdobia (ročnou teplotnou sumou).

Ako sa už uviedlo, medziročná oscilácia retencie ihlíc indikuje často klimatické pomery, najmä zrážkovú bilanciu v danom roku. Avšak tieto medziročné zmeny môžu spôsobiť aj niektoré iné činitele, napr. rôzni škodcovia. KONÔPKA et al. (2000a) touto metódou retrospektívne identifikoval premnoženie listožravého hmyzu *Dendrolimus spectabilis* na borovici čiernej. JALKANEN et al. (1994) využil metódu na retrospektívne zistenie výskytu sypaviek na borovici sosne spôsobených hubou *Lophodermella sulcigena*. Postupný dlhodobý pokles retencie ihlíc zaznamenl JALKANEN (1996) v borovicových porastoch nachádzajúcich sa v blízkosti imisného zdroja. Takže metóda má dobré uplatnenie na retrospektívne zisťovanie rastových podmienok, resp. následkov pôsobenia abiotických a biotických škodlivých činiteľov na kondíciu borovíc. JALKANEN et al. (1998) ďalej zistili, že aj hustota nasadenia ihlíc môže indikovať rastové podmienky v jednotlivých rokoch. Táto sa výrazne zvýšila podľa uvedeného autora vo Fínsku počas rokov s výskytom klimatických extrémov.

Z dosiahnutých výsledkov možno urobiť tieto závery:

– optimálny (maximálny) počet ročníkov ihlíc sa vyskytuje približne v jednej tretine zelenej časti koruny (pri 40- až 50-ročných boroviciach asi na 7. praslene odhora). Tam by sa mala sústrediť pozornosť hodnotiteľa pri vizuálnom odhade kondície koruny borovice,
– počet ročníkov ihlíc vo vrcholci (na kmeni) má blízku hodnotu k počtu ročníkov ihlíc na vetvách v osvetlenej časti koruny. Takže výsledky dosiahnuté pomocou NTM pre kmeň dobre odzrkadľujú aj situáciu na vetvách,
– medziročné rozdiely v počte ročníkov ihlíc sú výrazné (až do jedného ročníka ihlíc). Zhoršené rastové podmienky spôsobujú pokles hodnoty tohto ukazovateľa. Opačná situácia je pri hustote nasadenia ihlíc, kde sa v dôsledku dlhodobo zhoršených rastových podmienok zistil postupný nárast jej hodnôt,
– s nadmorskou výškou rastie prirodzený počet ročníkov ihlíc, avšak tento nárast je pomerne malý (0,35 ročníka ihlíc na 500 výškových metrov).

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