Needle longevity as a criterion of response to a climatic fluctuation (so called heat wave) in Scots pine populations at early phases of ontogeny

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ABSTRACT: The paper presents results of an assessment of needle age classes in Scots pine partial populations in the period of three and five years after outplanting in a lowland site in relation to conditions created by climatic elements. The method is based on Skuhravý's (1987) description when the state of needle age classes of the third whorl (from the apex) is evaluated just once. Five-year summary of meteorological data was assessed according to the criteria of determination of periods of heat waves and dry spells. Differences in numbers of living needle age classes in the groups of Scots pine populations in the period of three and five years after their outplanting in permanent lowland sites proved the highest total number of living needle classes in the group of local lowland populations. On the contrary, the lowest total number of living needle classes was found out in the group of mountain populations. Critical climatic periods are overlaps of heat waves and dry spells that illustrate the complexity of moisture and temperature conditions of lowland sites. Although the Scots pine is a xerophytic species, it responded to the cumulation of adverse factors by accelerated needle senescence. Its physiological response to heat and dry stress consists in needle shedding, i.e. reduction in the assimilating area. As mountain populations are not usually exposed to heat waves, the impact of this phenomenon on them was the highest. On the other hand, the local (lowland) populations carrying information on the patterns of local climate from the reproduction period do not undergo any marked reduction in needle age classes.

Keywords: Scots pine (*Pinus sylvestris*); number of needle age classes; needle retention; climatic episode of heat wave

The duration of foliage life, i.e. the time from needle flushing to needle shedding and/or the number of living needle age classes on macroblasts, is not long in Scots pine. Needle shedding as a result of natural senescence begins in the third to the fifth annual increment according to the area of growth and site (Hartmann et al. 2001). The capacity of trees to retain living (functional) needles for several vegetation periods is designated by the term "needle retention" in forestry literature (Jalkanen et al. 2000). The authors reported an increase in living needle age classes with the height above sea level (Ewers, Schmid 1981) and from south to north (Albrektson 1988). The longevity and age structure of needle biomass reflect the plant strategy of stress-tolerant strategists that have adapted themselves to environmental conditions (Lamppu, Huttunen 2001). The authors stated that the genetic regulation of the beginning of needle senescence was influenced by geographical latitude, height above sea level, light, temperature, moisture and nutrient conditions, and further by pathogens, environmental changes and negative impact of air-pollution stress.

The climatic elements of a permanent site, mainly climatic fluctuations, influence the physiological state of forest stands, and also the number of living needle age classes. An example of climatic fluctuations is a phenomenon called heat wave. The heat wave is defined in scholarly literature as a continu-

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ous period with above-average and maximal air temperatures (Kyselý 2002, 2003; Meehl, Tebaldi 2004; Cebrian et al. 2005; Frank et al. 2005). In Central Europe heat waves are conditioned by the advection of tropical air into the interior of the land or by the intensive radiation warming of polar air staying above the overheated land in the area of anticyclones (Sobíšek 1993). In the CR heat waves occur most frequently in the warmest lowland areas of Southern Moravia, Polabí and Poohří, and their incidence in areas at an altitude above 600 m is scarce (Kyselý 2006).

Periods when the growing season precipitation amount (from April to September) is lower than 340 mm are considered by Penka (1986) as dry spells. He highlighted the soil water deficit at the end of spring and at the beginning of summer (the period of fast growth of plants) when the competition of plant organs for water starts and water content in the plant body remains a substantial source of water. For site classification mainly in the agriculture sector and also in the forest sector, Lang's rainfall factor (LRF) is used which is defined as the ratio of precipitation amount (mm) to average temperature (°C) of the evaluated period (Kupka 2006). The aim of the present study was to determine and to assess needle senescence of partial Scots pine populations in relation to climatic conditions of a lowland site.

MATERIALS AND METHODS

Experimental outplantings of six Scots pine populations were carried out in a clear-cutting Scots pine area situated north of the Týniště nad Orlicí locality (GPS: 50°11'29.691"N, 16°2'54.643"E). The stand is located on Pleistocene gravel-sand terraces along the Divoká Orlice River at an altitude of 260 m a.s.l.; the original stand composition was nutrient-poor pine-oak forest. Climatic conditions are mildly warm and dry (average annual precipitation: 624 mm, average air temperature: 8.1°C). We established experimental plantations of Scots

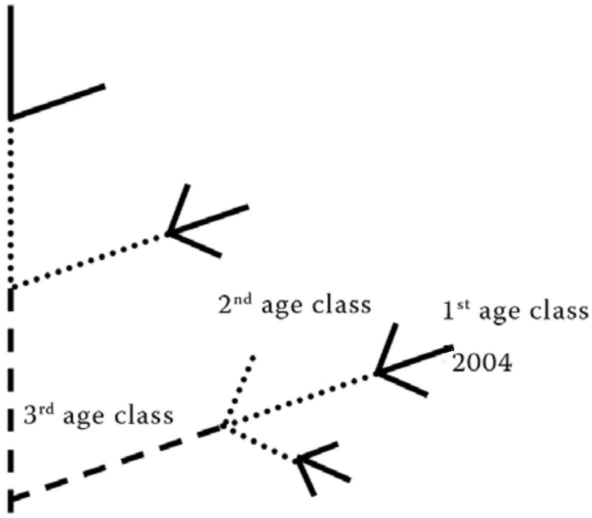

Fig. 1. Scheme of evaluation

pine populations originating from various parts of the Czech Republic. Studies were conducted on an experimental plot in the Týniště nad Orlicí locality in plantations of Scots pine of various provenances of the CR. The studied Scots pine populations came from a lowland area (Opočno – Op, Vysoké Chvojno – VCH), upland area (Křivoklát – K, Zbiroh – Zb) and mountain area (Prachatice – Pr, Nové Hrady – NH). Single measurements were done in 2004 and 2006 (three and five years after outplanting) in the autumn season, after shedding of dead needles or shedding of needles damaged by biotic or abiotic factors. Living needle age classes comprised only healthy green needles without symptoms of damage or dieback. The method was based on Skuhravý's (1987) description, and the state of needle age classes of the third whorl (from the apex) was evaluated (Fig. 1).

Measurements were done on 180 trees of each population. On four branches of each tree the values for the 1st, 2nd and 3rd needle age class were determined. Needles of a macroblast growing in the year of evaluation – so called one-year needles (growing in 2004 and/or 2006) were designated as the 1st age class. The 2nd age class was represented

Fig. 2. Macroblasts with one, two and three needle age classes (*Pinus sylvestris* [L.], Týniště nad Orlicí, 2006)

by needles occurring in a macroblast formed in the previous year – i.e. two-year needles (growing since 2003 and/or 2005). Needles growing in a macroblast formed two years ago – i.e. three-year needles (growing since 2002 and/or 2004) were designated as the 3rd age class of needles. Fig. 2 shows the photo of macroblasts with one, two and three age classes of needles. The needle foliage of a macroblast of the given age class was expressed by values in the numerical interval from (1) to zero (0). The value 1.00 expresses the coverage of the whole macroblast with green needles (no shedding of dead needles is observed). The value 0.00 describes the shedding of all macroblast needles. The percentage proportion of living (green) needles in a macroblast is expressed in hundredths of the value, e.g. for 50% of sound needles the value of living needle age classes is 0.50.

Data were processed to determine the representation of partial living needle age classes (the value in the range of 0–1) and the total number of living needle age classes (the sum of the values of the 1st to 3rd age classes, the value in the range of 0–3) for particular populations, for groups of populations and in total for Scots pine as a species. QC Expert programme, the module of sampling comparison, was used for identity determination. Thirteen thousand input data were processed for the particular annual evaluations.

The evaluation of data on the course of daily temperatures and precipitation amounts in the Týniště nad Orlicí area (small meteorological registration station operated by Opočno Research Station at a distance of 1 km from the plot under study) was aimed at finding the conditions that satisfy the criteria of heat waves for the studied period (2002–2006):

– maximal daily air temperature (T_{MAX}) ≥ 30.0°C on three days at least,
– average T_{MAX} for the whole period ≥ 30.0°C,
– T_{MAX} on all days ≥ 25.0°C.

Heat waves were described by duration (number of days), temperature sum TS30 defined as the sum of T_{MAX} – 30.0°C for days with T_{MAX} ≥ 30.0°C, average T_{MAX} (average of maximal daily temperatures) and precipitation amount in the course of their duration.

Precipitation amounts in the months of April to September were evaluated according to Penka (1986) to determine dry spells. The years in which

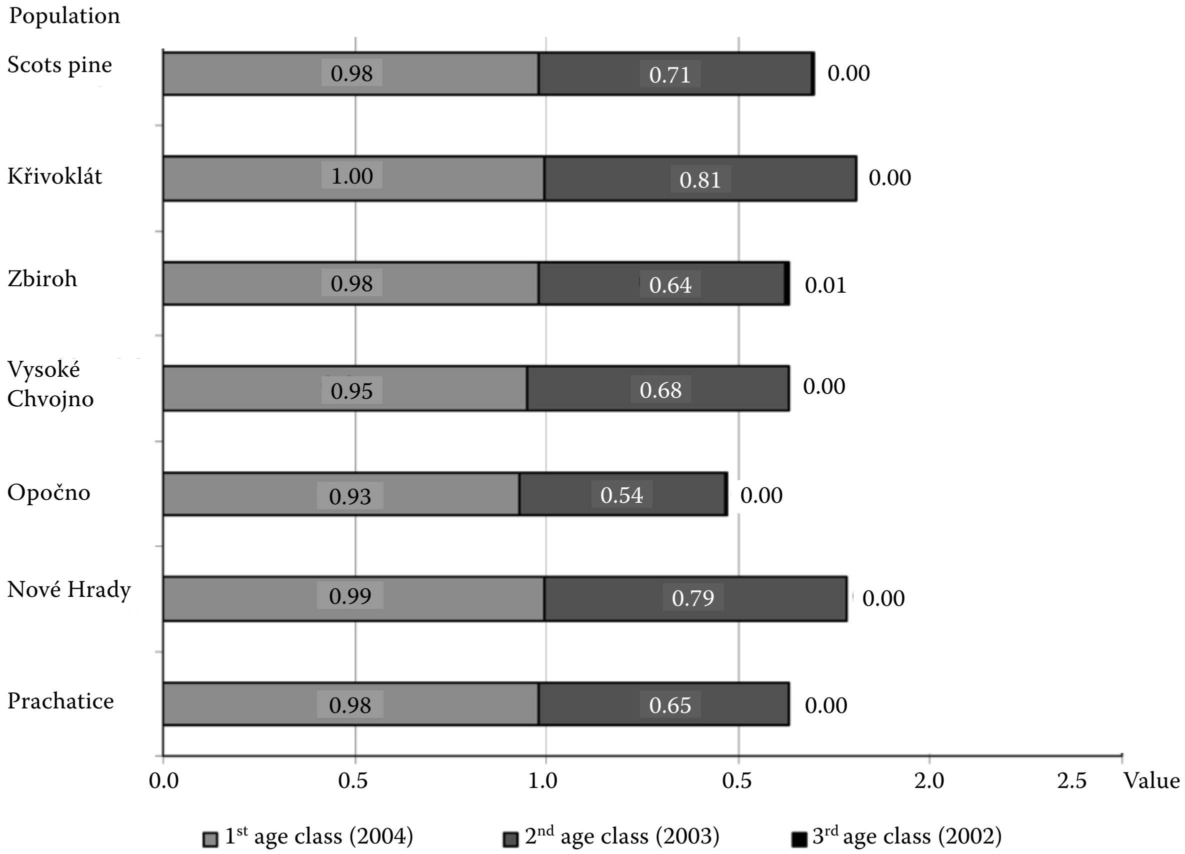

Fig. 3. Graphical representation of the value of partial living needle age classes in populations and in Scots pine as a species in the year of evaluation 2004 (three years after outplanting) (*Pinus sylvestris* [L.], Týniště nad Orlicí, 2004)

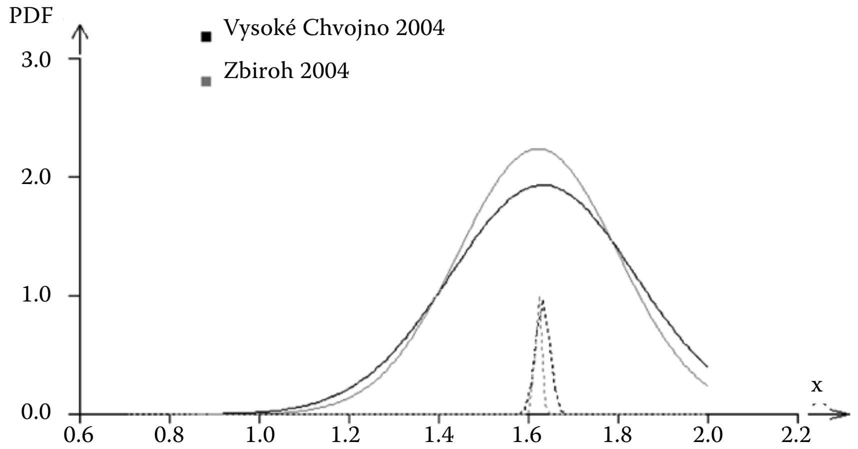

Fig. 4. Gaussian curve of normal distribution density (*Pinus sylvestris* [L.], Týniště nad Orlicí, 2004)

x-axis – value of the member of age class
y-axis – frequency of the value

precipitation amounts of the growing season did not reach 340 mm were identified. Dry months with precipitation amounts lower than 40 mm, or with the ratio of monthly precipitation amount to average monthly temperature (P/T_{month}) lower than 3, were identified for vegetation periods. The LRF of growing seasons was assessed. According to classification based on the LRF value (Anonymous 2007), the origin of the studied Scots pine populations corresponds with a very dry area (Vysoké Chvojno, Opočno, Křivoklát), dry area (Zbiroh) and very humid area (Prachatice, Nové Hrady).

RESULTS

In 2004 (Fig. 3) the total number of living needle age classes of Scots pine as a species reached the

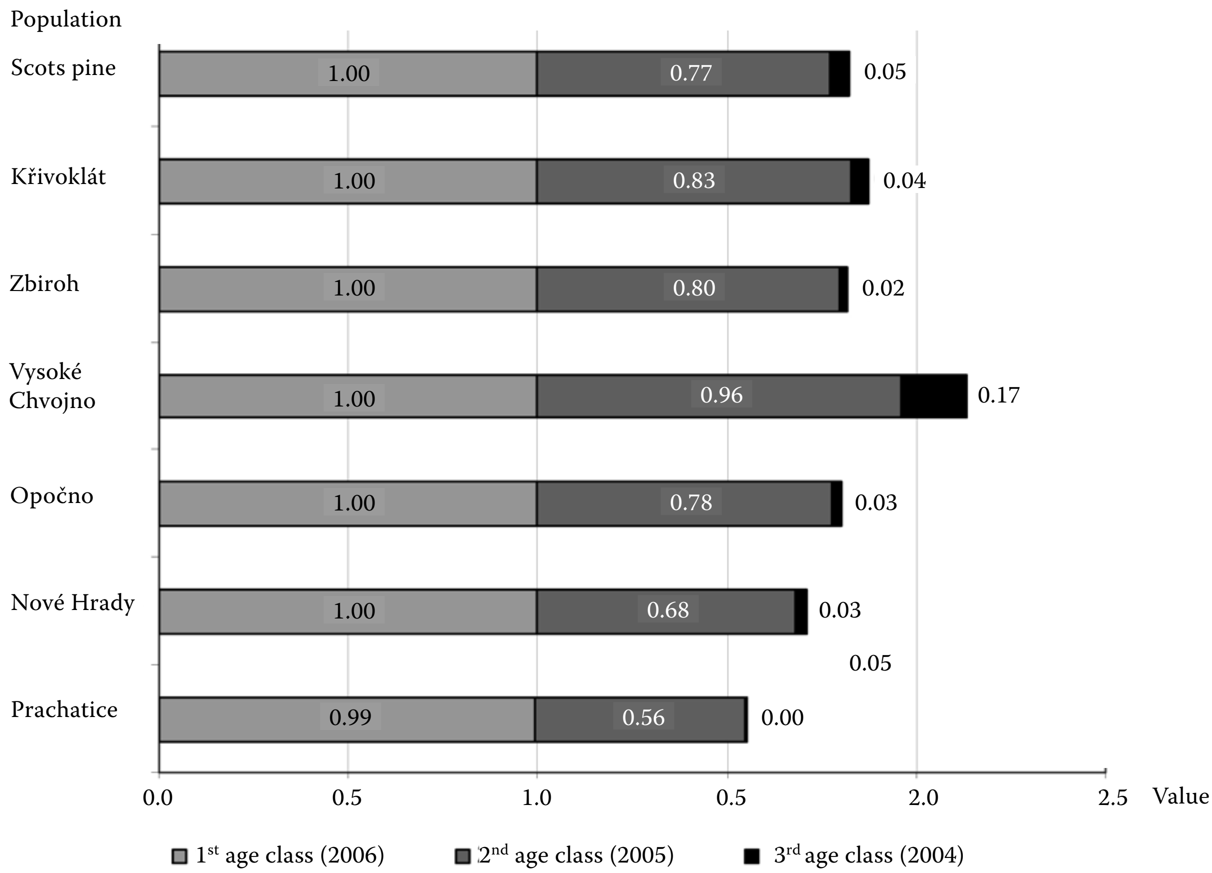

Fig. 5. Graphical representation of the value of partial living needle age classes in populations and in Scots pine as a species in the year of evaluation 2006 (five years after outplanting) (*Pinus sylvestris* [L.], Týniště nad Orlicí, 2006)

average value 1.70. In needles of the 1st age class, 2% shedding of needles was observed (the value 0.98), the 2nd needle age class had 71% of green needles on the macroblast of the previous year (0.71). The 3rd age class had only the residual amount of needles (0.004). The highest number of living needle age classes (1.8) was determined in Nové Hrady and Křivoklát populations. Statistical comparison of samplings showed identical means of the values of the number of living needle age classes in Vysoké Chvojno, Prachatice and Zbiroh populations (1.70). Fig. 4 is a graphical representation of the Gaussian curve of normal distribution density corresponding to the mean and variance of samplings of Vysoké Chvojno and Zbiroh populations. The curves of both samplings are almost concurrent, and the means of the number of age classes are identical with the 95% probability.

In 2006 the number of living needle age classes in Scots pine as a species reached the value 1.82 (1st age class: 1; 2nd age class: 0.77; 3rd age class: 0.05) (Fig. 5). The highest number of living needle age classes was recorded in Vysoké Chvojno population (2.13), while the lowest was observed in Prachatice population (1.55). Statistical identity of the total number of needle age classes was determined for Opočno and Zbiroh populations. Statistical comparison of the group of progenies of populations of lowland, upland and mountain type showed significant differences in the number of living needle age classes among the groups of populations of the species concerned. The significantly highest value of the number of living needle age classes (1.97) was determined in the group of lowland populations, a lower value was found out for the group of upland populations and the lowest value (1.63) was computed for mountain populations.

A comparison of the studied years 2004 and 2006 indicates statistical significance of the differences in the total number of living needle age classes among populations. In progenies of both mountain populations this number was statistically significantly reduced, while in progenies of the other populations there was a statistically significant increase in the number of living needle age classes in 2006 compared to 2004. The highest increase in the number of living needle age classes was recorded in Opočno and Vysoké Chvojno populations: the number of needle age classes increased to 123% and 131% in 2006 and 2004, respectively. In total for Scots pine, there was a 7% increase in the number of living needle age classes in 2006.

Based on the partial processing of temperature and precipitation data from the meteorological station in Týniště nad Orlicí in 2002–2006 the periods of extremely warm summer weather, so called heat waves, were identified. They are shown in Table 1.

The evaluation of the climate showed two heat waves in 2002, in the months of June and July. The heat wave in mid-June lasted for nine days, while rainfall was recorded both at the beginning and at the end of the period and the value TS30 reached 15.3°C. In the four-day heat wave at the end of July it was raining on the last day. In 2003 there were two heat waves again, in June and August. Only negligible rainfall was recorded in both periods, precipitation amounts being maximally 1.2 mm. The August heat wave in 2003 was the longest (19 days) in the studied five-year period, it had the highest value TS30 (35.8°C) and the average T_{MAX} was above 31°C. There was no heat wave in 2004. In 2005 the heat wave at the end of May lasted for 5 days and it was raining (10.6 mm) on the last day. In 2006 the heat wave was defined at the end of July, lasting for 16 days, and rainfall was recorded at its end.

Precipitation amounts of the vegetation period less than 340 mm (dry periods) were recorded in two years of the period under study, in 2003 (327 mm) and 2004 (290 mm). Table 2 shows the months with rainfall not amounting to 40 mm. The long-term precipitation amount for the area of

Table 1. The frequency of heat waves as a characteristic of the Polabí climate (Týniště nad Orlicí, 2002–2006)

Period	Number of days	TS30 (°C)	Average T_{MAX} (°C)	Precipitation amount (mm)	Average precipitation/day (mm)
15. 6. – 23. 6. 2002	9	15.3	30.4	28.8	3.20
28. 7. – 31. 7. 2002	4	3.9	30.5	3.4	0.85
2. 6. – 13. 6. 2003	12	9.1	30.1	0.4	0.03
31. 7. – 18. 8. 2003	19	35.8	31.1	1.2	0.06
26. 5. – 30. 5. 2005	5	7.1	30.3	10.6	2.12
17. 7. – 1. 8. 2006	16	25.6	30.8	15.0	0.93

Table 2. An overview of dry months (with rainfall < 40 mm) (Týniště nad Orlicí, 2002–2006)

Year	Dry month	Rainfall amount (mm)
2002	April	40
2003	April	26
	June	21
	September	35
2004	April	28
	September	38
2005	April	32
	June	34
2006	July	22
	September	7

Table 3. An overview of the months of vegetation periods with P/T_{month} < 3 (Týniště nad Orlicí, 2002–2006)

Year	Month	P/T_{month}
2002	June	2.5
2003	June	1.0
	August	2.9
	September	2.4
2004	September	2.9
2005	June	2.0
	September	2.9
2006	July	1.0
	September	0.4

Týniště nad Orlicí in April is 32 mm. The P/T_{month} ratio in the area of Týniště nad Orlicí in the vegetation period reaches the long-term average values 4–5. Table 3 documents the months of the vegetation period with the P/T_{month} ratio < 3.

DISCUSSION AND CONCLUSION

The number of living needle age classes is a very sensitive physiological, ecological and environmental indicator of the tree species health status. Its sudden decrease may be caused by various factors, e.g. damage by insects (Knížek, Kapitola 2001; Kapitola et al. 2006), fungal diseases (Šrůtka 1998), moisture deficit, climatic extremes, air pollutants (Konôpka et al. 1997) or by a combination of all these factors. The infection with the most significant disease of Scots pine in forest nurseries, i.e. with the pine needle-cast fungus *Lophodermium pinastri* (Shars.) Chev. (Jančařík 1988), also displays its symptoms after outplanting at permanent sites (especially in the first year) and in outbreak periods the damage may persist for the first decennium. In the Polabí lowland area the pine needle-cast fungus is a standard cause of needle shedding in Scots pine after outplanting (unpublished outputs of the advisory activity of Opočno Research Station), and it also participated in needle losses in the present experimental investigation. We could explain needle shedding and a decrease in the number of needle age classes in investigations carried out three years after outplanting by a partial share of the pine needle-cast fungus *Lophodermium pinastri* (Shars.) Chev.

Heat waves are dangerous climatic phenomena. A decrease in precipitation activity along with drought spells or heat waves brings about a great stress to forest ecosystems. Heat waves in May, after the outplanting of planting stock, are reflected in unsuccessful reforestation when losses exceed up to 50% (Anonymous 1997). Heat waves in June, July and August contribute first of all to smaller increments of tree species and are connected with the pest spread (Zahradník, Kapitola 2004; Anonymous 2004). After the outplanting of the studied forest stand the influence of heat waves was most significant in 2003, when their longest duration was recorded, along with maximal temperature sum, highest average maximal temperature and minimal precipitation amounts. Pavlík et al. (2003) accentuated the extraordinary summer of 2003 with respect to the duration of above-average temperatures combined with rainfall deficit. Zahradník and Kapitola (2004) also described the year 2003 as a mostly dry year with adverse impacts on the forest health status. Data in scholarly literature document the exceptionally warm period in the second half of the year 2006 (Němec 2007). The extreme climatic episode of the 2003 heat wave can be considered as a partial factor of the recorded decrease in the number of needle age classes in investigations conducted in the subsequent year 2004, i.e. three years after outplanting.

The number of functional needle age classes is a variable characteristic within the Scots pine range. Heinsdorf et al. (1993) found out three needle age classes in a five-year plantation in Austria while the third age class was heavily reduced. Muukkonen (2005) reported (for Finland) practically zero mortality of needles in the first two years when up to

15% of needles persisted up to six years and the average needle age was between 2.6 and 3.4 years. In a model study of the percentage proportions of needle age classes published by the Nordic authors we can deduce almost 100% proportion of the first and second needle age class, ca. 83% proportion of the third age class, 15% proportion of the 4th age class and ca. 5% proportion of the 5th and 6th needle age class. In Estonia the highest recorded age of pine needles was 6 years (non-fructiferous trees) and 4 ears (fructiferous years) (Pensa, Jalkanen 2005).

The determination of differences in the number of living needle age classes among the groups of Scots pine populations within five years after outplanting in a permanent site in Týniště nad Orlicí showed that the group of Opočno and Vysoké Chvojno local lowland populations had the highest total number of living needle age classes (1.97) in 2006. No shedding was observed in the 1st needle age class, green needles of the 2nd age class amounted to 87% of the original number and green needles of the 3rd year to 10% of the original number. The absolutely highest value of the total number of living needle age classes (2.13) was recorded in Vysoké Chvojno local population, which had the highest proportion of healthy green needles of the 3rd year (the value 0.17). On the contrary, the lowest total number of living needle age classes (1.63) was observed in this site in the group of populations of mountain type. Mountain populations had the lowest values of green needles of the 2nd age class (Prachatice population 56%, Nové Hrady population 75% of healthy needles) while the 3rd age class was not represented in Prachatice population at all and its proportion in Nové Hrady populations was only 3%. The values of upland populations are between those of the above-mentioned groups. The observed numbers of living needle age classes in 2006 were comparable with the results published by Skuhravý (1987, 1990), who determined 1.9 needle age classes for the environs of Týniště nad Orlicí in Scots pine stands 7–15 years after outplanting.

The concurrence of heat waves and dry periods (dry vegetation periods, dry months and also months with P/T ratio < 3) seems to contribute to critical climatic periods, illustrating the complexity of moisture and temperature conditions in the permanent site Týniště nad Orlicí. The evaluation of the concurrent incidence of heat waves and precipitation deficits demonstrated that not only the year 2003 but also the years 2002 and 2006 were the critical ones. Although the Scots pine is a xerophytic species, it responded to the cumulation of adverse factors by accelerated needle senescence. Its physiological adaptation to the stress caused by elevated temperatures and drought consisted in needle shedding and a reduction in the assimilating area. As mountain populations are not usually exposed to heat waves (Kyselý 2006), the impact of this phenomenon on them is expected to be the highest. The results of the present study (Týniště nad Orlicí area) document the lowest values of the number of living needle age classes in mountain populations. On the other hand, the local (lowland) populations carrying information on the patterns of local climate from the reproduction period (Bruns, Owens 2000) do not undergo any marked reduction in needle age classes. Therefore their performance is assumed to be higher in a subsequent period. Presented results of needle longevity assessment in Scots pine populations confirm the legitimacy of legislative restrictions in relation to the transfer of forest species reproductive material within forest vegetation zones, i.e. climatic ecotypes.

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