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Short research contribution

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LIFE SPAN OF NEEDLES OF *PINUS MUGO* TURRA: EFFECT OF ALTITUDE AND SPECIES ORIGIN

ABSTRACT: The needle life span of evergreen coniferous trees is a species-specific trait but can be also affected and modified by environmental conditions. On the basis of field observations of needle life span during three periods in two populations of *Pinus mugo* in the Tatra Mts (altitude: 1600–1700 m) and Sudety Mts (altitude 830–1420 m), 11 populations from various altitudes we concluded that: 1) within the same population needle life span remained the same over the three periods of observations, 2) needle life span in the Tatra Mts is about 1 year longer than in the Sudety Mts, ranging from 5.5 to 5.9 years and 3) needle life span in the Sudety Mts increases significantly with the altitude of the population. The longer life span of needles in the Tatra Mts may be specific for the population, i.e. it may be due to a different population origin (another Pleistocene centre of the species), and the shorter life span of needles noted in the Sudety Mts may be due to higher soil pollution in this region.

KEY WORDS: leaf life span, Sudety Mts, Tatra Mts, subalpine vegetation

Measures of plant characteristics are common tools for estimating their environmental and genetic variability (e.g. Li *et al.* 1998, Yuan and Chen 2009). In particular leaf life span, defined as the period between leaf emergence and leaf fall, is specific for particular species, but also strongly depends on ecological factors. Generally, species growing in extreme environmental conditions such as those near the upper forest line, are characterized by a longer leaf life span than those in milder climates (e.g. Hess *et al.* 1980, Moser *et al.* 2007). It is also known that individuals exposed to pollution lose their photosynthetic apparatus more rapidly (see Oleksyn 1998, Oleksyn *et al.* 1998, Modrzyński 1998, Werner 1998).

Among about 100 species of pine, a few have a needle life span longer than 3 to 4 years while others retain needles for 1 to 2 years (see Mirov 1967, Farjon 1984, Vidaković 1991). Only *P. aristata* Engelm. needles survive up to 12 to 17 (20) years (Farjon 1984, Vidaković 1991). *P. mugo* Turra, together with the closely related *P. uncinata* Ramond, are said to retain their needles for 5 or more years (Farjon 1984, Vidaković 1991), sometimes even to 10 years (Pawłowski 1956). These data come from direct field observations and have not been documented in a detailed study.

It has been reported that the longevity of needles of *Picea abies* (L.) Karst depends on the region and altitude (Burger 1927, Modrzyński 1998). The Norway spruce is found up to the tree line and down to the lowlands, and their needles persist for the longest time at the upper forest belt. *P. mugo* colonizes only the subalpine zone in the mountains of Central Europe, with much less variation in climatic conditions. For this reason one would expect needles to be retained for a similar period in different geographic regions. In addition, needle life span should not change in different periods of observation, but may vary depending on altitude.

The aim of this study was to estimate the longevity of needles of *P. mugo* – dwarf mountain pine – populations from the Tatra Mts and Sudety Mts during three different years (Table 1). The tested populations from the Carpathian and Sudetan parts of species geographic range are spatially isolated probably for a longer period than Holocene (Latałowa *et al.* 2005). This isolation caused genetic and morphological differentiation of *P. mugo* (e.g. Boratyńska *et al.* 2005).

The effect of altitude on the needle life span has been tested in 2008 by taking data from 2 different populations in the Tatra Mts (TATRA 1, TATRA 2) and 9 in the Sudety Mts (SUD 1). The Sudety Mountains are located close to large industrial centres in the Czech Republic, Germany and Poland and they are among the most threatened and damaged Polish area. The pollution (like acid rain) caused serious environmental damage in the Sudety Mts forest ecosystem (Boratyński *et al.* 1989, Grodzińska and Szarek-Łukaszewska 1997, Bochenek *et al.* 1997).

Pines, including *P. mugo*, are characterized by the ramification of sprouts from a set

Table 1. Localisation of the populations of *Pinus mugo* verified for longevity of needles; bolded populations verified during three periods.

Localities of populations (in brackets: local names)	Acronym	Geographic coordinates	Altitude (m)	Relief form	Years of observation	Number of individuals
Tatra Mts (ridge of Grześ – Wołowiec),	**TATRA-1-02** **TATRA-1-06** **TATRA-1-08**	N 49°14’05” E 19°46’00”	1600–1700	convex	2002 2006 2008	20
Tatra Mts (Sarnia Skała)	TATRA-2	N 49°15’53” E 19°56’21”	1300–1350	convex	2008	39
Sudety Mts (Karkonosze, Równia pod Śnieżką)	**SUD-1-02** **SUD-1-06** **SUD-1-08**	N 50°44’30” E 15°43’15”	1420	convex	2002 2006 2008	20
Sudety Mts (Karkonosze, Łomniczka)	SUD-2	N 50°44’43” E 15°43’59”	1200	concave	2008	20
Sudety Mts (Karkonosze, slopes above Mały Staw)	SUD-3	N 50°44’43” E 15°41’43”	1390	convex	2008	30
Sudety Mts (Karkonosze, below Mały Staw)	SUD-4	N 50°45’10” E 15°41’59”	1170	concave	2008	40
Sudety Mts (Karkonosze, above Pielgrzymy rocks)	SUD-5	N 50°46’03” E 15°41’00”	1220	convex	2008	20
Sudety Mts (Karkonosze, Łabski Szczyt, NE slopes)	SUD-6	N 50°46’54” E 15°33’03”	1280	convex	2008	30
Sudety Mts (Karkonosze, Szrenica, E slopes)	SUD-7	N 50°47’27” E 15°30’48”	1260	convex	2008	30
Sudety Mts (Izerskie Mts, Hala Izerska, above Jagnięcy Potok)	SUD-8	N 50°51’04” E 15°21’41”	830	flat	2008	28
Sudety Mts (Izerskie Mts, Hala Izerska, near Kobyla Łąka)	SUD-9	N 50°50’26” E 15°22’01”	825	flat	2008	42

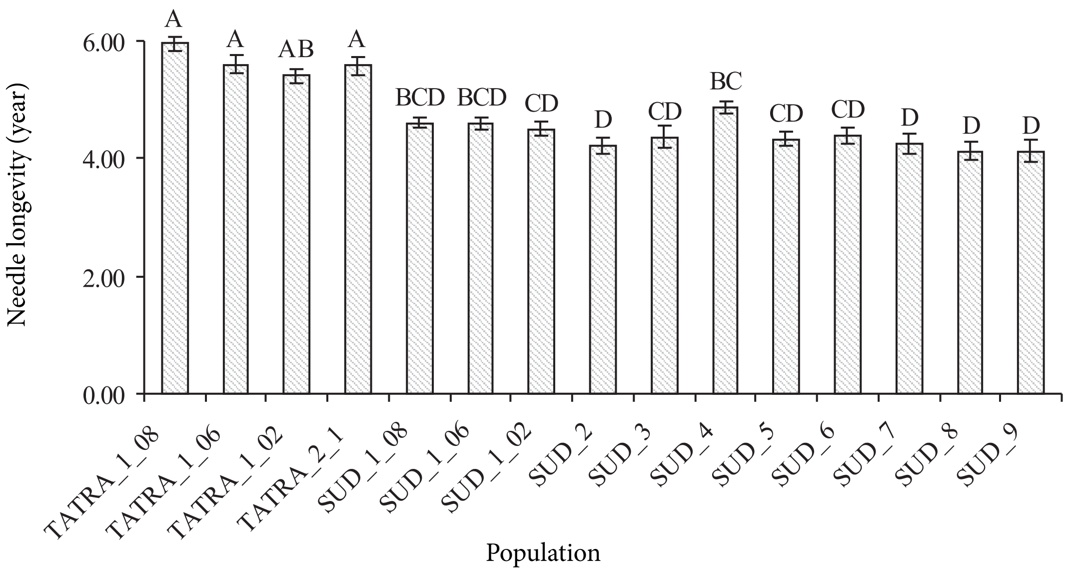

Fig. 1. Average needle longevity in populations of *Pinus mugo* (acronyms as in Table 1; various letters mean statistically significant differences between all populations at *P* = 0.05, Tukey-Kramer test).

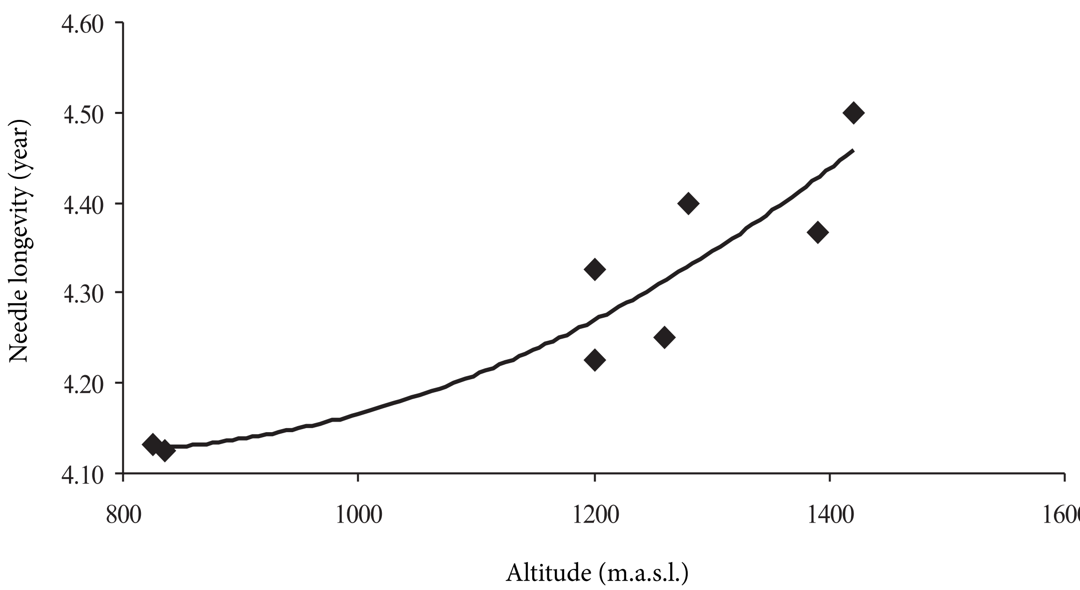

Fig. 2. Relationship between needle longevity of *Pinus mugo* and altitude in the Sudety Mts (acronyms as in Table 1; the localities with concave terrain are omitted), $R^2 = 0.84$ $P = 0.0103$.

of buds around the terminal bud. This enables the age of every yearly longitudinal increment of sprouts to be determined, and consequently, also the year of needle emergence. The life span of needles was determined in the field as the age (in years) of the oldest yearly increment of the sprout with a full set of needles. A further 0.5 was added in cases in which the next older yearly increment had about 50% of a full set of needles.

Observations were conducted in September 2002, 2006 and 2008, in two main centres of occurrence of *P. mugo* in Poland (Table 1) To verify the potential influence of the year of observation, the needle life span was determined for twenty individuals of each species in each three years in the Tatra Mts and Sudety Mts. Upright, terminal sprouts that were fully exposed to solar radiation, were tested, following a method of sampling used for morphological and genetic investigations (Boratyńska *et al.* 2005).

The Tukey-Kramer test was used to verify the statistical significance of the differences among populations, region of origin, year of observation and altitude. The dependence of average leaf longevity for a particular population on altitude was verified using regression and correlation tests (Sokal and Rohlf 2003).

The average leaf longevity in particular populations from the Tatra Mts and Sudety Mts differed significantly (Fig. 1). Generally, all populations of *P. mugo* in the Tatra Mts retained their leaves for an average of 5.4 to 5.9 years, which was about one year longer than those in the Sudety Mts. The needle longevity of *P. mugo* in the latter oscillated around 4.5 years, except for SUD-4, which had significantly higher needle longevity (Fig. 1). Samples SUD-8 and SUD-9 had the lowest average leaf longevity, which was significantly lower than that of sample SUD-4 (Fig. 1).

The differences in needle life span between populations from samples TATRA-1 and SUD-1 were similar over the three different years of observations. Every year the average longevity of needles in the Tatra Mts was about 1 year longer than in the Sudety Mts (Fig. 1) (Tukey-Kramer test, $P = 0.05$).

The correlation between altitude and needle life span was tested using the data from the Sudety Mts. The samples SUD-2 and SUD-4 were excluded from these analyses, as their relief form differed from the other samples (Table 1). Populations from higher altitudes had significantly higher average needle longevity (Fig. 2).

The life span of needles of *P. mugo* in the Tatra Mts has been reported to range between 5 to 10 years (Pawłowski 1956). The life span of the needles in our study varied between 4 and 7 years, with an average of 5.4, 5.6 and 5.96 years for 2002, 2006 and 2008, respectively. These values were similar during three years of observation and are similar to the lower value reported by Pawłowski (1956).

In the Sudety Mts leaf longevity was about 1 year shorter than in the Tatra Mts and varied between 3 and 6 years, with an average of 4.6, 4.6 and 4.5 years for 2002, 2006 and 2008, respectively. These values are similar to the lower of the previously reported range of 4 to 6 years (Skalická and Skalický 1988). This may indicate a longer needle life span in the latter mountains in the past. Our findings confirm the differences between the life span of needles of *P. mugo* in the Tatra Mts and Sudety Mts that were reported in the botanical literature (Pawłowski 1956, Skalická and Skalický 1988).

The longevity of *P. mugo* needles is closely correlated to altitude and is significantly prolonged at the highest locations, as described for *P. abies* (Burger 1927, Modrzyński 1998). The difference between the altitudes of the lowest and highest locality of *P. mugo* in the Sudety Mts was much less than between those of Norway spruce (Boratyński 1991, 1994). However, the dependence of needle life span on altitude was similar, especially where the relief was similar. *P. mugo* retains their needles for a longer period on concave than on convex relief forms (compare Table 1 and Fig. 1). This may reflect differences in exposure to winds and the higher temperature oscillations in the convex terrain, and also the inversion of temperatures in the valleys (Ermich 1962, Hess 1966, Hess *et al.* 1980).

Our study confirms the relationship between needle life span and altitude (e.g. Moser *et al.* 2007). The longer life span of leaves at higher altitudes results probably from the colder habitats (Hess *et al.* 1980). Populations of Scots pine and Norway spruce in northern Europe are characterized by longer needle life span and lower content of nitrogen in needles, in comparison with more southerly located populations in central and southern Europe (Reich *et al.* 1996, Oleksyn *et al.* 2003). This dependence is associated with the resource-conservation strategy for low nutrient supply that is observed at colder latitudes and altitudes (Reich *et al.* 2003). The lower content of nitrogen in plants from colder habitats is the consequence of the lower rate of litter decomposition in these habitats (Stump and Binkley 1993), especially during initial phase of that process (Melillo *et al.* 1989). In habitats with low nutrient availability, the selection of plant traits results in higher nutrient conservation, including longer leaf life span (Eckstein *et al.* 1999, Oleksyn *et al.* 2003).

In conclusion, the shorter life span of *P. mugo* needles in the Sudety Mts compared to the Tatra Mts may result from 1) the higher concentrations of pollutants in the soil due to high pollution in the past (e.g. Boratyński *et al.* 1989, Grodzińska and Szarek-Łukaszewska 1997, Bochenek *et al.* 1997, Werner 1998) or 2) genetic differences resulting of isolation for a long period during the Pleistocene (Latałowa *et al.* 2004, Boratyńska *et al.* 2005).

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REFERENCES

Bochenek Z., Ciołkosz A., Iracka M. 1997 – Deterioration of forests in the Sudety Mountains, Poland, detected on satellite images – Environmental Pollution, 98: 375–379.

Boratyńska K., Marcysiak K., Boratyński A. 2005 – *Pinus mugo* (Pinaceae) in the Abruzzi Mountains: high morphological variation in isolated population – Bot. J. Linn. Soc. 147: 309–316.

Boratyński A. 1991 – Chorologiczna analiza flory drzew i krzewów Sudetów Zachodnich. [Chorological analysis of woody flora of the Western Sudety Mts.] – Institute of Dendrology, Kórnik, 321 pp. (in Polish).

Boratyński A. 1994 – Chronione i godne ochrony drzewa i krzewy polskiej części Sudetów, Pogórza i Przedgórza Sudeckiego. 7. *Pinus mugo* Turra i *P. uliginosa* Neumann. [Protected and deserving protection trees and shrubs of the Polish Sudety Mts. with their prealps. 7. *Pinus mugo* Turra and *P. uliginosa* Neumann] – Arbor. Kornickie, 39: 64–85 (in Polish with English summary).

Boratyński A., Konca B., Zientarski J. 1989 – An instance of the most endangered forest association in the mountains of central Europe – Pirineos, 133: 3–32.

Burger H. 1927 – Die Lebensdauer der Fichtennadeln –Schweiz. Zeitschr. Forstwessen, 78: 372–375.

Eckstein R.L., Karlsson P.S., Weih M. 1999 – Leaf life span and nutrient resorption as determinants of plant nutrient conservation in temperate-arctic regions – New Phytol. 143: 177–189.

Ermich K. 1962 – Stosunki fitoklimatyczne na górnej granicy lasu i w piętrze kosodrzewiny w Tatrach. [Phytoclimatic conditions at the upper forest limit and in the mountain-pine zone in the Tatra Mountains] – Acta Agr. Silvestr. Ser. Leśna, 2: 117–161 (in Polish with English summary).

Farjon A. 1984 – Pines. E.J. Brill/Dr. W. Backhuys, Leiden, 220 pp.

Grodzinska K., Szarek-Łukaszewska G. 1997 – Evaluation of forest health – Regional perspective – Polish mountain forests: Past, present and future – Environmental Pollution, 98: 369–374.

Hess M. 1966 – O mezoklimacie wypukłych i wklęsłych form terenowych w Polsce południowej [About mesoclimate of the concave and convex relief forms in southern Poland] – Przegl. Geofiz. 11: 1 (in Polish).

Hess M., Niedźwiedź T., Obrębska-Starklowa B. 1980 – O prawidłowościach piętrowego zróżnicowania stosunków klimatycznych w Sudetach. [About regularities of differentiation of climate relations in the Sudety Mountains] – Roczn. Nauk Dydakt. WSP w Krakowie 71, Prace Geogr. 9: 167–201 (in Polish).

Latałowa M., Tobolski K., Nalepka D. 2005 – *Pinus* L. subgenus *Pinus* (subgen. *Diploxylon* (Koehne) Pilger) – Pine (In: Late glacial and holocene history of vegetation in Poland based on isopollen maps. Ed. M. Ralska-Jasiewiczowa) – W. Szafer Institute of Botany, Kraków, pp. 165–177.

Li B., Suzuki J.I., Hara T. 1998 – Latitudinal variation in plant size and relative growth rate in *Arabidopsis thaliana* – Oecologia, 115: 293–301.

Melillo J.M., Aber J.D., Linkins A.E., Ricca A., Fry B., Nadelhoffer K.J. 1989 – Carbon and nitrogen dynamics along the de-

cay continuum: plant litter to soil organic matter – Plant Soil, 115: 189–198.
Mirov N.T. 1967 – The genus *Pinus* – The Ronald Press Company, New York, 602 pp.
Modrzyński J. 1998 – Zarys ekologii świerka. [Outline of Norway spruce ecology]. (In: Biologia świerka pospolitego, Eds. A. Boratyński, W. Bugała) – Bogucki Wydawnictwo Naukowe, Poznań, pp. 303–359 (in Polish).
Moser G., Hertel D., Leuschner C. 2007 – Altitudinal Change in LAI and Stand Leaf Biomass in Tropical Montane Forests: a Transect Study in Ecuador and a Pan-Tropical Meta-Analysis – Ecosystems, 10: 924–935.
Oleksyn J. 1998 – Wymiana gazowa i gospodarka wodna [Gas exchange and water economy]. (In: Biologia świerka pospolitego [Biology of Norway spruce]. Eds. A. Boratyński, W. Bugała) – Bogucki Wydawnictwo Naukowe, Poznan, pp. 105–126 (in Polish).
Oleksyn J., Modrzyński J., Tjoelker M., Żytkowiak R., Reich P.B., Karolewski P. 1998 – Growth and physiology of *Picea abies* populations from a broad elevational gradients grown in a common garden: evidence for altitudinal ecotypes and adaptation to cold environment – Funct. Ecol. 12: 573–590.
Oleksyn J., Reich P.B., Żytkowiak R., Karolewski P., Tjoelker M.G. 2003 – Nutrient conservation increases with latitude of origin in European *Pinus sylvestris* populations – Oecologia, 136: 220–235.
Pawłowski B. 1956 – Flora Tatr, 1. Państwowe Wydawnictwo Nanukowe, Warszawa, 672 pp.
Reich P.B., Oleksyn J., Tjoelker M.G. 1996 – Needle respiration and nitrogen concentration in Scots pine populations from a broad latitudinal range: a common garden test with field-grown trees – Funct. Ecol. 10: 768–776.
Reich P.B., Wright I.J., Cavender-Bares J., Craine J.M., Oleksyn J., Westoby M., Walters M.B. 2003 – The evolution of plant functional variation: Traits, spectra, and strategies – Int. J. Plant. Sci. 164 (Suppl. S): 143–164.
Skalická A., Skalický V. 1988 – *Pinus* L. (In: Květena České Socialistické Republiky, 1, Eds. S. Hejny, B. Slavik) – Academia, Praha, pp. 289–308 (in Czech).
Sokal R.S., Rohlf F.F. 2003 – Biometry, 3rd edn. – W. H. Freeman, New York, 698 pp.
Stump L.M., Binkley D. 1993 – Relationships between litter quality and nitrogen availability in Rocky Mountain forests – Can. J. For. Res. 23: 492–502.
Vidaković M. 1991 – Conifers – Grafički Zavod Hrvatske, Zagreb, 755 pp.
Yuan Z.Y., Chen Y.H. 2009 – Global-scale patterns of nutrient resorption associated with latitude, temperature and precipitation – Global Ecol. Biogeogr.18: 11–18.
Werner A. 1998 – Wpływ skażonego środowiska na budowę anatomiczną [Influence of the polluted environment on the anatomical construction]. (In: Biologia świerka pospolitego [Biology of Norway spruce]. Eds. A. Boratyński, W. Bugała) – Bogucki Wydawnictwo Naukowe, Poznan, pp. 613–631 (in Polish).

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