# Frost cracks and their effect on the stability of birch stands in the Krušné hory Mts.

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**ABSTRACT**: Frost cracks which originated in birch due to bending during long-term icing in winter 1995/1996 became the place of entrance for the attack of birch stems by *Piptoporus betulinus* (Bull. ex Fr.) Karst. and subsequently for one of the causes of birch stand disintegration in the Krušné hory Mts. The hypothesis is substantiated on the basis of regularities of the frost crack dispersion in the stem profile, frequency of occurrence related to the stand age, altitude and cardinal points. The number of frost cracks increased with the transect profile altitude 700–850 m. One crack on the birch stem predominated (73%) while the higher number of frost cracks occurred at altitudes > 800 m. In stands younger than 20 years, frost crack damage was higher (34–47%) than in older stands (14%). Frost cracks occurred in the lower part of stems with the highest bending stress.

**Keywords**: *Betula pendula* Roth; frost cracks; icing; *Piptoporus betulinus* (Bull. ex Fr.) Karst.; Krušné hory Mts.

Birch as a highly tolerant species created together with blue spruce the basis of stands of substitute species in the eastern Krušné hory Mts. after 1980 (Kula 2006; Moravčík 1994). The birch stand disintegration at upland locations of the Krušné hory Mts. became evident after 1997 when birch did not come into bud. However, this physiological detriment was preceded by mechanical damage to stands by icing in winter 1995/1996 (Kula, Kawulok 1998; Kula et al. 1999). Causes of the birch stand dieback were dealt with by Šrámek (1998), Kula and Rybář (1998), Martinková et al. (2001), Mauer and Palátová (2003).

Frost cracks originate by freezing through a stem at a sudden change of a temperature in the form of longitudinal cracks in the lower part of the stem. Species with wide pith rays are affected (oak, poplar, elm, chestnut – Pfeffer 1961). Frost cracks are not frequent in nature. As for oak stands, Lamprecht (1950) mentions the increased frequency of frost cracks in 22% of trees on the northern and southern side. The cracks originating in consequence of drought and water stress are noted even in young spruce stands (20–40 years old) as radial cracks in sapwood. On the stem surface, only small grooves fringed by thin walls occur. High suction stress in sapwood leading water exceeds the resistance of a wood tissue formed from large thin-walled cells (Hartmann et al. 2001).

Unlike frost cracks which are orientated towards south or south-west cracks induced by drought occur along the whole stem girth not forming a marked frost crack. They are also substantially longer. On skeleton sites on slope tops, up to 100% trees tend to be damaged (Mrkva 2004; Riedl 2005). The cracks occur mainly on oak, hornbeam, lime and ash. In spite of the reasons of frost cracks in birch in the Krušné hory Mts. (Martinková et al. 2001; Mauer, Palátová 2003) we hypothesize that due to long-term icing and the load of trees bending of

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birch occurred particularly in young stands when frozen tissues were mechanically damaged and subsequently after release, trees straightened and frost cracks incurred became the place of entrance for wood-destroying fungi.

## MATERIAL AND METHODS

The control plots were chosen in the height transects of birch stands of Forest District Litvínov. The plots were differing in age, altitude and slope orientation. At least 100 trees on each plot were controlled. The study was concentrated on living trees being carried out in three levels:

- Basic study – specified the occurrence of frost cracks on stems (number, position in relation to cardinal points, sample tree dbh (diameter at breast height).
- Detailed study – moreover, the position of cracks was recorded in the tree profile, their length and width, creation of frost cracks, crown size.
- Special study – determination of the extent of rot on felled living trees after their cutting to sections.

To assess data obtained ANOVA statistics was used. The study was carried out in 28 sample plots including 2,904 trees of birch (*Betula pendula* Roth) 1,008 of them showing damage by frost cracks.

### Description of the area under study

Forest stands except of J1 and J2 (Forest District Litvínov, Forest Enterprise Janov) belong to Forests of the Town of Jirkov. The stands are situated at an altitude of 700–850 m; the areas occur partly on slopes of southern and northern orientation. In 1995, the stand age range was 7–24 years, 20 of 28 studied stands were established after 1980 following the large-area dieback of spruce stands, remaining stands come from the second half of the 70s of the 20th century. The area passing to a plateau of the Krušné hory Mts. is moderately cool. Mean annual temperature is 5°C depending on altitude. On plateaus, effects of inversions are evident and the highest temperature differences are at the beginning of winter (October–December). Mean annual total precipitation ranges from 430–920 mm, in the Fláje game preserve (Forest District Litvínov) up to 984 mm (Hošek et al. 1999).

Icing showed a high proportion in damages to forest stands of Forest Enterprise Janov. In the second half of the 70s, icing culminated in 1977 (14,930 $m^3$); in other years, losses exceeded 5,000 $m^3$. Also in the first half of the 80s, the height of damages remained in the same extent culminating in 1984 (9,333 $m^3$) and then gradually decreased. Increased negative impacts of icing on forest stands were evident as late as 1996 (3,260 $m^3$). Culmination values were not reached just because spruce stands of appropriate extent did not occur in the icing zone (Kula, Richterová 1999).

In the Krušné hory Mts., maximum icing damage occur on SE slopes at an altitude of 650–900 m (Singer 1916). Icing threatens particularly unprotected main and lateral ridges and steep windward slopes where it occurs at much lower locations. Negative impacts of icing are increased by their uneven deposition in tree crowns particularly on branches subject to air flow. Impacts of icing on spruce stands in 1995/1996 were described by Lomský et al. (1996), on birch stands by Kula and Kawulok (1998) and Kula (1998).

## RESULTS

The occurrence of frost cracks was assessed in birch stands on living trees at an altitudinal profile of 700–850 m regardless of aspect and stand age. Dif-

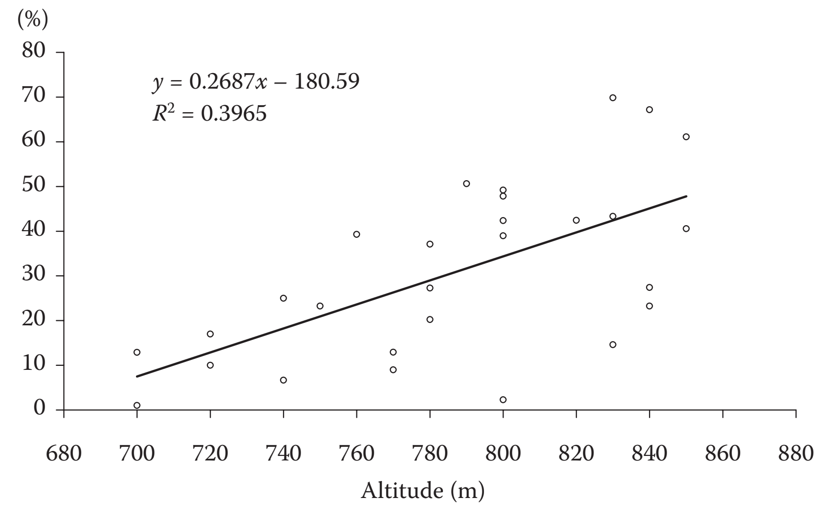


Fig. 1. The proportion of living trees with the occurrence of frost cracks according to altitude

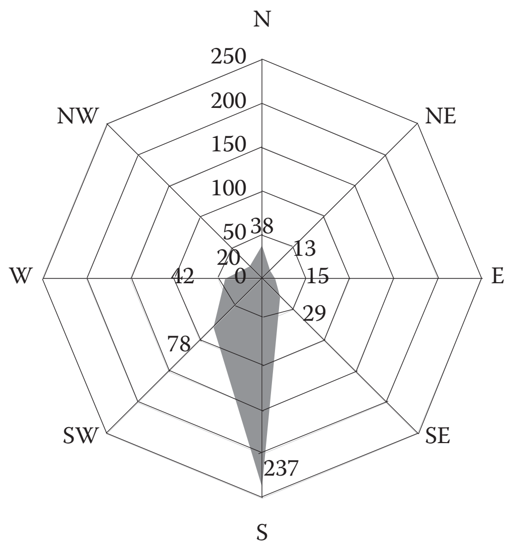


Fig. 2. The frequency of the occurrence of frost cracks according to their orientation on a stem

ferences between particular stands can be induced by the various degree of dieback in trees damaged by icing in 1995/1996 and failed budding in 1997. Nevertheless, it was possible to derive trends in the increase of the number of frost cracks with increasing altitude (Fig. 1). A transition between altitudes 700 and 750 m was particularly marked. Probability of the occurrence of frost cracks was there 17% while at altitudes 751–800 m and 801–850 m 40 and 43%, respectively. In affected trees (774), frost cracks occurred once (73%), twice (21%), three times (4.8%), four times (1.1%) and six times (0.1%). The frequency of two frost cracks per tree was higher at altitudes above 800 m, the frequency of four and more cracks occurred in trees at altitudes above 780–830 m.

The age of stands at the time of their load by icing (1995/1996) was an important attribute of the potential damage to stands in the form of bending, breakage and windfalls. There is a relationship between the proportion of frost cracks in young stands (up to 10 years 34.2%, 11–15 years 43.8%, 16–20 years 47% and 21–25 years only 14.2%) and a frequency of the number of frost cracks per tree changing also with age. Up to 20 years of the stand age, the occurrence of the only crack predominated (70–73%) and 94% proportion occurred in all older stands. At the occurrence of two cracks, stands younger than 20 years are on the level of 23–21% while in older stands we noted only 4.5%. A marked decrease with age was noted in the occurrence of three frost cracks (6.5–4.6–3.6–1.5%).

The area of frost cracks was expressed by an index which was a product of its length and width. If we ignore the position (720 m a.s.l.) markedly smaller cracks occurred in stands up to 800 m a.s.l. (average index values 67.8 or 81.4) than at higher locations (134.1). Even more marked differences were evident if the index referred to the frequency of the occurrence of cracks when in the lower part of the transect, the average area of damage was four times lower than above 800 m a.s.l.

The position of frost cracks predominated unambiguously on the southern side (S – 46.7%, SE + SW – 22.1%), northern positions were less important (N – 10.3%, NE + NW – 8%), E – 3.7%, W – 9% (Fig. 2). The frost crack centre occurred most frequently in the birch stem profile between 25 and 50 cm (25.2%). Cracks in a section above and below the position were in the same frequency (18%). A marked decrease in frost cracks occurred in higher parts of the stem profile (75–100 cm 14.3%, 100–125 cm 11.2% and in next three 25 cm long sections 7.5–4.7 – 0.8%). The whole position of the frost crack centre showed a decreasing trend with an increasing altitude (Fig. 3). The frost crack length does not exhibit a statistical dependence on altitude and age but short-

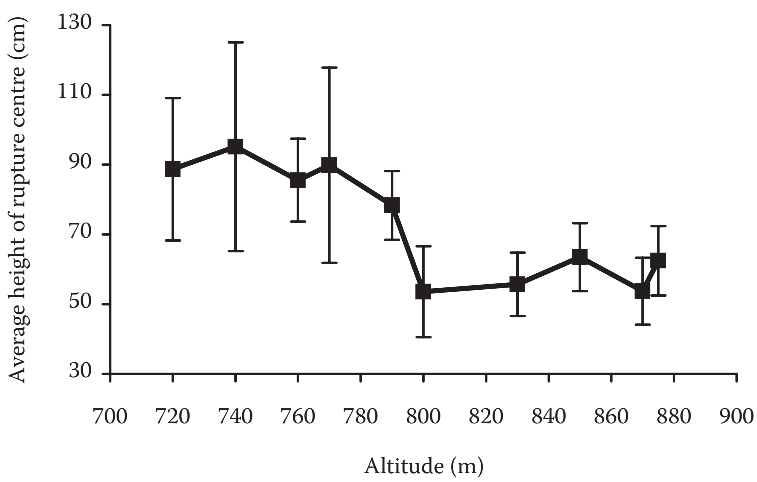


Fig. 3. The position of the frost crack centre on a stem in relation to altitude

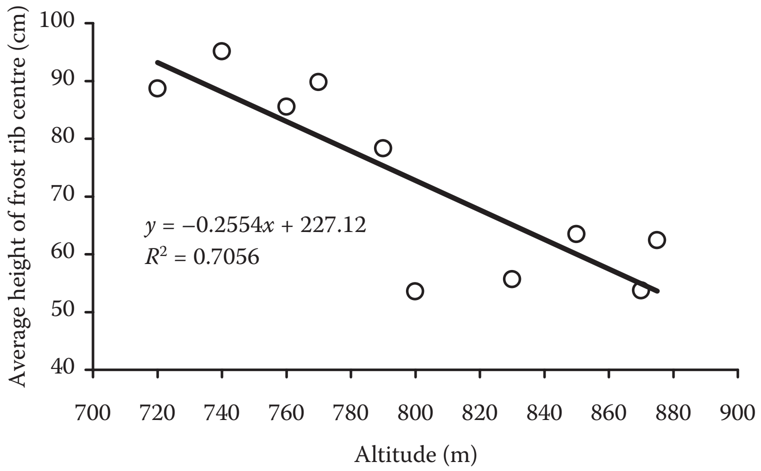


Fig. 4. The average position of frost cracks on a stem in relation to altitude

ens with the number of occurring cracks on a stem and on northern aspects.

In stands aged up to 10 years, frost cracks occurred most frequently at the stem foot 0–25 and 25–50 cm (21 and 20%); further in the profile, the proportion of frost cracks continually decreased. In stands aged 11–15 years, an area with the crack centre occurred at a position of 25–50 cm (27%) and stands aged 16–20 years can be characterized similarly (28.3%). In trees even with the course of 10 years short cracks predominated up to 10 cm (28%), 11–20 cm (25%) and 21–30 cm (24%). The position of the crack centre decreased with altitude (Fig. 4) and the crack length with age (Fig. 5). The frost crack width decreased only with the higher frequency of cracks on a sample tree. Effects of cardinal points on the crack width decreased from southern to northern locations (Fig. 6).

The occurrence of frost cracks is connected with rot caused by *Piptoporus betulinus* (Bull. ex Fr.) Karst.

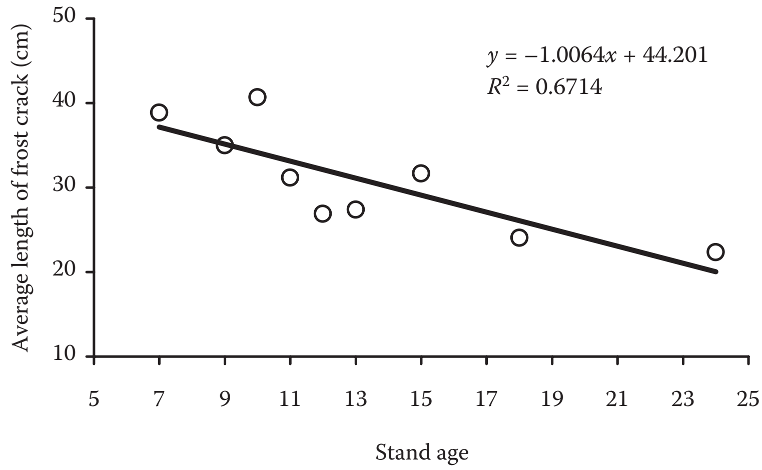


Fig. 5. The frost crack length in relation to the stand age

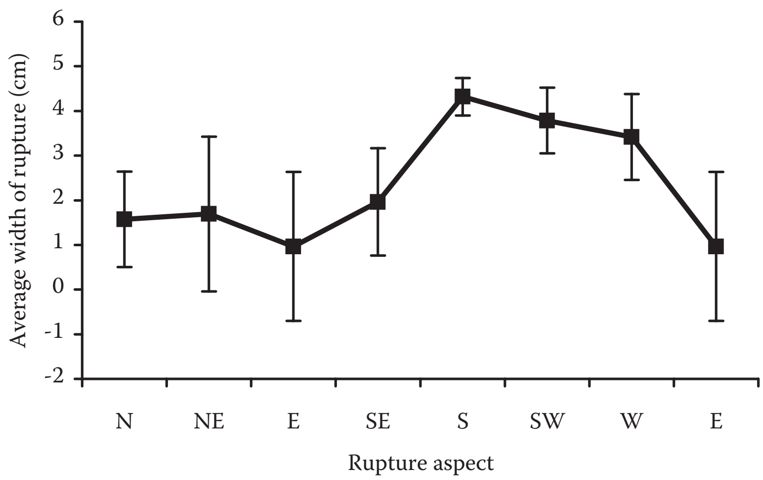


Fig. 6. The frost crack width according to the orientation on a stem

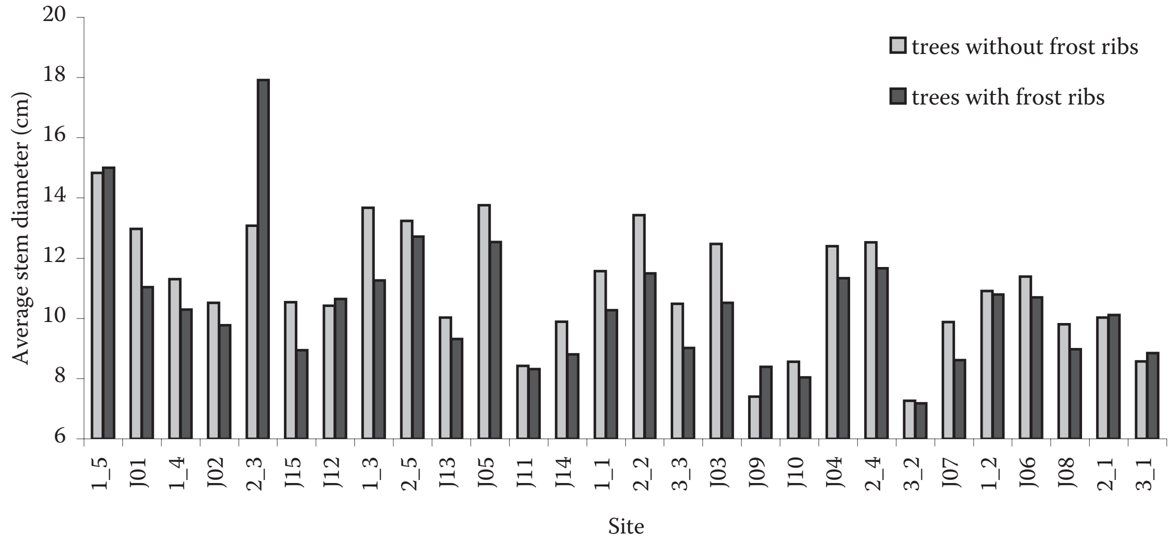


Fig. 7. The dependence of the living tree dbh on the occurrence of frost cracks

which passes through from the point of injury up to the crown level spreading rather quickly and affecting growth properties, dbh (breast-height diameter) of living and dead trees, living trees with frost cracks and without them decreased with altitude (Fig. 7) mean dbh of trees with frost cracks being lower (Fig. 8). It means that more than the actual position the occurrence of rot is important in attacked trees which effects not only growth properties but was also an important factor participating in the dieback of damaged stands and their disintegration. In this context, Mauer and Palátová (2003) draw attention to the presence of honey fungus [*Armillaria gallica* Marxmüller et Romagn, *A. ostoyae* (H. Romagnesi) Herink.] on the root system of birch with markedly decreased foliage.

## DISCUSSION

Frost cracks on birch in connection with the necrosis of tissues and decreased regeneration are mentioned by Martinková et al. (2001). To the primary water stress a secondary water stress was added (drought in crown, excessive water content in the stem base) as well as a tertiary stress as the consequence of reserve exhaustion for budding and formation of annual shoots. However, it refers to the description of the dieback of trees affected by failed budding in 1997 and not the description of causes of the origin of frost cracks. The primary stress was very probably caused by a specific pollutant disturbing dormancy. Stresses mentioned above are a side effect of the response of heavily weakened trees (Kula et al. 2000; Kula 1999).

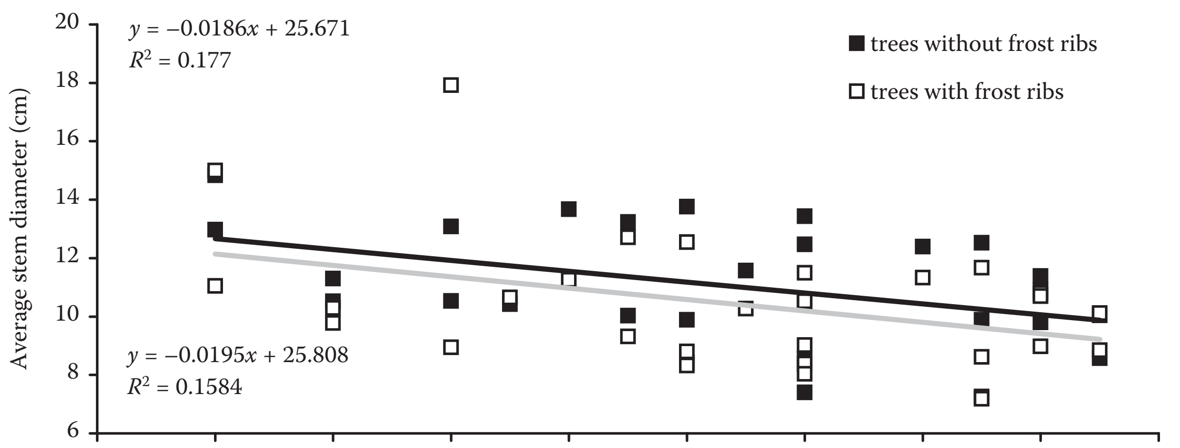


Fig. 8. Comparisons of the living sample tree dbh with a frost crack and without a frost crack in relation to altitude

Mauer and Palátová (2003) mention air pollution stress ($SO_2$) as a primary factor of the dieback of birch, however, at the same time, they also refer to the occurrence of frost cracks on stems with the subsequent enter of honey fungus to the root system of birch.

Icing caused extensive damage to spruce stands in the eastern Krušné hory Mts. in winter 1995/1996 (Lomský et al. 1996) and also markedly affected birch stands (Kula, Kawulok 1998; Kula 1998). Depending on stand age, altitude and stocking damage to birch by bending, stem and crown breakage was differentiated. The tree crown, shape, size and thus also the position of the centre of gravity (Zach, Kula 1999) have a decisive importance for the irreversible damage to a stem.

Extensive part of birch stands at the turn of the first and second age classes was bent by the mass of icing. After the receding of icing, particularly young stands of the higher degree of stocking returned to their original position and breakage damage was not important (Kula, Kawulok 1998). In 1995, there was the high proportion of young birch stands in the eastern Krušné hory Mts. at medium and higher locations where stem and crown breakage was not so frequent as at locations 550–650 m a.s.l. There, growth conditions were more favourable for birch and the species reached higher height and dbh with the lower plasticity for bending in the same age category (Kula 1998). In assessing the impact of icing on birch stands nobody dealt with frost cracks because they were not sufficiently striking and thus they escaped attention.

The age of stands in the studied region is not sufficiently differentiated because the majority of stands was established after 1979 and stands aged over 30 years, if affected by icing, did not exhibit frost cracks but damage due to stem and crown breakages. Extensive cracks at higher locations over 800 m can be related to the lower regeneration potential of birch affected by other forms of stress, e.g. failure of budding (Kula, Stoklasa 2002), higher site requirements (climatic, soil) and genetic lability due to the unsuitable transfer of seed. Trends in the increase of frost cracks with altitude can be related to the fact that stands situated at higher altitudes are characterized by lower height and dbh at the same age as stands at lower locations. Thus, they became more plastic and bent and returned to a great extent to their original position (Kula 1998; Kula, Kawulok 1998).

The origin of frost cracks is noted from the southern and northern side (Pfeffer 1961) unlike cracks induced by drought (Mrkva 2004). If the distribution of frost cracks agreed on all aspects in the dominant proportion on the southern side of stems regardless of other site factors (stocking) a phenomenon of the single-sided creation of icing cannot be excluded. The formation of icing was increased by an exceedingly long inversion situation accompanied by southeastern air flow and low temperatures. Such situation was observed in Forest District Děčín (formerly Sněžník) on the plateau of Tisá (600 m a.s.l.) in winter 1995/1996. Trees 3–6 m tall lay bent for a period of even 8 weeks because also a snow layer functioned simultaneously and crowns of the trees froze into the layer.

The start of icing in the eastern Krušné hory Mts. is dated 10. 11. 1995 with the permanent occurrence from 24, 11. 1995 to 23. 12. 1995 and from 31. 12. 1995 to 30. 1. 1996. For the whole period with continuous icing, temperature was below the freezing point. In the first stage, temperature oscillated between –1 and –12°C; in its end, the intense freezing out of tissues occurred and subsequently the second stage of icing followed (1. 1. 1996–30. 1. 1996) when temperatures decreased to –2 up to –14°C (Měděnec).

A hypothesis on freezing out the birch tissues, their mechanical damage during long-term bending and return to the original position after the end of icing and thawing out the tissues is based on findings mentioned above. The origin of frost cracks due to insolation and abrupt changes in temperatures could not occur because in 1996, temperatures persisted below the freezing point till mid-April and then they did not occur any more. Frost cracks are recorded in the same extent not only on southern slopes but also on slopes with northern orientation. After 1996, new frost cracks did not occur any more in localities under study.

Characteristics of frost cracks from the viewpoint of the length, width and position of the crack centre in the stem profile appear to be little dependent on aspect, altitude and age with respect to the relatively low amplitude and extent of altitudes as well as age classes. Concentration of cracks in the lower part of the tree stem corresponds to places most exposed to bending stress and with the lowest capacity to resist the bending load. The position and frequency of cracks agree with data given by Pfeffer (1961) on the occurrence of frost cracks. Although the length of cracks and cracks can reach even 2.5 m (Hartmann et al. 2001) cracks of shorter lengths predominated. Peeling off bark should be considered to be important as well. Although crack frosts are created in sapwood, the phloem part is also disturbed and the entrance of fungal pathogens cannot be excluded.

With the exception of MAUER and PALÁTOVÁ (2003) describing the occurrence of honey fungus on a root system nobody dealt with the health condition of birch according to the occurrence of *Piptoporus betulinus* mentioned in overmature birch stands. Under conditions of impaired and damaged birch stands in young age the fungus became an important factor accelerating the dieback of trees and disintegration of stands.

## CONCLUSION

A hypothesis has been proved that frost cracks originated on birch as a result of bending during long-term icing in winter 1995/1996 became the entrance point for the attack of birch stems by *Piptoporus betulinus* (Bull. ex Fr.) Karst. which was one of the causes of birch stand disintegration at higher locations of the Krušné hory Mts.

Climatic situations (inversions, SE air flow, low temperatures) made possible to form long-term icing and due to mechanical load bending occurred when tissues were damaged and frost cracks originated.

The number of frost cracks increased with the transect profile altitude 700–850 m the only crack on a stem predominating (73%). The higher frequency of frost cracks on a stem occurred at locations above 800 m a.s.l. A different response to the formation (size) of frost cracks can be linked with stress events (failure of budding) at higher locations and less favourable site conditions. In stands aged < 20 years, damage by frost cracks was higher (34–47%) than in older stands (14%). Frost cracks occurred in the lower part of stems where the highest bending stress occurs.

Frost cracks appear to be the entrance place for *Piptoporus betulinus* which rose in living trees up to the crown part of trees thus contributing to the dieback of trees and disintegration of stands.

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## Mrazové trhliny a jejich vliv na stabilitu březových porostů v Krušných horách

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**ABSTRAKT**: Hypotéza – mrazové trhliny vznikly na bříze v důsledku ohnutí stromu při dlouhodobé námraze v zimě 1995/1996. Poškozené břízy byly následně napadeny březovníkem obecným (*Piptoporus betulinus* (Bull. ex Fr.) Karst., který je jednou z příčin rozpadu porostů břízy ve vyšších polohách Krušných hor. Hypotéza je zdůvodněna na základě stanovené zákonitosti disperze mrazových trhlin v profilu kmene, četnosti výskytu v závislosti na věku porostu, na nadmořské výšce a světových stranách. Počet mrazových trhlin narůstal s nadmořskou výškou profilu transektu 700–850 m, přičemž převažovala jedna trhlina na kmen (73 %), vyšší frekvence kýl na kmeni byla v poloze nad 800 m n. m. V porostech do 20 let bylo vyšší poškození mrazovými trhlinami (34–47 %) než v porostech starších (14 %). Mrazové trhliny se nacházely ve spodní části kmene, kde bylo nejvyšší namáhání stromu v ohybu.

**Klíčová slova**: bříza *Betula pendula* Roth; mrazové trhliny; námraza; *Piptoporus betulinus* (Bull. ex Fr.) Karst.; Krušné hory

Rozpad porostů břízy v náhorních polohách Krušných hor se s vysokou intenzitou projevil po roce 1997, kdy bříza nevyrašila. Této rozsáhlé fyziologické újmě ale předcházelo mechanické poškození porostů námrazou v zimě 1995/1996 (Kula, Kawulok 1998; Kula et al. 1999).

Přes udávané příčiny vzniku mrazových kýl u břízy v Krušných horách (Martinková et al. 2001; Mauer, Palátová 2003) vyslovujeme hypotézu, že v důsledku dlouhodobé námrazy a zatížení stromů došlo k ohnutí břízy zvláště v mladých porostech, při němž zmrzlá pletiva byla mechanicky poškozena a následně po uvolnění ze zátěže se stromy narovnaly a vzniklé trhliny (mrazové kýly) se staly vstupem pro dřevokazné houby.

Ve výškových transektech LS Litvínov v porostech břízy se šetření soustředilo na živé stromy s cílem vymezit přítomnost mrazových trhlin na kmeni (počet, poloha ke světové straně a v profilu stromu, jejich délka a šířka, vytvoření závalu, přítomnost houbových patogenů, výčetní tloušťka).

K hodnocení získaných dat bylo užito statistiky ANOVA. Šetření se uskutečnilo na 28 zkusných plochách a zahrnuje 2 904 jedinců břízy bělokoré (*Betula pendula* Roth), z nichž 1 008 bříz bylo poškozeno mrazovou trhlinou.

Porosty (LS Litvínov, LHC Janov a Lesy města Jirkova) v nadmořské výšce 700–850 m, J a S expozice, v r. 1995 věkové rozpětí 7–24 let. Území přecházející v náhorní plošinu, roční průměrná teplota je 5 °C, průměrný roční úhrn srážek 430–920 mm (Hošek et al. 1999). Vysoký podíl na škodách v lesních porostech má námraza (Kula, Richterová 1999), jejíž dopady v zimě 1995/1996 popsal ve smrkových porostech Lomský et al. (1996), v porostech břízy Kula a Kawulok (1998) a Kula (1998).

Byl odvozen trend vzestupu počtu mrazových trhlin s narůstající nadmořskou výškou (obr. 1). Zvláště výrazný byl přechod mezi polohou 700–750 m n. m., kde byla pravděpodobnost výskytu trhliny 17 %, zatímco v poloze 751–800 a 801–850 m n. m. 40 % a 43 %. Na postižených stromech (774) byla mrazová trhlina jednou (73 %), dvakrát (21 %), třikrát (4,8 %), čtyřikrát (1,1 %) a šestkrát (0,1 %). Frekvence dvou kýl na strom byla vyšší v poloze nad 800 m n. m., frekvence čtyř a více trhlin se projevila na stromech v poloze 780–830 m n. m.

Věk porostů v době jejich zatížení námrazou (1995/1996) byl významným atributem potenciálního poškození ve formě ohnutí, zlomů a vývratů. Podíl mrazových trhlin se zastoupením profiloval v mladších porostech (do 10 let 34,2 %, 11–15 let 43,8 %, 16–20 let 47 % a 21–25 let pouze 14,2 %) s tím, že frekvence počtu kýl na stromech se s věkem rovněž měnila. Do 20 let věku porostu měl dominantní postavení výskyt jediné trhliny (70–73 %) a 94% podíl byl ve starších porostech, při výskytu dvou trhlin se shodují porosty do 20 let na úrovni 23–21 %, zatímco ve starších porostech jsme zaznamenali pouze 4,5 %. Výrazný ústup s věkem byl zaznamenán při výskytu tří kýl (6,5–4,6–3,6–1,5 %).

Poloha mrazových trhlin se profilovala jednoznačně na jižní stranu (J – 46,7 %, JV + JZ – 22,1 %), severní polohy byly méně významné (S – 10,3 %, SV + SZ – 8 %), V – 3,7 %, Z – 9 % (obr. 2). Střed mrazové trhliny se nejčastěji nacházel v profilu kmene břízy mezi 25–50 cm (25,2 %). Ve shodné frekvenci (18 %) byly trhliny v sekci pod tímto prostorem a nad ním. Výše v profilu kmene se projevil výrazný pokles mrazových trhlin (75–100 cm 14,3 %, 100–125 cm 11,2 % a v následujících třech 25 cm dlouhých sekcích 7,5–4,7–0,8 %). Celková poloha středu mrazové trhliny měla sestupný trend s narůstající nadmořskou výškou (obr. 3). Délka mrazové trhliny nevykazuje statistickou závislost na nadmořské výšce, věku, ale zkracuje se s počtem vyskytujících se trhlin na kmeni a na severní expozici.

S nadmořskou výškou se snižovala poloha středu trhliny (obr. 4) a délka trhliny s věkem (obr. 5). Šířka mrazové trhliny se snižovala pouze při vyšší četnosti trhlin na vzorníku. Vliv světové strany na šířku trhliny byl klesající od jižních poloh k severním (obr. 6).

Přítomnost mrazových trhlin je spojena s hnilobou březovníka obecného [*Piptoporus betulinus* (Bull. ex Fr.) Karst.], který prostupuje od místa poranění až do úrovně koruny, šíří se relativně rychle a ovlivňuje růstové vlastnosti. Výčetní tloušťka jedinců odumřelých a živých, živých s mrazovými trhlinami a bez nich klesla s nadmořskou výškou (obr. 7), přičemž průměrná výčetní tloušťka stromů s mrazovými trhlinami byla nižší (obr. 8). Znamená to, že více než samotná poloha je významný výskyt hniloby u napadených stromů, který nejen ovlivňuje růstové vlastnosti, ale byl i významným činitelem podílejícím se na odumírání poškozených porostů a jejich rozpadu. Vyslovená hypotéza byla potvrzena.

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