Beskydy, 2014, 7 (2): 87–98

ISSN: 1803-2451 (Print)
http://dx.doi.org/10.11118/beskyd201407020087

Ecological stability of alpine treeline ecotone formed by beech (*Fagus sylvatica* L.) in Ďumbier Low Tatras

J. Mičovský

Forests of the Slovak Republic, state enterprise, Forest District Brusno, Oremlaz 410, 976 62 Brusno, External PhD student at the Department of Silviculture, Technical University in Zvolen, e -mail: jan.micovsky@gmail.com

Abstract: Mičovský, J. 2014: Ecological stability of alpine treeline ecotone formed by beech (*Fagus sylvatica* L.) in Ďumbier Low Tatras. *Beskydy,* 7 (2): 87–98

The paper analyses the results of the ecological stability research of beech (*Fagus sylvatica* L.) stands at the alpine tree-line ecotone in the Ďumbier part of Law Tatras. The applied methodology by Vološčuk (2000) is based on the approximation of the current tree species composition with respect to the original ones, crown ratio, slenderness quotient, sanitary coefficient and vertical species profile of the stands. The resulting value of ecological stability of the stands, typologically classified into a group of forest types *Fageto-Aceretum humile*, was increased by approximation of 80.0–82.5%, slenderness quotient 0.55–0.60 $m.cm^{-1}$ and sanitary coefficient. Vitality was assessed with regard to the most common damage to individual, more than 160-year-old beech trees at the alpine treeline ecotone in the form of necrosis. Vertical and horizontal structure of the stands was influenced mainly by dense tree clusters. The value of ecological stability was decreased by average crown ratio of individual trees ranging from 0.47–0.57. Based on the final index of ecological stability ES 16–24, beech forests in the alpine treeline ecotone may be considered as very stable.

Keywords: European beech (*Fagus sylvatica* L.), alpine treeline ecotone, ecological stability

Introduction

The southern part of the Ďumbier Law Tatras in the 6th vegetation zone was originally formed by beech (*Fagus sylvatica* L.), which was in the 7th vegetation zone naturally followed by spruce forests (*Eu-Vaccinio-Piceenion p.p*) (Bystrický 2007). The changes in structure and tree species composition began to occur first in the lower parts of the mountains in the 13th and 14th century during the great German colonization, and then later in the third period of the settlement during the Wallachian colonization also in the high altitude forests (Midriak 1973). Wallachians cut down forests and burned them down to enlarge pastures. Particularly the southern exposures were completely deforested (Holtmeier 2009). This created the upper treeline formed by beech. Since beech does not naturally reach the alpine tundra ecotone in our region (Plesník 1971), it represents the declined altitudinal treeline, with functions of alpine forests in 7th vegetation zone in the areas where forest has been previously destroyed by grazing (Gubka 1999).

Plesník's (1971) definition of the alpine treeline, who defines it as a line connecting the highest points of a continuous forest, is the most often used definition in our field. The strict line of the previous definition is often modified by a term ecotone, which indicates a transition zone between two communities – forest and alpine tundra (Holtmeier 2009).

Fekete, Blattny (1914) report the upper treeline of beech in the Slovak Carpathians at an altitude of 1485 m a.s.l. According to Kukla (2011) the vitality of beech in macroclimatic conditions of 6th vegetation zone is already greatly reduced. It maintains the dominant position to fir particularly in mesotrophic and eutrophic natural geobiocenosis, or in geobiocenoses influenced by alpine phenomenon where fir and spruce is damaged by abiotic (wet snow, wind, frost) and consequently biotic factors. Beech enters alpine spruce stands in a shrub form especially in the area south of the main climate partition line of Slovakia, for example the western part of the Low Tatras (Kukla 2011).

Beech forests at the treeline ecotone with an admixture of rowan, sycamore, fir and spruce has a limited vertical growth conditioned by a long-term exposure to intense air flow in the ridge lines of upper areas at an altitude above 1000 m a.s.l. They represent mostly sparse, low-quality vegetation (Pagan 1999). Due to inaccessibility and assortment structure were the stands below the upper treeline for the decades left untouched, and despite the Wallachian colonization in the 15th and 16th centuries, current ecotone consists of a high proportion of native forests (Zdycha *et al.* 1992).

As the main object of interest in solving problems of alpine forests in Slovakia are spruce forests of supramontane and subalpine level (Kucbel 2011), papers analyzing primeval forests with the dominance of beech located in the 6th forest vegetation zone reaching the upper treeline are absent in the available literature (Saniga *et al.* 2013).

The aim of this article is to analyze the ecological stability of the alpine treeline ecotone that consists of beech (*Fagus sylvatica* L.), as well as verify the hypothesis that near-natural beech stands at the alpine treeline ecotone maintain sufficient ecological stability even when facing various intensity of human intervention.

Materials and Methodology

Permanent research plots were established at the alpine treeline ecotone in the southern exposure of the Ďumbier Law Tatras. From the climatic point of view is the researched area situated between cool to cold mountain areas with an average July temperature ≤ 12 °C (Lapin *et al.* 2002). The average annual air temperature is 2–4 °C (Šťastný *et al.* 2002), the average annual temperature of the active surface of soil is 4–5 °C (Tomlain, Hrvoľ 2002), average annual rainfall is 1600 to 2000 mm (Faško, Šťastný 2002). Geological underlay consists of muscovite-biotite granodiorites to granites (Biely *et al.* 1992).

Empirical material comes from compartments 2252A (48°53′14.99″S, 19°20′56.50″V) and 2128 (48°52′23.86″S, 19°23′14.30″V), belonging to forest management unit Slovenská Ľupča, forest unit Brusno – state. In the compartment 2252A was established a transect T_I with a dimension of 50 × 100 m having a longer side running along the fall line, which was divided into four permanent research plots TVP_A–TVP_D measuring 25 × 50 m. In the compartment 2128 was established an identical transect T_{II} with TVP_E–TVP_H. Individual $TVP_{A–H}$ in transects T_I and T_{II} define altitude zones with an interval of approximately 10 vertical meters from the altitude of 1340–1380 m a.s.l. All individual trees with diameter $d_{1,3} \geq$ 5cm were noted into the system of vectors X, Y in the transects.

The area of the compartment 2252A is 17.23 hectares, southern exposure, slope 45%, age 160 years, stand density 0.8, species structure beech 90, spruce 10, growing stock 257 $m^3.ha^{-1}$, basal area 35.12 m^2. ha^{-1}, average stand diameter 25.42 cm.

The area of the compartment 2128 is 8.62 hectares, southern exposure, slope 45%, age 160 years, stand density 0.9, species structure beech 93, maple 2.5, spruce 2.5, larch 2, growing stock 295 m^3. ha^{-1}, basal area 37.88 $m^2.ha^{-1}$, average stand diameter 38.71 cm. When identifying primeval forests residuals in Slovakia (Jasík, Polák 2011), the stand was included in the native stands with a primeval forest character.

The compartments are typologically classified according to Hančinský (1972) into alpine beech forests, a group of forest types *Fageto-Aceretum humile* (Fac hum v), forest type 6411 – Stunted sycamore – beech woods. In the system Natura 2000 these are identified as maple-beech mountain forests (9140 – NATURA code, LS 5.3 – code SK).

Ecological stability (ES) of the stands was evaluated using methodology by Vološčuk (2000), which consists of approximation of the current tree species composition in regard to native species dominance (a), crown ratio (cr), slenderness quotient (sq), sanitary coefficient (sc) and a deviation of a current vertical structure from a model of the three-layer structure (cl). ES index is calculated by the formula (Vološčuk 2000): ES = 5a + 3 sc + cr + sq + cl

According to the resulting index ES, the stands were included in the scale (Vološčuk 2000): high ecological stability – resulting index 11–15, very good ecological stability (ES 16–24), medium ecological stability (ES 25–35), small ecological stability (ES 36–46), ecosystem labile (ES 47–55).

1) The percentage of approximation (a) represents a deviation of the current tree species structure from the original (potential) structure. It is calculated by the formula (Papánek 1967):

$$a = 100.\left(1 - \frac{SO}{200}\right)$$

SO – the degree of deviation of the current structure of each tree species from the original outlook representation according to the methodology by Vološčuk (2000).

According to the calculated percentage of approximation the stands were classified into the following scale of stability (Vološčuk 2000):

1. highly stable	above 91%
2. very stable	71–90%
3. moderately stable	51–70%
4. less stable	31–50%
5. labile	up to 30%

2) The level of static stability is expressed by crown ratio (cr) – the ratio of crown length (m) to tree height (m), and slenderness quotient (sq) – the ratio of the height (m) and a diameter in the height of 1.3 m above ground $d_{1,3}$ (Šmelko 2000).

Based on the value of the slenderness quotient, the static stability of trees was estimated according to the classification scheme (Míchal 1992):

sq > 1.0	trees statically unstable
sq 0.80–1.0	trees stable
sq 0.55–0.8	trees very stable
sq < 0.55	solitaires with the highest stability

By the values of crown ratio (cr) and slenderness quotient (sq) the stands were classified in a scale of stability (Vološčuk 2000):

	cr:	sq:
1. highly stable	over 0.81	less than 0.50
2. very stable	0.71–0.80	0.51–0.65
3. moderately stable	0.51–0.70	0.66–0.80
4. less stable	0.41–0.50	0.81–0.95
5. labile	less than 0.40	over 0.96

3) Sanitary coefficient (sc) was calculated as a proportion of necrotically damaged individual trees to the total number of trees in the area. As damaged were considered the trees with a degree of disease 3 and 4 according to the classification scale (Cicák, Mihál 2000):

Grade 0: no necrotic wounds on the bark,

Grade 1: small necrotic wounds (slits, cracks) occurring singly or in isolated clusters, visible only in closer inspection of the trunk,

Grade 2: small necrotic wounds (such as in grade 1) and at the same time the occurrence of larger necrotic wounds (larger cracks, fissured bark), visible by a casual inspection of the trunk,

Grade 3: larger necrotic wounds exposing the wood and partly distorting the trunk, bursting and deciduous bark, already visible from a greater distance,

Grade 4: large necrotic wounds strongly distorting the trunk or forming "break necrosis", bursting and deciduous bark, visible from the distance.

By the value of sanitary coefficient the stands were classified in a scale of ecological stability (Vološčuk 2000):

1. highly stable	to 20% damage
2. very stable	21–30%
3. moderately stable	31–40%
4. less stable	41–50%
5. labile	more than 51%

4. To determine the deviation of the current vertical structure from the model of the three-layer structure (vs), the growth area of the stands was divided on the basis of a upper height $h_{10\%}$ into three regular layers (Korpeľ 1991). The upper height corresponds the average diameter of the top 10% of the thickest living tree individuals in transect ($h_{10\%} = f(d_{10\%})$). The upper level includes the trees with a height greater than 2/3 of the upper height, the middle level includes the trees between 1/3 and 2/3 of the upper height and the low level includes the trees with the height less than 1/3 of the upper height. The layer should only be noted when its representation is at least 10% of the total tree number.

Vertical position of trees is estimated by the classification scale by Assmann (1961 in Saniga 2009):

1) Dominant – trees with extremely firmly developed crowns.
2) Level – trees with relatively well developed (proportionally large and regular) crowns, which constitute the main stand.
3) Partially level – crowns that are still relatively normal, but compared to previous classes they are less developed. These form the lower interface of the main stand.

4) Subdominant shaded – with a more or less shortened crown that is unilaterally developed and is cramped from two or more sides.
5) Supressed (with a compromised lifespan) – a living crown, which is capable of living only with shade-tolerant species, trees with a dying crown or completely dead trees.

A scale of ecological stability, according to the coefficient of layering (cl), represents a deviation of layering of the current stand from the model of the three-layer stand (Vološčuk 2000):

Scale of ecological stability	Deviation from three-layer stand	Characteristics
1. very large	up to 10%	three layers of native species
2. high	11–35%	two layers of native species
3. medium	36–50%	two layers, 50% of native species
4. small	51–75%	two layers, 25% of native species
5. unsuitable	over 76%	one layer of non-native species

According to Ott *et al.* (1995) a transition from regularly and individually structured montane forests to trees arranged in clusters or biogroups has a decisive importance in the lasting stability and maintenance of favourable conditions for the restoration of subalpine forests. Therefore the paper analyses the change of horizontal structure with the change of altitude in the form of cluster-forming individuals. Frequency of individual trees and clusters was recorded in the following interval groups – 1, 2, 3–5, 5–10, 10–15 tree individuals.

In order to detect the statistical dependence between the evaluated parameters and the altitude there was used a one-way analysis of variance. The software STATISTICA 7.0 was used to do the calculation.

Results

The approximation *(a)* of the current tree species composition with respect to the original ones.

For the forest type 6411 Stunted sycamore - beech woods (HSLT 618 European subalpine beech woods, SLT – *Fageto Aceretum humile*) there is the following original representation of tree species: Beech 80, Maple 15, Rowan 5.

In transect $T_{I,}$ compartment 2252A there is the following current tree species representation rounded: Beech 90, Spruce 10 (Table 1); in transect $T_{II,}$ compartment 2128 the representation is as follows: Beech 93, Maple 2.5, Spruce 2.5, Larch 2 (Tab. 2).

The representation of beech is mutually comparable in both transects, and basically did not change with altitude. The representation of spruce, which was not to be found in the original tree species composition, is higher only in the compartment 2252A at an altitude of 1370–1380 m a.s.l. at the top of the transect T_I characterized by $TVP_{D.}$

The formula for calculating the approximation by Papánek (1967) shows the following values of approximation: in compartment 2252A *a* (T_I) = 80.0%, in compartment 2128 *a* (T_{II}) = 82.5%, which represents a high level of suitability of the current tree species with

Table 1: Frequency of tree individuals with diameter d1,3 ≥5 cm and tree species representation in transect TI, compartment 2252A.

	Transect T_I		TVP_A		TVP_B		TVP_C		TVP_D	
	pcs.ha^{-1}	%	pcs.ha^{-1}	%	pcs.ha-1	%	pcs.ha^{-1}	%	pcs.ha^{-1}	%
Beech	620	89.60	456	98,30	624	100.00	864	94.70	536	69.80
Spruce	72	10.40	8	1.70	0	0.00	48	5.30	232	30.20
Σ	692	100.0	464	100.0	624	100.0	912	100.0	768	100.0

$$a(T_I) = 100.\left(1 - \frac{40}{200}\right) = 80\%$$

Table 2: Frequency of tree individuals with diameter $d_{1,3} \geq 5$ cm and tree species representation in transect $T_{II,}$ compartment 2128.

	Transect T_{II}		**TVP_E**		**TVP_F**		**TVP_G**		**TVP_H**	
	pcs.ha^{-1}	%	pcs.ha^{-1}	%	pcs.ha^{-1}	%	pcs.ha^{-1}	%	pcs.ha^{-1}	%
Beech	300	93.20	224	93.40	256	94.10	320	95.20	400	90.90
Maple	8	2.48	8	3.30	16	5.90	0	0.00	8	1.80
Spruce	8	2.48	8	3.30	0	0.00	16	4.80	8	1.80
Larch	6	1.86	0	0.00	0	0.00	0	0.00	24	5.50
Σ	322	100.0	240	100.0	272	100.0	336	100.0	440	100.0

$$a(T_{II}) = 100.\left(1 - \frac{35}{200}\right) = 82,5\%$$

respect to the original ones. Based on the calculated percentage of approximation we qualified both stands according to the classification scale (Vološčuk 2000) as very stable degree of ecological stability. The index of approximation *(a)* has a value 2 in both stands.

Crown ratio (*cr*)

Average values of crown ratio of all trees in transect $T_{I,}$ compartment 2252A reach 0.47 ± 0.16. Average crown ratio of beech was 0.49 ± 0.15. Spruce is located in the 4th grade of relative height position of trees by Assmann (1961 *in* Saniga 2009). Their average crown ratio was 0.27 ± 0.10. Crown ratio of the trees in compartment 2252A decreases with increasing altitude (Fig. 1). In the lower half of the transect (TVP_A–TVP_B) it decreased by 5.77% from 0.52 ± 0.11 at an altitude of 1340–1350 m a. s.l. to 0.49 ± 0.16 at an altitude of 1350–1360 m a. s. l. In the upper half of the transect (TVP_C–TVP_D) it decreased by 16.67% from 0.48 ± 0.15 at an altitude of 1360–1370 m a.s.l. to 0.40 ± 0.18 at an altitude of 1370–1380 m a.s.l.

Average crown ratio of all trees, in transect $T_{II,}$ compartment 2252A, reached 0.57 ± 0.13. Average crown ratio value of beech was 0.57 ± 0.13. The highest values of average crown ratio are attributed to conifer species – spruce 0.70 ± 0.07, larch 0.63 ± 0.12. The lowest average crown ratio is attributed to maple 0.54 ± 0.14.

Analysis of variance in compartment 2252A statistically highly significantly ($p < 0.0001$) confirmed the relationship between crown ratio and altitude. This relationship did not appear in compartment 2128 to be statistically significant at the 95% of the significance level ($p > 0.05$) (Fig. 1).

Based on the average crown ratio of tree individuals we classified compartment 2252A in grade 4 (less stable), index *cr* $T_I = 4$, and compartment 2128 to grade 3 (moderately stable), index cr $T_{II} = 3$ in the classification scale by Vološčuk (2000).

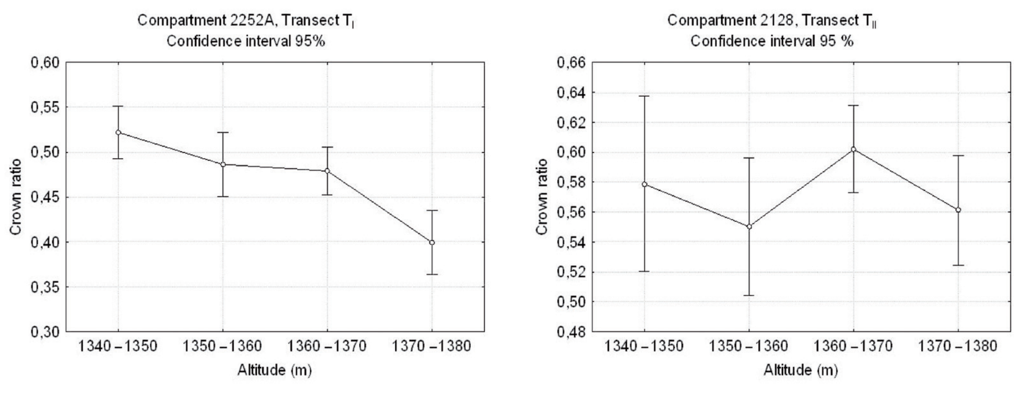

Fig. 1: Progress of crown ratio of tree individuals in transect T_I and T_{II} depending on the altitude.

Slenderness quotient *(sq)*

The sq in transect T_I in the compartment 2252A reached the value 0.60 ± 0.17 m.cm^{-1}. It decreases with altitude and static stability of trees theoretically increases (Fig. 2). In the lower half of transect (TVP_A–TVP_B) the value of *sq* decreases by 7.25%, from 0.69 ± 0.17 m.cm^{-1} at an altitude of 1340–1350 m a.s.l. to 0.64 ± 0.14 m.cm^{-1} at an altitude of 1350–1360 m a.s.l. In the upper half of transect (TVP_C–TVP_D) it decreases by 5.26% of 0.57 ± 0.15 m.cm^{-1} at an altitude of 1360–1370 m a.s.l. to 0.54 ± 0.18 m.cm^{-1} at an altitude of 1370–1380 m a.s.l. (Fig. 2).

The sq in transect T_{II} compartment 2128 reach the value 0.55 ± 0.19 m.cm^{-1}. It increases with altitude, static stability of tree individuals theoretically decreases. Even in the upper part of transect characterized as TVP_H it still falls into the grade of highly stable trees in the classification scheme by Míchal (1992).

The analysis of variance confirmed a statistically highly significant dependence of slenderness quotient on altitude in transect T_I ($p<0,0001$) and T_{II} ($p<0,001$).

Based on the values of sq both stands were classified into the 2nd grade of stability (very stable) of the classification scale by Vološčuk (2000). Index *sq* $T_I = 2$. Index *sq* $T_{II} = 2$.

Sanitary coefficient *(sc)*

Sanitary coefficient was calculated with respect to the most common damage to trees at the upper treeline ecotone in the form of necrotic damage to the bark.

When calculating ecological stability, as damaged were considered the tree individuals, where necrotisation became evident by wood denudation with a degree of necrotisation 3 and 4 in the classification scale Cicák, Mihál (2000). In the compartment 2252A there is 26,93% of the tree individuals with a specific degree of necrotisation, in the part 2128 there is approximately the same share of 25.16% (Table 3).

Based on the values of sanitary coefficient (25.16–26.93%) were both compartments included in the second grade of ecological stability (percentage of damage 21–30%) of the classification scale by Vološčuk (2000). Index sc $T_I = 2$. Index sc $T_{II} = 2$.

Coefficient of layering (*cl*)

Transect T_I in compartment 2252A is multilayered with the representation of the upper layer of 47.7%, middle layer of 38.2%, and the bottom layer of 14.1% of the total number of tree individuals with diameter at breast height $d_{1,3} \geq 5$ cm. Since spruce is not to be found in the original, outlook representation, when classifying a stand into a grade of ecological stability by Vološčuk (2000) we characterize vertical construction as two layers of native species with 2nd grade of ecological stability

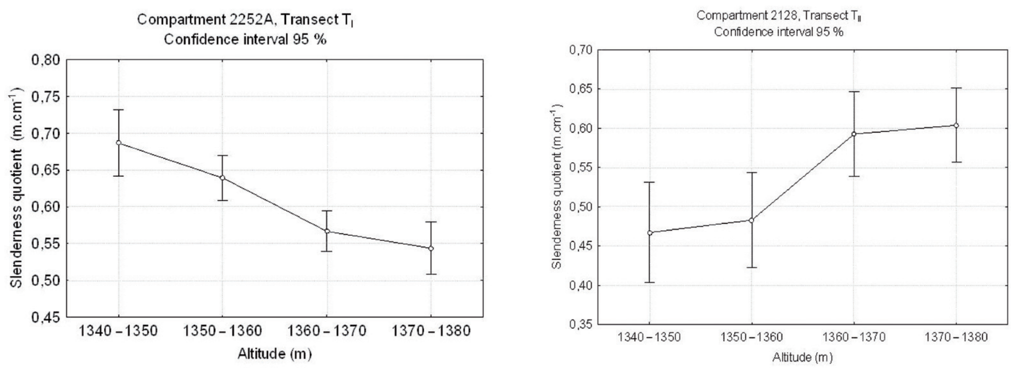

Fig. 2: Progress of slenderness quotient in transect T_I and T_{II} depending on altitude.

Table 3: The proportion of trees et each stage of necrotisation in registered compartments.

	Stage of necrotisation/proportion of individuals (%)					Total %
	0	1	2	3	4	
2252A	26.44	32.21	14.42	16.35	10.58	100.00
2128	36.77	25.81	12.26	10.32	14.84	100.00

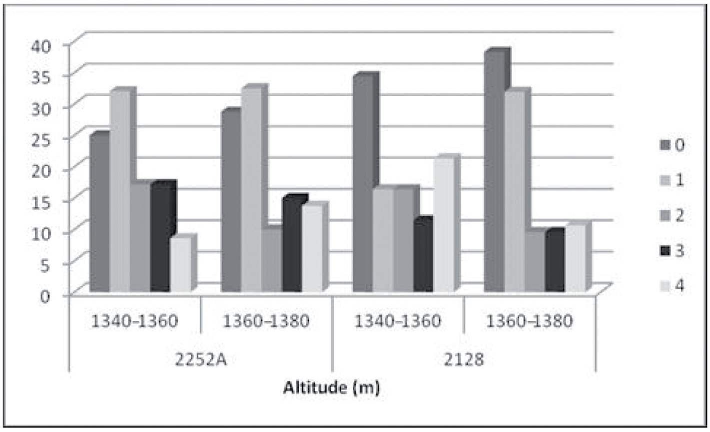

Fig. 3: The proportion of trees with a varying degree of necrotisation (0 – no necrotic wounds to 4 – large necrotic wounds) in the lower and upper half of transects in the registered compartments.

and a deviation from a three-layered stand of 11–35%. Index cl $T_I = 2$.

Transect T_{II} compartment 2128 is two-layered with the representation of the top layer of 74.53% and the middle layer of 25,47% of the total number of tree individuals with diameter at breast height $d_{1,3} \geq 5$ cm. Based on two layers of native species we estimate the ecological stability of the compartment 2128 as high (2nd grade), with a deviation from the three-layer stand of 11–35%. Index cl $T_{II} = 2$. Vertical construction of the treeline is affected by clusters of beech (Fig. 4).

Fig. 4: The proportion of individuals in clusters, transect T_I compartment 2252A and transect T_{II} compartment 2128.

The resulting value of ecological stability

Part 2252A: $ES\ T_I = 5.2 + 3.2 + 4 + 2 + 2 = 24$
Part 2128: $ES\ T_{II} = 5.2 + 3.2 + 3 + 2 + 2 = 23$

Based on the resulting index of ecological stability ($ES\ T_I = 24$, $ES\ T_{II} = 23$), the studied ecosystems at the treeline ecotone were classified in the second most stable grade of a 5-grade

Table 4: Biosociological position of trees in a classification scale by Assmann (1961 in Saniga 2009)(%).

	Dominant	Level	Semi-level	Underlevel shaded	Supressed	Total
2252	6.00	18.00	34.85	26.29	14.86	100
2128	21.12	27.33	24.22	21.74	5.59	100

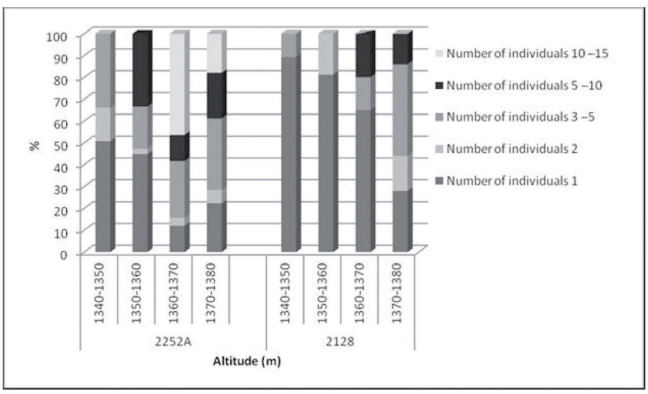

Fig. 4: The proportion of individuals in clusters, transect T_I compartment 2252A and transect T_{II} compartment 2128.

scale by Vološčuk (2000). We estimate the ecological stability in the registered transects T_I and T_{II} as "very good" (Index ES 16–24).

Discussion

The resulting index of ecological stability is composed of five indicators that change dynamically at extreme conditions of growth at the upper treeline ecotone.

Approximation of the current tree species composition with respect to the original ones reached high values (80.0–82.5%) in the registered transects T_I and T_{II} at the upper treeline ecotone formed by beech. The ratio of tree species composition did not change significantly with the change of altitude. The basic tree species in all TVP_{A-H} was beech represented by 69.8–98.3% (Tab. 1, Tab. 2). Beech proportion in both parts was lowest in the upper part of transects (TVP_D, TVP_H) at an altitude of 1370–1380 m a.s.l. In compartment 2252A, there was an increased proportion of spruce (30.2%) (Tab. 1) in $TVP_{D,}$ which boarders with the alpine zone (ridges) at an altitude of 1370–1380 m a.s.l. Within compartment 2128 in the peripheral TVP_H of the transect T_{II} at an altitude of 1370–1380 m a.s.l. there was increased proportion of spruce, larch and maple (Tab. 2). The southern exposure of the Low Tatras expanding from Hiadeľská valley to Telgárt was originally formed by acidophilous beech forests (*Luzulo-Fagion p.p.maj.*) and calcareous beech forests (*Cephalanthero-Fagenion*). These were followed by spruce blueberry forests (*Eu-Vaccinio-Piceenion p.p.*) (Bystrický 2007). An increased representation of spruce in the upper part of the transects (TVP_D, TVP_H) is therefore natural, even though spruce does not occur in the original representation in group of forests types *Fageto-Aceretum humile*. In the beech variation of the treeline in the Carpathians. Kricsfalusy *et al.* (2008) describes a tree species composition that comprises beech with admixture of sycamore (*Acer pseudoplatanus*) and rowan (*Sorbus aucuparia subs. Glabrata*), which corresponds to the species composition in our compartments. Rowan was not registered among the tree individuals with diameter $d_{1,3} \geq 5$ cm, however it is dominant among the individuals of natural regeneration (Gubka 1999, Mičovský 2013). Approximately the same tree species representation – beech 77%, maple 17%, spruce 6% is mentioned by Saniga *et al.* (2013) in group of forests types *FAc hum* in the beech primeval forest Skalná Alpa.

The average crown ratio value provides very useful information about existing silviculture management as well as resistance potential of stands (Šmelko 2000). Crown ratio of individual trees in the registered transects ranged from 0.47 ± 0.16 in the transect T_I to 0.57 ± 0.13 in the transect T_{II} (Fig.1). Crown ratio value declined with increasing altitude in compartment 2252A from 0.52 ± 0.11 at an altitude of 1340–1350 m a.s.l. to 0.40 ± 0.18 at an altitude of 1370–1380 m a.s.l. (Fig. 1). Crown ratio in compartment 2128 was higher compared to the 2252A, it ranged from 0.55 ± 0.13 at an altitude of 1350–1360 m a.s.l. to 0.60 ± 0.09 at an altitude of 1360–1370 m a.s.l. (Fig. 1). In compartment 2128 the change in crown ratio with the change in altitude did not show to be statistically significant. Reduction of crown ratio with increasing altitude in part 2252A may be associated with density and increased canopy in the upper part of registered transects (TVP_D, TVP_H). Increased canopy is specified by changing of horizontal structure, which is significantly shaped by clusters of trees (Fig. 4). Similar results have been confirmed in the analysis of the horizontal structure based on the aggregation index of Clark-Evans at the upper treeline ecotone formed by beech in the Ďumbierske Tatras (Mičovský, Gubka 2012). Small crowns and a centre of gravity set high result in reduced static stability of the trees against the wind (Gubka 1999, Saniga 2011). This risk is naturally reduced in the upper treeline ecotone formed by beech by a formation of clusters of trees (Fig. 4). Although beech has the ability to significantly enlarge the volume of the crown having enough space, and after heavy interventions in a short time it can once again create a strong canopy (Šmelko *et al.* 1992), such interventions in the upper treeline ecotone would not be adequate in terms of stability as well as competitively strong herbal vegetation.

Slenderness quotient as the main indicator of static stability of stands is important in assessing the stands particularly with regard to mechanically acting factors causing damage (wind, snow, frost) (Vorčák *et al.* 2007). In the registered transects it ranged from 0.55 ± 0.19 m.cm^{-1} (T_{II}) to 0,60 ± 0,17 (T_I) (Fig. 2). Trees with a slenderness quotient of less than 0.80 are considered very stable, and those of less than 0.55 are considered the trees with the highest stability (Míchal 1992). Analysis of variance confirmed a highly significant dependence ($p < 0.001$) between the slenderness quotient and altitude. Kucbel

(2011) reports values of slenderness quotient in the alpine forest located on the western slopes of Prašivá in the Low Tatras in *Sobreto-Piceetum* in the range of 0.80–0.81. This means that beech in the upper treeline ecotone compared to spruce exhibit comparable or better static stability.

When assessing the health status of the registered transects, damaged trees were considered those with fractured bark and exposed timber according to the methodology by Cicák, Mihál (2000). Despite the fact that at least small bark damage (grade of necrotisation 1, 2) was recorded at 38.07–46.43% of individuals (Tab. 3), it is not necessary to consider this range of damage as damage interrupting the stability of the upper treeline ecotone. The proportion of trees without any necrotic bark disease (gr. 0) increased in the upper half of registered transects (TVP_C, TVP_D, TVP_G, TVP_H) at an altitude of 1360–1380 m a. s. l. (Fig. 3). The proportion of tree individuals with a degree of necrotic disease 3 and 4 in the upper area of the transects (TVP_D, TVP_H) in compartment 2252A increased by 2.97%, while in the compartment 2128 it decreased by 12.57% (Fig. 3). Therefore it is not possible to confirm the results by Vorčák *et al.* (2007) from NPR Babia Hora, where the increase of altitude significantly increased the average percentage of damaged trees.

Vertical structure of registered compartments was evaluated as two-layer. The compartment 2252A could be evaluated as a three-layer one with non-native species of spruce in the lower layer. Mičovský, Gubka (2012) evaluated the vertical differentiation of the upper treeline ecotone using the Gini's coefficient. Its values indicate a higher vertical differentiation in the upper area of the ecotone. Presumably, the clusters of trees on the border with the alpine zone increase the static stability of individuals. Multi-trunk, widely branched forms resembling spruce biogroups in the upper forest boundaries indicate previous anthropic impacts in the areas (cattle grazing) (Svoboda, Pagan 1965). The reason of the cluster formation according to several authors (Šebeň, Kucbel 2003, Holtmeier 2009) is their growth in microhabitats-like suitable areas as well as the formation of a crown shell, which serves as a protection from adverse climatic factors. Trees in biogroups best benefit from light. Clusters of beech in the upper treeline ecotone may arise from vegetative restoration of the lower branches of juvenile trees.

Conclusion

With regard to climate changes in the future it is possible to expect a gradual increase of periods of moisture in forest soils and a reduction of the amount of available water. Combined with other negative harmful factors, namely the increase of the concentration of heterogeneous contaminants, particularly in the surface layers of soil, this assumes great danger especially for shallow-rooted spruce (Tužinský 1993), which constitutes the largest share of stands in the upper treeline.

Based on the methodology by Vološčuk (2000) this paper confirmed a very good ecological stability of the upper treeline ecotone, which in a part of the Ďumbierské Low Tatras is formed by beech. In conjunction with the analysis of the regenerative capacity of treeline beech forests in the area (Mičovský 2013) it is possible to confirm a hypothesis that close to nature beech stands in the upper treeline ecotone maintain the natural ecological coupling even with the varying intensity of human intervention, they have considerable ecological stability and are capable of spontaneous natural recovery.

It is more than likely that the current development of climate will first destroy non-native spruce forests in lower locations. Due to this there is an urgent need in forestry management and nature protection to respect and maintain the original ecotypes of species, though unproven, because the remnants of native vegetation are the best guarantee for natural regeneration, conservation of gene pool and ecological stability of forest ecosystems even under changed ecological conditions (Križová 2001).

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