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The structure analysis of the Norway spruce stands after schematic thinning in the 1st protected zone of water-supply storage

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The water-supply storages are important resources of drinking water in some regions of Slovakia, especially in surrounding of Banská Bystrica. Málinec is one of the three storages in this region. In protected zone of this storage are planted Norway spruce (hereinafter „spruce“) stands monocultures because of ensuring required water quality in storage. There are 24 years old spruce stands without admixture of deciduous trees in the upper layer. Understory is formed by blackthorn (PRP 1). On this locality was carried out geometric (schematic) thinning what is not recommended in protected zones because of worse influencing of soil permeability, humus decomposition and open forest edge creating. There was identified one older permanent research plot (PRP) and established one new PRP where was performed own measurements. Into the PRPs there are transekts and remaining area. Acreage of PRP is 0,234 and 0,315 ha. On the whole area were measured tree diameter and assessed tree classes (5 degrees–Polanský 1955). Moreover, on transekts were measured tree and also crown height. Based of measured variables were calculated stand characteristics like slenderness ratio, crown ratio, growing stock and basal area. If it is possible, these were compared with older results. The aim of this work is evaluation of spruce stands structure and their stability after schematic thinning. This kind of silvicultural treatment is absolutely unfit in stands with specific (water-protested) function (Slodičák et al. 2010). These stands are from the perspective of static stability too unfit–basal area and abundance of trees is nearly as in yield tables (Kolektív 1992) but growing stock is much higher and a lot of trees is too slim. The slenderness ratio is from 75 to 90%. But the crown lenght is quite good with crown ratio 52–64%. In these ages of stands are crowns reduced too much. Suitable individual thinning has been in these stands neglected (growing stock is higher than normal). There is assumed reduced stand lifetime after schematic thinning. Current stand structure is due to the young age inappropriate.

Introduction

In Slovakia, two main part of environment (water and forests) is managed by the different administrators - Ministry of Agriculture and Rural Development (administrator of forests) and the Ministry of Environment (administrator of water). Administration of two main and mutually affected environment components is politicaly divided what significantly affected a care of them. The marketing strategy of forestry is significantly weakened and fragmented and therefore a marginal interest of state about them is weaker (Krečmer 2010). Conversely, water industry is now prosperous sector with many incentives.

However, the really producent of water is a forest. The benefits from water production have water companies not foresters. The role of the forest ecosystems for acumulation, retention and infiltration of rainfall water is very important (Hamilton et al. 2008). The major climatic factors enter to hydrological cycles of forest with importance of rainfall (precipitation, evapotranspiration and runoff) (Correll 2005). In fact, the first recipient of rainfall water are the crowns of the trees. The density of forest stands, the lenght and width of crowns and also diameter distribution of trees affected amount of water which is distributed to the soil.

Suply of drinking water is provided by surface and subsurface resources. Drinking water reservoirs are the main surface resources of water in some regions of Slovakia (Jasaň 2003). There are 8 water resources. In some regions some of those are the only possibilities of acquir drinking water for the people. Rapidly changes of chemical composition of the water cause by exogenous influences (climatic factors, organic material - eutrophication) are the reason why is protection of water complicated. Therefore, the cleaning and filtering of water from reservoirs becomes too costly (Elek 2000).

Therefore the quality of water must be ensure by the forest protected zones. There are three protected zones around the Málinec water storage. Structure of forest stands in the first protected zone is the main factor for transformation of precipitation and for water quality preservation. Forest stands in catchment area of the water storage are divided into several functional groups (according to Krečmer, Peřina 1987): water-protected function (1st protected zone), antierosive function (potential surface erosion), desiccation function (retention and retardation of surface runoff, drying), infiltrative function and forming of precipitation (capturing of fog precipitation in crowns, 3rd protected zone).

The main function of forest stands in the 1st protected zone of Málinec water storage is the water-protected function. In therms of eutrophication the best tree species in these zone are Norway spruce stands which are prescribed by low (The Water Act no. 364/2004 Z.z. Decree no. 29/2005 Z.z. about determining the protective zones of water resources). Influence of the schematic, low or crown thinning to stand structure and density is positive or negative. It depends on the main functions of forest ecosystems. The sense of thinning is keeping of trees static stability, their good healthy condition and ensure favourable humus decomposition (Slodičák et al. 2010). The importance of silviculture operations are more important in those conditions because these stands are negatively influenced by their site position–the spruce stands in the low altitude (Matthes, Ammer 2000). Changes of canopy and stand density have the important role (Moravčík 2007, Slodičák et al. 2010).

First measurment in the PRP A was performed and published by Bača (1998) in 1997. The second measurment performed Szeghö in 2007 (unpublished).

The aim of these work is to describe the structure of Norway spruce stands (*Picea abies* [L.] Karst.) in the 1st protected zone of Málinec drinking water reservoir. We can compare results with older measurements of quantitative biometrical characteristics since 2007. In addition, we can compare the values of biometrical signs before and after schematic thinning on the permanent research plots and judge changes of derived biometrical characteristics (crown ratio, slenderness ratio, stand volume and basal area) (Mäkinen, Isomäki 2004). The knowledges about stand structure are good basic for maintaining of stand functions according to site conditions (Holuša et al. 2010). Our theory of this research is based on the assumption that slenderness ratio and crown ratio are changed with changing of stand density. The static stability is very important factor for assessment how can forest stands provide their own role by the water protective function. Secondly, we can judge effect of schematic thinning for keeping static stability. This kind of silvicultural treatment is absolutely unfit in stands with specific (water-protected) function (Slodičák et al. 2010).

Materials and methods

The Málinec water storage is situate in central part of Slovakia between two villages, Málinec and Hámor, in western part of the Slovenské Rudohorie Mts. It was builded on the Ipeľ river and the highest peak of catchment area is Bykov (1110 m a. s. l.). Floodwater line is between 315 and 345 m a. s. l. The catchment area is around 82 km^2. The storage was builded in 1989–1994. The area of storage is 153 ha with capacity 23 mil.m^3 of water.

The area is made by paleozoic limestones as crystalline granitoides, minerals are represented by biotite, quartz and green plagioclases. The most common soil type of catchement are cambisols, in the highest peak also podzolic soils and partly gleyed soils (by the river). The soils contain in average 30% of clay particles. There are mostly light permeable soils.

The average temperature durinng growing season is around 16°C, in ungrowing season 2.3°C. The average annual rainfall is 793 mm (by the storage), in the catchment 680–1100 mm. Average number of days with snow cover is 70–125 from November to March.

Forests of the catchments occupies 4th and 6th altitudinal vegetation zone. The 1st protected zone is around 100 m above maximum water level. In the first 50 m there is only Norway spruce planted, above are planted also European beech (20%) and sessile and red oak (10%) in squares. The samplings of Norway spruce were planted in numbers 2500 pieces per hectar.

Two research plots (A and B) are situated in the compartment no. 908 in the right site of storage. The stands were planted in lines only with Norway spruce. In the lower part of PRP A there is rich understory of black thorn. On both PRPs were made schematic thinninig. There was felled every fourth row of trees down the slopes and also three rows across the slopes. Thinning was made in 2011.

Slope of the plot A is 25° and B 19° on the south exposition (A) and north exposition (B). Both are around 360 m a. s. l. The age of both plots is the same–24 years.

Field measurement

PRP B is new, PRP A were measured also in 2007. Our measurements were made in 2011 and 2012, before and after thinning. The plots sizes are ca 60×49 m and 30×105 m. There are three transekts on PRP A and two transekts on PRP B for better rationalisation of measurements. The sizes of transekts are ca 6×49 m (A) and 5×105 m (A). Plot area is around 0.234 (A) and 0.325 ha (B). In every transekt there are three line of trees. Around the research plots are white stripes on the trees in $d_{1.3}$ (these trees are not part of the plot). All trees on the transekts are numbered with white color in $d_{1.3}$ for better repeated of measurements. On PRPs were measured all trees before and also after thinning.

Measured and considered variables on the whole area of research plots (2007, 2012):

- tree species (only Norway spruce)
- tree diameter in $d_{1.3}$ ($d_{1.3} \geq 0.1$ cm, average of two perpendicular directions), accuracy 1 mm, measured by millimeter caliper; trees under 2 cm were not present)
- tree classes, 5 degree according to Polanský (1955)
- abundance of dead trees after thinning

Another variables measured only on the transekts:

- height of the trees ($d_{1.3} \geq 2$ cm), accuracy 0.1 m, measured by VERTEX III.
- crown height ($d_{1.3} \geq 2$ cm), accuracy 0.1 m, only in tree alive by VERTEX III.

Office data processing

During the data processing were calculate the variables of forest stands:

- abundance of trees per hectar according to tree classes (tree.ha^{-1}). Tree classes: 1–above-level trees, 2–main tree layer, 3–partly lighted trees reaching to the main layer, 4–showed trees, 5–standing dying or dead trees
- abundance of trees (tree.ha^{-1}) according to diameter classes (diameter class has 4 cm, number of class means its median value: 2 (0.1–4 cm), 6 (4.1–8 cm), 10 (8.1–12 cm), 14 (12.1–16 cm), 18 (16.1–20 cm), 22 (20.1–24 cm), 26 (24.1–28 cm)
- creation of height curves according to average height of stands and diameter classes
- crown ratio (relation between crown lenghts and height of trees) (%)
- slendernesss ratio (relation between height of trees and $d_{1.3}$) (%)
- basal area divided according to tree classes per hectar (m^2)
- growing stock according to tree clesses per hectar (m^2)

For the structural diversity analysis of these stands we used the diameter differentiation index (TM) according to Füldner (1995) and the Gini hight differentiation index (Dixon et al. 1987). We use 5 level scale of TM index according to Aguirre et al. (1998). The principle of this is to assess of 3 neighboring trees (T_1, T_2, T_3) of central tree.

Results

In the PRP there were 2454 and 2044 trees before thinning, it is less than in 2007 (2546 tree.ha^{-1}). In 1997 there were 2953 tree.ha^{-1} (A). The most common of tree classes is second tree class in which tree number down against 2007 for 518 tree.ha^{-1} (A). In 2007 there were much more trees in 4. tree class (from 115 to 60). The power of thinning was ca 25%, mostly from 2. tree class. The conversion rate for hectar number is 4.27 (A) and 3.17 (B). Abundance of trees are shown in Tab. 1 and Fig. 1, 2.

From Fig. 1 and 2. is evident that power of thinning is on both PRPs very similar. The curves of diameter classes before and after thinning are situated in very similar position and amount of removed trees is comparable (cca 200 tree. .ha^{-1} in 14. and 18. diameter class). However, initial abundance of trees were different. It means maintaining of trees diameter distribution.

Tab. 1: Abundance of trees according to tree classes and year of measurement (A, B)

Tree class	2007		Before thinning		After thinning				Power of thinning			
	tree.ha^{-1}	%	tree.ha^{-1}	%	tree.ha^{-1}	%	% Σ before	% before	tree.ha^{-1}	%	% Σ before	% before
1	679	26.7	316	12.9	222	12.0	9.0	70.2	94	15.5	3.9	29.6
2	1226	48.2	1744	71.1	1343	72.7	54.8	77.1	401	66.2	16.3	23.0
3	500	19.6	244	9.9	201	10.9	8.2	82.4	43	7.1	1.7	17.5
4	115	4.5	60	2.4	22	1.2	0.9	36.7	38	6.3	1.5	63.3
5	26	1.0	90	3.7	60	3.2	2.4	66.7	30	5.0	1.3	33.2
Together	2546	100.0	2454	100.0	1848	100.0	75.3		606	100.0	24.7	
1			460	22.5	292	19.3	14.3	63.4	168	31.6	8.2	36.6
2			1377	67.4	1105	73.1	54.0	80.2	273	51.2	13.3	19.8
3	no data		121	5.9	60	4.0	3.0	50.0	60	11.2	3.0	50.0
4			51	2.5	25	1.7	1.2	50.0	26	4.8	1.3	51.2
5			35	1.7	29	1.9	1.4	81.8	6	1.2	0.3	18.2
Together			2044	100.0	1511	100.0	73.9		533	100.0	26.1	

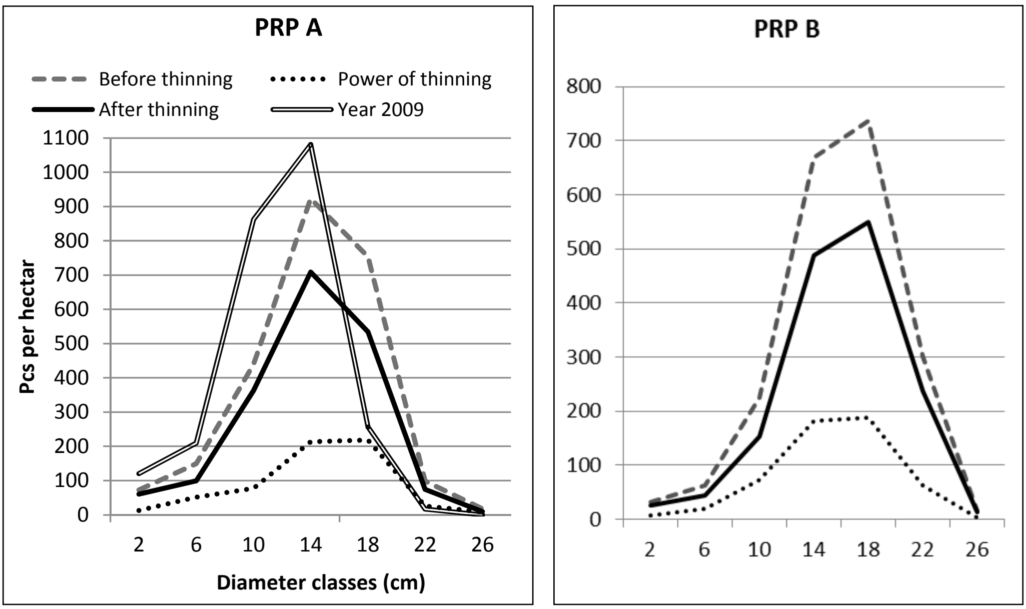

Fig. 1 and 2: Abundance of trees according to diameter classes in 2007 and 2012 (tree.ha^{-1}).

Here can be shown only stand height curve after thinning (Fig. 3, 4) because stand height was not measured in 2007 and 2011 (before thinning). Measured trees were ≥ 2 cm. The most of trees were in interval from 10 to 14 m (A) and from 11 to 16 m (B). A lot of trees in lower diameter classes are higher than those from lower diameter classes. It suggest their higher growth vitality.

Characteristics of static stability resulted from mechanical characteristics of trees and are represented by slenderness ratio, crown ratio, tree and crown height (Tab. 2).

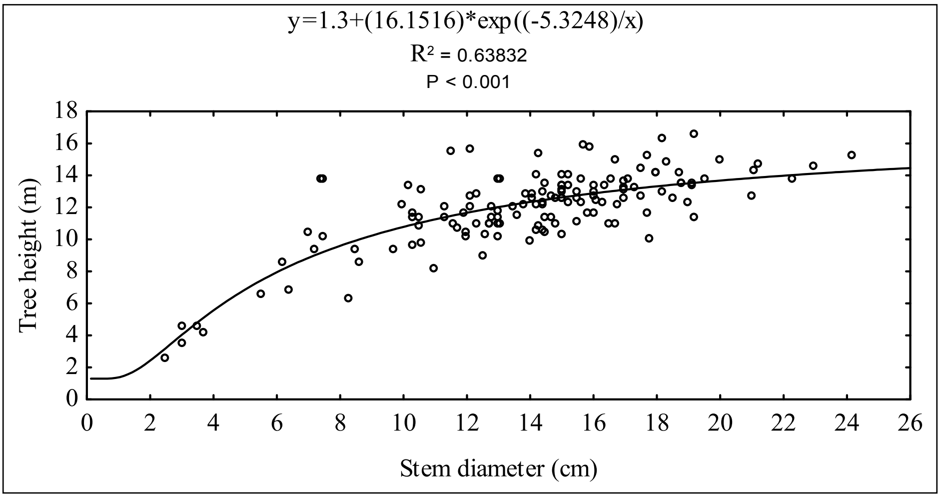

Fig. 3: Stand height curve after thinning according to diameter classes (PRP A).

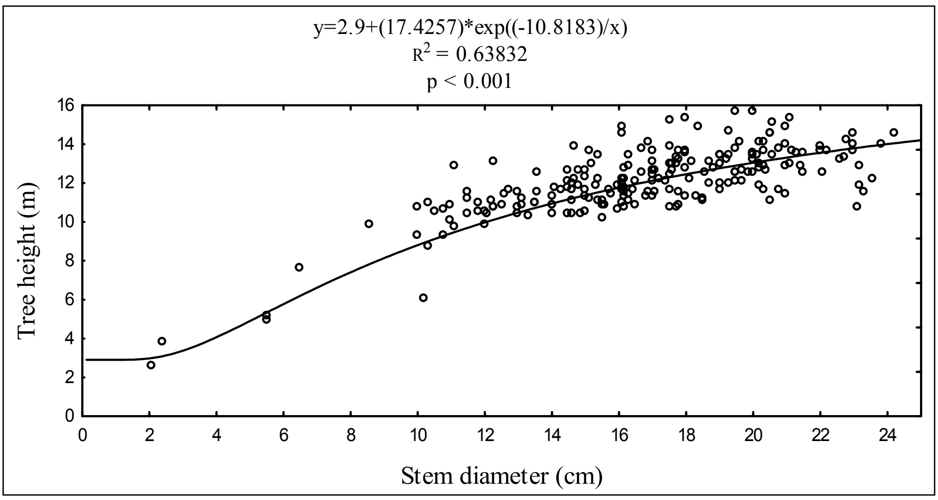

Fig. 4: Stand height curve after thinning according to diameter classes (PRP B).

Between crown height of 2007 and 2012 is very strong differentiation. There are too large diferences by contrast of relatively short period (5 years). We can not evaluate crown ratio, slenderness ratio and tree height bacause in 2007 were not measured height of trees. These stands are young and the slenderness ratio is getting higher as is normal for keeping static stability. According Vološčuk (2001) they are less stable (A) and medium stable (B). It is evident that this ratio is the worst by the lover tree classes. The crown ratio is around 53 % (A) and 64 % (B), what is much better than slenderness ratio. However, the crowns are shortes than it is desirable in this age of stands (Slodičák et al. 2010). PRP B have generally better parameters of static stability what is supported also slower height of trees. Fluctuations of standard deviation are very strong (slenderness ratio, crown ratio) because individual systematic thinning was neglected.

Relation between trees can be explained by the abundance of standing dead trees. The abundance of dead trees is shown in Tab. 3.

While in 2012 the most amount of dead trees were in lower tree classes (3–5), in 2007 were it in higher classes (1–3). Therefore the vertical structure is changed in favor to homogeneous structure with horizontal tree layer already at those young-aged stands.

Power of thinning were in second tree class around 66 % tree.ha^{-1} (A) what were 67 % of basal area (A), on PRP B were power 51 tree.ha^{-1} what

Tab. 2: The selected characteristics of stand stability (A, B)

Tree class	Tree height (m)		Crown height (m)				Slenderness ratio (u. l.)		Crown ratio (u. l.)	
	2012 (after)		2007		2012 (after)		2012 (after)		2012 (after)	
	Mean*	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	15.3	0.71	1.6	0.92	7.3	1.36	89.7	21.01	52.5	7.45
2	12.4	1.97	1.5	0.84	5.7	0.96	87.4	21.79	54.2	12.21
3	9.4	0.91	1.6	0.98	4.6	1.13	92.5	22.18	51.0	11.50
4	6.4	0.10	0.7	0.31	4.9	0.00	97.0	21.14	24.6	0.00
5	2.3	1.00	0.8	0.21	-	-	122.0	16.15	-	-
Average	11.9	2.58	1.5	0.90	5.7	1.57	89.3	20.46	53.4	10.37
1	14.1	0.71			4.7	0.70	72.5	9.13	66.5	4.30
2	11.7	0.82			4.2	1.04	73.9	13.07	63.9	9.11
3	9.1	0.75	no data		3.6	1.10	97.0	13.34	60.4	12.19
4	5.4	0.51			2.8	1.01	81.1	15.26	50.0	13.32
5	3.2	0.60			-	-	141.1	17.26	-	-
Average	12.1	1.81			4.3	1.14	74.9	14.11	64.3	9.58

*Mean = Average Values, SD = Standard Deviation

were 45% of basal area (Tab. 3, 4). Basal area was changed from 42 m^2 before thinning to 31 m^2 after thinning what were similar position as in 2007. The basal area were changed in favor of second tree class, the area of first and third tree class decreased and the stand ever more consist as single layer. Basal area is showed in Tab. 4. The power of thinning were around 25% (every 4. row) from basal area. The growing stock can be determined only in year 2012 because in 2007 was not measured tree height.

Around 20% from growing stock (Tab. 5) were removed. Schematic thinning are not suitable for this forest bacause removal of whole rows have negative influence to water regime and it icreases surface runoof. The stand volume is changed in favor to second tree class (74% of growing stock include 2. tree layer) and it have influence to levelling of stand height structure.

Average values of TM index (A/B) are T_1=0.246/0.253, T_2=0.222/0.218 and T_3=0.253/0.265. It means small level of diameter differentiation between trees on transekts. The values of Gini index (A/B) are 0.08909/0.09521 what means too small height differentiation. This stand is relatively young. Small diameter and hight differentiation is typical for plant spruce monocultures without conceptual silvicultural operations.

Discussion

Schematic thinning in water-protected areas and protected zones is not typical silvicultural operation. For maintaining of required water quality is better silvicultural system when is full area of the 1st protected zone covered by trees. Because of their much better influenced of soil characteristics (Bátor, Gubka 2011). Stand stocking should be around 0.7 (it is around 40% from table value) bacause of faster humus decomposition (Slodičák et al. 2010). The power of

Tab. 3: Abundance of standing dead trees according to tree classes

Tree class	2007	2012 (after thinning)	
	PRP A	PRP A	PRP B
1	4	-	-
2	25	-	3
3	9	21	6
4	4	10	3
5	13	56	25

Tab. 4: Basal area according to tree classes (m²) (A, B)

Tree class	2007		Before thinning		After thinning				Power of thinning			
	m²	%	m²	%	m²	%	%Σ before	% before	m²	%	% Σbefore	% before
1	11.4	36.5	9.1	21.7	6.1	19.8	14.3	66.7	3.2	28.3	7.4	34.3
2	16.6	53.1	30.9	73.3	23.1	75.1	55.4	75.7	7.4	67.1	17.9	24.3
3	3.1	10.0	1.8	4.3	1.5	4.7	3.5	81.5	0.3	3.0	0.8	18.5
4	0.1	0.4	0.2	0.5	0.1	0.2	0.2	32.6	0.1	1.2	0.3	67.4
5	0.0	0.0	0.1	0.2	0.1	0.2	0.1	57.6	0.1	0.4	0.1	42.4
Together	31.2	100.0	42.1	100.0	30.9	100.0	73.3		11.1	100.0	26.3	
1			14.5	33.3	9.3	28.4	21.3	63.9	5.2	48.1	12.0	36.0
2			27.7	63.8	22.8	69.8	52.4	82.2	4.9	45.6	11.3	17.8
3	no data		1.1	2.4	0.4	1.4	1.0	42.5	0.6	5.5	1.4	57.5
4			0.2	0.4	0.1	0.3	0.2	44.1	0.1	0.8	0.2	45.7
5			0.0	0.1	0.0	0.1	0.0	79.5	0.0	0.0	0.0	20.5
Together			43.5	100.0	32.6	100.0	74.9		10.8	100.0	24.9	

Tab. 5: Growing stock according to the tree classes (m³) (A, B)

Tree class	Before thinning		Power of thinning				After thinning			
	m³	%	m³	%	% Σ before	% before	m³	%	% Σ before	% before
1	108.1	23.4	38.1	38.8	8.2	35.2	70.1	19.1	15.2	64.8
2	324.5	70.3	54.7	55.6	11.0	16.8	273.6	74.5	59.3	84.2
3	27.2	5.9	4.5	4.6	1.0	16.7	22.6	6.2	4.9	83.3
4	1.2	0.3	0.8	0.8	0.2	61.9	0.5	0.1	0.1	38.1
5	0.5	0.1	0.2	0.2	0.0	34.1	0.3	0.1	0.1	65.9
Together	461.5	100.0	98.3	100.0	20.4		367.1	100.0	79.6	
1	140.1	40.0	40.6	56.9	11.6	29.0	99.5	35.7	28.4	71.0
2	205.0	58.7	28.4	39.8	8.1	13.9	176.6	63.4	50.5	86.2
3	4.2	1.1	2.1	2.9	0.6	49.9	2.1	0.8	0.6	50.1
4	0.6	0.2	0.3	0.4	0.1	44.8	0.4	0.1	0.1	55.3
5	0.1	0.0	0.0	0.0	0.0	57.9	0.0	0.0	0.0	41.3
Together	350.0	100.0	71.4	100.0	20.4		278.6	100.0	79.6	

schematic thinning around Málinec storage is only 21% from growing stock. Schematic thinning has also another negative properties–creating of forest edges. López (2006) suggested that open forest edge has negative influence to vertical stand structure and along the stand edge can be situated more dead trees as in fully covered areas. In the stands the edge effects is evident in the zone 4–6 m fom corridor (Mäkinen at al. 2006). In Málinec will be these principles probably shown in few next year.

Bátor, Gubka (2011) evaluated the structure of similar old spruce stand in west site of Málinec storage. Terrain of this sites is much bouldering and mixed with deciduous trees. The average tree hight is there lower (9 m) and trees are steadier (Sx = 0.9 toward 2.58). It is interesting that crown height is in our research plot much more higher, around 5.7 m, similarly slenderness ratio (89% (A) toward 75%) and crown ratio (53% (A) toward 79%) are worse. We believe that spruce monocultures without mixturing of deciduous trees in upper tree cover have worse characteristics of static stability. However, deciduous shrubs in understory influenced forming of spruce crowns probably negatively (different between PRP A and B).

Importance role in homogeneous Norway spruce stands have spacing of plants. Štefančík (2013) says that mortality of trees in spacing 2×2 m is around 823 psc. It was in Málinec 500 tree.ha^{-1} (before thinning), so decreasing of abundance was not so strong. Holodynski (1995) considers schematic thinning as useful tool for increasing of stand static stability according to slenderness ratio. This ratio is in Málinec 84–90% (1–3 tree class). It means that the stands have bad static stability (according to Vološčuk 2001). Stability according the crown ratio (53–64% in 1–3 tree class) is quite better but not the best. It means the lenghts of crowns are better than total mechanical ability of trees (stems are too much slender).

Mráček, Pařez (1986) claims that schematic thinning is useful only in very young spruce stands where the boundary spacing is 1.5×1.5 m. When we consider these facts using of schematic thinning do not shown improving of static stability because it effected only the part of research area. The characteristics of individual trees are not taken into account. Slodičák et al. (2010) recommended application of low thinning with negative selection. Though in Málinec are the stands with neglected silvicultural operations. It causes decreasing of diameter increament, increasing of slenderness ratio and than deterioration of the stand static stability (Slodičák et al. 2010). The authors recommended to applicate thinning with power to 10% (for the prevention against damage by wind). The power of thinning in Málinec is than too strong. The understory of blackthorn on PRP A may caused that the stems are relatively slim and during their younger age were growing up for light.

Norway spruce stands in the protected zones of Málinec storage can be compared also according to the mixture of deciduous trees. Gubka (2011) states that in the same aged stand in the west site are worse values of slenderness ratio–99% but better values of crown ratio–91%. Crown lenght is very important indicator of the stand static stability. There is assumption that deciduous trees have positive influence to lenghts of crowns and are important element of the stand stabilisation. According to the yield tables (Kolektív 1992) the growing stock of 25 year stand would be 147 m^3.ha^{-1}, what is less than in Málinec (461 A/350 B m^3 before thinning, 367 A/280 B m^3 after thinning). The value of basal area is according yield tables lower with comparing of current state in Málinec (27 m^2).

Conclusion

Thinning in Norway spruce stands should by carried out mainly for increasing of stand stability represented by slenderness and crown ratio (Štefančík 2013). These properties are much more urgent in protected zones around water-supply storages, where is necessary permanent existence of stands (Slodičák et al. 2010). Differentiation of trees according to age and vertical structure is base for future stability (Holuša et al. 2010). Parameters of static stability are in Málinec according to age of stands substandard. Schematic thinning does not solve either parameters of crowns neither stand height. Its importance is only regulation of growing stock is choosen parts of stands (Mäkinen, Isomäki 2004, Mäkinen et al. 2006). High growing stock and quite high basal area in Málinec suggest that there is a lot of too slim trees. Breakdown of stands by felled lines caused predisposition of stand for damage. There were removed a lot of trees from 3 and 4 tree classes and stand became more homogenous (according to diameter classes and tree classes). Average crown height is rapidly changed in comprison with 2007 because of high density of stands. That unfavorable situation is possible to change only by choosen of individual trees with regard to supporting of all trees classes. But on whole stand area, not only in ineffective felled lines.

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