THE VITALITY OF *TAXUS BACCATA* L. IN FOREST STANDS IN SLITERE NATIONAL PARK, LATVIA

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Abstract

Taxus baccata L., a relic of the Atlantic flora, is fourth of Latvia's coniferous tree species, and it is endangered with a limited utilization because of its rare distribution. Evaluation of species condition, tree vitality and unfavourable factors influencing tree growth is crucial to improve species status. Measurements of forest stands with *T. baccata* autochthon and anthropogenic populations were collected, crown condition was rated, damages of trees were assessed, and projective cover of vegetation (canopy closure, shrub and herbaceous layer) was evaluated to determine the effect on *T. baccata* populations in Slitere National Park, Latvia. Main results show that factors strongly influencing the vitality of *T. baccata* are soil reaction and light conditions. Mostly the light conditions were determined by the canopy closure. Major conditions of shade negatively influenced the vitality and distribution of *T. baccata*.

Key words: *T. baccata*, vitality, light conditions, crown parameters, soil pH.

Introduction

Nowadays it is difficult to imagine forest stands with up to 28 m high trees of *T. baccata* (Thomas & Polwart, 2003). Nevertheless, not long ago, *T. baccata* was a common component of forest stands across Europe – from Fennoscandia to Mediterranean region and Caucasia (Dovčiak, 2002). Valuable properties of wood were the cause of intensive cutting of large arrays of millennial forest stands of *T. baccata* (Riekstiņš, 1986; Thomas & Garcia-Martí, 2015). Further several reasons poorly impacted the distribution of *T. baccata*: utilization by humans, destruction of forests as a result of wars, fragmentation of the populations, climate change (Riekstiņš, 1986; Thomas & Polwart, 2003).

The north-east borderland of natural distribution of the species is in Latvia (Riekstiņš, 1986). It grows mainly on coastal lowland: distribution is limited by mild oceanic climate and specific edaphic conditions (Riekstiņš & Laiviņš, 1984; Thomas & Garcia-Martí, 2015; Thomas & Polwart, 2003). The largest autochthon population of *T. baccata* in the country is in Slitere National Park, where it has been under different protection regimes since 1921 (Riekstiņš, 1981). Population is located on approximately 7 km long and 0.5-1 km wide region along hillside of Zilie kalni, including three geologically diverse structures: moraine, a bluff of the Baltic Ice Lake and abrasion-accumulation low land (Blūms, 1987).

Among other coniferous tree species *T. baccata* is highly distinguished because of its eminent vitality and ecological plasticity which allows it to reach extremely old age – up to 2000 years (Thomas & Garcia-Martí, 2015). Although it can adapt to changes, it has become endangered in a number of European countries, including Latvia. Despite its shade-tolerance, insufficient light conditions and prolonged shading can decrease the vitality of the tree (Devaney *et al*., 2015; Riekstiņš, 1981). Light conditions are influenced by dominant trees within the forest stand, shrub layer and the density of forest stand (Dovčiak, 2002). Some countries have developed special forestry methods of stand thinning to increase the light conditions. It results as an increase of crown dimensions of *T. baccata*, which also increases the vitality of the tree (Vacik *et al*., 2001). Another negative impact on *T. baccata* well-being is density of herbivore population: often they tend to feed on tree leaves, shoots and bark and they also strongly impact the natural regeneration of species by fully exterminating the seedlings (Blūms, 1982; Thomas & Polwart, 2003).

One of the essential factors influencing the vitality of *T. baccata* is soil reaction (pH) (Riekstiņš & Laiviņš, 1984). It requires alkaline soils, most favourable are sandy loam and clay with fine drainage and suitable moisture levels. Another limiting factor is climate (Thomas & Garcia-Martí, 2015; Thomas & Polwart, 2003). As a species loving warmth, high relative air humidity and mild oceanic climatic conditions, *T. baccata* is an indicator species for climate change (Thomas & Garcia-Martí, 2015).

The aim of the study was to determine which factors – stand density, soil pH, damages, light conditions and projective cover of vegetation – influenced the vitality and distribution of *T. baccata* in Slitere National Park.

Materials and Methods

Data was collected in Slitere National Park. To determine what conditions are favourable for distribution of *T. baccata*, three forest stands with anthropogenic plantations (Zviedri – ZV (*Myrtilloso-polytrichosa*), Juši – JU (*Oxalidosa*, *Aegopodiosa*, *Myrtilloso-polytrichosa, Dryopterioso-caricosa, Filipendulosa, Myrtillosa turf.mel., Oxalidosa turf.mel.*), Dadzīši – DA (*Oxalidosa*)) and three autochthon provenances (Vilku līnija – VL

(*Dryopterioso-caricosa*), ‘Jaunlīdumu’ grava – JG (*Aegopodiosa*), Daiķu īvju liegums – DIL (*Aegopodiosa*)) of *T. baccata* were selected for data collection. 22 sample plots (500 m^2) were made to collect dendrometric measurements (height, diameter at breast hight (DBH)) of forest stand to determine stand variables, such as forest stand basal area, growing stock and density and if or how it affects development and growth of *T. baccata*. In addition, for each *T. baccata* individual diameter at ground level, crown length and diameter were measured, foliage transparency (FT), crown density, crown dieback (CD) was evaluated to establish favourable light conditions for species. Crown dieback helps to evaluate if there are significant damages caused by insects, wind, unfavourable growing conditions or herbivores. Dying of fine twigs in the outer or upper part of the tree were counted, if it could be determined that dying began at the terminal part of the branch (Schomaker *et al*., 2007). Indices are related to tree growth, survival and vitality. To determine *T. baccata* potential to obtain and exploit solar energy (Devaney *et al*., 2015), composite crown volume (CCV) was calculated *(Schomaker et al*., 2007).

In order to determine the overall status of the species, tree vitality was assessed. Vitality of trees was estimated visually in grades:
vigorous (3) – healthy tree with symmetrical crown, dense foliage, without observed damages or negative impact of damage on tree growth;
supressed (2) – healthy but damaged tree or with signs of possible competition or other unfavourable impact of growing conditions, medium foliage density;
low-vigour (1) – unhealthy tree with distinct damages, high foliage transparency, underdevelopment in growth, dissymmetrical crown, adventive buds;
withered (0) – dry, dead tree with no indication of growth.

Occurrence of damages (biotic – caused by ungulates, entomological, phytopathological and abiotic) was established to determine if they impact the vitality of *T. baccata*.

Soil samples (200) were collected from upper layer of soil (0–20 cm) and below (20–40 cm) to establish favourable soil reaction (pH) levels for *T. baccata*. Soil reaction was determined potentiometrically in laboratory. For each sample two tests were made with distilled water and two with potassium chloride (KCl). The average variables were calculated to determine the amplitude of soil reaction in which T. *baccata* occurs.

Growing conditions in and between the objects were compared using Ellenberg indicator values. The projective cover of vegetation was measured in summer. It was measured in forest stand layer (canopy closure, E3), shrub layer (E2), herbaceous layer (E1). Percentage of all layers was calculated, to determine, if it influences the vitality of *T. baccata*. Linear Regression Analysis was used to indicate if and how the factors (light, moisture, soil reaction, nitrogen) interacts with analysed groups (study areas) (Lund & Lund, 2018a). Analysis of variance (ANOVA) was selected as statistical technique to compare the means of factors that are defined by single categorical variable (Lund & Lund, 2018b) and to estimate if the factors had a significant impact on study areas. Post-hoc test was used to estimate if there are essential differences between study areas. An indicator of similarity between study areas was attached.

Spearman’s rank correlation coefficient r_s was used to determine if there is a correlation between the composite crown volume and factors determining growing conditions, between the average forest stand density and the number of *T. baccata* individuals per hectare and between the average forest stand density and the average DBH and diameter at root collar.

Results and Discussion

The study was conducted in old, broadleaved and mixed forest stands, typical in nature reserve area which is located in the south part of Slitere National park. Forest stands on mesotrophic, meso-eutrophic and eutrophic soils were surveyed. In general, all forest stands in study areas were high density, rich in species diversity, fertile in terms of soil conditions with medium or high moisture levels. The most common tree species in the study areas were *Alnus glutinosa* (L.) Gaertn. and *Picea abies* (L.) H.Karst. Overall, the state of *T. baccata* populations, both autochthonic and anthropogenic were satisfactory with some exceptions. Species distribution range widely in different geological structures; however, the edaphic conditions were similar in terms of pH levels.

The average forest stand parameters are summarized in Table 1. All analysed forest stands were full density stands, except for forest stand in study area ‘Jaunlīdumu’ grava (JG), respectively 0.7. The drying out of large dimension trees (*Fraxinus excelsior* L. and *Ulmus glabra* Huds.) had resulted in widespread of openings. The second lowest forest stand density was found in study area Vilku līnija (VL), respectively 0.97: the reason was a forest site type – *Dryopterioso-caricosa*. Forest stand grows on 2.25 m deep peat (*Eutric Rheic Histosol* (*Hyperorganic Lignic*)) layer with alkaline underground outflows, which causes openings in the forest stand where moisture level is too high for tree survival. The high indexes of density could be a result of old, natural, undisturbed forest stands.

Table 1

Dendrometric parameters of forest stands with *Taxus baccata*

Object ID	*Basal area*, m^2 ha^{-1}	*Growing stock*, m^3 ha^{-1}	*Density*
ZV	30.8	288.7	1.09
JU	30.8	305.8	1.03
DA	30.5	285.2	1.05
VL	27.1	243.7	0.97
JG	20.7	217.5	0.70
DIL	33.1	337.7	1.31

The percentage of healthy *T. baccata* individuals in study areas (Table 2) indicates general state of vitality. Study areas with autochthon provenance of *T. baccata* in forest stands had the highest proportion of healthy trees, because of preferable growing conditions. The highest proportion of healthy individuals were in study area Daiķu īvju liegums (DIL) (80%), but it should be taken in account that there were only 33 individuals of *T. baccata* per hectare. DBH and diameter at root collar range widely (respectively 0.4 (DA) – 26.2 cm (VL) and 0.6 (VL) – 34.8 cm (VL)) due to low vigour or high level of natural regeneration of species. If second, it shows strong vitality of the population. It should be taken in account that diameter at root collar is essentially influenced by the form of the tree: *T. baccata* tends to form as a shrub or it can have more than one dominant stem (Thomas & Polwart, 2003). The height of *T. baccata* varied between 0.37 m (JU) and 11 m (JG) which could be interpreted as a result of different growing conditions. It also could characterise the state of natural regeneration.

Higher density of forest stand decreased the distribution of *T. baccata*: a significant negative correlation (r_s = -0.8678; $p < 0.001$) was found between the average forest stand density and the number of *T. baccata* individuals per hectare (Alavi *et al*., 2020; Dovčiak, 2002). We also found a positive correlation (r_s = 0.6942; $p = 0.01$)) between the average density of forest stand and average DBH and diameter at root collar. Density of forest stand influenced the microclimatic conditions: forest stand acts as a shield for severe frosts.

The average CCV characterizes crown dimensions, density and biomass. Increase of the volume intensifies receiving the sunlight and vice versa, which is vital for tree to provide itself with chemical energy (Devaney *et al*., 2015). Largest average CCV was found in study area Daiķu īvju liegums (CCV = 4.9 ± 12.27 m^3), but it should be taken in consideration that the occurrence of *T. baccata* in this study area was only 33 trees per hectare. Second largest CCV was found in Vilku līnija (CCV = 3.5 ± 9.7 m^3): it could indicate a vigorous population with favourable light conditions (Devaney *et al*., 2015). The influence of surrounding trees and the level of competition could be a cause for smallest CCV found in Dadzīši (CCV = 1.9 ± 2.4 m^3) (Thomas & Garcia-Martí, 2015). A significant negative correlation r_s = -0.627 ($p = 0.02$) was found between the average forest stand basal area and CCV, indicating that the dimensions of *T. baccata* crown were undersized in forest stands with high density index: being slow growing but tenacious species, *T. baccata* can withstand unfavourable conditions (Thomas & Polwart, 2003).

The average index of foliage transparency (FT) is

Table 2

Vitality of *Taxus baccata* and average dendrometric and crown variables

Object ID	ZV	JU	DA	VL	JG	DIL
Healthy individuals, %	69	43	34	78	78	80
T. baccata trees per hectare	100	180	293	255	266	33
$D_{1,3}$, cm	5.76 ± 2.81	3.52 ± 3.32	3.95 ± 2.4	6.18 ± 4.07	5.72 ± 3.99	7.58 ± 3.06
D_{sk}, cm	9.61 ± 3.69	6.46 ± 4.69	8.84 ± 3.3	10.70 ± 5.89	11.13 ± 6.37	11.62 ± 4.59
H, m	3.88 ± 1.39	2.96 ± 1.6	3.47 ± 1.2	5.27 ± 2.02	4.03 ± 2.53	6.00 ± 3.37
Composite crown volume, m^3	2.0 ± 4.2	1.7 ± 7.73	1.9 ± 2.4	3.5 ± 9.7	2.6 ± 9.72	4.9 ± 12.27
Foliage transparency, %	74.5 ± 24.24	71.0 ± 28.07	55.0 ± 25.13	68.3 ± 20.66	65.3 ± 15.76	37.5 ± 10.95
Crown dieback, %	54.3 ± 38.4	64.8 ± 40.91	14.7 ± 30.15	48.0 ± 23.8	49.3 ± 15.4	5.0 ± 2.74

known to negatively correlate with tree vitality and health (Schomaker *et al.*, 2007). Almost all of the study sites where FT index indicated dense crown (Daiķu īvju liegums (37.5 ± 10.95%), Dadzīši (55 ± 28.07%), 'Jaunlīdumu' grava (65.3 ± 15.76%) and Vilku līnija (68.3 ± 20.66%)) were autochthon provenances. Therefore it implies favourable light conditions. A significant negative correlation $r_s = -0.6719$; ($p = 0.01$) has been found between the CCV and FT *(Schomaker et al.*, 2007).

Crown dieback (CD) shows the amount of crown parts that has recently died. The largest index (CD = 64.8 ± 40.91) was found in *T. baccata* plantation Juši (JU), that could indicate early signs of stress (Schomaker *et al.*, 2007). In comparison to that, remaining populations with lower CD indexes could imply more favourable conditions.

The largest proportion of vigorous trees were situated in forest stands with autochthon populations of *T. baccata* (Vilku līnija (78%), 'Jaunlīdumu' grava (78%), Daiķu īvju liegums (80%)). A considerable number of vigorous individuals were in study area Zviedri (ZV) (69%) – an anthropogenic plantation. It indicates that there were favourable growing conditions for *T. baccata*. The smallest proportion of withered trees are in Vilku līnija (2%) and 'Jaunlīdumu' grava (2%), but in Daiķu īvju liegums and Dadzīši (DA) withered trees were not observed. In Dadzīši individuals of *T. baccata* showed a strong vitality although trees were severely damaged by herbivores and abiotic factors, such as wind. In Daiķu īvju liegums no withered or low-vigour class individuals were observed. But it should be taken in consideration that only 6 individuals of *T. baccata* were found within the sample plots. In study areas Zviedri, Juši, Vilku līnija, 'Jaunlīdumu' grava most of low-vigour trees were small in dimensions and there were phytophatalogical damages observed, such as withering of shoots, yellowing of leaves and defoliation. Figure 2 shows further details of occurrence of damages.

The average values of soil reaction (pH) are summarised in Table 3. Almost all pH levels in forest stands with autochthon populations of *T. baccata* were higher – more alkaline than acidic. It represents the favourable pH levels for *T. baccata*: $pH_{KCl} = 5.41 \pm 0.3$ – $pH_{KCl} = 5.79 \pm 0.5$ (0–20 cm) and $pH_{KCl} = 5.52 \pm 0.11$ – $pH_{KCl} = 5.8 \pm 0.22$ (20–40 cm). Similar results were found in study area Zviedri (ZV): $pH_{KCl} = 5.24 \pm 0.58$ (0–20 cm) and $pH_{KCl} = 5.73 \pm 0.45$ (20–40 cm). In Slitere National Park *T. baccata* range widely, displaying the ability to adapt (respectively pH_{KCl}: 3.36–7.02 in the upper layer of soil and 3.73–6.7 in deeper layer of soil). In general, it is observed that soil reaction in upper layer of the soil is more acidic than in deeper layer. Figure 1 represents the vitality and occurrence of *T. baccata* in relation of soil pH levels. The litter of dominant stand and the advanced growth creates layer of possibly acidic conditions (Amacher *et al.*, 2007), whereas in deeper layers of soil the hydrogen ions (H+) are leaching through. The fine roots of *T. baccata* responsible for absorbing nutrients and water are situated in the upper layer of soil; therefore, the pH levels in the surface of soil are most crucial. High pH levels in the upper layer of soil had positive effect on *T. baccata* vitality. Figure 1 represents the link between pH levels and CCV. A significant positive correlation $r_s = 0.7241$ ($p < 0.001$) between the CCV and the levels of pH in the upper layer of soil (0–20 cm) was found.

The occurrence of damages observed in forest stands with *T. baccata* in Slitere National Park is summarised in Figure 2. It shows that increase of damages caused by ungulates reduces the composite crown volume. Most observed damages were caused by ungulates: herbivores, such as *Cervus elaphus* L., *Capreolus capreolus* L. and *Alces alces* L. The

Table 3

Soil reaction in study areas in Slitere National Park

Soil reaction (pH)	Object ID					
	ZV	JU	DA	VL	JG	DIL
pH_{H2O} (0–20 cm)	6.20 ± 0.35	5.94 ± 0.82	5.35 ± 0.41	6.71 ± 0.26	6.56 ± 0.34	6.26 ± 0.32
pH_{KCl} (0–20 cm)	5.24 ± 0.58	4.94 ± 0.92	4.28 ± 0.38	5.67 ± 0.28	5.79 ± 0.5	5.41 ± 0.3
pH_{H2O} (20–40 cm)	6.44 ± 0.4	5.99 ± 0.65	5.60 ± 0.41	6.80 ± 0.27	6.55 ± 0.25	6.45 ± 0.23
pH_{KCl} (20–40 cm)	5.73 ± 0.45	5.06 ± 0.9	4.52 ± 0.48	5.8 ± 0.22	5.53 ± 0.3	5.52 ± 0.11

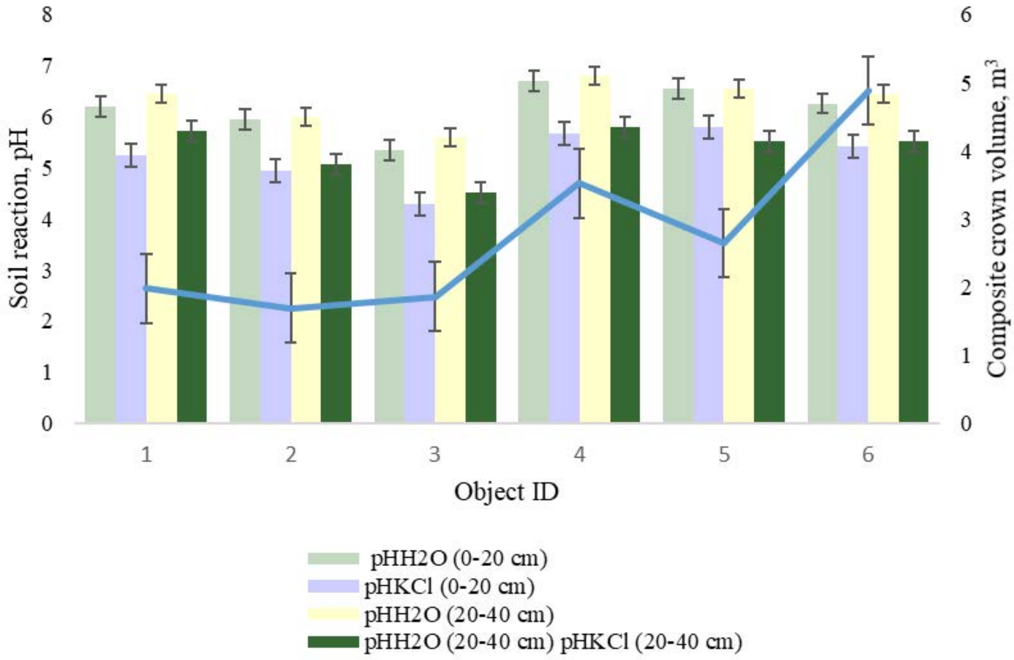

Figure 1. The vitality of *Taxus baccata* in relation of soil reaction in Slitere National Park.

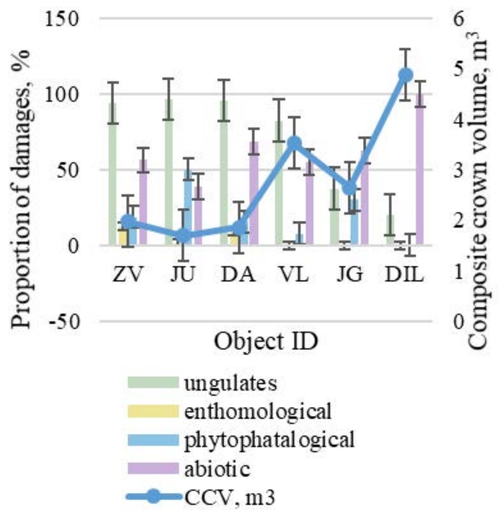

Figure 2. The occurrence of biotic and abiotic damages of *Taxus baccata* in relation with composite crown volume in Slitere National Park.

damages they caused were bit shoots and branches, teared bark, chipped branches or even the top of the tree. On some occasions there were signs of damaged root system, caused by hoofs. The least observed were enthomological damages, such as damages, where insects had been feeding on the bark or leaves of *T. baccata*, which indicates low impact on the vitality of tree. In some of the studied areas a considerable amount of phytophatalogical damages were found, such as die-back of young shoots and yellowing of the leaves. It was observed, that phytopathological damages were widely distributed in anthropogenic plantations, which indicates, that the growing conditions were not suitable for *T. baccata*; therefore, the resistance to pathogens was low. Commonly observed were abiotic damages mostly caused by wind: often fallen deadwood supressed *T. baccata*. Still, most of the trees were able to continue their growth: a new dominant shoot was observed, or the tree became more shrub-like. Verifying the relationship between damages and CCV, significant negative correlation $r_s = -0.787$ ($p = 0.002$) was found only between the CCV and the damages caused by ungulates. The frequent occurrence of damages caused by herbivores could affect the distribution and vitality of *T. baccata* even more in the future (Thomas & Garcia-Martí, 2015).

The projective cover of vegetation (Table 4) was analysed using Ellenberg indicator values. Indices indirectly imply the growing conditions, based on the environmental necessities of the species. The conditions of light, moisture, soil reaction and nitrogen in all study areas were determined. Similarity between the study areas Zviedri, Juši, Dadzīši and 'Jaunlīdumu' grava was explained by a similar – medium amount of herbaceous plants. Significant distinction was found in Vilku līnija where the cover of vegetation was 100% due to distinctive charesteristics of forest site type *Dryopterioso-caricosa* where extremely wet areas were covered by hydrophilic species and the light conditions were sufficient. In Daiķu īvju liegums, the cover of vegetation was only 41% (Table 4), indicating low light conditions, probably caused by dense shrub layer. Similar moisture conditions were found in herbaceous layer in all study areas except Dadzīši and Vilku līnija. In the first area, the moisture

Table 4

Ellenberg indicator values in study areas in Slitere National Park

Object ID	Light	Moisture	Soil reaction	Nitrogen
ZV	3.87^{a}	5.29^{ab}	4.34^{a}	5.18^{ab}
JU	4.40^{a}	5.95^{ab}	4.62^{a}	6.46^{b}
DA	2.83^{a}	4.29^{a}	5.09^{a}	5.50^{ab}
VL	5.94^{b}	6.80^{b}	5.74^{a}	5.18^{ab}
JG	3.60^{a}	5.79^{ab}	5.53^{a}	6.48^{ab}
DIL	4.30^{ab}	4.90^{ab}	3.95^{a}	4.76^{a}

conditions were extremely low, but in second – extremely high. Similarity was found between study areas Zviedri, 'Jaunlīdumu' grava and Daiķu īvju liegums: in these areas moisture level was medium. Essential similarity between study areas in terms of soil reaction conditions were found; therefore, it indicates soil reaction as a limiting factor of *T. baccata* distribution. Similarity between study areas was found in conditions of nitrogen levels except for Daiķu īvju liegums and Juši.

Vital similarities between study areas were found in terms of soil reaction and light conditions. Therefor it shows that these factors influence the vitality and distribution of *T. baccata* above all.

To indicate if there is a vital impact of projective cover of vegetation on the vitality of *T. baccata*, the average percentage of vegetation cover was calculated (Table 5).

Table 5

Proportion of vegetation cover in study areas in Slitere National Park

Object ID	Canopy closure, %	Shrub layer, %	Herbaceous layer, %
ZV	92 ± 10	32 ± 7	79 ± 22
JU	84 ± 20	52 ± 22	79 ± 26
DA	96 ± 6	62 ± 47	90 ± 17
VL	86 ± 12	57 ± 9	100 ± 0
JG	81 ± 13	64 ± 32	79 ± 18
DIL	99 ± 3	75 ± 2	41 ± 10

The immense percentage of vegetation cover in all study areas, is common in broad-leaved and mixed forests. The projective cover of dominant stand was within 81–99%: it indicates that trees were exploiting the growing area to the maximum, but it also created shady conditions below the canopy. The percentage of shrub layer was lesser than in the stand layer, usually composed of *Corylus avellana* L. and *Picea abies* (L.) H.Karst. A significant negative correlation $r_s = - 0.6299$ ($p < 0.001$) between CCV and the projective cover of stand layer was found, indicating that intensive shading caused by closed canopy negatively influences the vitality of *T. baccata* (Dobson *et al.*, 2021; Dovčiak, 2002). A negative correlation $r_s = -0.6538$ $p < 0.001$) between CCV and herbaceous layer was also found, but in this case the herbaceous layer was negatively impacted by the dimensions of crown density of *T. baccata*.

Conclusions

1. The dimensions of *T. baccata* were positively influenced by dense forest stands, decreasing several risk factors. However, the distribution of *T. baccata* tends to increase in more open forest stands.
2. The crown dimensions of *T. baccata* decreased within an increase of forest stand basal area, which has resulted as a weaker ability to produce energy in the process of photosynthesis; therefore it reduced the vitality of *T. baccata*.
3. *T. baccata* negatively responded to poor light conditions, which were mainly determined by the canopy closure.
4. Soil reaction influenced the distribution and vitality of *T. baccata*. However, the wide range of pH levels within the areas where *T. baccata* were distributed, shows its ability to adapt.

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