EUTROPHICATION OF STRENČU INLAND DUNE TRACT IN LATVIA

***Inga Straupe, Antra Jansone, Ieva Erdberga**
Latvia University of Life sciences and Technologies, Latvia
*Corresponding author's email: inga.straupe@lbtu.lv

Abstract

Climate change and humans affect changes in biotopes, which cause loss in habitat diversity. One of the factors that is considered vulnerable to biodiversity in Europe is eutrophication. It affects both aquatic and terrestrial habitats, by enriching them with nutrients, causing their flora and fauna to change. Eutrophication is usually detectable in places where nutrient poor habitats are slowly disappearing, for example, lichen rich pine forests that can be found in inland dunes. The aim of this study is to assess the impact of eutrophication on *Cladinoso–callunosa* and *Vacciniosa* forest type on flat terrain and on dunes. A total of 12 plots have been established, six in each forest type. Sample plots are square, sized 400 m^2 each. In all plots, the height and diameter of the growing trees were measured, and all plant species, the projective cover of moss, herbaceous, shrub and tree layer and individual species were recorded. In addition, four soil profiles were created and 21 soil samples were analysed. The hypothesis of the work is that the eutrophication of *Cladinoso–callunosa* is more rapid in flat and lower terrain than in dune tops. This study showed that terrain does not significantly affect tree heights and diameters, but it does affect the soil. The soil in dune tops is less acidic than in the plains. The effect of eutrophication is not noticeable in the *Cladinoso–callunosa* forests, but only in the *Vacciniosa* forests, where it is higher in the plains.

Keywords: eutrophication, inland dunes, *Cladinoso–callunosa*, *Vacciniosa*, soil.

Introduction

Latvia is located in the boreal biogeographic region, hemiboreal zone, which borders on the continental geobotanical region (Esseen et al., 1997; Cervellini et al., 2020). Boreal forests occupy about 29% of all forest areas and about a third of the world's timber exports are obtained from these forests (Kayes & Mallik, 2020). The dominant species are Scot's pine, Norway spruce, birches and aspen, but in total about 20 tree species grow in this region, which is less than in other biogeographic regions of Europe (Puumalainen et al., 2003; Kayes & Mallik, 2020). In the hemiboreal zone, the dominance of deciduous trees typical of the temperate zone is increasing in the Baltic States, but the amount of coniferous forests is decreasing (Jõgiste et al., 2018). Pine stands are decreasing most in Latvia. They are being replaced by birches; in some cases, it can be replaced also by spruce and other deciduous trees. In total, coniferous forests occupy about 45% of the forest area in Latvia (Laiviņš et al., 2021).

Pines can grow in poor soils where there is not much competition although they grow best in moderately rich forest types - *Myrtillosa*, *Hylocomiosa* (Dreimanis, 2016). Conifers, especially pines, are characterized by podzol sand soils, where the amount of nutrients depends on the fallen deadwood and plant litter, its composition and meteorological conditions. Podzols are acidic, poor-reaction soils, which are usually formed on carbonate-free sandy mother rocks (Kārkliņš, 2008). In the soil horizons, including fungi form organic acids that degrade minerals, except quartz, and leach clay particles and nutrients from the upper horizons, forming a grey low-fertility leaching horizon and a wash-in, or illuvial horizon, in which fulvic acids with iron, aluminium hydroxides can form a dense iron sedimented horizon layer. Coniferous soil is acidic and low in nutrients; therefore, some plants have adapted to fixing nitrogen, such as *Pleurozium schreberi* (Brid.) Mitt. and *Hylocomium splendens* (Hedw.) B., S. et G., which contain cyanobacteria capable of fixing atmospheric nitrogen (Stuiver et al., 2015).

Since the degradation of organic matter in boreal coniferous forests is slow, the fallen deadwood and plant litter layer is thick and interferes with the growth of seedlings, forest fires are necessary for the natural regeneration of forests (Kayes & Mallik, 2020). Due to proper forest management, the number of wildfires has decreased, but under the influence of climate change the number of wildfires may increase due to the increased amount of forest debris and higher temperatures (DeAngelis, 2008; Manton et al., 2022). After forest fires the amount of potassium and phosphorus increases in oligotrophic soils (Gilliam, 1991). In mesotrophic soils, after ground and surface fires soil fertility, species diversity and soil moisture increase (Laiviņš et al., 2019).

Cladinoso–callunosa is an oligotrophic dry site forest type that is rare in Latvia (Liepa et al., 2014). It occupies approximately 1% of all Latvian forests. In this forest type, the ground cover is dominated by small shrubs, mosses and lichens typical of boreal forests (Laiviņš, 1998) - more than 50 plant species (Liepa et al., 2014). In the forest stand, only pine is purposefully grown for forestry, and they form forest stands of quality class IV-V (Bušs, 1981). The average standing volume of *Cladinoso–callunosa* pine stands is 150 m^3 per 1 ha (National forest monitoring, 2018). Naturally *Cladinoso–callunosa* pine regenerates slowly, only 10% after final felling can regenerate within 10 years (Bušs, 1981); therefore, *Cladinoso–callunosa* is most often regenerated artificially – by seeding or planting (Dreimanis, 2016). *Cladinoso–callunosa* is a very poor mineral soil, formed by quartz sand (Bušs, 1981). The organic top layer of the soil is thin, approximately 1-3 cm thick (Liepa et al., 2014). In *Cladinoso–callunosa* podzol is formed - a soil type in which leaching of nutrients from the upper soil horizons is a distinct feature. As for oligotrophic soils, *Cladinoso–callunosa* nutrients penetrate the soil with atmospheric precipitation (Liepa et al., 2014). In Latvia, *Cladinoso–callunosa* is most often found in dune landscapes and wind-borne sand dunes, with the largest areas occurring at the seaside (Bušs, 1981).

Vacciniosa is an oligomesotrophic dry forest type that occupies approximately 3% of Latvian forests (Liepa et al., 2014; National forest monitoring, 2018). More than 80 plant species are found in the *Vacciniosa* ground cover (Liepa et al., 2014). The forest stand is mainly composed of pine, which forms the stands of site index or site quality class III although low-value birch or spruce stands can also be formed (Bušs, 1981). The average standing volume is 200 m^3 per 1 ha (National forest monitoring, 2018). Understorey is rare, and it comprises spruce, birch, juniper and mountain ash (Liepa et al., 2014).

Vacciniosa soil is slightly more fertile than that of *Caldinoso-callunosa;* it is podzolized, with an approximately 4 cm thick organic top layer, most often sandy bedrock (Liepa et al., 2014). On slopes and in places with greater water inflow, soil horizons are more clearly distinguishable and deeper (Bušs, 1981). The soil is poor in minerals, an iron sedimentation horizon layer may form in it. *Vacciniosa* as well as *Cladinoso-callunosa* are found in dune areas and inland sand drifts (Bušs, 1981). In *Vacciniosa* a small overgrowth is formed after the final felling, which does not interfere with forest regeneration (Bušs, 1981). Forests are regenerated artificially by sowing pine seeds in furrows or planting two-year-old seedlings (Dreimanis, 2016).

Eutrophication is an increase in the biomass of living organisms and an increase in the intensity of biological processes caused by an increase of nutrients. As a result of climate change, the vegetation period increases, the amount of precipitation increases and growing conditions for some species improve and for some – worsen. Forest eutrophication is a process that occurs naturally very slowly, but it is accelerated by climate changes and anthropogenic factors. Under the influence of eutrophication and other factors, nutrient-poor forest areas in which stable stands of *Pinus sylvestris* are formed, decrease. They may become unstable, and an admixture of other less economically valuable trees and shrubs can form in those stands, which can overshadow and compete with the desired stands of *Pinus sylvestris*. When these stands become more fertile, the number of herbaceous plants increases, thus increasing competition (Laiviņš, 1998). The process of eutrophication also occurs in soils, where soils change from oligotrophic to mesotrophic. One of the forest types where the disappearance and replacement of characteristic ground vegetation species can be observed is *Cladinoso–callunosa*, which transforms into *Vacciniosa* in the process of eutrophication.

Nitrogen emissions are one of the major air pollutants affecting the eutrophication process (Bonten et al., 2016). In Europe, eutrophication is considered one of the most serious environmental threats. Although the areas affected by eutrophication are slowly declining, they still threaten a large number of Latvian ecosystems - about 85% compared to other European countries. Eutrophication processes and their development are clearly indicated on poor forest types, whereas proportion of these forest types have been decreasing in Latvia since 1940 (Laiviņš, 1998). Eutrophication of Latvian forest ecosystems is caused by an increase in the amount of atmospheric nitrogen in the soil and pollution, as a result of which the plant community typical of conifers is replaced by that of broad-leaves. This eutrophication is sometimes difficult to notice because plants that grow in nitrogen-rich soils cannot survive in drought (Reinecke et al., 2013). Forest eutrophication is positive if the purpose of forest cultivation is the introduction of new species or the cultivation of broad-leaved trees. As a result of human-influenced eutrophication, the change of tree species occurs in coniferous forests - hardwood species appear in the undergrowth or in birch or aspen stands start to appear instead of conifers. *Cladinoso–callunosa* and *Vacciniosa* birch admixture, which can occur due to eutrophication, reduces wood production. With each tenth of admixture, wood production decreases by approximately 7% (Bušs, 1981). The increase in nitrogen in the soil not only negatively affects the productivity of pine and other oligotrophic plant areas, but also increases the plant intolerance to various pathogens, causing additional stress (Lupi et al., 2013). By changing the plant composition of the ecosystem, eutrophication also changes the access to light and increases competition between plants, creating winner-plants that are more shade-tolerant, and loser-plants that are light tolerant species (Johnson et al., 2008). Although the replacement of coniferous forests by hardwood forests is predictable, the current speed of change is negatively affecting not only the productivity of forest stands, but also animal habitats and ecosystem services.

As nutrients in the soil increase, areas can become overgrown with shrubs and vascular plants, which interfere with the establishment of living spaces for partridges, capercaillie and other birds that require mosaic patches with open area (Smith et al., 1999). With the change in tree species, many birds find it difficult to establish nesting sites (DeAngelis, 2008).

One of the biotopes threatened by eutrophication and the biotic homogenization caused by it in Central Europe is lichen-rich pine forest, where lichens are replaced by mosses and small shrubs (Stefańska-Krzaczek, 2018).

Vegetation in forests is most affected by the amount of nitrogen in the soil, which is increased by the effects of eutrophication (Reinecke et al., 2013). An increase in the amount of nitrogen in the soil promotes graminification, which is the spread of grasses outside grasslands. *Dactylis glomerata* L., *Veronica chamaedrys* L. and *Artemisia vulgaris* L. can be used as indicator species for graminification (Laiviņš, 1998). Additional species observed in the studies on the effects of nitrogen on vegetation are *Deschampsia flexuosa* (L.) Nees, less commonly *Chamaenerion angustifolium* (L.) Scop and *Rubus idaeus* L. (Van Dobben et al., 1999). In Central European forests, it has been observed that under the influence of increased amount of nitrogen forests are slowly changing their taxonomic group from less to more fertile. In particular, the replacement of lichen-rich oligotrophic forests by mesotrophic forests has been observed (Reinecke et al., 2013). This indicates a possible replacement of *Cladinoso-callunosa* by *Vacciniosa*, and replacement of *Vacciniosa* by *Myrtillosa*, thus reducing the vegetation characteristic of *Cladinoso-callunosa* and increasing the vegetation of more fertile forest types in forest stands.

In peri-urban forests, eutrophication, due to pollution, is visible not only in the ground cover, but also in the undergrowth (Laiviņš et al., 2021). In coniferous forests, the presence of *Acer platanoides* L. and other deciduous trees in the undergrowth is observed (Laiviņš et al., 2021). In addition, due to the succession of the undergrowth and ground cover, forests become wetter and darker or shadier, which reduces the number of sun-loving species in the ground cover (Laiviņš, 1998). Lichens suffer the most from the increased amount of shade, they are replaced by mosses, small shrubs and grasses (Van Dobben et al, 1999; Stefańska-Krzaczek et al., 2018). In urban forests, ground cover species such as *Impatiens parviflora* DC., *Chelidonium majus* L., *Stellaria media* (L.) Vill., *Urtica dioica* L., *Geum urbanum* L., *Plantago major* L., *Artemisia campestris* L. and *Berteroa incana* (L.) DC. may be used as eutrophication indicator species in pine forests (Laiviņš, 1998). Eutrophication also has a positive effect on the spread of invasive species, especially in peri-urban forests. The impact of eutrophication on invasive species in Latvia has not been directly studied, but it has been observed that unstable ground cover plant communities, where invasive species can be introduced, are usually peri-urban forests (Laiviņš, 1998).

Vegetation succession caused by eutrophication occurs slowly but at a noticeable rate. In Germany, the studies on the eutrophication of oligotrophic forests found that over a 45-year period, most of the studied areas had faced a complete or partial vegetation replacement, thus locally increasing the number of species in ground but decreasing them regionally (Reinecke et al., 2013). Although eutrophication most often has irreversible effects on vegetation, in some places the decrease of vegetation replacement is possible as forest stands grow. A decrease in grasses was observed in mature pine forests in Sweden, but this did not change the irreversible effects on lichens (Jonsson, 2021). Under the influence of eutrophication, light demanding species and oligotrophic species disappear, shade-tolerant and nitrogen demanding species appear, and the areas in which oligotrophic species can survive are reduced, thus reducing the diversity of regional species and creating biotic homogenization (Reinecke et al., 2013).

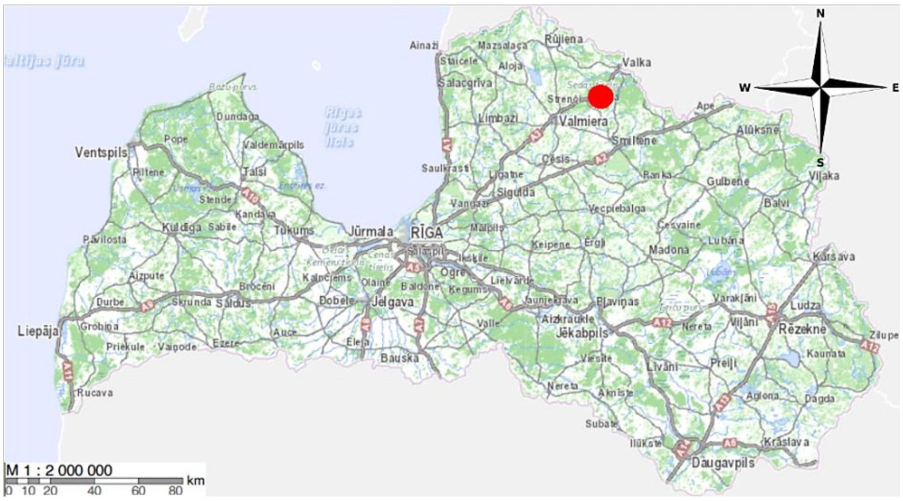
The aim of the study was to compare the impact of eutrophication on vegetation and soils on different microrelief, specifically, on dune tops and on plain sites of *Cladinoso-callunosa* and *Vaccinios* forests.

Materials and Methods

The territory of the research is the Strenči area of dunes, located in Valmiera region, where the dominant forest types are *Cladinoso-callunosa* and *Vacciniosa*. The forests there are located in the Seda plain, approximately 60-65 meters above sea level, in a place where inland dunes have formed. The average air temperature in Valmiera region is + 6.5 °C, the average temperature in July, the warmest month, is +17.8°C, but in February, the coldest month, -3.9 °C. The total amount of precipitation on average is 685.5 mm. The duration of the vegetation period is 192 days ʽFigure 1’.

Figure1

Location of the research site



12 square sample plots measuring 20 x 20 meters were established. The sample plots were located in the 70-year-old *Cadinoso-callunosa* and *Vacciniosa* forest stands in the inland dune area - three and three on the dune tops and three and three on plains, respectively. In each plot, all growing trees were listed and their species determined. The diameter of the trees was measured with a calliper at a height of 1.3 meters from the root collar or at breast height, with an accuracy of ±0.1 cm. A Suunto altimeter was used to measure the height of the trees, with an accuracy of ±0.1 m. All species were determined in the sample plots. The projective covers of each vegetation layer and each separate species, except for lichen and moss species, were estimated by sight and recorded in percentages. Four vegetation layers were used: E3 - tree layer, which includes all woody plants taller than 7 m, E2 - shrub layer, which consists of shrubs and trees 0.5-7 m high, E1 – herbaceous plant layer, which includes herbaceous plants, small shrubs and young woody plants not exceeding 0.5 m, and E0 – moss and lichen layer (Mueller-Dombois & Ellenberg, 1974).

In addition, soil profiles were created in four sample plots – respectively on the *Cladinoso-callunosa* dune tops and plain and also the same for *Vacciniosa* forests. Descriptions were created for the soil profiles. Soil analysis was performed to study the soil. A potentiometer was used to determine soil reaction or active and exchange acidity. Based on the results obtained, it was determined which soil group each soil sample corresponds to. The content of organic substances for the soil horizons was determined using the ashing method. Hydrolytic acidity, the amount of potassium and phosphorus in the soil and the aluminum concentration were calculated (Kārkliņš, 2008).

For each plot the average tree diameter, average tree basal area, volume, growing stock and number of trees per ha were calculated using generally accepted formulas in forest inventory.

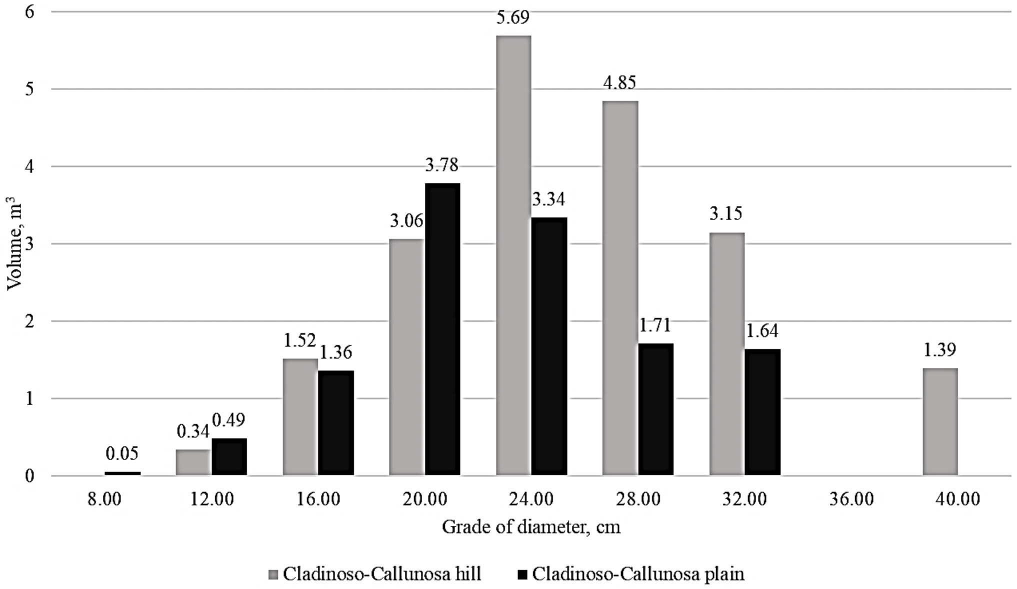
To compare the calculated and measured values of the *Cladinoso-callunosa* and *Vacciniosa* hills and plains, a one-way ANOVA with a 95% confidence level or significance level α =0.05 was used.

Results and Discussion

Growing trees. In total, 53 trees were measured in the plots of *Cladinoso-Callunosa* dune tops, of which 52 are *Pinus sylvestris*. The average diameter of trees on *Cladinoso-Callunosa* dunes is 21.72 cm, the diameter in the sample plots varies from 10 to 39.4 cm. Most trees correspond to the diameter grade of 24 cm. This diameter grade also has the largest standing volume, which can be observed in 'Figure 2'.

The average diameter corresponds to the site quality class IV, which is 20.9 m. The average height is 18.35 m. In the sample plots, the heights vary from 12 to 25 m.

Figure 2
Distribution of the volume by diameter grades in the hills and plains of Cladinoso-Callunosa forests



Comparing the average height to the average height of 61-70-year- old *Pinus sylvestris* which is 21.73 m, it is much smaller, but comparing it to the average height of the pines on the first layer according to the site quality classes, it can be observed that such a height corresponds to the stands of the site quality class III, where the average height is 16.74 m. The height of the trees is definitely affected by both site quality class and age (National forest monitoring, 2018). The average standing volume per hectare is 160.3 m^3. The obtained volume per ha is similar to the one obtained by the National Forest Monitoring cycle III, where the average standing volume per ha in *Cladinoso-Callunosa* is 158 m^3 ha^{-1} (National forest monitoring, 2018). The average number of trees per hectare in these sample plots is 441.

A total of 41 trees were measured in the sample plots of *Cladinoso-Callunosa* plain, and all of these trees are *Pinus sylvestris.* The average diameter in the sample plots is 19.75 cm, the diameter there varying from 9.9 to 32.8 cm, and most trees are in the 20 cm diameter grade. The average diameter is slightly smaller than the average diameter of *Pinus sylvestris* of the site quality class IV obtained by the National Forest Monitoring - 20.9 cm, but much larger than the average diameter of that of *Pinus sylvestris* of the site quality V, which is 17.39 cm. The average height is 18.69 m. In the sample plots, the height varies from 12 to 22.1 m. Unlike the height on the *Cladinoso-Callunosa* hill, this height corresponds to the 61-70-year-old *Pinus sylvestris* of the first layer, whose average height is 21.73 m. The average standing volume per hectare is 98 m^3, which is much less than that obtained on the hills and by the National Forest Monitoring, and the number of trees per hectare is 341 (National forest monitoring, 2018).

Comparing the *Cladinoso-Callunosa* hill and plain, it can be observed that although the average diameter is larger on the hills than on the plains, when checking these values by univariate analysis of variance, it can be found that the differences are not significant at 95% confidence level (p=0.109>0.05). No significant differences exist in heights between the sample plots (p=0.514>0.05). The greatest difference is observed in the standing volume and the number of trees. On the plains the standing volume is by 62 m^3 ha^{-1} smaller than in the hills, but when checking the data of the sample plots with univariate variance analysis, at 95% confidence level, no significant differences are found (p=0.426>0.05). This difference is most likely affected by the small number of trees in some sample plots. It can be concluded that no significant differences have been found between *Cladinoso-Callunosa* hills and plains regarding the parameters of forest stand and growing trees.

In the sample plots of *Vacciniosa* hill forests, 58 trees are listed, three of which are *Betula pendula* and 55 – *Pinus sylvestris*. In all sample plots, the forest stand is divided into two layers. In the sample plots, the diameter varies from 8.4 to 39.9 cm, but the average diameter is 22.11 cm, which is a little smaller than the average diameter of the pines. *Pinus sylvestris* of the site quality class III of the National Forest Monitoring obtained in the III rd cycle, which is 22.58 cm, but larger than that of the site class IV class pines - 20.9 cm (National forest monitoring, 2018). Most trees are in the 24 cm diameter grade - with a diameter from 22 to 25.9 cm respectively. On the hills, the 24 cm diameter grade accounts for the largest standing volume. The height, which varies from 11 to 31 m, is 19.53 m on average, which is less than the national average height of 61-70-year-old Ist layer *Pinus sylvestris* (21.73 m), but it corresponds to the average height of the site quality class III pine stands (National forest monitoring, 2018). The standing volume for the first layer per hectare is 177.23 m^3, but for the second layer - 14.86 m^3. The total standing volume which is 192.09 m^3 ha^{-1} is slightly less than 219.22, which is the average standing volume per hectare obtained in the III cycle by the National Forest Monitoring (National forest monitoring, 2018). The number of trees per ha is 457.

A total of 66 trees, all of which are *Pinus sylvestris*, were measured in the sample plots of the *Vaccinosa* forest plains. In all plots, trees are divided into two layers based on tree heights. The average diameter is 21.75 cm, and in the sample plots the diameter varies from 13.6 to 38 cm, but most trees are from 18 to 21.9 cm in diameter, which is the 20 cm diameter grade, but this diameter grade is not the one with the largest volume. The highest standing volume is for the 24 cm diameter grade. Comparing the obtained diameter, it can be concluded that this stand is most likely of the site quality class IV, since this diameter is the average between the average diameters of pines of the site quality class III and site quality class IV obtained by the National Forest Monitoring, respectively 22.58 cm and 20.9 cm ʻFigure 3’ (National forest monitoring, 2018).

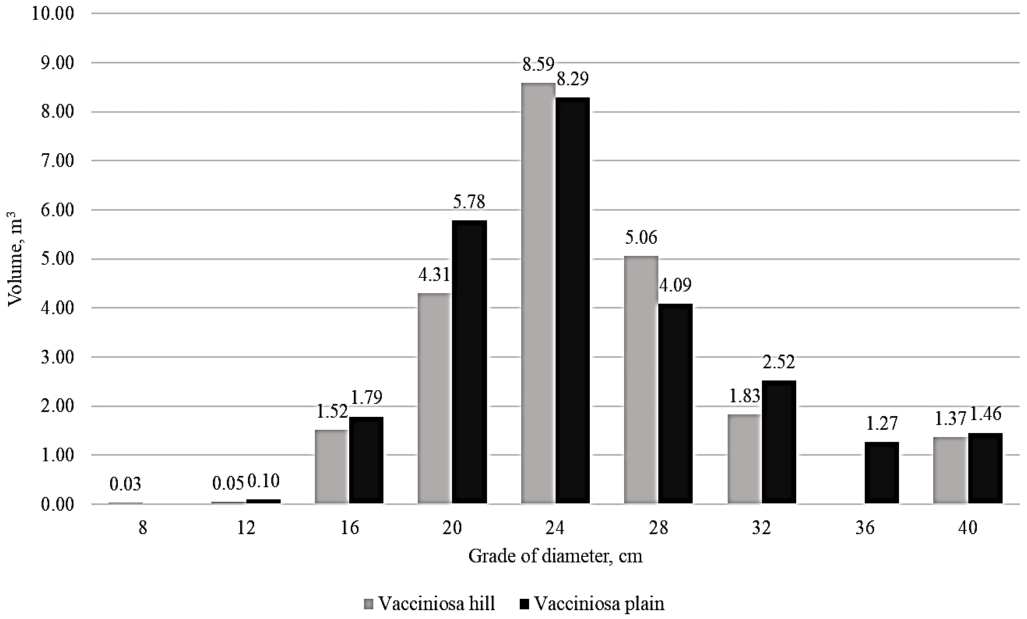
The height varying from 13.2 to 32 m, is 19.46 m on average. The height is lower than that of 61-70-year-old pines of the first layer, which have an average height of 21.73 m, but higher than the average heights of the pines of the first layer of the site quality class III and IV, for the site quality class III - 16.74 m, for the site quality class IV - 14.81 m (National forest monitoring, 2018).

The standing volume per hectare for the first layer trees is 188.3 m^3 and for the second layer trees - 14.67 m^3. The total standing volume is 202.97 m^3 ha^{-1}, which, as on the *Vaccinosa* hills, is slightly less than the average in *Vaccinosa* plains - 219.22 m^3 ha^{-1} (National forest monitoring, 2018). On average, there are 550 trees per ha on the plains of *Vaccinosa*. Comparing the plain and the hill of *Vaccinosa*, no significant differences were found either in diameters (p=0.702>0.05) or in heights (p=0.902>0.05). There are no significant differences also between standing volume (p=0.738>0.05) and number of trees (p=0.239>0.05). There are no significant differences in the indices of inventory and growing trees between *Vaccinosa* hill and plain forests.

Comparing *Vacciniosa* with *Cladinoso-Callunosa*, there are significant differences in the diameters of the hills of *Vacciniosa* and *Cladinoso-Callunosa* (p=0.034<0.05), where the diameter in *Vacciniosa* is significantly larger than in *Cladinoso-Callunosa,* but there are no significant differences in tree heights on the hills (p=0.14>0.05). The opposite can be observed for the plains of *Cladinoso-Callunosa* and *Vacciniosa*: there are no significant differences in the diameters (p=0.179>0.05), but a significant difference has been found in the heights (p=0.049<0.05); the height of the trees growing on the plains of *Vacciniosa* is greater than that of the trees growing on the plains of *Cladinoso-Callunosa* forests. Judging by these data, it can be concluded that the location of the place in the relief does not significantly affect the course of tree growth and the parameters of forest stand inventory that is affected by the forest type and the factors related to it.

Figure 3

Distribution of the stock by diameter grades in the hills and plains of Vacciniosa



Soil characterization and analysis. Four soil profiles were established in the research area: on the hill of and on the plain of *Cladinoso-Callunosa* and on the hill of and on the plain of *Vacciniosa*.

A typical podzol was found on *Cladinoso-Callunosa* hill, according to the FAO soil classification - Dystric Arenosol. The soil profile created on *Cladinoso-Callunosa* plain was classified as ortstein podzol, according to the FAO soil classification - Albic Rustic Ortsteinic Podzol.

According to the soil classification, the profile created on *Vacciniosa* hill is an illuvial humus podzol or, according to the FAO soil classification Dystric Arenosol. According to the Latvian classification, the soil profile on *Vacciniosa* plain is peaty podzolic glayish soil, according to the FAO soil classification - Hemic Folic Histosol.

Comparing all soils, it was concluded that the most alkaline soil is on *Cladinoso-Callunosa* hill, where already at a depth of 50 cm the pH H_2O is approximately 6.7, which is close to neutral acidity. The most acidic soil is on *Vacciniosa* plain, where at a depth of 50 cm the pH H_2O is only 2.9, but higher up it is 2.475, which is the lowest pH of all the samples or horizons. The highest level of pH in *Cladinoso-Callunosa* could be due to human influence, since charcoal was found in the soils of *Cladinoso-Callunosa*, indicating burning. *Vacciniosa* hill has a more neutral soil than that of *Cladinoso-Callunosa* plain, but the differences are not significant. When testing pH H_2O with univariate analysis of variance, it was found that, at 95% confidence level, there are significant differences between the soils, which, upon additional testing, are formed exactly by *Vacciniosa* plain ($p=0.034<0.05$). There are also significant differences not only between the soil of *Vacciniosa* plain and other soils but also between pH KCl ($p=0.034<0.05$). Since both the exchange and active acidity in this profile are significantly lower, the hydrolytic acidity in the soil is also significantly higher. These differences could indicate that the site is not correctly assessed as *Vacciniosa*, but it should be separated and the forest type changed. All soils have very acidic upper horizons. Compared to the forest soil study conducted in 2012, where on average the pH H_2O in the horizons of the organic top layer of *Vacciniosa* and *Cladinoso-Callunosa* is from 3.6 to 4.2, they are more acidic, but in the lower layers they correspond to the study of 2012 (Kasparinskis, 2012). A potential cause of soil acidification is the increase in nitrogen concentration in the soil, which changes the vegetation. There is no significant difference for potassium concentration in soils at 95% confidence level. When comparing the concentration of phosphorus (V) oxide in the soil, it can be concluded that there are significant differences between the soil of *Vacciniosa* plain and the other soils ($p=0.007<0.05$). The soil of *Vacciniosa* plain contains significantly less phosphorus (V) oxide than the other soils, which means that *Vacciniosa* plain presumably contains smaller amount of nitrophilic plants, since nitrophilic species require sufficient amount of phosphorus to survive (Roth et al., 2021). The same is true regarding the concentration of aluminium in soils, but the concentration of aluminium on *Vacciniosa* plain is significantly higher than in other soils ($p=0.0005<0.05$).

Number of vegetation species. In total, 24 plant species have been determined in all 12 sample plots: two - in tree layer, four - in shrub, nine - in herbaceous plant and nine - in moss and lichen layers. Five species occur in all sample plots: *Pinus sylvestris*, *Calluna vulgaris* L.Hull, *Cladina arbuscula*, *Cladina rangiferina* and *Pleurozium schreberi*. About 50 plant species can be found in *Cladinoso-Callunosa* and about 80 species in *Vacciniosa*

(Liepa et al., 2014). On average, 13 plant species are registered in one sample plot. In all places, the number of species in the moss and lichen layer is the same, but the species differ slightly. The greatest number of species can be found on *Vacciniosa* plain, while the smallest is found on *Cladinoso-Callunosa* plain.

Projective cover of vegetation species. *Vacciniosa* plain has the largest projective covers of herbaceous plant and tree layers (Table 1). *Cladinoso-Callunosa* hill and *Vacciniosa* plain have the same projective cover of shrub layer - 4%, but in *Cladinoso-Callunosa* it is made up only of *Betula pendula*.

In *Vacciniosa* this cover is made up of five species. The largest projective cover of mosses and lichens occurs on the plain of *Cladinoso-Callunosa*, but the smallest on both reliefs of *Vacciniosa* forests. *Cladinoso-Callunosa* hill and plain have the same projective tree layer cover. *Pinus sylvestris* (mean projective cover 55%) and *Betula pendula* were found in the tree layer of *Cladinoso-Callunosa* hills.

Betula pendula also occurs in the shrub layer together with *Juniperus communis* L. *Calluna vulgaris* L., *Vaccinium vitis-idea* L. and *Vaccinium myrtillus* L. occur in the herbaceous layer.

Table 1

Projective coverage of vegetation layers, %

Layer	*C-C hill*	*C-C plain*	*V hill*	*V plain*
E3	55	55	69	74
E2	4	1	2	4
E1	40	48	32	73
E0	97	98	94	94

Abbreviations: *C-C – Cladinoso-Callunosa*; *V – Vacciniosa*.

On the plains of *Cladinoso-Callunosa*, only *Pinus sylvestris* has been found in the tree layer (mean projective cover 55%). On the plains of *Cladinoso-Callunosa*, no shrub layer has been found. *Calluna vulgaris*, *Vaccinium vitis-idea* and *Vaccinium myrtillus* occur in the herbaceous layer.

In the tree layer of *Vacciniosa* plain, the dominant tree is *Pinus sylvestris* (average projective cover 67%). The shrub layer includes *Juniperus communis* that has been found in all sample plots, *Betula pendula* and *Picea abies*. *Calluna vulgaris*, *Vaccinium vitis-idea*, *Vaccinium myrtillus*, *Festuca ovina* occur in the herbaceous layer. Only pines are listed in the tree layer of *Vacciniosa* plain (mean projective cover 74%). There are five species in the shrub layer with a very small projective cover - *Juniperus communis*, *Betula pendula*, *Picea abies*, *Frangula alnus* Mill. and *Salix cinerea* L. In the herbaceous plant layer, the largest projective covers are made by *Calluna vulgaris*, *Vaccinium vitis-idea*, *Vaccinium myrtillus*, *Festuca ovina* and *Deshampsia flexuosa*, *Ledum palustre* L. was also found.

All sites have approximately the same projective cover of the moss and lichen layer and the same number of species, only the species differ. In *Cladinoso-Callunosa* and on *Vacciniosa* hill, *Cetraria islandica* is found. *Polytrichum commune* is not found on *Cladinoso-Callunosa* hills, and *Polytrichum juniperinum* is found only on *Vacciniosa* plain.

When comparing the projective covers, it can be concluded that in the tree layer of both *Cladinoso-Callunosa* and *Vacciniosa* birch admixture is rarely found. It has been found only on hills. The largest projective cover of the shrub layer is on *Cladinoso-Callunosa* hill and on *Vacciniosa* plain, but on the plain of *Vacciniosa* this layer is made up of more species, some of which are not typical for *Vacciniosa*. On *Vacciniosa* plain, the projective cover of the herbaceous plant layer is considerably larger. The distinct dominance of the herbaceous plant layer is most likely the reason why *Cetraria islandica* (L.) Ach. was not found on the plain of *Vacciniosa*. In *Vacciniosa* - especially on *Vacciniosa* plain - the amount of lichens decreases, but the variety of mosses increases. Also, in Germany, the findings from studies on the succession of pine forests report about the replacement of lichens by herbaceous plants in oligotrophic forests (Reinecke et al., 2013).

The studies on the species occurrence ratio and the consistency classes show that there are species that often appear in the sample plots and are present in all the sample plots. More common species (groups V and IV) are typical of *Cladinoso-Callunosa* and *Vacciniosa*, whereas the species that occur more rarely are those which are not typical of *Vacciniosa* and *Cladinoso-Callunosa* (*Frangula alnus* is typical of *Myrtillosa* and *Salix cinerea* is more typical of wetter soils (Straupe & Indriksons, 2014). Another atypical species is *Ledum palustre*, which has been found in all *Vacciniosa* sample plots, but it typically grows in swampy areas (Straupe & Indriksons, 2014). By projective cover it is most often found just on *Vacciniosa* plain. In the areas which have been defined as *Vacciniosa*, the soil can be atypically peaty, with a thick top layer of peat, which is why *Ledum palustre* can be found there.

The following indicator species of graminification *Deshampsia flexuosa* was found both - on the hill and on the plain of *Vacciniosa*. Atypical species are found exactly in those sample plots which have lower lichen projective cover and number of species, indicating a possible increased amount of nitrogen in the soil, which can promote succession (Laiviņš et al., 2008; Reinecke et al., 2013). Since the occurrence of graminification indicator species is low, the process of graminification in *Cladinoso-Callunosa* is probably much slower than in *Vacciniosa*, regardless of the relief of the site. Other study in 1998 verified that in oligotrophic forests, the process of graminification is slower than in mesotrophic and eutrophic forests (Laiviņš, 1998) – thus, the process of graminification is slower in less fertile forests. Since the soil in *Cladinoso-Callunosa* and *Vacciniosa* is very acidic, many nitrophilous species are unable to establish in such soil and the increase in nitrogen in the soil is rather difficult to observe (Diekmann et al., 1999). The increase in nitrogen concentration and acidity in dry and acidic soils is difficult to notice by using indicator species. It can be observed by studying changes in the distribution of plants of the genus *Vaccinium* (Diekmann et al., 1999). When studying the projection cover of forest atypical species and graminification indicator species, it can be concluded that succession is easier to observe, so the impact of eutrophication as well as the impact of people is the greatest on the *Vacciniosa* plains, but the impact of eutrophication is not observable in *Cladinoso-Callunosa*.

Conclusions

1. The relief does not significantly affect the height, diameter and standing volume of trees. Tree heights and diameters depend on the forest type. Tree diameters on *Vacciniosa* hills are significantly larger than on *Cladinoso-Callunosa* hills, but there are no differences between the heights. Tree heights are significantly greater on *Vacciniosa* plains than on *Cladinoso-Callunosa*, but there are no differences in tree diameters.
2. Forest soils differ in different reliefs; on hills the podzolization process is slower and no ortstein layer is formed, on plains the soil is more acidic than on hills.
3. A statistically significantly higher concentration of aluminium in the soil and lower concentration of P_2O_5 has been found on *Vacciniosa* plain than on *Vacciniosa* hill and in the soils of Cladinoso-Callunosa.
4. The peaty soil found on *Vacciniosa* plain and *Ledum palustre* growing in the sample plots of Vacciniosa indicate the possible water-logging of the soil.
5. When studying the differences in soil properties, it can be concluded that succession is influenced by the accumulation of organic substances and not by the increase in the concentration of nutrients in the soil. This fact is also confirmed by the low occurrence of graminification indicator species.
6. The impact of eutrophication has been more observed on *Vacciniosa* plain than on *Vacciniosa* hill or in *Cladinoso-Callunosa*. No impact of eutrophication was observed in *Cladinoso-Callunosa*. To observe eutrophication and succession of vegetation in *Cladinoso-Callunosa*, repeated larger-scale studies would be necessary.

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