THE FEATURES OF LIME STANDS ON PERMANENT RESEARCH PLOTS IN LENINGRAD REGION

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Abstract
The objects of research are the lime-tree forests of the Leningrad region. The studies were carried out on 2 permanent plots established by the authors in May 2013 in the Lisino forest district (Leningrad region, Russia). The goal of research was to obtain a complex characteristic of stands dominated by linden *(Tilia cordata)*. The objective of the research included a taxation and geobotanical description on permanent plots and studies of the soil cover (morphological and agrochemical characteristics of soils). The general health status of stands on the surveyed areas was determined as satisfactory – mean score 2.5 and 2.8 (relevant health status was determined with the help of the following 6-grade scale for each tree: 1 – no signs of weakening; 2 – weakened tree; 3 – very weakened tree; 4 – partial mortality of the tree; 5 – dead-standing trees of the current year; 6 – dead-standing trees of previous years). The average mortality rate varies from 3.05% year^{-1} on the sample plot 2 to 5.7% year^{-1} on the sample plot 1. Vegetation on sample plots attributes to a nemorose-herbal series of forest types, soils – to a podzolic type with a weak development of the podzol-forming process. They were well-mediated ones by humus in the upper horizon. This fact was facilitated by the lime litter: a lime has a deep root system to take up nutritional chemicals from a greater depth, where moraine loams enriched with calcium carbonate located. Old-aged forests of this type are being in the phase of gap dynamics now. This means that they can occur for a rather long time in the same place, however, the lime-tree forests of natural origin are constantly under threat of being replaced by spruce. The results of our study have shown that low levels of soil mineral nutrients supply are sufficient for the successful linden growth.
Key words: biogeocoenosis, lime-tree forests, old-aged forest, broadleaved species, Lisino forest district, agrochemical characteristic.

Introduction

Within the territory of the Lisino forest district, as well as within the entire territory of the Leningrad region, stands, which consist of *Tilia cordata*, are rare relict formations existing on the north of its areal (Eaton, Caudullo, & de Rigo, 2016; Василевич & Бибикова, 2002; Hulten & Fries, 1986). Predominance of the lime trees is characteristic for the final stages of dynamics of the forest vegetation in the conditions of soft and relatively warm climate, which makes it possible for the lime-tree to renew under the maternal leaf canopy / shelterwood due to its high shade tolerance (Андерссон *et al.*, 2007). According to the data provided by the governmental forest management, total area of the lime stands along with oak stands within the Leningrad region does not exceed 2 thousand hectares (Федорчук, Нешатаев, & Кузнецова, 2005). They are considered as biologically valuable forests, which require special protection in the North-West of the Russian Federation (the RF) (Андерссон *et al.*, 2007), as well as in many countries of the European Union (Jensen, 2003).

Lime trees require edaphic conditions; they cannot grow on acid and dry soils (Eaton *et al.*, 2016). There is very little information in the scientific literature concerning the soils of the lime-tree forests in the Leningrad region, as well as within the entire North-West of the Russia.

The main goal of the present research was to determine complex characteristics for the biogeocenosis of the lime-forests, which were included on the list of the species of special concern within the Lisino forest reserve.

Specific tasks of this research were as follows: continuous forest inventory within the permanent study areas; geobotanical description of vegetation on the study areas; establishment of soil pits on the study areas; morphological characteristics of soils; chemical and agrochemical investigations of the soil samples.

Materials and Methods

This article is based on the investigations performed within the permanent study areas (PSA), which were established by the authors in May 2013 within the 71-st Quarter of the Lisino forest district (Leningrad region). Re-calculation of the stands characteristics were carried out in June 2017.

Lisino forest district is situated at the distance of 50 km to the Southeast from Saint Petersburg in the central part of Tosno district of the Leningrad region. Total length of these wooded lands from north to south is 34 km, while their length from east to west is 18 km. This forest district consists of three sectional forest districts. Total area of Lisino sectional forest district is 28,384 hectares.

Landform of the territory of this forest district is a flat and undulating plain, which is smoothly stooped to the east and southeast in the direction of Tosno River (Тимофеев & Савицкая, 2011). Height above sea level within the forest district varies from 35 to 70 metres. Positive forms of the landform are eskers (inconsiderable in number), as well as small flat hills, which consist of the glacial drifted materials. Relative height of these hills achieves 2.5 m, horizontal dimensions from 100 to 200 m. From a geological viewpoint, the territory of the forest district is the bottom of the glaciolacustrine basin along with the lacustrine deposits being varved clays, from under which ice-laid deposits (boulder loams) emerge at the elevated areas of the landform. The main soil-forming materials are as follows: varved clays and moraine loams (boulder and driftless argillaceous sand grounds).

There are many two-layer drifts within the territory of the forest district: a thick bed of heavy-textured soils lays under the small layer of light-textured soils (sands, gravelly sand loams) or vice versa, and this fact has influenced the drainage to an essential degree.

In accordance with the geobotanical subdivision of the Nonblack Soil Zone (Александрова *et al.*, 1989), the district of our investigations is situated within the smooth of the southern boreal forest of Luga forest circle of the North-European Taiga Province. The spruce-forest of the sorrel family is the native forest association within the zone of the normally drained clay loams. Spruce forests dominate within the forest district under investigation (34%). Pine-forests are on the second place (28%), while birch-forests occupy the third place (23%). The area of aspen-forests is equal to 14%, while the rest of the forest formations occupy approximately 1%.

Climatic, soil, and hydrographical features of the territory ensure powerful superficial moistening of soils, which are presented by weakly- and insufficiently-drained soils, as well as by marshy types of lands at the 2/3 of the total area of this forest district (Тимофеев & Савицкая, 2011).

Methodology of mensurational description of the growing stock and methodology of the geobotanical description. In 2013, the areas with domination of the lime tree were found, and two permanent study areas (PSA) were established within the 71-st Quarter in the taxation plots/stratums 8 (PSA 2) and 11 (PSA 1). The area of each PSA was 0.25 ha (50×50м).

Later on, the complete enumeration of trees was performed within these PSAs. In the course of this enumeration, the following parameters were determined for each tree: the diameter at breast height of 1.3 m (for more accuracy, this diameter (DBH) was calculated as the length of circumference divided by 3.14); height; exploitable age; category of sanitary state; the presence of diseases of trees and pests; leaf formation and uniformity of the crown, as well as position of the crown in respect of other trees. In the case of demolition or fall of trees, they were counted separately as broken or windfall trees. Various trees were counted in one or another category of state in accordance with the following set of biomorphological parameters: colour of leaves and crown density, availability and share of the dead branches in the crown, state of bark, signs of attack of secondary timber insects etc. Relevant health status was determined with the help of the following 6-grade scale:

1 – no signs of weakening;
2 – weakened tree;
3 – very weakened tree;
4 – partial mortality of the tree;
5 – dried-up tree of the current year (dead-standing trees of the current year);
6 – dead-standing trees of previous years.

Mortality rates were calculated as:

$$\text{Annual mortality rate} = 1 - (C/N0)^{1/y} \quad (1)$$

where C was the number of currently recorded living trees, N0 original number of living trees, y – number of years between resamples (4 years, in our study).

The age of the trees was determined by the counting year rings on the cores for 22 trees on PSA 2 (except *Sorbus aucuparia,* for which age was determined by expert assessment since a small number of trees and obvious signs of rot did not allow the drilling method) and 28 trees on PSA 1. For better visualization of age rings, cores were colored with organic dyes. Spruce age partly was determined by pith node counting method.

Floristic composition of the understory trees, as well as the projective cover of various species of both the understory trees and the forest live cover were determined within the PSAs. Scientific names (Latin botanical names) of vascular plants according to the method of Cvelev (Цвелев, 2000) and bryophytes according to the method of M.S. Ignatov (Ignatov, Afonina, & Ignatova, 2006) were presented.

Methodology of soil descriptions and analytical investigations. In order to ensure investigations of morphological and agrochemical characteristics of soils, two soil pits were established on the study areas, one soil pit for each PSA. Later on, we performed morphological description and selection of the soil samples in order to perform investigations of agrochemical parameters of various soils. Establishment of the soil pits was made in accordance with the generally accepted methods (Van Breemen & Buurman, 2003). We selected places for establishment of the soil pits in the most typical land plots of the PSA, which were free from the roots of trees. Upon completion of digging-out the relevant hollow, we described the soil profile and collected samples of soil from various horizons of the profile.

We also performed the effervescent test in the field conditions with the help of 10% hydrochloric acid solution.

Later on, under laboratory conditions for each horizon of soil we determined humus content (according to the method of I.V. Tyurin), actual acidity and exchange soil acidity (by potentiometry), hydrolytic acidity and total exchangeable bases (S-value) (according to the method of Kapen), active forms of nitrogen (with the help of phenoldisulfonic acid method), potassium (according to the method of Peyve), and phosphorus (according to the method of Kirsanov) (Аринушкина, 1970).

In order to test the differences between obtained data and the inventory, we ran analysis of variance using t-test. Statistical processing of obtained data was done in the Microsoft Excel package.

Results and Discussion

The data that make it possible to calculate average taxational parameters were obtained with the help of the results of the complete enumeration of trees within the PSAs. Total quantities of the registered trees of various species, as well as their characteristics are presented in Tables 1 and 2.

There is a brook that glides along the boundary of the PSA-1, and there are trees of the European black alder (*Alnus glutinosa*) along this brook, as well as the following indicators of high soil moistening by the streaming water are present within the live ground cover: meadow-sweet (*Filipendula ulmaria*), water avens (*Geum rivale*), and creeping crowfoot (*Ranunculus repens*).

Statistical analysis of the data did not show a significant difference in the height and diameter at a 5% level of significance in all studied breeds between inventories.

General health status of stands within the PSA-1 is estimated as satisfactory one and it is characterized by the average mark of state at the level of 2.8. Within these stands, the best state was found for the trees of the European black alder (2.4), average health status: lime-trees – 2.8; birch-trees – 2.7; fir-trees are in an unsatisfactory state (3.5).

One-half of the inspected lime trees within the PSA-2 are in a good state, while the rest lime trees are in a satisfactory state. The average mark of state

Table 1

Permanent study area 1: Dynamics of stands characteristics

Species	Average age, years (2013)	Amount of trees (2013)	Amount of trees (2017)	DBH, cm (2013)	DBH, cm (2017)	Height, m (2013)	Height, m (2017)
Tilia cordata	85	61	48	18.6	21.8	17.5	20.2
Alnus incana	85	69	62	24.6	26.4	23.6	24.1
Betula pendula	85	69	56	22.6	24.9	21.6	23.7
Alnus glutinosa	85	8	5	25	26	23.2	23.4
Picea abies	50	45	30	10.6	12.8	6.1	9.6
Acer platanoides	40	14	9	14.3	15	14	17.6

Table 2

Permanent study area 2: Dynamics of stands characteristics

Species	Average age, years (2013)	Amount of trees (2013)	Amount of trees (2017)	DBH, cm (2013)	DBH, cm (2017)	Height, m (2013)	Height, m (2017)
Tilia cordata	130	73	71	35	37	25	28
Betula pendula	70	17	17	21	22	23	25
Populus tremula	110	7	6	33	38	29	30
Alnus glutinosa	130	1	1	39	41	32	34
Picea abies	70	43	31	21	22	17	18
Acer platanoides	40	12	10	8	11	9	13
Ulmus glabra	40	8	8	11	12	12	12
Sorbus aucuparia	40	2	-	20	-	16	-

Using last inventory data general stands characteristics were summarized (Table 3).

Table 3

General stands parameters

PSA	Type of stands; undergrowth	Average age, years	Average high, m	DBH of the main breed, cm	Site Index (Bonitet)	Basal Area m^2 ha^{-1}	Volume, $м^3$ ha^{-1}	Regeneration (density, st. ha^{-1})
1	linden -dominated mixed stands undergrowth: maple, rowan, bird cherry	85	22	23	II	37	389	*Tilia cordata* (1000) *Acer platanoides* (400) *Picea abies* (150)
2	linden-dominated mixed stands undergrowth: maple, elm, rowan	130	28	35	II	44	579	*Acer platanoides* (500) *Tilia cordata* (250) *Picea abies* (250) *Ulmus glabra* (100)

of the lime trees is equal to 2.5. Frost clefts are the most widespread damages (20% of the inspected lime trees). Average marks of state: aspen-trees – 2.9; fir-trees – 2.8; birch-trees – 2.6.

The average annual mortality rate of trees within the PSA-1 was equal to 5.7% $year^{-1}$, while within the PSA-2 it was equal to 3.05% $year^{-1}$. These high parameters of mortality are indicators that confirm the fact that these stands are in the stage of decline.

It should also be noted that in general, the stand, surveyed on permanent study areas is not typical for the conditions of the Leningrad region. Especially, it is necessary to note the parameters of *Alnus incana* on PSA 1 with height around 24 meters. Typically, in conditions of the Leningrad Region, the *Alnus incana* rarely reaches the height of 20 meters.

As it may be seen from the results of comparison of parameters of stands in 2013 and in 2017, mortality of trees within both permanent study areas is connected, for the most part, with the trees, stem diameters of which are lesser than the average stem diameter (so-called 'mortality from below').

The ground vegetation of both PSAs contains very many various species, for example, the following: wood stitchwort (*Stellaria nemorum*), aise-weed (*Aegopodium podagraria*), wood anemone (*Anemonoides nemorosa*), asarabacca (*Asarum europaeum*), sweet woodruff (*Galium odoratum*), hepatica (*Hepatica nobilis*), yellow archangel (*Galeobdolonluteum*),bitterpeavine(*Lathyrusvernus*), lungwort (*Pulmonaria obscura*), fig-root buttercup (*Ficaria verna*), herb Paris (*Pariqsuadrifolia*), and wood millet (*Milium effusum*). In addition, there also may be found wood sorrel (*Oxalis acetosella*) and meadow horsetail (*Equisetum pretense*). There are no subshrubs (huckleberry, clusterberry etc.) or they play an inessential role. Moss-and-lichen layer is thinned. The following species may be found in this layer: *Atrichum undulatum, Brachythecium salebrosum, Cirriphyllum piliferum, Plagiomnium cuspidatumm,*

Table 4

Morphological description of horizons on permanent study area 2

Horizon	Thicknesses of horizons, cm	Characteristics
A_0	0...3	Forest leaf litter horizon, well-decomposed, leaves, grasses, branches, roots
A_1	3...17	Humus-accumulated horizon, dark-brown colour, fine grained structure, fluffy consistence, sabulous, roots may be found, smooth transitions
$A_{2fe,h}$	17...30	Cryptopodzolic horizon, light gray colour, with dark spots, pulverescent structure, fluffy consistence, sabulous, roots may be found, smooth transitions
B_{fe}	30...70	Illuvial horizon, yellowish colour with brown spots, lumpy structure, firm consistency, sandy, and ferruginous murrams may be found, smooth transitions
C	>70	Esker coarse-grained sand

Table 5

Agrochemical parameters of soils on permanent study area 2

Horizon	Thicknesses of horizons, cm	Humus content, %	pH		Content, mg eq. (100 g)$^{-1}$ of soil					Degree of base saturation, %
			H_2O	KCl	HSA	TEB	K_2O	P_2O_5	NO_3	
PSA-1										
A_1	4...14	4.49	5.8	3.6	12.74	5.41	4.2	5.9	0.8	29.8
$A_{2fe,h}$	14...20	1.86	6.1	4.2	3.09	0.21	4.2	8.0	5.3	6.3
B	20...77	0.63	5.7	4.2	5.64	0.42	4.0	7.2	0.5	6.8
BC	>77	0.55	5.8	4.4	2.55	0.83	4.0	9.0	3.7	24.6
PSA-2										
A_1	3...17	3.65	6.8	4.8	4.00	5.2	4.6	11.0	2.3	56.5
$A_{2fe,h}$	17...30	0.97	6.9	4.7	1.64	1.66	4.2	7.6	5.0	50.4
B_{fe}	30...70	1.28	6.9	4.6	2.00	2.29	4.2	14.5	0.5	53.3
C	>70	0.68	6.8	4.8	2.37	2.08	4.2	22.0	4.5	46.8

Note. HSA – hydrolytic soil acidity; TEB – total exchangeable bases.

Rhytidiadelphus triquetrus, Rhodobryum roseum, Sciuro-hypnum oedipodium, S. reflexum.

Lime-forests within these permanent study areas are classified as the nemoral series of types of forests; this nemoral series is described in the typological classification of the Saint Petersburg Research Institute of Forestry (Федорчук *et al.*, 2005). In accordance with the ecologo-phytocenotic classification in the modification of Vasilevich (Василевич & Бибикова, 2002), these forests are classified as the forests that belong to *Aegopodio–Tilietum* association. In accordance with the floristic classification of the R&D school that is headed by J. Braun-Blanquet (Dierssen, 1996), the nemoral lime-tree forests correspond to *Aegopodio–Tilietum* association. In accordance with the vegetation classification of the Scandinavian countries (Pahlsson, 1994), the above-described communities may be classified as *Tilia cordata–typ*, which may be found in Finland, Denmark, Norway, and Sweden. As concerns Estonia, the communities having similar composition with predominance of the lime trees are classified as *Aegopodium–site type*.

The soil composition studies were performed within the permanent study areas. Morphological description of the pit No. 2 within the PSA-2 is presented in Table 3, while main parameters of productive capacity of soils are presented in Table 4.

In accordance with the Russian classification of forest soils, this soil has the following name: mull humus cryptopodzolic ferrous-and-illuvial sandy soil on the esker sand.

As concerns humus content in the upper horizon, these soils are classified as well-saturated soils (more than 4.0%), and this fact is not the characteristic property of the soils of the taiga zone. As concerns humus content and thickness of the humus horizon, they correspond to the soils of two series of forest associations: both on the carbonate-free clay loams and on the carbonate clay loams, which were described in the Leningrad region (Федорчук *et al.*, 2005). These series are characterised by the most fertile soils of forests in this region (Федорчук *et al.*, 2005). Apparently, litter leaf fall of the lime tree ensures high humus content. It is known that lime tree has a deeper root system as compared with fur trees; therefore, such a root system is capable to take up nutritional substances from the more depths, where nutritional moraine loams with calcium carbonate are situated. This fact results in an increase of both pH value and concentration of the interchangeable calcium (Ca+2) on the soil surface, as well as improves conditions for decomposition of the litter leaf fall and accumulation of humus (Van Breemen & Buurman, 2003; Dijkstra, 2000), thus increasing rate of growth of the lime tree. It is confirmed by the high reserves of woodlands. Thus, according to the inventory data, standing volume within the PSA-2 was 579 cu.m ha^{-1}; however, this standing volume is absolutely nontypical for the conditions of Lisino forest district.

Base saturation percentage in the humus horizon is 29.0 and 56.0% and these levels may be compared with results for the upper horizons of soil (down to the depth of 80 cm) of the nemoral series of forest associations on the carbonate-free clay loams (27.1 ± 5.5)% and on the carbonate clay loams (61.7 ± 10.1)% (Федорчук *et al.*, 2005). Regarding the degree of base saturation, these soils are classified as unsaturated soils, and this is, in principle, the characteristic for the forest soils (and the soil water regime ensures this level).

The degree of exchangeable soil acidity (pH_{KCl}) varies from the very highly acidic level up to the average acidic level (from 3.6 up to 4.8 units). It is evidence of the absence of the carbonate rocks or carbonate ground waters at the depth down to 80 cm. As concerns the soils of the nemoral series of forest associations on the carbonate clay loams, which were described in the Leningrad region at the depth of occurrence of the carbonate moraine (approximately 80 cm), value of pH_{KCl} is equal to 7.0 ± 0.26 (Федорчук *et al.*, 2005). Soil effervescence within the PSA-1 and PSA-2 was not found for the entire length of profiles, that is, at the depth down to 80 cm.

Availability of the mobile potassium in the soils is considered too low for the optimum plant growth, and this fact is typical for the soils of the taiga zone.

Availability of phosphorus increases with depth: it changes from the low level up to the average level in the soil pit 1, while in the soil pit 2 it changes from the average level up to the high level. Such an increase is typical for the podzolic soils, because the podzol-forming process ensures washing of soils, and thus causes migration of phosphorus and interaction of the latter with iron.

Degree of availability of nitrogen (in moving active forms) is low, provided that the greater values (5.0...5.3 mg·eq. $(100\ g)^{-1}$) are usually fixed in the leached horizon (as well as in the maternal rock (3.7...4.5 mg eq. $(100\ g)^{-1}$), while the illuvial horizon is characterised by lesser values (approximately 0.5 mg eq. $(100\ g)^{-1}$).

In accordance with the previously performed investigations of soils within the nemoral series of forest associations, the total nitrogen content is equal to approximately 1.0…2.0%. However, this fact is connected with the reserves of nitrogen in organic substances (which includes not only active moving forms), that is, it is not correct to compare these parameters with other companies.

Results of the morphological investigations demonstrate that the soils with weakly-expressed podzol-forming characteristics are created on the washed-out esker podzolic due to the efficient drainage of sandy soils. It is a typical characteristic for the soils on the sands and moraine boulder loams, in respect of which results of previous investigations confirm that typical podzolic horizon is rarely created; more frequently, this horizon is the horizon of a transitional type (in the form of spots) or it is not available in principle (Федорчук *et al.*, 2005).

It is very interesting to determine the origin and period of existence of the lime-tree forest in the Lisino forest district. Analysis of mortality rates of the lime trees in the North-West (Eaton, Caudullo & de Rigo, 2016), as well as results of subsequent models of dynamics of the lime-tree forests (Drobyshev *et al.*, 2009) evidence that the lime-tree woodlands can exist without reproduction during 400 years as a minimum. In accordance with the data provided by C.D. Pigott (Pigott, 1989), the maximum age of lime trees can achieve 1300 years. It is known that lime-tree forests exist in the Northern England (within the same region) 3…4 thousand years (Pigott, 1989), that is, the beginning of the Holocene optimum. It is possible to explain existence of the lime trees to the north from the terrestrial latitude of the Lisino forest district (where seeds of the lime trees cannot grow ripe (Булыгин & Ярмишко, 2003) as follows: the lime trees are capable to ensure sucker regeneration following the death of trees due to windfalls or extraction of timber. Therefore, it is possible to assume that the lime-tree forests in the Lisino sectional forest district are relicts of the warm Atlantic period of the Holocene.

Conclusions

1. The lime-tree forests under this investigation are the old-aged forests, which exist in the stage of gap dynamics, and this conclusion is confirmed by predominance of the lime trees both in the growing stock, and in the understory. Therefore, they existed and can exist further within the same region during sufficiently long period of time. However, the lime-tree forests under this investigation are characterized by high annual mortality percentage, and this fact can cause subsequent replacement of the lime by spruce if introduction of the spruce seeds is possible.
2. The ground vegetation within the lime-tree forests under this investigation is characterised by predomination of the species that are more typical for the southern regions of the broadleaved woodland zone.
3. The lime-tree forests under this investigation occupy those localities, which are characterize by high humus content and relatively thick humus horizon, although these soils were formed on the carbonate-free rocks and they are characterised by the low content of movable forms of mineral elements. However, soils of study area are rich in respect of organic substances, the content of which exceeds average values by several times. This fact makes it possible to classify these soils as the soils that are well saturated with humus. Availability of essential volumes of organic substances in these soils confirms potential reserves of nitrogen, which (in the course of subsequent mineralization) will transform in other forms (accessible for vegetation) and assist to development of the lime-tree growing stock.

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