The natural mortality in pine dominating forest stands of Lisino training and experimental forest of Saint-Petersburg State Forest Technical University

I Nikiforchin1*, L Vetrov1, M Guryanov1, S Vavilov1, S Farkhullina2

1 Department of forest inventory, forest management and GIS, St. Petersburg State Forest-Technical University, 5 Institutskiy Lane, St. Petersburg 194021, Russian Federation
2 OOO «Lesproekt», 33 Zastavskaya Street, Saint Petersburg 196084, Russian Federation

*Corresponding email: nikiforchin@mail.ru

Abstract. Over a long period of time, an extensive network of permanent growth plots covering the main plantations variety has been created in the educational-experimental forest area. Periodic observations at these sites provide detailed information about the growth of stands, the magnitude of growth and mortality. In the process of work the value of the annual natural mortality in Piceetum oxalidosum and Piceetum myrtilosum by component breeds, as well as in the whole of stands, was determined; studied the structure of mortality; the reduction numbers of trees of mortality are determined by diameter, height and volume. The data obtained during the study can be used to determine the size of a selectable part of tree stands during improvement cutting to clarify the available tables of growth.

1. Introduction
Natural mortality is the trees died as a result of self-thinning of the forest stand. Studying of dynamics of a natural mortality in forest stands is of great importance for forestry and, in particular, for rational improvement cutting. It is necessary to understand the laws of growth of stands, determine the value of potential productivity and the volume of intermediate use of wood.

The question of the natural self-thinning of plantations has a long history which is associated with the development of biological science. Charles Darwin considered the manifestation of tree differentiation as indisputable evidence of natural selection and the struggle for existence in forest plantations [1]. G F Morozov studied the influence of competition in the stands. It consisted in the fact that the right to live belongs to the most adapted trees - the winners of the living space, and not to the defeated [2].

Vargas de Bedemar was the first to quantify the self-thinning process by compiling tables for the growth of plantations in the St. Petersburg province [3]. A V Tyurin continued the study of natural mortality, which is reflected in the general tables of the growth of plantations [4].

A study of natural mortality in forest stands have been studied by many researchers. Among them Verkhunov [5]; Kushelis [6]; Sennov [7]; Chirkov [8]; Nikiforchin, [9] and others.

Information about the dynamics of the mortality, contained in the tables of growth, are not sufficiently reliable for methodological reasons. More reliable information about the dynamics of the mortality and the ratio of its magnitude with the growth and stock of tree stands of different
composition, age and yield class can be obtained by long-term observations on permanent growth plots. The purpose of this work was to study the natural mortality in pine dominating forest stands of Lisino training and experimental forest of Saint-Petersburg State Forest Technical University. The experimental basis for this was the data of taxation and registration of the mortality on permanent growth plots.

2. Methods and Materials
For the development of the theme, the data of the taxation of 8 permanent growth plots, which were laid in the Piceetum oxalidum and Piceetum myrtilosum, were used. The studies were conducted in tree stands aged from 70 to 170 years. The size of the growth plots vary from 0.18 to 0.74 ha. Observations were carried out from 1960 to 2017 by repeated measurements and counting trees every 5 years. As a result, data have been accumulated in order of successive increase in ages, which can characterize the dynamics of changes in the composition, height, diameter, number of trees, stock, mortality, growth and other taxation indicators of forest stands.

In the course of our research, stands of one natural series of growth and development were selected on the basis of the general forest type and yield class. Further, belonging to the same natural series was verified by the method of straight lines (Figure 1). In plantations, which are links of one natural series, the product of the average height of the predominant breed for age and average diameter for age should have been located in one straight line [10].

![Figure 1. Verification of tree stands belonging to one natural series of growth and development (on the example of pine).](image)

Growth plots whose indicators gave deviations from straight lines in height of no more than ± 10%, and in diameter did not exceed ± 15%, belonged to one natural series. With a larger difference, they were either completely excluded from further processing, or joined another yield class close in dynamics. Grouped by homogeneous natural series of growth and development, growth plots were further processed.

To determine the value of the mortality, the results of measurements of each tree of two adjacent observation periods (for example, for 2008 and 2013) were compared. Since each tree on a constant growth plot has its own number, it is possible to identify the numbers and taxational characteristics of those trees that made up the natural mortality for the period under consideration. The diameters of these trees for breeds, categories of technical validity and diameter class were recorded in the check list. The data for constructing the height curve were taken from the results of a selective measurement.
of tree heights by diameter classes. Further processing of materials was carried out by the program "Growth plot".

As a result of processing, diameters, heights, volumes of average trees of mortality were obtained, as well as the number and stocks of naturally fallen trees by breeds for each observation period. By dividing the amount of mortality by the value of this period, the average indicators of natural mortality for one year were calculated.

The average percentage of the mortality of each breed by the number of trunks and the stock was determined as the ratio of the magnitude of the mortality to the number of trunks or the stock of growing stand, expressed as a percentage.

To identify the features of natural mortality, reduction numbers were used. Reduction numbers in diameter \( R_d \) were determined by the ratio of the average diameter of the dead trees \( D_{mort} \) to the average diameter of the growing stand \( D_m \):

\[
R_d = \frac{D_{mort}}{D_m}
\]

and reduction numbers in height \( R_h \) were calculated by the ratio of the average height \( H_{mort} \) of dead trees to the average height of the growing stand \( H_m \):

\[
R_h = \frac{H_{mort}}{H_m}
\]

The fall of trunks, depending on the age of the stand, can have three stages: lower, proportional and raised. At the lower stage, the reduction number is \( R <1 \), which means that trees with diameters less than the average fall off, i.e. growing in depression, competing for access to the first tree layer. At the proportional stage \( R = 1 \), the fall occurs mainly at the expense of medium in diameter and height of trees. In the riding stage \( R> 1 \), therefore, trees with diameters and heights of large average indices die.

3. Results and Discussion

The obtained reduction numbers of trees of mortality on the main taxation indicators were approximated using a linear equation. The dynamics of the aligned values of the reduction numbers of the natural mortality in diameter, height and volume in the Piceetum oxalidosum is reflected in the Table 1.

By the values of the reduction numbers, it has been established that in Piceetum oxalidosum lowerland mortality is mainly observed. The exception is the stands of spruce and birch (starting from 120 years) in which the fall is due to larger trees.

Table 1. Dynamics of the reduction numbers of natural mortality in diameter, height and volume in Piceetum oxalidosum.

| Forest element | Age of tree stands, years | Reduction numbers: diameter |
|----------------|--------------------------|-----------------------------|
|                | 61–80 | 81–100 | 101–120 | 121–140 | 141–160 | 161–180 |
| Pine           | 0.54-0.57 | 0.58-0.62 | 0.63-0.66 | 0.67-0.70 | 0.71-0.74 | 0.75-0.79 |
| Spruce         | 0.74-0.79 | 0.80-0.85 | 0.86-0.91 | 0.92-0.97 | 0.98-1.03 | 1.04-1.10 |
| Birch          | 0.52-0.62 | 0.63-0.73 | 0.74-0.84 | 0.85-0.95 | 0.96-1.05 | 1.06-1.17 |
Reduction numbers: height

| Forest element | 71-80 | 81-90 | 91-100 | 101-110 | 111-120 | 121-130 | 131-140 | 141-150 | 151-160 | 161-170 |
|----------------|-------|-------|--------|---------|---------|---------|---------|---------|---------|---------|
| Pine           | 0.77-0.80 | 0.81-0.85 | 0.86-0.89 | 0.90-0.93 | 0.94-0.97 | 0.98-1.02 |
| Spruce         | 0.79-0.84 | 0.85-0.90 | 0.91-0.96 | 0.97-1.02 | 1.03-1.09 | 1.10-1.16 |
| Birch          | 0.50-0.65 | 0.66-0.81 | 0.82-0.96 | 0.97-1.12 | 1.13-1.28 | 1.29-1.45 |

Reduction numbers: volume

| Forest element | 71-80 | 81-90 | 91-100 | 101-110 | 111-120 | 121-130 | 131-140 | 141-150 | 151-160 | 161-170 |
|----------------|-------|-------|--------|---------|---------|---------|---------|---------|---------|---------|
| Pine           | 0.19-0.28 | 0.29-0.37 | 0.38-0.47 | 0.48-0.57 | 0.58-0.66 | 0.67-0.77 |
| Spruce         | 0.72-0.73 | 0.74-0.75 | 0.76-0.77 | 0.78-0.79 | 0.80-0.81 | 0.82-0.84 |
| Birch          | 0.17-0.35 | 0.36-0.54 | 0.55-0.73 | 0.74-0.93 | 0.94-1.12 | 1.13-1.32 |

With age in *Piceetum myrtilosum* the reduction numbers also increase in diameter, height, and volume of mortality trees, but their values do not exceed 1 (R <1). Thus, mortality occurs due to trees, which are smaller than average in their parameters.

The largest range of change in reduction numbers is characteristic of the height of the trees of mortality, a little smaller is characteristically for diameters. The smallest change compared with other indicators is characteristic of reduction numbers in terms of volume. In general, the change in reduction numbers with age is more pronounced in *Piceetum oxalidosum* than in *Piceetum myrtilosum*.

To simulate the magnitude of the natural mortality by stock and the number of trunks with a change in the age of the stands, a second-degree polynomial equation was chosen. The results of such an approximation of breeds in the *Piceetum oxalidosum* are presented in Table 2.

From the data of Table 2 it follows that with the increase in the age of stands, the value of the mortality in stock increases, reaches a maximum, and then naturally decreases. The maximum mortality in stock for individual species occurs in different periods: for pine in 101-110 years, for spruce in 121-130 years, and for birch in 91-100 years.

**Table 2.** The mean amount of the annual mortality per 10 years periods in *Piceetum oxalidosum* by age generations.

| Forest element | 71-80 | 81-90 | 91-100 | 101-110 | 111-120 | 121-130 | 131-140 | 141-150 | 151-160 | 161-170 |
|----------------|-------|-------|--------|---------|---------|---------|---------|---------|---------|---------|
| Mortality in stock (m³/ha) |       |       |        |         |         |         |         |         |
| Pine           | 1.26  | 1.37  | 1.40   | 1.41    | 1.33    | 1.20    | 1.00    | 0.76    | 0.45    | 0.16    |
| Spruce         | 0.53  | 0.67  | 0.79   | 0.90    | 0.98    | 1.04    | 0.99    | 0.91    | 0.83    | 0.74    |
| Birch          | 0.20  | 0.22  | 0.24   | 0.23    | 0.22    | 0.20    | 0.17    | 0.14    | -       | -       |

| Mortality in the number of trunks (pcs / ha) |       |       |        |         |         |         |         |
| Pine           | 5.6   | 4.5   | 3.6    | 2.8     | 2.1     | 1.5     | 1.1     | 0.7     | 0.5     | 0.3     |
| Spruce         | 8.7   | 6.7   | 5.0    | 3.6     | 2.5     | 1.5     | 0.9     | 0.5     | 0.4     | 0.5     |
| Birch          | 3.2   | 2.4   | 1.7    | 1.1     | 0.7     | 0.3     | 0.1     | 0.0     | -       | -       |

The mortality rate in terms of the number of trunks for all breeds naturally decreases with increasing the sequence number of a generation, which is similar to a decrease in the mortality in normal stands with increasing age. In *Piceetum myrtilosum* the number of natural mortality in pine
with age varies from 11.7 to 2.8 pcs/ha, and in *Piceetum oxalidiosum* from 5.6 to 0.3 pcs/ha, indicating a more stable dynamics of mortality indicators in the latter.

The most intensively the process of mortality in terms of stock takes place in middle-aged plantations of *Piceetum myrtilosum*. This may be due to worse growth conditions than in *Piceetum oxalidiosum* and a large number of trunks in the initial age.

The absolute values of the natural mortality in stock (m³/ha), as well as the number of trunks (pcs/ha) do not allow to estimate the intensity of this process, as well as to conduct a comparative analysis between stands of different species and types of forests. A more objective characteristic of the process of natural mortality can be obtained by evaluating it in relative terms (percent).

The percentage of mortality in terms of stock was calculated as the ratio of the absolute value of the natural mortality (m³/ha) to the stock of growing stand of this breed (m³/ha). In the same way was calculated the percent of mortality according to the number of trunks. The values of the relative magnitude of natural mortality by constituent breeds were approximated by a power equation. Percent changes in mortality in *Piceetum oxalidiosum* presented in Table 3.

**Table 3. Change in the percentage of mortality in the *Piceetum oxalidiosum* by age generations.**

| Forest element | Age of tree stands, years | Mortality in stock, % | Mortality in the number of trunks, % |
|----------------|--------------------------|----------------------|-------------------------------------|
|                | 71-80        | 81-90      | 91-100     | 101-110    | 111-120    | 121-130    | 131-140    | 141-150    | 151-160    |
| Pine           | 0.83         | 0.67       | 0.55       | 0.47       | 0.40       | 0.35       | 0.30       | 0.27       | 0.25       |
| Spruce         | 0.85         | 0.67       | 0.54       | 0.45       | 0.37       | 0.32       | 0.27       | 0.24       | 0.23       |
| Birch          | 0.78         | 0.77       | 0.76       | 0.75       | 0.75       | 0.74       | 0.73       | 0.73       | 0.72       |
| Average        | 0.82         | 0.70       | 0.62       | 0.55       | 0.51       | 0.47       | 0.44       | 0.41       | 0.40       |

In *Piceetum oxalidiosum* with increasing age of stands from 70 to 160 years, the percentage of mortality in stock decreases from an average of 0.82 to 0.40%. The most intensive decrease the percentage of mortality happens in the spruce stand: from 0.85 to 0.23%. The lowest dynamics of changes in the relative magnitude of the mortality observed in birch forest: from 0.78 to 0.72 percent. The dynamics of changes in the percentage of mortality in stock in the pine tree stand is close in magnitude to the spruce stand and varies from 0.83 to 0.25% per year. Similar conclusions about the magnitude of the natural mortality in stock were also obtained for *Piceetum myrtilosum*.

To compare the results obtained in the course of the study with the data of other authors, the percentages of the natural mortality in stock and number of trunks were selected. We have established the values of the magnitude of natural mortality for modal stands and table values were for normal stands. The percentage values are relative, which means the error of the comparison results is minimal.
The comparison was made with tables A V Tyurin [4] and Vargas de Bedemar [3]. In the general tables of the growth of Professor A V Tyurin [4] compiled about 70 years ago, data are given for plantations of pine, spruce, birch, aspen and black alder of normal productivity. Well-known experimental tables of the growth of normal plantations of pine, spruce, birch and aspen in the Leningrad Region were compiled by Vargas de Bedemar about 170 years ago. The results of the comparison of our data with the tables of the above authors are given in Table 4. The comparison was carried out separately by stock and separately by the number of dead trees.

Table 4. Comparison of the relative magnitude of the annual mortality (%) in Piceetum oxalidosum with various tables of growth.

| Age, years | Percentage of annual mortality | Deviations of the annual mortality rate (%) |
|------------|---------------------------------|------------------------------------------|
|            | Growth tables of Vargas de Bedemar | General tables of growth of Professor A V Tyurin | Our data | General tables of Vargas de Bedemar | General tables of growth of Professor A V Tyurin |
|            | on stock                         |                                         |                    |                                      |                                  |
| 70         | 0.81                            | 1.02                                    | 0.82               | 1.2                                  | -19.6                            |
| 80         | 0.80                            | 0.89                                    | 0.70               | -12.5                                | -21.3                            |
| 90         | 0.69                            | 0.78                                    | 0.62               | -10.1                                | -20.5                            |
| 100        | 0.60                            | 0.65                                    | 0.55               | -8.3                                 | -15.4                            |
| 110        | 0.50                            | 0.54                                    | 0.51               | 2.0                                  | -5.6                             |
| 120        | 0.40                            | 0.44                                    | 0.47               | 17.5                                 | 6.8                              |
| 130        | 0.38                            | 0.38                                    | 0.44               | 15.8                                 | 15.8                             |
| 140        | 0.30                            | 0.33                                    | 0.41               | 36.7                                 | 24.2                             |
|            | by the number of trunks          |                                         |                    |                                      |                                  |
| 70         | 3.67                            | 2.44                                    | 1.68               | -54.2                                | -31.1                            |
| 80         | 2.59                            | 1.86                                    | 1.34               | -48.3                                | -28.0                            |
| 90         | 1.35                            | 1.60                                    | 1.11               | -17.8                                | -30.6                            |
| 100        | 1.22                            | 1.36                                    | 0.95               | -22.1                                | -30.1                            |
| 110        | 1.06                            | 1.22                                    | 0.82               | -22.6                                | -32.8                            |
| 120        | 0.89                            | 0.89                                    | 0.72               | -19.1                                | -19.1                            |
| 130        | 0.52                            | 0.71                                    | 0.64               | 23.1                                 | -9.9                             |
| 140        | 0.56                            | 0.50                                    | 0.58               | 3.6                                  | 16.0                             |

The deviations of the annual value of the natural mortality in the terms of stock, obtained by us, from the data of the growth tables of Vargas de Bedemar during certain periods of growth in Piceetum oxalidosum vary from 36.7% to -12.5%, and from the general growth tables of prof. A V Tyurin - from 24.2% to -21.3%. The relative declining values we obtained in stock in Piceetum oxalidosum are somewhat closer in their values to the general growth tables of prof. A V Tyurin.

The analysis of the deviations in the annual value of natural mortality by the number of trunks obtained by us and from the data of the growth progress tables of Vargas de Bedemar showed that in certain periods of growth in Piceetum oxalidosum their values change from 23.1% to -54.2% and from the data of growth tables of prof. A V Tyurina [4] - from 16.0% to -32.8% (Table 4). And in this case, we can conclude that the relative magnitudes of mortality, obtained by us in Piceetum oxalidosum, by the number of trunks, are slightly closer in their values to the general growth tables of prof. A V Tyurin. Similar trends in changes in the relative magnitude of the mortality in stock and the number of trunks were obtained in Piceetum myrtilosum. The differences between the data obtained by us and the data of other authors can be explained by the fact that the tables of the growth of Vargas de Bedemar and A V Tyurin cover a larger area and have an average value and we considered only the
local conditions of Lisino training and experimental forest of Saint-Petersburg State Forest Technical University.

4. Conclusion

- According to the values of the reduction numbers, it has been established that in *Piceetum oxalidosum* lower fall is mainly observed. Similarly, the process of mortality occurs in *Piceetum myrtilosum*.

- The greatest range of variation of the reduction numbers is typical for the height of trees in mortality and slightly lower for diameters. The smallest change in comparison with other indicators is characteristic of the reduction number in volume.

- With an increase in the age of forest stands, the magnitude of the mortality in stock increases, reaches a maximum, and then naturally decreases. In the pine forests of our forest maximum mortality in stock for individual species occurs in different periods: for pine – in 101-110 years, for spruce – in 121-130 years, for birch – in 91-100 years.

- The number dead trees of all species naturally decreases with an increase in the sequence number of generation, which is similar to a decrease in mortality in normal stands with increasing age.

- In Lisino pine forests with an increase in the age of tree stands from 70 to 160 years the percentage of mortality, both in terms of stock and in the number of trees, is constantly decreasing.

- Comparison of the relative magnitude of natural mortality in stock and the number of trees that we received from the growth tables of Vargas de Bedemar and the data of general growth tables of prof. A V Tyurin showed that our data are somewhat lower than those of the authors, both in the *Piceetum oxalidosum*, and in the *Piceetum myrtilosum*.

References

[1] Darwin H 1991 *The origin of species by natural selection or maintaining favorable races in fight for life. The lane with English. edition Takhtadzhyan A.L.; Academy of Sciences of the USSR* (St.Petersburg: Science) p 539

[2] Morozov G 1930 *The doctrine about the wood. Manual, edition Matreninsky V V Prod. the 5* (Moscow, Leningrad) p 440

[3] Vargas de Bedemar A 1850 *The researches of a stock and gain of afforestations in the St. Petersburg province made from 1843 to 1848 (St.Petersburg)* p 200

[4] Tyurin A 1956 *The forest auxiliary book (on valuation of the wood): tables / Tyurin A.V., Naumenko I.M., Voropanov P.V. Prod. the 2nd, additional* (Moscow, Leningrad) p 532

[5] Verkhunov P 1975 *The process of differentiation and natural mortality of trees in uneven-aged pine stands. The processes of formation of stands in Siberia* (Krasnoyarsk) pp136-159

[6] Kuleshis A 1986 *Standards for dynamic assessment of growth conditions and self-thinning of tree stands (Kaunas: Lithuanian Research Institute of State Forestry of the USSR)*

[7] Sennov S N 1999 *The results of 60-year observations of the natural dynamics of the forest* (St.Petersburg: SPbNIILH) p 98

[8] Chirkov G V 2004 *Mechanism of the formation of tree mortality in coniferous stands of the Leningrad region*, PhD tesis, St.Petersburg forest Academy

[9] Nikiforchin I V, Veschchikova N A, Toropova S J and Lisitsa V R 2014 *Stocks of large woody detritus in the forest fund of the Lisinsky training and experimental forest area. Information technologies in forestry, nature protection and landscape construction* [A collection of articles of Forestry Faculty employees on the results of completed research works] (St.Petersburg:GLTU). Issue 1 (14) pp 47-52

[10] Tretyakov N V1927 *The law of unity in the structure of plants* (Leningrad:New village). p 113