The earliest research of tending felling established according to IUFRO system in north-west of Russia

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Abstract. Research facilities on thinning operations for forests in North-West of Russia were established during 1929-1930 according to technique accepted by the II World Forestry Congress in 1928 in Rome. The purpose of this work originally consist on clarification of effectiveness of this forestry measures, degree of its influence on an increase for growing stock, height, and on quality of timber. This necessity was caused by the fact that it was the first such experience at that time. The main objective consisted in specification of intensity and techniques of thinning. There are structural changes in elevated and underground plants biomass in a stand. On all research facilities the appearance of spruce-tree advance growth is noted. The thinning can affect on the course of natural reforestation and does not cause fundamental change in the ratio between a grass and moss layers. They shift this ratio in favor of the first one and it allows claiming about the possibility of bio-circulation intensity increase by means of regular tending felling of the forest. Now it is the most valuable research facility allowing coming to scientifically substantiated conclusion about techniques of thinning which correspond to exact combination the silvicultural and economic requirements for forest management.

1. Introduction
Research facilities on thinning for forest in Siversky forestry unit of Leningrad Region were established during 1929-1930. The purpose of this work originally consist on clarification of effectiveness of this forestry measure, degree of its influence on an increase of growing stock, height, and also on quality of wood. This necessity was caused by the fact that it was the first such experience in North-West Russia at that time. The scheme of research facilities establishment corresponded to the method accepted by the II World Forestry Congress in 1928 in Rome.

Research works on areas establishment were performed by A V Davydov, Z Ya Solntsev under supervision of Professor V V Guman.

For profound development of a problem the common research technique was expanded and made more profound by additional researches in which the influence of thinning on intensity and the nature of photosynthesis, on root systems grow, on branch in essand form of stems, on density and anatomic structure of timber was studied. Also influence of intensity of thinning on competitive relationships between wood species, on a condition of herbs ground cover and underwood and also on forest renewal processes of a spruce under maternal canopy was investigated further.
2. Methods and Materials
A remarkable example of this research is a series of permanent experimental plots No 1 (PEP 1) established in mixed stand with spruce and deciduous of Betuletum oxalidosum type at birch layer of 40 years old and at spruce layer of 38 years old. Advance growth and underwood were absent and grass cover was poor and Oxalis dominated; moss cover was presented by spots of shining moss.

The area surface on sections of the constant growth plots is composed by the quaternary deposits which are based upon species belonging to the Devonian system. The soil on research facilities is well drained moderhumus, weak podzolsabulous and clay-loam soil on red boulderyclay loam. Sections of 0.25 hectares were allocated on research facilities. The following variants of research were established: A control variant was for monitoring, B variant was for weak thinning (intensity of tending felling was up to 20% of growing stock), C variant was for average thinning intensity (20–34%), D variant was for strong thinning intensity (35–44%), E variant was for very strong thinning intensity (45% and more of growing stock). The data provided in tables 1 and 2 give an idea of changing a growing stock and efficiency of thinning in the stands during research period. On permanent experimental plot (PEP) # 1 the combined method of thinning of a stand with an approximation to lower was applied.

Table 1. Initial characteristic of research subject (1929).

| Series of PEP | Number of sample plots | Tree species composition of stand according to layers | Age | Bonitet class | Forest type |
|---------------|------------------------|-----------------------------------------------------|-----|--------------|-------------|
| 1             | 5                      | 1 layer: 10B + Asp+P                                 | 43  | Ia           | Betuletum oxalidosum |
|               |                        | 2 layer: 10S                                        |     | III          |              |

*B – Betula pendula; Asp – Populus tremula; P – Pinus sylvestris; S – Picea abies

Table 2. Characteristic of research subject according to data of last taxation (2010).

| Sample plots (control) | Layer | Tree species composition of stand according to layers | Age | Bonitet class | Forest type            | Relative density | Growing stock, m³/ha |
|------------------------|-------|------------------------------------------------------|-----|--------------|------------------------|------------------|---------------------|
| 1A                     | I     | 10B+A+P                                              | 125 | Ia           | Betuletum oxalidosum   | 0.9              | 384                 |
| 1B                     | II    | 10S                                                  |     | III          | Piceaetum oxalidosum   | 0.3              | 148                 |
| 1C                     | I     | 9S1P                                                 | 125 | II           | Piceaetum oxalidosum   | 0.5              | 301                 |
| 1D                     | I     | 8S2P                                                 | 125 | II           | Piceaetum oxalidosum   | 0.6              | 321                 |
| 1E                     | I     | 10S+P                                                | 125 | II           | Piceaetum oxalidosum   | 0.7              | 432                 |

*B – Betula pendula; Asp – Populus tremula; P – Pinus sylvestris; S – Picea abies

3. Results and Discussion
The outside influence by way of tending felling causes changing the character of current increase fluctuations in spruce stand (figure 1). At that two aspects should be noted.

– Current increase fluctuations amplitude on sites passed through by weak and very strong thinning is the closest variant to fluctuations amplitude on control plot. Consequently if we want to receive the closest ecologically stand to a natural one but of high productiveness the thinning of weak and very high intensity should be used. It is explained by that the
fluctuations the stronger, the lower the possibility of system transfer is (biogeocenosis) to the higher level of productivity and vice versa the higher such possibility is the weaker fluctuations are.

— Thinning of very high intensity smooth the fluctuation amplitude of current increase and decrease their frequency, i.e. optimize the ligneous plant food regime and make them less depend on external and internal medium factors as compared to other variants of research.

Figure 1. Current increase fluctuations on research facilities.

Analysing data on series PEP 1 it is obvious that in the first 5 years decrease of total productivity of a stand generally compared to control plot (PP 1A) is observed on all stands with conducted thinning. But the total productivity of a stand is restored up to control level only 10 years after on sample plot 1C with thinning of average intensity and on sample plot 1D of high intensity and 15 years after on areas of weak (PP 1B) and of very strong (PP 1E) intensity of tending felling. There are structural changes in ground and underground plants biomass in a stand after a thinning. The ratio between the stem, crown and underground plants biomass of stand changes in favour of the last two ones. At common determining of a stock this event remains unnoticed. Meanwhile, such restructuring is followed by energetic and resource expenses.

Thus, costs for restructuring in a stand, intense development of above soil vegetation and reservation of resources part in a rhizosphere result in decrease of the total efficiency of a stand. Resource-saving function of a forest ecosystem is implemented in this way, and in course of time there is a step-by-step involvement of the stored resources in production process which would have further to lead to restitution of the common efficiency of a thinning stand. The common efficiency on a spruce part of a stand on all research areas passed through by tending felling (PP 1B, 1C, 1D, 1E) continued to grow throughout the entire period of research and to the end of the observation moment considerably exceeded a control indicator. However at PP 1D passed through by strong tending felling, the common efficiency of a spruce part turned out to be lower than on other research facilities that is bound to the larger value of a drain on this site.

The studied indexes dynamics analysis for trade structure of a spruce part of stands (figure 2) shows at the end of the observation period that a larger output of large timber is observed on sections
with thinning out in comparison with control sites where tending felling for the forest were not carried out.

![Trade structure of wood sorrel spruce branches for 1960](a)

![Trade structure of wood sorrel spruce branches for 2012](b)

**Figure 2.** Sortment structure of wood in spruce forest.

It should be also noted that on all areas with spruce layer thinning the average diameter after felling of plantation part increased during research, i.e. the stunted or defective trees of spruce were chosen. In general results of the long-term experiments with tending felling show that at more intensive thinning of spruce wood layer both the forest stand stock and large trade structure of plantation has not decreased and on the contrary it has increased in comparison with areas with lesser intensity of trees selection. Despite any orders of tending felling intensity and the present stock the trade structure of stand spruce part develops in a percentage ratio at the research facilities passed through by tending felling of average, strong and very strong intensity is approximately identical: 43-46% comprises of large wood, 36-38% comprises of average wood and 10-12% comprises of small wood. This fact serves as a growth processes stability indicator in a spruce part of a phytocoenosis.

The spruce stands thinned by thinning form not only various reserve of stem wood, but also various stem plants biomass to exploitability age. The major quality factor of wood is its density. The analysis of wood density distribution of a spruce show that density varies considerably in each of research options (on steps of stands’ thickness). Big range of oscillation of density on various objects predetermined the analysis of its average values both by separate options of research, and on
diameter class in facilities. This is due to the fact that the quantitative representation of trees in distribution series according to planting diameter class by options on research facilities. At analysis of average density distribution of spruce timber on diameter class in general at all studied facilities the clear decrease tendency for density and coefficient of its variation with stems diameter increase is observed. As a result despite the considerable variability of density in thinned stands the average density of wood in general remains at control level. Therefore, not only no decrease of stem plants biomass in areas with thinning carried out but also its increase is observed in compliance with large volumes of stem wood and stability of wood density. Now on research facilities there are high-efficiency conifer plantings with a wood density the surpassing average values for the region.

The average width of annual growth layer over experimentation period at areas with felling makes no more than 1 cm and only at the most extreme stems among stems distribution series this index is higher. According to the obtained data on the content of late wood portion in a year increase for the period which passed after tending felling this indicator of a growth layer structure has not decreased significantly on stand diameter class below indexes on control area without felling for research period.

A dispersion analysis of the data obtained during data research on the content of late wood and early xylem structure at this age-related stage of coniferous plantings growth. On the average the portion of late wood on diameter class at areas with felling in nominal clear plantings of a spruce ranges from 25 to 35%.

The width of a growth layer during this period of planting growth has smaller influence on wood density characteristics. It should be noted that this pattern becomes clear concerning spruce forest stands irrespective of intensity of tending felling [1].

Forest phytocoenosis is a composite study subject of a system form which responds to the outside impact by all components. Intrastructural reconstructions having a purpose of maintaining the wholeness and stability of system as a whole take part in all layers after thinning [2, 3].

But such reaction is caused not only by ecological conditions changing but also by reaction of a phytocoenosis to the arisen threat of resources loss and to violation of biocirculation stability. Therefore a response of all phytocoenosis components is directed to preservation and the fastest development of additional resources, their involvement in biocirculation and restitution of system efficiency level is possible. Representatives of the lower plantation layers play an important role among which are advance growth, live ground cover and underwood.

The success of natural reforestation can’t be counted as the purposes and objects of forest tending, but it is important to know what conditions for natural reforestation are created after tending felling. The main objective of tending felling is the improvement of stands’ content, their sanitary state and increase of stability. Felling of any intensity changes not only the structure, but also the established links between phytocoenosis components at any age. Therefore tending felling especially thinning one can also affect on the course of natural reforestation [2-4].

As it is clear from data of table 3 the appearance of spruce advance growth is noted at all study subjects, irrespective of research option. The common tendency is as follows: the higher intensity of the felling, the smaller the number of the appeared spruce advance growth is.

**Table 3. Characteristics of advance growth on study subject.**

| GP  | Content | Age ($A_{av}$), years | Height ($H_{av}$), cm | Height growth $Z_{av}$, cm/year | Number, piece/ha | Frequency of occurrence, $\tau$, % |
|-----|---------|----------------------|----------------------|---------------------------------|------------------|----------------------------------|
| 1A  | 10E     | 9                    | 125.1±5.8            | 13.9±0.3                        | 4130             | 93                               |
| 1B  | 10E     | 8                    | 107.2±6.8            | 13.4±0.3                        | 3210             | 93                               |
| 1C  | 10E     | 8                    | 93.1±7.2             | 11.6±0.4                        | 3003             | 97                               |
| 1D  | 10E     | 7                    | 104.6±8.9            | 14.3±0.3                        | 3537             | 80                               |
| 1E  | 10E     | 6                    | 96.0±13.4            | 16.0±2.6                        | 490              | 47                               |
The spruce self-sowing which appeared right after the felling is affected by the strong competition on the part of live herbs ground cover and underwood and dies. It is evidence that the major limiting factors of spruce younger generation development at the first stage after tending felling are live herbs ground cover and underwood described below.

The data obtained by us allow conclude that both thickness of an underwood and its structure on height affects on renewing of a spruce. This conclusion is confirmed by the experimental data obtained at all experimental plots.

The greatest number of advance growth is noted during the control (PP1A) that first of all is caused in our opinion by existence of a birch as a part of a stand that is 3.0 m high. Besides the underwood settles down with groups and has different height at this facility. The similar situation developed at 1B, 1C, 1D sample plots. At these research areas a large underwood with average height of 3.5; 3.6 and 4.3 m respectively is settled down by groups evenly on the area and do not form closed canopy. It promotes the appearance of group spruce advance growth.

It is established by our researches that tending felling promotes the dynamic growth of a live herbs ground cover.

Data on dynamics of live ground cover under the influence of thinning of different intensity in wood sorrel spruce forest for more than 80 years are presented in article. The accounting of a project of a live ground cover was carried out in 1975, 1989, 1993 and 2010 for the purpose of definition of influence of different intensity thinning on dynamics of a live herbs ground cover. Let's analyse dynamics of live ground cover structure on subjects of thinning.

According to numerous researches [1, 2] it is established that thinning causes change of the ecological kind, the decrease of competition on the part of a stand, the release of a part of soil resources and rise of actual fertility of the soil, and as a result, growth of the ground vegetation performing soil-protective and resource-saving function. As a result the structural reorganization directed to fixing of additional resources in biocirculation in phytocoenosis is performed. This hypothesis is confirmed also by results of our researches.

At research areas where strong (PP 1D) and the very strong intensity of thinning (PP 1E) were carried out five years after the last reception the portion of low shrubs and semi-bushes (raspberry) was 1.7-2.2 times higher in comparison with control plot and becomes respectively 11.4 and 8.5% of the total general projective covering. At the same time it should be noted that there was a gradual replacement of cowberry with bilberry and growth of raspberry that in turn demonstrates the improvement of conditions of a site.

Besides thinning on PP 1D and PP 1E led to temporary increase in mosses projective covering in comparison with control option (GP 1A). Along with development of a moss layer after the strong and very strong tending felling of the wood the active growth of a grass layer is also observed. Thus if thinning does not cause cardinal change in the ratio between a grass and moss layer, at least it shifts this ratio in favour of the first one which demonstrates the positive role of thinning allows us claiming about a possibility of biocirculation intensity increase by means of the regular tending felling.

As it is clear from data that 15-20 years after the last reception of forest tending felling at facilities passed through by tending felling (PP 1C, 1D, 1E), the portion of low shrubs, herbs and mosses corresponds to control indexes (PP 1A) that demonstrates the system return to a state of the labile stable balance.

Results of the last inventory (2010, i.e. 35-40 years after performed tender felling) show that distribution of types according to layers has changed a little. This in our opinion is the result of the natural processes appearing in overmature forest stand and also of influence of forest tending felling that has been performed in these stands for 50 years (from 1929 to 1979).

Let's consider the results of researches received in 2010 in detail. As it is clear from the data at all sample plots the total projective covering of grass and fruticulose plantation exceeds 100% in 2010 that is bound to absence of zones with no live ground cover in the studied plantings and well expressed storeyed structure, i.e. taiga short herbs and mosses are as a rule situated under canopy of low shrubs.
and mosses. On all areas passed through by thinning the growth of live ground cover is noted. Its total projective covering ranges from 135.0 to 168.6% depending on option of research and exceeds the indicators on control almost for 50%.

The least total projective covering of a live ground cover is recorded on the control area (PP 1A) and it equals to 100.3% that is explained by high relative density of a stand of the first layer (0.9), by existence of the second spruce layer and underwood of a rowan more than 3.0 m high, numbering more than 16 thousand pieces/ha. Besides there is at hick advance growth height of a spruce of any age and various height (more than 6 thousand pieces/ha) on control area. As a result of the specified reasons the competition for light, moisture and food compounds, and, as a result, the probability of photophilous species of grassland vegetation decreases. At the areas after thinning irrespective of their intensity to the end of observation period a decrease of low shrubs portion in comparison with control option was recorded. It is explained most likely by the fact that low shrubs as an element of ‘conservative’ vegetation are forced out by more dynamic types, generally by herbs [1, 2] and first of all by the vegetatively relative species [1, 2]. Besides, tending felling of weak and average intensity lead to an increase of herbs portion by 5-10% in comparison with control and this testifies a positive role of this type of thinning.

It is established that an increase of herbs portion demonstrates an increase in biocirculation intensity [1, 2]. A bit different picture is observed at research areas with conducted thinning of the strong and very strong intensity (PP 1D and 1E). At the specified facilities the portion of mosses in total projective covering has increased in comparison with control plot on the average by 20% 5 years after tending felling and by 49.3% 40 years after it, and in comparison with the growth plots where weak and average thinning were carried out it has increased by 3.5 times. We consider that the strong tending felling cause an increase of soil humidity and promote increasing in a portion of mosses that, in turn, is one of noticeable indexes of delayed biocirculation. Also delayed process of natural reforestation of conifer species at PP 1E (only 490 pieces/ha) in comparison with other options of experiment can in our opinion be considered the proof of it.

4. Conclusion
Summing up the results of the analysis of lower vegetation layers development after tending felling of different intensity in general it is possible to note the following:

1) With an increase on thinning intensity the number of advance growth decreases as such felling promote the active growth of an underwood;

2) The intensity of tending felling has significant effect on development of a live ground cover, i.e. the higher the intensity of the thinning is, higher the cooperative projective covering is;

3) Thinning leads to decrease in a portion of low shrubs irrespective of their intensity. Thinning of weak and average intensity promotes the increase herbs portion, and of the strong and very strong intensity promotes the increase portion of mosses:

4) The success of natural regeneration of a spruce on the with thinning of different intensity first of all is influenced by cereal and sedge plants, mosses and a mixed herbs cover. At increase of a total projective cover of these groups the number of advance growth decreases significantly.

Summarizing the obtained results on influence of tending felling on formation of spruce stand it is possible to make the conclusion that depending on the order of thinning the forest phytocoenosis responds all the components on the made impact. In general thinning has positively influenced on the structure of the created spruce stands at the qualitative and quantitative level. The positive role of thinning consists on change of the ecological order, in decrease of competition from a stand, in release of a part of the soil resources and increase of actual soil fertility leading to growth of the ground vegetation performing soil-protective and resource-saving function. Now it is the most valuable research facility allowing making evidence-based conclusions about expediency of these or those methods of thinning which answer the exact combination of silvicultural and economic requirements for forest management.
References

[1] Danilov D A, Smirnov A P and Smirnov A A 2015 Impact of thinning intensity on wood density of mature wood sorrel spruce forest type Proceedings of the Saint Petersburg Forest Technical Academy 212 (St. Petersburg: SPbFTA) pp 18-28

[2] Belyaeva N V and D A Danilov 2009 Regularity of natural forest regeneration at tending felling facilities and complex forest management Proceedings of the Saint Petersburg Forest Technical Academy 188 (St. Petersburg: SPbFTA) pp 30-39

[3] Melnikov E S, Belyaeva N V and Bogdanova L S 2006 Impact of complex forest management on development of lower layers of vegetation of pine and spruce phytocoenoses of south taiga Proceedings of the Saint Petersburg Forest Technical Academy 178 (St. Petersburg: SPbFTA) pp 4-12

[4] Sennov S N 1984 Forest management (ecological bases) (Moscow – Leningrad: Nauka) p 128