Development of process flow charts for growing ball-rooted planting stock: issues and solutions

S V Bobushkina and N A Demina
Northern Research Institute of Forestry, Nikitova Street 13, Arkhangelsk 163062, Russian Federation

*Corresponding email: svetlana.bobushkina@sevniilh-arh.ru

Abstract. In order to create process flow charts for more efficient operation of enterprises for the production of pine and spruce ball-rooted planting stock for reforestation, research and comparative analysis of technologies of three nurseries in the Arkhangelsk region were conducted. Significant differences in capacity, equipment sets, greenhouse characteristics, number of rotations, etc. in greenhouse complexes do not allow the development of a single standardized document. The results of the analysis allowed us to divide technological methods into two blocks: the main ones and additional (or auxiliary) ones. The first block of operations in the process flow charts of different nurseries will differ in time, duration and ways of their realization. The second one consists of those operations that are carried out only under certain conditions of forest nursery functioning, with the appropriate equipment of enterprises and their financial capabilities. The results of the conducted comprehensive research will serve as the basis for the development of regional documents, which will offer the most rational methods of carrying out certain types of work, as well as build a chain of technological operations for growing high-quality planting stock in a particular greenhouse complex.

1. Introduction

Ensuring quality reproduction of forest resources is a mandatory element of forest management. For this, 1207 forest nurseries with a total area of 8806.8 hectares have been created on the territory of the Russian Federation, of which 64 forest nurseries (including forest breeding and seed centers and greenhouse complexes), where ball-rooted planting stock is grown with the total area of 398.9 ha. At the same time, due to the regulatory requirements introduced in 2018-2019 to increase the proportion of artificial reforestation using ball-rooted seedlings, the need for planting stock with a lump of substrate is increasing. The volume of seedlings growing at the existing infrastructure facilities does not correspond to the production needs [1].

The technology of cultivation of ball-rooted planting stock differs from the traditional one in high technological efficiency of production, reduction of seedlings cultivation period, absence of competition between plants, efficient use of seeds. Plants in cells form a compact root system, which helps to reduce the risk of its damage during transportation and planting [2-5].

A mandatory document for the effective functioning of an enterprise for the production of any planting material is a process flow chart. For open field nurseries, such standardized documents have been developed [6, 7] and successfully introduced into production. For greenhouse complexes specializing in growing seedlings in containers, there are no process flow charts yet.

In addition, it was noted that there are not enough qualified workers in greenhouse complexes for the production of ball-rooted planting stock, which leads to the impossibility of high-quality
performance of the simplest works. On the other hand, with the expansion of production and research, modernization of equipment, new types of operations may appear, therefore even an experienced worker or foreman often does not know how to correctly and as quickly as possible fulfill the duties assigned to them. In this regard, a process flow chart should be developed for each enterprise, describing the procedure, terms and features of each operation. Therefore, the relevance of work in this direction is not in doubt.

Process flow charts must be drawn up taking into account the latest scientific achievements, as well as contain recommendations for the use of modern equipment for growing planting stock to obtain the maximum amount of standard planting stock of wood species at the lowest cost of labor and money.

The aim of the work is to search for rational and science-based solutions for the creation of process flow charts in the field of cultivation of ball-rooted planting stock of European spruce and Scots pine in the taiga zone of the North of the European part of Russia.

Main tasks:
1. study and analysis of the technology of growing ball-rooted planting stock in greenhouse complexes of the Arkhangelsk region;
2. experimental sowing of pine and spruce seeds at different dates, testing and comparing different regimes of seedlings cultivation;
3. monitoring of growth and development of ball-rooted planting stock in different variants, collection of field material, its processing and analysis.

The study involves the deepening of knowledge on the production of forest ball-rooted planting stock, taking into account regional soil and climatic conditions and the existing developments of the FBU "Northern Research Institute of Forestry", is one of the stages of research in the field of improving technologies for the production of seedlings in containers.

2. Methods and Materials
Currently, in the Arkhangelsk region there are 3 enterprises for the production of ball-rooted planting stock: Velsky greenhouse complex, Ustyansky forest selection and seed production center and Shenkursky forest nursery. The object of the study was the production process of cultivation of ball-rooted planting stock, including a comparative assessment of technological operations, features and timing of their implementation, the equipment used at the enterprises of the region.

In the course of ongoing research, literature data in the field of production of seedlings in containers in Russia and abroad, as well as regulations were studied. For the development of process flow charts, we monitored the production processes, their timing and duration, as well as the quality of technological techniques and operations.

Experimental variants were laid with different terms for sowing seeds and carrying cassettes to the growing area, tested substrates of various manufacturers and compositions, as well as growth stimulants.

In studies on the use of various additives, on the selection of the optimal timing of sowing and removal of cassettes to the growing area and other technological methods, their influence on the development of roots and the stability of the substrate clump when removing seedlings from the cassettes is established. The stability of the clump was determined at the end of the growing season in two or three terms by weighing the seedlings with and without clump. Chemical characteristics of the substrate were determined according to generally accepted methods. The height and diameter of the seedlings were measured 3-4 times per season, the weight of the needles, stem and roots in an absolutely dry state was determined. All measurement materials were processed statistically.

Due to the fact that the seedlings grown in the studied nurseries can be used for planting on a silvicultural area in two taiga regions of the Russian Federation, the share of the output of standard planting material for the north-taiga forest region of the European part of the Russian Federation (height not less than 10 cm, diameter not less than 2 mm) and the Dvinsko-Vychegodsky forest region (height not less than 12 cm, diameter not less than 2 mm).
Microclimate in greenhouses and on the growing platform was determined by a weather station, which records the temperature, humidity and light at intervals of 30 minutes.

3. Results and Discussion

The production of planting stock begins with the planning of a forest nursery; this is one of the most important stages in the life cycle of such an enterprise. The development of an architectural and planning solution must necessarily include: the conditions for the future location of the complex for the cultivation of forest planting stock (regional features); actions for the selection of the required set of equipment; determination of the required number of personnel; work schedule; product range; calculation of energy efficiency and autonomy of work; accounting for main, auxiliary processes and management processes; conditions for ensuring economical and ergonomic operation [8].

Along with the stages of planning, design, construction of the nursery, as noted earlier, for its effective functioning, it is required to develop a convenient and understandable form, including all technological operations carried out in the production of seedlings (process flow chart).

Process flow chart is a standardized document containing a consistent statement of technological and agro-technical methods and techniques of growing coniferous planting stock for reforestation with the indication of materials and equipment used. The process flow chart must necessarily contain a list of operations, their sequence, timing and frequency of implementation, used equipment and units.

In the process of studying the conditions and analyzing the technologies of three enterprises of the Arkhangelsk region, it was noted that greenhouse complexes within one region differ greatly in their capacities, equipment sets, characteristics of greenhouses, the number of rotations, etc. (table 1). In this connection, it is not possible to develop a unified process flow chart for nurseries for growing seedlings in containers. For each type of ball-rooted planting stock (breed, age, set parameters) and a specific greenhouse complex, a separate document must be drawn up.

Table 1. Brief characteristics of greenhouse complexes in the Arkhangelsk region.

| Indicators (parameters)     | Velsky greenhouse complex | Ustyanovsky Forest Breeding and Seed Center | Shenkursky forest nursery |
|----------------------------|---------------------------|--------------------------------------------|---------------------------|
| Opening, year              | 1997                      | 2013                                       | 2017                      |
| Object area, ha            | 1.1                       | 5.4                                        | 0.4                       |
| Number of greenhouses      | 2                         | 7                                          | 1                         |
| Greenhouse heating         | no                        | yes                                       | yes                       |
| Covering greenhouses       | Plastic sheeting          | Plastic sheeting                           | Polycarbonate             |
| Area of 1 greenhouse sq. m| 720                       | 1300                                       | 960                       |
| Cultivated species         | Pine (Pinus sylvestris L.), spruce (Picea abies) |
| Productivity (number of seedlings per year, mln. pcs.) | 0.5 | 9 | 1 |
| Number of rotations        | 1                         | 3                                          | 2                         |
| Type of container          | Pant 81 F; Plantek 81F    | Plantek 100; Side Slit 81                 | Plantek 81F               |
|                            |                           | Plantek 121F                              |

So, in small nurseries, the filling of cassettes with peat, sowing of seeds and mulching is carried out manually, at productions with a large volume, automated flow lines are used for these purposes. At the same time, some producers use single-seeded sowing, others place 2-3 seeds in one cell, which will further affect the duration and timing of picking seedlings.

For growing seedlings in containers, it is recommended to use selectively improved seeds, however, such seeds are extremely scarce in the region. In this regard, the enterprises of the Arkhangelsk region use seed material of mass collection. In this case, preference should be given to high quality seeds with a high soil germination rate of more than 80% [9] or 90-96% [10]. However, as practice shows, the germination capacity of seeds available for purchase and sowing in greenhouses does not always have the necessary indicators; this requires preliminary preparation of seeds.
The Ustyansky Forest Breeding and Seed Center has the ability to conduct a full cycle of processing of forest seed raw materials: calibration, sorting, cleaning, and preparation for sowing, as recommended by many researchers [10-13]. In addition, there is the possibility of obtaining seeds on our own using a cone processing line. Other nurseries in the region, bypassing these operations, start the production process immediately with the pre-sowing treatment of seeds by snowing, bubbling, and soaking in fungicides and stimulants.

Studies have proved that growth stimulants accelerate seed germination, increase germination, have a positive effect on the development of the ground part and root system of seedlings, increase the survival rate at transplanting and contribute to better survival in extreme conditions [14-16]. Currently, there is a large number of different preparations with growth-stimulating effect, but preference is given to environmentally safe ones [17-19].

Our studies confirmed the effectiveness of humic preparations for seed pre-sowing treatment and their use as seedling dressing during the growing season. Thus, in the first case we observed an increase in spruce seed germination energy up to 13% and germination rate up to 12.3%. During root dressing with the preparation the average height of pine seedlings was higher than that of seedlings on the control by almost 20%, for spruce seedlings - up to 16%.

Some greenhouse complexes in Scandinavia use short daylight treatment [20, 21], artificially limiting the light supply to seedlings for certain time intervals. In addition, scientists in Finland have investigated the effect of additional lighting of different duration [22], long wave red light [23, 24], different light spectra [25] in order to increase the efficiency of growing planting stock.

In general, the equipment systems between greenhouse complexes and selection centers are different, which will also affect the number and name of operations in the process flow chart.

The absence of frames in greenhouses, on which containers are installed to provide "air root pruning", will determine the presence of an additional operation of mechanical pruning of roots that have gone beyond the container before removing the seedlings for packaging. Our research [26] found that the length of the roots of seedlings that went beyond the container, located on the ground in the growing area and on the floor in the greenhouse, reaches more than 50 cm, and their weight per seedling is up to 0.131 g.

The number of rotations and the timing of sowing seeds into containers depend on the area where the planting stock is grown. Even within the Arkhangelsk region, the climatic characteristics of the southern and northern territories are different (table 2). There will be a significant difference in sowing dates in greenhouse complexes equipped with heating systems and without them.

### Table 2. Climatic characteristics of the Arkhangelsk region [27].

| Part of the Arkhangelsk region | Average duration of the growing season, days | Average annual air temperature, °C | Sum of temperatures above 5 °C | Annual precipitation, mm | Hydrothermal coefficient | Average air temperature, °C (continental climate, %) |
|-------------------------------|---------------------------------------------|------------------------------------|-------------------------------|--------------------------|-------------------------|---------------------------------------------------|
| North                         | 132                                         | -0.1                               | 1510                          | 500                      | 1.8                     | -12.5/10 (38-42)                                  |
| South                         | 148                                         | 1.0                                | 1810                          | 400                      | 1.8                     | -12/10 (40-50)                                    |

In the conditions of the Arkhangelsk region, the return of cold weather (frost) can be in any period of the growing season. Therefore, for seed germination and active growth of seedlings, it is important to maintain the necessary microclimate in greenhouses.

The recommended air humidity in the greenhouse during the period of rapid growth of seedlings should be maintained at a level of 50-70% [28].

Studies by Chechueva T A et al [29, 30] found that the optimal parameters of the air temperature under the plastic sheeting are values from +10 to +28 °C. At temperatures above and below these indicators, photosynthesis decreases and the growth rate of seedlings decreases, which noticeably affects the quality of the planting stock. However, according to our observations, it is extremely
difficult to ensure optimal temperatures in greenhouses that are not equipped with heating systems and forced ventilation in the north. It has been established that in such greenhouses at night the temperature can drop to 2 ºС, and in hot periods it can reach + 35 ... + 40 ºС.

According to the results of our studies, we can conclude that under the conditions of the southern part of the Arkhangelsk region, it is possible to obtain two rotations of standard coniferous seedlings in 1 year only of early sowing (end of March - beginning of April), mandatory heating of greenhouses at the beginning of the season and when cold weather returns to during the summer, strict adherence to technological discipline, the timing and quality of work, the use of high-quality substrates and fertilizers, the use of growth stimulants. At the same time, it is recommended to sow spruce in the first place. The second rotation should be started in the second decade of June and pine should be grown as a faster growing species. In this case, the overwhelming number of spruce seedlings reach standard values by the end of the first year of cultivation. The pine planting stock of the second rotation during the spring months of the next growing season must be grown to standard sizes in an open area (table 3). The use of the third rotation in the conditions of the taiga zone of the North of the European part of Russia is not advisable.

Table 3. Average parameters of seedlings in 2019 in the Shenkursky forest nursery (greenhouse with heating).

| Species | Date of sowing | Date of taking the cassettes to the growing area | Number of days of cultivation / under the plastic sheeting | Height, cm | Diameter, mm | Output of standard seedlings in height, % |
|---------|---------------|-----------------------------------------------|----------------------------------------------------------|------------|-------------|----------------------------------------|
| Pine    | 13.06         | 14.09                                         | 94/94                                                   | 9.8±0.11   | 1.6±0.03    | 48.3 ± 0.05                            |
| Spruce  | 03.04         | 9.06                                          | 165/68                                                  | 14.0±0.23  | 2.2±0.05    | 92.5 ± 0.05                            |
|         | 12.06         | 14.09                                         | 95/95                                                   | 7.9±0.12   | 1.3±0.04    | 6.2 ± 0.05                             |

Growing high-quality seedlings of ball-rooted conifers in greenhouses not equipped with a heating system in the Arkhangelsk region is possible in the first rotation with the sale of seedlings in spring - early summer next year. As can be seen from table 4, by the end of the first growing season, the plants do not reach standard values.

Table 4. Average indicators of ball-rooted seedlings in the Velsky greenhouse complex (sowing 26.04.2019, greenhouse without heating).

| Species | September 13, 2019 | June 25, 2020 |
|---------|-------------------|---------------|
|         | Height, cm | Diameter, mm | Standard in height, % | Diameter, mm | Standard in diameter, % |
| Pine    | 10.2±0.14 | 1.8±0.03     | 19.3±0.13 | 99.4       | 2.6±0.06 | 92.2          |
| Spruce  | 6.8±0.13 | 1.3±0.03     | 11.2±0.15 | 97.2       | 1.8±0.04 | 38.1          |

Thus, the maximum disclosure of the biological potential of coniferous plants in greenhouse complexes in the taiga zone of the North of European Russia is due to the development of effective and science-based technologies for growing planting stock for reforestation.

4. Conclusion
In conclusion, it should be noted that industrial production of ball-rooted planting stock simultaneously with the creation of the technology of growing ball-rooted seedlings depends on the technical conditions and decisions of management, the requirements of customers. Each object is unique, has its own specifics and capabilities. Therefore, it is not possible to make a single process flow chart for all enterprises.

In the course of our research, we reviewed and analyzed a large number of techniques and operations performed in nurseries of the Arkhangelsk region and, according to literary sources, outside
of it. On the basis of which, all technological processes can be divided into 2 blocks: main and additional (or auxiliary).

The first block includes a number of operations, which are an integral part of the technology of cultivation of ball-rooted planting stock of any enterprise. For example, preparation of seeds for sowing, seed dressing, filling cassettes with peat, sowing seeds, mulching, watering, picking, weeding, fertilizing with nitrogen and potassium-phosphorus fertilizers according to phases of seedling growth, protection against diseases and pests, taking to the growing site, hardening, winter storage of seedlings, nursery hygiene, etc. In the process flow charts of nurseries, these operations may differ only in the time, duration and methods of their implementation.

The second block consists of such operations, which will be necessary only under certain conditions of forest nursery operation, with appropriate equipment of enterprises and their financial capabilities. Examples are the following types of operations: sorting and calibration of seeds, treatment of seeds by electromagnetic field, pruning of roots that have gone beyond the cassettes, treatment of seedlings by short day, etc.

Analysis of working schemes of technological operations, operating nurseries in the Arkhangelsk region, as well as the results of scientific research with the use of growth stimulants, different terms of seeding pine and spruce seeds, will be the basis for the development of regional documents, which will propose the most rational methods of some types of work, and build a chain of technological operations for growing high-quality planting material in a particular greenhouse complex.

It is quite natural that a large number of indicators will lead to the complexity of the scheme of process flow charts. In our opinion, drawing up of process flow charts should be carried out first of all on a number of greenhouses, species and age of ball-rooted planting stock in the system of pilot-production testing (PPT) for at least 2 years. After working out all technological operations and obtaining positive results, start implementing the technology on a wide scale.

Acknowledgments

The work was carried out on the basis of the results of research carried out within the framework of the state assignment of FBI "Northern Research Institute of Forestry" to conduct applied scientific research. Registration number of the topic: AAAA-A19-119012590182-1.

References

[1] Order of the Government of the Russian Federation of February 11, 2021 №312-р "On approval of the Strategy for the development of the forestry complex of the Russian Federation until 2030". URL: http://www.consultant.ru/document/cons_doc_LAW_377162/8682410a81b111b1a646c02317d2a07c3374e058/ (Accessed 25 February 2021)

[2] Lubimov V B, Larionov M V, Melnikov I V and Moskalenko I V 2015 High efficiency of using the container method of growing planting stock of woody plants, regardless of the soil and climatic conditions of the region Fundamental research vol 2 (22) pp 4909-13

[3] Taylor E L, Blazier M and Holley A G 2007 New pine planting strategies for the western Gulf States USDA Forest Service Proceedings RMRS-P-50 pp 104-109

[4] Rodin S A, Rodin A R 2010 Improving the efficiency of growing forest crops with ball-rooted planting stock Forestry Bulletin vol 5 pp 7-10

[5] Nilsson U, Louranen J, Kolström T, Örlander G and Puttonen P 2010 Reforestation with planting in northern Europe Scandinavian Journal of Forest Research vol 25 pp 283-294. ISSN 0282-7581

[6] Sinnikov A S, Mochalov B A, Smirnov N A, Godnev L E, Yushka V I and Kirklis A A 1982 Technological maps for growing coniferous planting stock in a controlled environment in a zonal section (Arkhangelsk: Arkhangelsk Institute of Forestry and Forest Chemistry) p 88

[7] Mochalov B A 2005 Recommendations and technological maps for growing seedlings of pine and spruce in nurseries of northern and middle taiga sub-zones of European Russia (Arkhangelsk: Northern Scientific Research Institute of Forestry) p 36
[8] Vasilev O I 2019 Reforestation infrastructure LesPromInform vol 2 (140). Available at: https://lesprominform.ru/jarticles.html?id=5264 (Accessed 24 February 2021)

[9] Mochalov B A 2011 Some results of Russian-Finnish reforestation projects in the Arkhangelsk region Proceedings NRIF based on the results of research work for 2005-2009 (Arkhangelsk: Northern (Arctic) Federal University named after M V Lomonosov) p 75-93

[10] Zhigunov A V 2000 The theory and practice of growing ball-rooted planting stock Saint-Petersburg: Saint-Petersburg forestry research institute p 294

[11] Himanen K, Helenius P, Ylioja T and Nygren M 2016 Intracore variation explains most of the variance in Picea abies seed weight: Implications for seed sorting Canadian Journal of Forest Research vol 46 iss 4 pp 470-477. DOI: 10.1139/cjfr2015-0379

[12] Himanen K and Nygren M 2015 Seed soak-sorting prior to sowing affects the size and quality of 1.5-year-old containerized Picea abies seedlings Silva Fennica vol 49 iss 3 p 15 DOI: 10.14214/sf.1056

[13] Himanen K and Nygren M 2014 Effects of seed pre-soaking on the emergence and early growth of containerized Norway spruce seedlings New Forests. vol 45 iss 1 pp 71-82. DOI: 10.1007/s11056-013-9392-6

[14] Andreeva E M, Stecenko S K, Kuchin A V, Terehov G G and Hurshkainen T V 2016 Influence of natural growth stimulants on coniferous seedlings Forestry Engineering Journal (Voronezh State Forestry University) vol 3 pp 10-19

[15] Kabanova S A, Danchenko M A, Bortsov V A and Kocherganov I S 2017 Results of pre-sowing treatment of Scots pine seeds with growth stimulants Forestry Engineering Journal (Voronezh State Forestry University) vol 2 pp 75-83

[16] Frolenkova M S and Volkovich 2016 Influence of pre-sowing treatment of Scots pine and European spruce seeds on their germination and germination energy Scientific journal “Proceedings of BSTU” vol 1 pp 148-152

[17] Khitrova V I 2012 Comparative evaluation of humic fertilizers efficiency in the technology of spring wheat cultivation in the non-chernozem zone of Russia. Extended abstract of PhD thesis. Speciality 06.01.04 Agrochemistry Tver, p 19

[18] Neganova N M 2011 Humic fertilizers as a factor to optimize growth and development conditions of ornamental plants Scientific Thought of Caucasus vol 3 pp 96-99

[19] Yasser G, Maha A, Mohamed E and Yousry M 2021 Enhancing growth, productivity and artemisinin content of Artemisia annua L. Plant using seaweed extract and micronutrients Industrial Crops and Products, vol 161 113202 DOI: 10.1016/j.indcrop.2020.113202

[20] Luoranen J and Sutinen S 2017 Reduced height of short day induced bud scale complex may partly explain early bud burst in Norway spruce seedlings Silva Fennica vol 51 iss 5 Article No 7759 p 16 DOI: 10.14214/sf.7759

[21] Fløistad I S and Eldhuset T D 2017 Effect of photoperiod and fertilization on shoot and fine root growth in picea abies seedlings Silva Fennica vol 51, iss 1, Article No 1704. https://silvafennica.fi/article/1704 DOI: 10.14214/sf.1704

[22] Riikonen J and Lappi J 2016 Responses of Norway spruce seedlings to different night interruption treatments in autumn Canadian Journal of Forest Research vol 46 iss 4 pp 478-484. DOI: 10.1139/cjfr-2015-0355

[23] Riikonen J 2018 Efficiency of night interruption treatments with red and far-red light-emitting diodes (LEDs) in preventing bud set in norway spruce seedlings Canadian Journal of Forest Research vol 48, iss 9 pp 1001-6 DOI: 10.1139/cjfr-2018-0170

[24] De La Rosa T M, Lehto T and Aphalo P J 1999 Does far-red light affect growth and mycorrhizas of Scots pine seedlings grown in forest soil? Plant and Soil vol 211 iss 2 pp 259-268 DOI: 10.1023/A:1004630524168

[25] Riikonen J, Kettunen N, Gritsevich M, Hakala T, Särkkä L and Tahvonen R 2016 Growth and development of Norway spruce and Scots pine seedlings under different light spectra
Environmental and Experimental Botany vol 121 pp 112-120 DOI: 10.1016/j.envexpbot.2015.06.006

[26] Bobushkina S V 2014 Intensity of growth and development of pine ball-rooted planting stock under different growing regimes for reforestation in the Arkhangelsk region. PhD thesis. Arkhangelsk, p 196

[27] 1982 Forest seed zoning of the main forest-forming species in the USSR "Timber Industry". Moscow, p 368

[28] Zhigunov A V, Sokolov A I and Haritonov V A 2016 Growing of ball-rooted planting stock in the Ustyansky greenhouse complex. Practical advice (Petrozavodsk: Karelian Research Centre Russian Academy of Sciences) p 43

[29] Chechueva T A and Mochalov B A 1980 Materials of the annual session based on the results of research work for 1979 ed A S Sinnikov et al (Arkhangelsk: Arkhangelsk Institute of Forestry and forest chemistry) pp 81-83

[30] Sinnikov A S, Mochalov B A and Drachkov V N 1986 Growing seedlings of conifers in polyethylene greenhouses (Moscow: Agropromizdat) p 126