Silvicultural felling in priority-target silvicultural systems and their use

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Abstract. Considering the issues of the successive development of historically formed systems of silvicultural felling, a certain functional purpose for forest maintenance (thinning), and the replacement of mature stands for timber harvesting and forest renewal (reforestation). The solution of issues is ensured by the formation of priority-functional-target subsystems of silvicultural felling within the framework of the developed priority-target systems of forestry for forests of various purposes - operational, protective. The creation and use of such subsystems predetermine the possibility and necessity of developing an unlimited set of new efficient, environmentally friendly types and options for forest felling that are in demand in the process of forestry development.

1. Introduction

“Silvicultural felling”, also called “Forest felling” and defined as “silvicultural systems”, along with forest management and reforestation, are the most well-known and practiced forest management measures throughout the history of forestry. The system of silvicultural felling in Russia, in its main characteristics, took shape at the end of the 19th century - the beginning of the XX century and was reflected in the works of G F Morozov [1] and M M Orlov [2]. It was formed based on studying the achievements of foreign forestry in this area [3], as well as generalizing the results of the Russian experience, as a single complex multi-species system of functional forestry activities. For many decades, the main goal of felling forest stands has been timber harvesting, with a gradual strengthening of the functional goals of renewal - the restoration of forest stands (in place of felled stands) and care for them. Accordingly, the main goal of all these silvicultural activities of the system was the cultivation of stands, valuable for timber harvesting, with the gradual addition of goals - ensuring the fulfillment of water protection, protective, and other ecological functions by forests. At the same time, becoming more complex over more than a century, the system has remained a single undifferentiated one with all the diversity of its composition [1-4].

However, in this form, it does not seem to be mobile enough and effective for use in solving emerging new priority tasks in the context of forest differentiation by purpose. In connection with the change in natural climatic and other conditions, the properties of the forests themselves significantly changed under the influence of anthropogenic economic influences, the same multiple fellings, the replacement of indigenous forest stands with less stable derivatives. As well as the growing social, ecological, nature conservation significance of forests, with their continued and even increasing value as a source of wood and other forest resources. Accordingly, there is a need to differentiate silvicultural
felling not only traditionally in terms of functional, but also priority target designation within the framework of the developed priority-target systems of silvicultural activities [5].

**Purpose of the work:** to formulate a successively developed subsystem of silvicultural felling, differentiated according to the intended purpose of forestry objects, within the framework of priority-targeted systems of silvicultural activities.

The achievement of the goal is ensured by the solution of the following tasks:

- assessing the state and trends of the historical development of forest felling with the identification of unsolved in the past and new problems of their effective use in forestry;
- determining the place and significance of silvicultural felling in the priority-target systems of silvicultural activities for the cycles of forest reproduction - the dynamics of forest plantations;
- development of a conceptual scheme for the formation of subsystems of silvicultural felling in priority-target systems of silviculture for forests of various purposes - operational and protective;

### 2. Methods and Materials

As research materials were used historically accumulated scientific and practical data presented in literary sources. Which reflect the results of the application and development of forest cuttings for timber harvesting, reforestation, and forest maintenance. This took into account the functional purpose of felling, their methods. Based on these methods, a fundamental division of felling was carried out into two main systems - clear and selective. These, in turn, have their advantages and disadvantages in different conditions, including operational and silvicultural - ecological ones.

The solution of the set tasks was based on the systemic method of forestry, which was historically developed and tested in scientific research, in combination with the methods of identifying priority among the set of goals for the implementation of silvicultural activities (including felling of forest stands). The achievement of which, in the first place, is the implementation of the developed activities. Consequently, such priority-target measures (silvicultural felling) are filled as much as possible when they are created, formed with certain properties, techniques, methods, organizational and technical elements. What ensures, when applied, the achievement of the main priority goals and, in combination with them, of other goals.

### 3. Results and Discussion

**3.1. Assessment of the state and trends in the historical development of forest felling with the identification of unsolved in the past and new problems of their effective use in forestry**

Over the more than three-hundred-year historical period in the development of forestry, various terms have been developed and are still used in many respects to this day, incl. "Felling", "silvicultural felling", "final felling" and "thinning", "reforestation" or "reforestation-forest use felling", "felling systems", as well as used in the current legislation of the country - "felling of forest plantations which, along with the term "forestry felling", can be used as a conditionally generalizing in this work, when temporary or other concretization of "forestry felling - forest use" is not required. The very concept of this phenomenon in all the variety of definitions and the reality reflected by it - certain measures of impact on the forest by a mechanical method ("chopping" - in Russian in a broad sense - sharply divided into parts), were formed in the 18th - 19th centuries. At the beginning of the XX century, the system of felling forest use - forestry has received certain completeness in its main components in Germany, other countries of Western Europe, and in Russia [1, 6-8]. With all the differences in the content of the developed classifications of "felling of forest use - forestry" or "felling of forest stands", they were divided according to their functional orientation (for cutting down mature stands - logging and reforestation, forest care). And also, by the method of selecting trees for felling and, accordingly, cutting them down on the site. – clear (complete or almost complete felling of all trees) - "clear cut" or selective, including in several steps - "gradual felling" and periodic cutting of unwanted trees to create favorable conditions for the growth of young trees of valuable species - "thinning" [1, 6, 8-11].
At the same time, the advantages and disadvantages of clear and selective felling, including operational and environmental, are well studied, which are reflected in forestry textbooks and monographs [4, 8, 11, 12]. As a result of generalization of the great historical experience of using different types and variants of clear and selective felling in practice and obtaining data from many years of research, including the study of their influence on forest regeneration, the sustainability of stands at different intensities of selective felling in stands of different forest-forming species and conditions, provided an opportunity to develop certain regulatory and methodological provisions governing the effective use of specific types and options for clear, gradual and selective felling in forests of various species composition, forest typological conditions, age and spatial structure of stands and other natural properties of forests. At the same time, the knowledge gained made it possible to conclude that it is impossible to develop some kind of universal felling system for various natural geographic and other conditions. And the main directions of the development of felling systems are associated with the search for an optimal combination of economic, including operational and silvicultural goals [8, 11].

Forests allocated before the beginning of the 20th century in the country, which have special nature conservation, ecological significance - in modern terminology - forests of specially protected natural areas, as well as water protection, protective, occupied small areas and did not have great economic importance. This made it possible for their preservation to prohibit or sharply limit the use of forest cuttings in these forests in general, or to provide for only low-intensity selective felling. And although for such forests the use of selective felling was recognized as the most acceptable, if necessary, the use of clear-felling was justified as an exception [13]. Subsequently, with the massive identification of protective forests (regardless of their terminological designation, including forests of the first group), it is of fundamental importance to solve the problem of using certain types and systems of felling in these forests.

Consequently, along with the traditional criteria for choosing fellings corresponding to the natural properties of forests and forest growing conditions, to achieve traditional silvicultural and operational goals, it becomes urgent to consider and use the criterion for the compliance of felling and other activities with the designated purpose of forests and forest areas. At the same time, it was necessary to develop certain principles for a balanced account of three main factors - the compliance of felling with the intended purpose, natural forest typological, in essence, and their silvicultural properties, with the inevitable taking into account also the economic conditions of the use of felling. A stereotyped choice of one or even two of these factors will inevitably lead to negative consequences. A fundamental solution to the problem is achieved by establishing and ranking the priorities of the ecological and resource or economic factor - the value of forests, with unconditional consideration of the potential of natural properties for the effective implementation of one or another type of felling of forest stands. In connection with the implementation of international climate agreements, the choice of existing or the development of new silvicultural measures, including the types of forest cuttings to preserve and increase the amount of carbon deposition by the forest, turns into a vital problem [14, 15].

3.2. Determination of the place and significance of silvicultural cuttings in the priority-target systems of silvicultural activities for the cycles of forest reproduction - the dynamics of forest plantations

Orderly effective solutions to the remaining from the past and emerging or exacerbated problems adequate to the growing (social) needs of society in forests and forest resources are possible within the framework of the creation and use of priority-targeted silvicultural systems for forestry, forest maintenance, and forest use. Covering the full cycles of the dynamics of forest generations or reforestation [5]. At the same time, the solution of a set of issues is ensured, including the determination of the place and value of felling of forest stands in the priority-target forestry - forest use; establishing the specific nature and differences of felling options in priority target silvicultural systems (PTSS) for various purposes (operational, protective, recreational and others); establishment of priority-functional-target types and types of silvicultural felling (PFTF) in functional PTSS of the main, derivative, transitional and initial forest-forming types. Taking into account the complex
availability of forests for the implementation of silvicultural activities, the types, and variants of PFTF are also established in silvicultural systems of complete, incomplete special, and initial reforestation. Covering, respectively, the entire cycle of the silvicultural process. Its main part is the formation of target plantings or only the initial one - the formation of young stands, including a stable target species composition [16].

Regardless of the types of priority-target silvicultural systems formed for forests of a certain purpose - operational, protective, including especially protective forest areas, united into silvicultural types of designated purpose forests (DPF), their traditional functional significance and their place in the systems is preserved. In PTSS for operational and multipurpose purposes (respectively, for operational and multipurpose or limited operational forests - in the past, forests of the second group), which are similar in essence and content to a single historically developed silvicultural system that has been used for more than a century [1, 3, 4], felling reforestation - forest use (regardless of the changing names) retains not only its function (replacing the old ripe stand and promoting the renewal of a new one) but also essentially "intended purpose" - "launching" the next process of the growing cycle (planting). Designed as a priority for obtaining a quality resource - wood, as well as performing many ecological (water protection, environment-forming, protective and other) functions during the existence of a plantation (or forest generation). In contrast to the typically historical of this type of forestry felling systems (called in Russia final felling or final felling in the cycle of reforestation), in the modern historical period of the first decades of the twenty-first century, the priority of the ecological purpose of reforestation - forest use is increasing. Although in practical terms, they have not yet changed their essence.

In turn, the historically developed functional silvicultural system of thinning is the main component of the activities of the greater part of the reforestation cycle. From the formation of plantations to the change of forest generations, forest stands of the same age, which also does not change its essence in the PTSS of the considered type of target designation. Although their ecological orientation, including the preservation and enhancement of the water-protective, protective, environment-forming, and, consequently, the carbon-depositing function of forests, is increasing. [16, 17].

In PTSS for ecological, nature conservation purposes, intended for protective forests, the development of which in accordance with the current legislation and is carried out in order to preserve the environment-forming, water protection, sanitary-hygienic, health-improving and other useful properties and functions of forests, traditional reforestation felling, especially those used historically, in the form of final felling, as well as the "cut ripe, over-mature stands for timber harvesting" established by the current legislation, clearly do not correspond to the intended purpose. The goals of development are, in essence, forestry (better than "forest maintenance" - reproduction, conservation, and protection of forests). For almost all forests belonging to protective forests of various priority ecological purposes, the achievement of the "ripeness age" or "maturity age" (at which it can be assigned to felling in commercial forests) means the achievement of the state of its most effective functioning, fulfillment of target ecological functions.

Accordingly, for these forests, one of the main goals of the economy is to maintain the plantings in a state of effective functioning for the longest time possible. Until signs of a decrease in the viability and stability of plantations appear, excluding a decrease in the efficiency of performing target functions, especially their loss, through a timely change of forest generations (stands of the same age). Rational use of wood, in this case, is certainly important, but far from being a priority, but a concomitant one. Consequently, silvicultural activities, including felling of trees, forest stands to achieve this goal as smoothly as possible in specific natural and economic conditions, retain their traditional functions. But with a significant change in target priorities, respectively, forest care, reforestation, replacement of old stands or forest generations, with a significant decrease in the value of the function of using wood.

With the increasing importance of the target function of the continuous conservation of forest ecosystems, the function of caring for not only undergrowth, renewal, but also all other components of the forest that are valuable in ecological and nature protection terms is enhanced. Including potentially
possible for the emergence - by providing a management silvicultural impact on, identified as a target, natural processes. As such measures for the care of the forest at the stage of changing its generations, the measures of "renewal of forest plantations" have been developed in the process of scientific research and practical experience. The need to develop was determined already in the first half of the XX century [12, 13] but remained unrealized until the last decades of the XX century - the first XXI century [16, 17].

At the same time, felling of the change of forest generations in any target forestry system is a key activity that largely determines the content of the entire system and its other components. Thinning is used in protective forests in the first half of the reforestation cycle. They perform traditional silvicultural functions of forming target ecologically mature (ripe) plantings and then preserving them for the longest possible time in an efficiently functioning state and timely, possibly the smoothest change - renewal of plantations that are losing their target functions.

3.3. Development of a conceptual scheme for the formation of subsystems of silvicultural cuttings (cuttings of forest stands) in priority-target systems of silviculture for forests of various purposes - operational and protective

The development within the framework of the PTSS of a hierarchical system, respectively, of priority-target subsystems of silvicultural felling, traditionally intended to perform certain target functions in the system of forest growing - forest use, regardless of differentiation, division of forests for their intended purpose, is carried out on silvicultural principles of consistency, continuity, and development. Taking into account the provision of solutions to new social problems associated with changes in natural environmental and economic conditions.

Proceeding from these fundamental principles, it is advisable to use (observing continuity) as classification signs, properties, characteristics of silvicultural felling, first of all, the main traditional indicators that have not lost their significance. What are established depending on the natural properties of the objects of their application, reflected by the age of forest stands, their structure, the potential of natural renewal, and the formation of plantations. These are signs of a functional purpose, including the performance of the function of caring for the forest or, more precisely, of forest plantations and the function of changing forest generations. The second functional feature associated with the natural properties of the objects of felling, mainly the change of forest generations, is based on the method of dividing felling into clear and selective. Including gradual or periodically selective. And also with the possible use of other signs and criteria for dividing these fellings at the next level of classification.

As a fundamental systemic attribute of the division (classification) of silvicultural felling (when implementing the developed approach), the attribute of their designated purpose is used, corresponding to the designated purpose of forests - the object of felling within the PTSS framework. In addition, for the orderly selection or development of species, felling options for PTSS, established for non-target forestry objects (forest areas) with the aim of converting them to target, it is advisable to use indicators and criteria for the selection of thinning (including in combination with other measures) - components of the main, derivative, transitional and initial-forest-forming priority-target systems of measures.

At the same time, in the hierarchical classification system of silvicultural fellings being formed within the framework of the PTSS, at the highest level of the system, it is advisable to establish taxa of priority-target designation - felling complexes - subsystems of nodal activities of silvicultural systems, including: operational recovery felling (for production forests); recovery-exploitation or reforestation felling (for forests of limited-exploitation or multi-purpose); regeneration felling (for protective and similar forests of priority ecological, nature conservation purposes); which have the exclusive necessary local application of silvicultural felling of the conservation and restoration complex PTSS. For forests, forest areas of temporary and permanent ecological, environmental protection - respectively, reserve potential resource exploitation, as well as heavily disturbed - restored mainly in a natural way with possible individual measures to promote forestry targeted natural processes. Or
inaccessible, often unproductive forests that exist for an infinitely long time in natural dynamics, performing ecological, nature conservation functions, including preserving the reserves of deposited carbon in the stand, litter, and on waterlogged soils with stagnant moisture and in the formed peat layer.

At the second level of the formed system of silvicultural felling, it is necessary, based on the use of indicators and criteria for identifying functional priority-target systems of the main, derivative, transitional, initial forest-forming types, to establish the corresponding subtypes of silvicultural felling. To simplify the selection of the most acceptable and effective options for these activities. In turn, silvicultural felling, as the key activities of silvicultural systems, determine the content of most of their identified types. Including the main and derivative, transitional reformation, and reconstructive parts of sanitary and restoration - in combination with reforestation measures. In the primary-restoration transitional type and primary-educational systems, the measures of reforestation and afforestation are decisive, respectively. Which complement the felling of the formation - the preservation of forest stands during the transition to typical silvicultural systems of the main or derived type.

At the third level of the classification, within the framework of priority-target complexes or types of silvicultural felling, differentiated into subtypes of the main derivatives, transitional and initial forest-forming PTSS, essentially traditional, supplemented by a middle link, stage functional-target types of silvicultural felling are distinguished: formation-preservation-change of forest generations, additionally, if necessary, at any stage, sanitary and fire-prevention felling.

The fourth-fifth and possibly subsequent levels of the hierarchical system - classification are represented by forestry logging taxa. That is determined traditionally by the felling method, with the allocation, first of all, of clear and selective felling systems. Including as a separate system and periodically - selective or gradual two-five fostering for the change of generations of the same-age and complex (two-three-tiered) plantings. The number of felling techniques for changing generations of coeval forest stands with undergrowth is also used as the most important complementary feature of felling classification. That is not included in the inventory in the stand but often forms a closed young generation. With sufficient, determined by silvicultural criteria, its sustainability, in such plantations, single-stage selective felling is used, which is not related to either gradual or traditional typical selective felling.

Accordingly, with the traditional allocation of two or three felling systems for the change of forest generations - forest stands, in general, selective (established by the felling method) are subdivided not only into uniformly and unevenly selective ones with constant repetition for cutting down the older generation in a forest of different ages with several generations of forest-forming plants. But also, single-reception selective in stands of the same age and complex with a young stable sub-forest generation freed from under the canopy by single-reception selective felling. Clearcuts are traditionally subdivided according to the size and width of cutting areas, but with greater differentiation, in order to provide a wider choice of types and options for target purposes. Including narrow and shallow felling areas with a width of cutting areas equal to the two heights of forest stands. - on average 50 m and three to four 75-100 m (area, respectively, up to 1.0-1.5 hectares and 2.5 hectares), medium-cutting - with a width of cutting areas up to 200-250 m and a length of up to 500 m and 1000 m - respectively, with an area of up to 10-15 hectares and 20-25 hectares, as well as broad-logging (large-logging) with a width of cutting areas up to 500 m and an area of up to 50 hectares.

In turn, the classification also retains periodically selective multi-stage felling (2-5 stages) with a relatively uniform and uneven - group, curtain selective felling of trees.- corresponding to the natural structure of plantations and copying to a certain extent the natural processes of renewal, formation, dynamics, and change of forest generations. At the same time, they are supplemented by the felling of a schematic continuous sampling of trees by plots, strips not exceeding the width of the upper height of the stand canopy (30-35 m). This simplifies felling while maintaining to a large extent the ecological effect of a smooth change of old stands. At the same time, many features of selective felling, including schematic site and strip (discrete) selective, are complicated to enhance their differentiation by the duration of the repetition of felling techniques.- from the minimum necessary to ensure the renewal of
forest-forming plants and their adaptation to changing conditions (4-6 years), the formation of a closed young stock - a plantation (6-8 years) to the reformation of a plant of the same age into a different-age plant (with a repetition period equal to 0.8-1, 2 age classes). To improve, substantiate and increase the efficiency of regulation of the intensity of selective felling of any functional purpose, especially when changing generations of forest stands, a complex indicator of the total relative density of a plantation - forest stand and undergrowth are introduced.

4. Conclusion.
Based on the analysis and assessment of the state and historical development of forestry felling - forest use, it was concluded that there is a need for the successive development of this one of the basic measures for the maintenance and use of forests. Despite the creation in the past of a sufficiently substantiated and proven long-term practice of a system of silvicultural felling in connection with changes in socio-ecological and economic conditions, the manifestation of negative for the existence of forests climatic and other natural processes, as well as anthropogenic impacts on forests, the increasing ecological, nature conservation value of forests and their differentiation according to their intended purpose.

At the conceptual and methodological level, this urgent problem has been solved within the framework of the creation and development of priority-target forestry systems for forests of various purposes. Including, the operational and protective ones allocated in Russia with many categories of these forests (over three dozen) and an even larger number of specially protected areas. For the purpose of orderly selection and development of effective systemic forestry measures, including forestry felling, all forestry objects represented in Russian legislation by types of forests for their intended purpose, categories of protective forests, and specially protected areas are combined by similarity and difference into certain taxa. For which the corresponding types and types of silvicultural systems are formed, including felling.

In such systems, silvicultural felling with a traditional functional purpose, including for forest maintenance and for replacing old (mature) stands - timber harvesting and reforestation are not strictly differentiated according to their compliance with the intended purpose of PTSS objects. At the highest level of classification, they are combined into complexes of priority-target felling - operational-restoration, reforestation-operational, ecological-renewal, as well as measures to promote targeted natural restoration processes.

The complexes or types of priority-target functional silvicultural felling identified within the framework of the PTSS at the highest level of their classification with their subsequent differentiation by functional types of systems of the main, derivative, transitional, and initial forest-forming types (including reformation, reconstruction, sanitary-restoration) provide an opportunity for choice. When it's necessary for the development of certain types and species similar to the traditional functional purpose (formation, conservation - change of forest generations). And also, by the method of felling - various options for clear, selective, and transitional forms of felling. At the same time, taking into account the existing and ever-increasing differentiation of forests according to their intended purpose (water protection, environmental protection, sanitary and hygienic, environment-forming, and other purposes, including for increasing the level of carbon sequestration, etc.), a system developed at the conceptual level, with an unlimitedly increasing demand filling its blocks with a variety of necessary elements (types, cutting options), stimulates the innovative process of the development of silvicultural felling, as well as other systemic forestry activities.

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