Research of the trunk lower part form of the tree-like willow in the north-taiga area and development of transition tables from the stump diameter to the diameter at breast height

A A Paramonov 1,2*, S V Tretyakov 1,2, S V Koptev 1,2, S V Yaroslavtsev 1 and I V Tsvetkov 1,2

1 Federal State Budgetary Institution «Northern Research Institute of Forestry», 13 Nikitova Street, Arkhangelsk 163062, Russian Federation
2 Northern (Arctic) Federal University named after M.V. Lomonosov, 17 Naberezhnaya Severnoy Dviny, Arkhangelsk 163002, Russian Federation

*Corresponding email: vagner93@inbox.ru

Abstract. The paper considers the results of studying the shape of the lower part of tree-like willow trunks in the north-taiga area of the Arkhangelsk region. As a result of the studies, the diameters of willow trees at the 1.3 m height were calculated depending on the stump-level diameter at various heights from 0 to 1.3 m. This work aims at the development of two versions of tables for receiving trunk diameter at the 1.3 m height basing on stump diameter. Standards development for the transition from the stump diameter (at heights from 0 to 100 cm) to the diameter at the 1.3 m height is essential since the height and diameter at 1.3 m are the input parameters to the tables for determining trunk volumes. A need to determine the volume of felled trees’ trunks arises while performing various kinds of examinations, and need to determine the stock of stands arises when addressing issues related to the evaluation of illegal logging. Various input and output data options allow more flexible use of patterns established during research and more rational use of tables in practice. Processing of field materials was carried out by methods generally accepted in forest evaluation practice.

1. Introduction
Forestry activities and implementation of measures for management, reproduction, conservation and protection of forests, require accurate and reliable standards for the evaluation of individual tree trunks and stands. In forestry practice, forest conservation and protection, there is a need for standards of the transition from the diameter in the lower part of the trunk (stump diameter) to the diameter at a height of 1.3 m, since the volumetric tables used in forest evaluation practice are based on measuring the taxation diameter (at a height of 1.3 m) and trunk height. For example: evaluating the volume of the illegally logged wood and restoring the characteristics of the stand which were before cutting, and performing expert assessments, it is necessary to determine a trunk diameter at 1.3 m basing on the stump diameter. The application of relevant standards allows expert assessments with minimal errors. The trunk shape as a whole can be described using high-order parabola equations or by a spline. Gusev I I used a seventh-order parabola, but he recommended modelling the lower part of the spruce trunks in the European North separately using a second-order parabola [1]. The transition from a stump-level diameter to a diameter at 1.3 m can be described using the equation of straight line regardless of stump height.
2. Methods and Materials
The field methodology consisted of measurements of the diameters in the lower part of the trunk of willow trees. Trunk diameters were measured on the heights of 10, 20, 50, 100 cm and 1.3 m from the neck of the root using measuring fork on the bark. To study the shape of the lower part of willow trunks and compile the standards in the field season of 2018, 100 willow trees were measured.

Based on the measurements made, models of the dependence of the stump diameters at 0, 10, 20, 50 and 100 cm on the diameters at the 1.3 m height were obtained. Aligned values were used to compile transition tables from the stump diameter to the diameter at the 1.3 m height. The paper presents equations characterizing the dependence of the willow diameter at the 1.3 m height on the stump diameter, used to obtain data that are outside the developed tables.

3. Results and Discussion
In the surveyed areas, the most common species were: the Northern willow (Salix borealis Fries), somewhat less the Goat willow (Salix caprea L.) and, less commonly, the Almond-leaved willow (Salix triandra L.) and their hybrids [2]. In the North-Taiga region, the Northern Willow (Salix borealis Fries) is a small tree with a height up to 10 m. It forms strong shoots with white-tomentose pubescence. The leaves are elliptical, ovate, oblong, the widest near the middle and above, serrulate at the edges; adult leaves are naked or pubescent, young - tomentose, villous, green from above, bluish on the underside, with a green tip at the top of the leaf; turn black after drying; hard, large, 3-5 cm wide and 7 to 13 cm long. Leaf edges are serrulate or sinuate-serrulate. 10-12 pairs of strongly protruding lateral veins are usually formed. Petioles are thick naked, lowered. Stipules are large. The species blooms at the same time as or after the leaves. Earrings are apical, on a lowered leg, long, up to 12 cm. The ovary is naked and thick. Northern Willow belongs to the North of the European part of Russia by its geographical distribution. The place of growth is forest-tundra, forest zone and on the forest belt of mountains in the northern strip of the forest zone. The ecological group refers to non-alluvial species. The species has strong reddish wood, suitable for cellulose production. The bark is used to obtain tannin extract [3-5].

The Goat willow (Salix caprea L.) is a fast-growing tree 6-10 m tall (up to 15 m) and trunk diameter up to 75 cm, less often is a tree-like shrub 5-7 m high. It grows everywhere in the European North. In most cases, it occurs as undergrowth in closed stands on drained soils. Closed goat willow stands or hybrids with other species are formed in areas specific to ecological conditions for the willow growth, especially along the rivers and lakes banks. Branches are thick, spreading, greenish-grey, brown or yellowish-brown at a young age, later grey, brown or dark, covered with cracks, knotty and brittle. The bark is smooth, greenish-grey, becomes covered with cracks and brown with age. Large (up to 5 mm long and up to 3 mm wide) ovoid brown buds deflect from the shoot. Ovate to lanceolate leaves from 6 to 18 cm long and 2 to 8 cm wide are the widest near the middle of the leaf blade. Leaves are leathery, wrinkled by indented veins from above; dark green veins are grey-tomentose. 6-9 pairs of lateral veins form wide rounded loops around the edge of the leaf. The network of veins is sharply protruding with large cells. Leaves are wavy sinuate or solid along the edge, the edge of the leaf is unevenly serrated. The wood is strong and reddish, suitable for cellulose production. The bark is used to obtain tannin extract. [3-5]. The species is good as an early honey plant.

The Almond-leaved willow (Salix triandra L.) is more common as a shrub 2-6 m high. In the north-taiga region, trees of 8 - 10 m height are formed under conditions characteristic for willow. It forms long, thin, yellowish-green matte shoots, young shoots are slightly villous. The buds are ovoid, pressed to the shoot, bare, light brown. Leaves are oblong-lanceolate, lanceolate, ovoid-elliptic, narrow-elliptic, narrow-lanceolate, 4 to 15 cm long and 0.5 to 3.5 cm wide, pressed to the shoot, glabrous, light brown. They have a pointed shape, are round or wedge-shaped at the base, iron-toothed or spaced-toothed along the edge, dark green from above, green or blue-grey and whitish-grey from below, slightly loose and not sticky when blooming, later completely naked. Petioles are formed with
two glands at the base of the leaf blade, first villous, later glabrous, often reddish or brown, 1-1.5 cm long. The wood is solid and white, used either for crafts or as a fuel, possibly for pulp production. The bark is used to obtain tannin extract [3-5].

The transition tables from the diameter on the stump to the diameter the 1.3 m height were not previously compiled for willow. The forest evaluation handbooks provide similar tables for the main forest-forming species for the northeast of the European part of Russia (pine, larch, spruce, birch and aspen) [6-8]. In 2016, similar tables were compiled for grey alder [9].

According to the results of processing the measured diameters of 100 willow trees, a graph of the dependence of willow tree diameters at the 1.3 m height on the stump diameters at its different heights (0, 10, 20, 50 and 100 cm) was produced (figure 1).

![Figure 1. The dependence of the willow tree diameter at the 1.3 m height on stump diameter at its different heights (0 cm, 10 cm, 20 cm, 50 cm, 1 m).](image)

The equations for determining the willow diameter at the 1.3 m height depending on the stump diameter at the height of 0, 10, 20, 50 and 100 cm are shown in table 1.

| Stump height, cm | Equation                | R²  |
|-----------------|------------------------|-----|
| 0               | y = 0.6186x + 1.9633    | 0.802|
| 10              | y = 0.6568x + 2.3272    | 0.819|
| 20              | y = 0.6857x + 2.4843    | 0.824|
| 50              | y = 0.8861x + 0.567     | 0.946|
| 100             | y = 0.9426x + 0.4615    | 0.969|
| 130             | y = 0.9571x + 0.6475    | 0.986|

where, ‘y’ is the diameter (thickness step) at 1.3 m; ‘x’ is the stump diameter measured at various heights, cm.

The equations in tables 1 and 2 make it possible to obtain not only the values given in tables 3 and 4 but also data that are outside of the tables.
Table 2. Equations of willow tree diameters at the 1.3 m height depending on the stumps diameters with their height (0 cm, 10 cm, 20 cm, 50 cm, 1 m).

| Stump height, cm | Equation                  | \( R^2 \) |
|------------------|---------------------------|-----------|
| 0                | \( y = 1.2574x + 1.5249 \) | 0.812     |
| 10               | \( y = 1.2132x + 0.5175 \) | 0.834     |
| 20               | \( y = 1.1705x + 0.1601 \) | 0.841     |
| 50               | \( y = 1.0384x + 0.6155 \) | 0.963     |
| 100              | \( y = 0.9987x + 0.4071 \) | 0.984     |

where, ‘y’ is the stump diameter, measured at various heights, cm; ‘x’ - diameter (thickness step) at 1.3 m.

To improve the usability and accuracy of evaluation, two tables 3 and 4 were developed for the transition from the stump diameter to the diameter at the 1.3 m height.

Table 3. Diameters of willow trunks at the 1.3 m height depending on the stump diameter at heights from 0 to 100 cm.

| Willow tree diameters at the 1.3 m height, cm | Stump diameters, cm at its height, cm | 0 | 10 | 20 | 50 | 100 |
|---------------------------------------------|--------------------------------------|---|----|----|----|-----|
| 4                                           |                                      | 3.3 | 2.5 | 2.2 | 3.9 | 3.7 |
| 6                                           |                                      | 6.5 | 5.6 | 5.1 | 6.1 | 5.9 |
| 8                                           |                                      | 9.8 | 8.6 | 8.0 | 8.4 | 8.0 |
| 10                                          |                                      | 13.0 | 11.7 | 11.0 | 10.6 | 10.1 |
| 12                                          |                                      | 16.2 | 14.7 | 13.9 | 12.9 | 12.2 |
| 14                                          |                                      | 19.5 | 17.8 | 16.8 | 15.2 | 14.4 |
| 16                                          |                                      | 22.7 | 20.8 | 19.7 | 17.4 | 16.5 |
| 18                                          |                                      | 26.0 | 23.9 | 22.6 | 19.7 | 18.6 |
| 20                                          |                                      | 29.2 | 26.9 | 25.5 | 21.9 | 20.7 |
| 22                                          |                                      | 32.4 | 29.9 | 28.5 | 24.2 | 22.8 |
| 24                                          |                                      | 35.6 | 33.0 | 31.4 | 26.4 | 25.0 |
| 26                                          |                                      | 38.9 | 36.0 | 34.3 | 28.7 | 27.1 |
| 28                                          |                                      | 42.1 | 39.1 | 37.2 | 31.0 | 29.2 |

Another option for determining the trunk diameter at the 1.3 m height depending on the stump diameter is shown in table 2.
Table 4. Willow trees diameters at the 1.3 m height depending on the stump diameter.

| Stump diameter, cm | Willow trees diameters at the 1.3 m height depending on the stump diameter |
|-------------------|--------------------------------------------------------------------------------|
| 2                 | 0.4 1.2 1.6 1.3 1.6                                                             |
| 4                 | 2.0 2.9 3.3 3.3 3.6                                                             |
| 6                 | 3.6 4.5 5.0 5.2 5.6                                                             |
| 8                 | 5.1 6.2 6.7 7.1 7.6                                                             |
| 10                | 6.7 7.8 8.4 9.0 9.6                                                             |
| 12                | 8.3 9.5 10.1 11.0 11.6                                                          |
| 14                | 9.9 11.1 11.8 12.9 13.6                                                          |
| 16                | 11.5 12.8 13.5 14.8 15.6                                                         |
| 18                | 13.1 14.4 15.2 16.7 17.6                                                         |
| 20                | 14.7 16.1 16.9 18.7 19.6                                                         |
| 22                | 16.3 17.7 18.7 20.6 21.6                                                         |
| 24                | 17.8 19.4 20.4 22.5 23.6                                                         |
| 26                | 19.5 21.0 22.1 24.4 25.6                                                         |
| 28                | 21.1 22.6 23.8 26.4 27.6                                                         |
| 30                | 22.6 24.3 25.5 28.3 29.6                                                         |
| 32                | 24.2 25.9 27.2 30.2 31.6                                                         |
| 34                | 25.8 27.6 28.9 32.1 33.6                                                         |
| 36                | 27.4 29.2 30.6 34.1 35.6                                                         |
| 38                | 29.0 30.9 32.3 36.0 37.6                                                         |

4. Conclusions
The data obtained for the transition from the stump diameter to the diameter at breast height can be used in places where it is impossible to determine the taxation diameter of willow trees, for example, when a felled tree was removed from the cutting place. In this situation, only the stump diameter will be the only indicator available for measurement. The height of the trunks can be measured in adjacent stands with similar taxation indicators or according to forest inventory.

References
[1] Gusev I I 1978 Productivity of spruce forests of the North [In Russian – Produktivnost’ el’nikov Severa] Publishing house of Leningrad State University [Izdatel’stvo Leningradskij gosudarstvennyj universitet] p 232
[2] Morozov I R 1966 The determinant of willows of the USSR and their culture [In Russian – Opredelitel’ iv SSSR i ih kul’tura] Lesnaya promyshlennost’ p 254
[3] Gubanov I A, Kiseleva K V, Novikov V S and Tikhomirov V N 2003 Illustrated identifier of plants in Central Russia [In Russian – Illyustrirovannyy opredelitel’ rastenij Srednej Rossii] Angiosperms (dicotyledonous: diverse) (Moscow: KMK scientific publications, Institute of Technological Research) 2 p 665
[4] Trees and shrubs of the USSR: Wild, cultivated and perspective for the introduction 1951 [In Russian – Derev’ya i kustarniki SSSR: Dikorastushchie, kul’tiviruemye i perspektivnye dlya
introduckii] ed Sokolov Publishing House of the Academy of Sciences of the USSR [Izdatel'stvo Akademii nauk SSSR] 2 p 612

[5] Flora of the USSR 1951 [In Russian – Flora SSSR] ed V L Komarov (Publishing House of the USSR Academy of Sciences) 5 p 762

[6] Forest evaluation reference book in the north-east of the European part of the Russian Federation: (regulatory materials for the Nenets Autonomous Okrug, Arkhangelsk, Vologda Oblasts and the Komi Republic) 2012 [In Russian – Lesotaksacionnyj spravochnik po severo-vostoku evropejskoj chasti Rossiijskoj Federacii: (normativnye materialy dlya Neneckogo avtonomnogo gokruga, Arhangel'skoj, Vologodskoj oblastej i Respubliki Komi)] Feder. Forestry Agency, Feder. budget. institution "North. scientific-research institute of forestry [comp. PhD Voinov G S, etc.] (Arkhangelsk: OAO IPP Pravda Severa) p 672

[7] Gusev I I et al 1971 Taxiator's field guide (For taiga forests of the European North) [In Russian – Polevoj spravochnik taksatora dlya taezhnyh lesov Evropejskogo Severa] (Arkhangelsk: North-West Publishing House) p 196

[8] Zagreev V V, Suhii V I, Shvidenko A Z, Gusev N N and Moshkalev A G 1992 Union-wide standards for forest evaluation [In Russian – Obshchesoyuznye normativy dlya taksacii lesov] (Moscow, Kolos) p 495

[9] Koptev S V, Tretyakov S V, Bogdanov A P, Ilintsev A S and Demidenko S A 2017 Evaluation standards for alder stands by the method of reloscopic circular plots [In Russian – Normativy taksacii ol'hopohykh drevostoev metodom relaskopicheskikh krugovyh ploshchadok] News of higher educational institutions. Forest Journal 5 pp 53-63