Modeling the dynamics of forest inventory indicators and building growth tables for sprout-origin oak stands of the Voronezh region by type of forest growing conditions

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Abstract. In the Voronezh region, sprout-origin oak forests currently occupy an area of 94.7 thousand ha; these forests are a major element of the region’s forests after the wild fires of 2010. For evaluation of sprout-origin oak forests, forest managers use growth tables based on yield classes; those tables reflect neither forest growing conditions nor the diversity of the region’s sprout-origin oak forest stands and have an industrial focus. Based on the data of a mass forest inventory of more than 2,000 forest plots established in 11 types of forest growing conditions characterised by a variety of soil richness and moisture content, multidimensional equations have been derived and growth rate tables built for sprout-origin oak forests of the Voronezh region. The resulting growth tables demonstrate the dynamics of forest inventory indicators of the forest stands studied in the age range 10-160 years, basal area range 0.3-1.0 and the share of oak in the forest composition from 1 to 10 units. The tables allow evaluation of modal tree stands to be based on the measurements of average heights, diameters and areas of cross-sections and can be used in assessments of forest stands during forest inventory.

1. Introduction
Sprout-origin oak stands of the Voronezh region occupy an area of 94.7 thousand ha (27.8%); they are the result of anthropogenic impact on seed oak phytocenoses. For their evaluation, forest managers use M Orlov’s yield scale for sprout-origin tree stands [1-3], as well as growth rate tables (GRTs) compiled by A D Dudarev [2, 3] using yield classes disconnected from the growing conditions and having an industrial focus.

The method of compiling GRTs by yield class has been in use for more than 100 years; however, no new developments have been proposed to improve the accuracy of forest assessments.

We believe that a study of the dynamics of forest inventory indicators and compilation of GRTs should be carried out according to types of forest growing conditions (TFC), which allows making GRTs more environmentally and scientifically sound, and reflecting the natural growth processes of forest plantations [4-6].

The GRTs currently used by the forest industry in sprout-origin oak stands were compiled for I - V yield classes aged 10 - 120 years, while in the forest fund of the region there are stands of Ia and Va yield classes and over 120 years old.
2. Methods and Materials

To build GRTs by type of forest growing conditions, the edaphic grid of P S Pogrebnyak [6] was used, in which all types of forest habitat had been characterized by a combination of soil fertility and humidity.

The transition from a yield to a forest typological scale was performed using multiple regression models constructed using the block dummy variable method [4, 5], when the independent variables (TFC) represented by their quality indicators, \( D_0 \) (very dry oak stand), \( D_1 \) (dry oak stand), \( D_2 \) (fresh oak stand), \( D_2P \) (fresh oak stand on a flood plain), \( D_3 \) (wet oak stand), \( D_3P \) (wet oak stand on a flood plain), \( E_0 \) (very dry oak stand in a gully), \( E_1 \) (dry oak stand in a gully), \( E_2 \) (fresh oak stand in a gully), \( C_2 \) (fresh sudubrava, a type of forest growing conditions in transition from a pine to oak forest), \( C_2D \) (sudubrava dominated by oak) [6, 7], were expressed by dummy variables in a matrix (table 1).

Forest inventory data of more than 2000 plantations, obtained by enumerative and measuring methods of forest inventory of sprout-origin oak stands of the Voronezh region of different ages, with different basal area and the share of oak in the species composition, served as a basis for the simulation.

Table 1. Matrix of binary variables characterizing TFC.

| TFC  | Dummy variables |
|------|-----------------|
|      | \( X_1 \) | \( X_2 \) | \( X_3 \) | \( X_4 \) | \( X_5 \) | \( X_6 \) | \( X_7 \) | \( X_8 \) | \( X_9 \) | \( X_{10} \) |
| \( D_0 \) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| \( D_1 \) | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| \( D_2 \) | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| \( D_2P \) | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| \( D_3 \) | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| \( D_3P \) | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| \( E_0 \) | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| \( E_1 \) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| \( E_2 \) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| \( C_2 \) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| \( C_2D \) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

3. Results and Discussion

On the basis of forest inventory indicators of sample plots, using the method of statistical modeling, equation (1) was derived as a growth function of Korsun-Backman [8], which made it possible to characterize the dynamics of the average heights (H) of sprout-origin oak stands of the Voronezh region depending on the age (A) and basal area (P) across the range of TFC:

\[
H = e^{0.33588 + 0.385594X_1 + 0.55097X_2 + 0.424954X_3 + 0.527568X_4 + \nonumber \\
+ 0.50868X_5 + 0.073369X_6 + 0.323764X_7 + 0.463866X_8 + 0.423152X_9 + \nonumber \\
+ 0.510781X_{10} - 0.0277\ln A - 0.369551\ln P - 0.04743\ln A + 0.144304\ln P) \quad (1)
\]

\( R^2=0.940; \) \( m=0.1242; \) \( t_p> t_{0.5}=2.0; \) \( F=22186.4; \) \( P<0.05 \)

The resulting model has a high value of the Fisher criterion equal to 22186.4 at a probability level of 0.95 [9], which confirms its reliability.

Digital interpretation was performed for all TFCs at a 5 year age interval, in the age range from 5 to 160 years, in the basal area range from 0.3 to 1.0, and in the range of share of oak in the species composition of forest stands from 1 to 10 units.
The resulting regression model (1) made it possible to establish that the average height of the studied stands decreased with deterioration of growing conditions and a decrease in the basal area (table 2).

The best increase in height was observed in TFC D_2, reaching 26.9 m at the age of 100 years. It was followed by D_3 (26.3 m); D_3P (25.8 m); C_2D (25.8 m) and D_2P (28.5 m).

With deterioration of the quality of soil, the height also decreased: in TFC D_1, to 22.8 m; and in E_1, to 21.4 m.

In the Voronezh region, the least favourable conditions for oak stands are D_0 (15.5 m) and E_0 (16.7 m).

Comparing the average heights of all TFCs with the best of them for oak (D_2), we can conclude that in TFC D_3, the increase in height was lower by 2.2%; in D_3P and C_2D, by 4.1%; in E_2, by 8.2%; in D_3P and C_2, by 11.9%; in D_1, by 15.2%; in E_1, by 20.4%; in E_0, by 37.9%; and in D_0, by 42.4% (table 2).

The calculations demonstrated that the difference between the average heights of tree stands within one TFC with a change in the basal area from 1.0 to 0.3 could reach 15.8 - 16.1%, or from 2.9 m (in E_0) to 4.7 m (in D_2), which significantly affects the accuracy of the growing stock estimates [4].

The developed model reflects the effect of soil moisture on the increase in height of the studied forest stands; with a decrease in soil moisture, the height decreases significantly, by 15.2% and 42.4% in TFC D_1 and D_0 compared with D_2; and by 20.4% and 37.9% in TFC E_1 and E_0 compared with E_2.

The obtained results confirm the validity of distinguishing three ecotypes of oak forests in the Voronezh region: upland, gully and floodplain.

Table 2. Forest type scale of average heights (fragment). Basal area 1.0.

| A, years | D_0 | D_1 | D_2 | D_3P | D_3 | D_2P | D_3P | E_0 | E_1 | E_2 | C_2 | C_2D |
|----------|-----|-----|-----|------|-----|------|------|-----|-----|-----|-----|-----|
| 5        | 1.5 | 2.1 | 2.5 | 2.2  | 2.5 | 2.4  | 1.6  | 2.0 | 2.3 | 2.2 | 2.2 | 2.4 |
| 10       | 2.7 | 3.9 | 4.6 | 4.1  | 4.5 | 4.4  | 2.9  | 3.7 | 4.2 | 4.1 | 4.4 |      |
| 15       | 3.9 | 5.7 | 6.7 | 5.9  | 6.6 | 6.5  | 4.2  | 5.4 | 6.2 | 5.9 | 6.5 |      |
| 20       | 5.1 | 7.4 | 8.8 | 7.7  | 8.6 | 8.4  | 5.4  | 7.0 | 8.1 | 7.7 | 8.4 |      |
| 40       | 9.1 | 13.4| 15.8| 13.9 | 15.4| 15.2 | 9.8  | 12.6| 14.5| 13.9| 15.2|      |
| 60       | 12.1| 17.7| 20.9| 18.4 | 20.4| 20.1 | 13.0 | 16.7| 19.2| 18.4| 20.1|      |
| 80       | 14.1| 20.8| 24.5| 21.6 | 23.9| 23.5 | 15.2 | 19.5| 22.5| 21.6| 23.5|      |
| 100      | 15.5| 22.8| 26.9| 23.7 | 26.3| 25.8 | 16.7 | 21.4| 24.7| 23.7| 25.8|      |
| 120      | 16.4| 24.1| 28.4| 25.1 | 27.8| 27.3 | 17.6 | 22.7| 26.1| 25.0| 27.3|      |
| 140      | 16.9| 24.9| 29.3| 25.9 | 28.6| 28.1 | 18.2 | 23.4| 26.9| 25.8| 28.2|      |
| 160      | 17.1| 25.2| 29.7| 26.2 | 29.0| 28.5 | 18.4 | 23.7| 27.3| 26.2| 28.6|      |

In addition to studying the dynamics of average heights of sprout-origin oak forests, when studying their patterns of growth, it is necessary to consider their variability in diameter with age [1, 2].

On the basis of the source data, as a result of multivariate statistical modeling of the average diameters of the studied stands, an equation of the following type was derived:

\[
D = \exp(-0.31396 + 0.318598X_1 + 0.415225X_2 + 0.353044X_3 + 0.423711X_4 + 0.45271X_5 + 0.151622X_6 + 0.319246X_7 + 0.397548X_8 + 0.331501X_9 + 0.372971X_{10} + 0.0567lnA + 0.320148ln^2A - 0.03742ln^3A - 0.10354lnP) \] (2)

\[
R^2=0.928; \quad m_r=0.1486; \quad t_p> t_{0.5}=2.0; \quad F=18448.4; \quad P<0.05
\]

The reliability of model (2) is confirmed by a high determination coefficient (R 2= 0.928) and a significant value of the actual Fisher criterion of 18448.4 at a probability level of 0.95 [9].
The study of the simulation results (table 3) shows that the average diameters of sprout-origin oak stands decrease with deterioration of TFC from the maximum observed in floodplain wet oak forests (TFC D₃P, 34.3 cm at the age of 100 years), to the minimum (21.8 cm) observed in very dry oak stands (D₃).

By age dynamics of the indicators in question, all TFCs can be divided into three groups: the first group includes TFC D₃P, characterized by the highest rate of increase in the diameter of tree stands; the second group includes TFCs with a medium rate of increase in diameter (D₃, D₂, E₂, C₂D, D₃P, C₂, D₁ and E₁); the third group, tree stands with a slow increase in diameter (D₀) and tree stands with the worst growing conditions (E₀) for oak.

The obtained model of the age dynamics of the average diameter of the oak element according to TFC (2) allowed a multiple regression to differentiate its values within the ecological niches of growth of the studied stands in the conditions of the Voronezh region and to identify the features of its increase with an increase in age and a decrease in basal area.

Table 3. Dynamics of average diameters according to TFC (fragment). Basal area 1.0.

| A, years | D₀ | D₁ | D₂ | D₃P | D₁P | E₀ | E₁ | C₂ | C₂D |
|---------|----|----|----|-----|-----|----|----|----|-----|
| 5       | 1.6| 2.2| 2.4| 2.2 | 2.4 | 1.8| 2.2| 2.3| 2.3 |
| 10      | 2.9| 4.0| 4.4| 4.1 | 4.4 | 3.3| 4.0| 4.3| 4.0 |
| 15      | 4.2| 5.8| 6.4| 6.0 | 6.5 | 6.7| 4.9| 6.3| 5.9 |
| 20      | 5.6| 7.7| 8.5| 8.0 | 8.6 | 8.8| 6.5| 7.7| 7.8 |
| 40      | 10.7| 14.8| 16.3| 15.3| 16.4| 16.9| 12.5| 14.8| 16.0| 15.0| 15.6|
| 60      | 15.1| 20.8| 22.9| 21.5| 23.1| 23.8| 17.6| 20.8| 22.5| 21.1| 22.0|
| 80      | 18.8| 25.8| 28.5| 26.7| 28.7| 29.6| 21.9| 25.9| 28.0| 26.2| 27.3|
| 100     | 21.8| 30.0| 33.0| 31.0| 33.3| 34.3| 25.4| 30.0| 32.5| 30.4| 31.7|
| 120     | 24.3| 33.4| 36.8| 34.5| 37.1| 38.2| 28.2| 33.4| 36.1| 33.8| 35.2|
| 140     | 26.3| 36.1| 39.8| 37.4| 40.1| 41.3| 30.6| 36.2| 39.1| 36.6| 38.2|
| 160     | 27.9| 38.4| 42.3| 39.7| 42.6| 43.9| 32.5| 38.4| 41.5| 38.9| 40.5|

In addition to studying the patterns of change in average heights and diameters, we performed a simulation of the age dynamics of the average growing stock.

In the process of modeling, a multiple regression equation (3) of changes in the growing stock per 1 ha of oak stands (M) was derived based on the average height (H), basal area (P) and the share of oak in the overall species composition (S):

\[ M = \exp(-0.6757 + 1.162345\ln H + 0.054189\ln^2 H + 1.0\ln P + 1.0\ln S) \]  \hspace{1cm} (3)

\[ R^2=0.996; \hspace{0.5cm} m_R = 0.0683; \hspace{0.5cm} t_p > t_{0.05} = 2.0; \hspace{0.5cm} F = 370656.9, \hspace{0.5cm} at \hspace{0.5cm} P<0.05 \]

A high value of the multiple coefficient of determination \( R^2 = 0.996 \) and the actual value of the Fisher criterion \( F = 370656.9 \) indicate the reliability of the obtained model (3).

All coefficients of the regression equation and the synchrony of the regression lines also confirm the reliability of the simulation, the results of which are shown in table 3.

The obtained models of the dynamics of productivity of the oak element for all TFCs are within the boundaries of the I and V yield classes [2-3], which also confirms their reliability; at the same time, the results (table 3) indicate the characteristic features of accumulation of the growing stock of the studied oak stands in different TFCs.
In particular, the average values of the growing stock in the most productive forest growing conditions $D_2$ and $D_3$ fall within the boundaries of the I yield class, but have the absolute values 17.0-19.8% lower than those GRTs used by the industry [3].

The stock accumulation dynamics in the worst forest growing conditions of very dry upland and gully oak forests ($D_0$ and $E_0$) differ by 10-12%. In the industrial assessment of sprout-origin oak stands, the characteristics of growth and accumulation of wood stock by various ecotypes of oak stands are not taken into account.

All calculations are performed using general, rather than regional tables [3], which, of course, affects the accuracy of assessments.

The results obtained on the basis of multivariate modeling show the particular characteristics of growth and productivity dynamics in each of the TFC (table 4) and the need to adjust the approach to their inventory in order to obtain more accurate data.

The obtained regression equation for the accumulation of growing stock (3) allows us to perform the necessary calculations for the oak element of the forest aged 5-160 years, with the share in the species composition of 1-10 units, and with the basal area of 0.3-1.0.

The results demonstrated that the most productive type of forest conditions for sprout-origin oak forests in the Voronezh region was fresh oak fores ($D_2$), accumulating 1.0–420 m³/ha by the age of 100 years. It is followed by TFC $D_3$, $D_3P$ and $C_2D$, which differ from $D_2$ by no more than 4.7-6.3%. TFC $E_2$, $D_3P$ and $C_2$ are somewhat less productive; their accumulated wood stock is by 12.4-17.6% lower compared to $D_2$.

In dry TFC $D_1$ and $E_1$, productivity is even lower, 71.0-77.9% of $D_2$. Very dry TFC $D_0$ and $E_0$ are the least productive, with the growing stock 2.1 and 2.3 times lower compared to $D_2$.

Thus, forest-type scales of the productivity of tree stands in the context of all TFC found in the Voronezh region were obtained for sprout-origin oak forests; the scales allow us to numerically reflect the patterns of changes in forest inventory indicators depending on the age and basal area of the tree stands under study (table 4).

| $A_c$ | Average growing stock of sprout-origin oak stands by TFC, m³/ha |
|-------|---------------------------------------------------------------|
| years | $D_0$ | $D_1$ | $D_2$ | $D_3P$ | $D_3$ | $D_3P$ | $E_0$ | $E_1$ | $E_2$ | $C_2$ | $C_2D$ |
| 5     | 8    | 13   | 16    | 13    | 15    | 15    | 9    | 12    | 14    | 13    | 15    |
| 10    | 17   | 28   | 34    | 29    | 33    | 32    | 18   | 25    | 31    | 29    | 32    |
| 15    | 27   | 45   | 57    | 48    | 55    | 54    | 30   | 42    | 31    | 31    | 31    |
| 20    | 39   | 65   | 82    | 69    | 80    | 77    | 43   | 60    | 73    | 69    | 78    |
| 40    | 86   | 150  | 190   | 158   | 184   | 179   | 96   | 137   | 168   | 158   | 179   |
| 60    | 129  | 225  | 288   | 239   | 278   | 270   | 143  | 206   | 253   | 238   | 271   |
| 80    | 161  | 285  | 365   | 302   | 352   | 342   | 180  | 260   | 320   | 301   | 343   |
| 100   | 185  | 327  | 420   | 347   | 406   | 394   | 206  | 298   | 368   | 346   | 395   |
| 120   | 201  | 356  | 457   | 378   | 441   | 429   | 223  | 324   | 401   | 377   | 430   |
| 140   | 210  | 373  | 479   | 396   | 462   | 449   | 234  | 340   | 420   | 395   | 451   |
| 160   | 214  | 381  | 490   | 404   | 472   | 459   | 239  | 347   | 429   | 403   | 460   |

Modeling the growth of sprout-origin oak stands of the Voronezh region using the main forest inventory indicators based on the derived regression models (1-3) allowed us to build complete tables of the age dynamics of forest inventory indicators of the studied forest stands on a forest-ecological basis in the conditions of the Voronezh region, a fragment of which is shown in tables 5 and 6.

The obtained standards are classified as regional; they have been developed for the first time.

The proposed models and tables will allow us to take into account the characteristic features of the growth of the oak element in forest stands with different basal area and share of oak in the species composition of forest stands.
composition on the territory of the Voronezh region, and to improve the accuracy of forest inventory assessments.

The process of building growth tables on a forest-typological basis was different from the classical approaches [1, 2].

First, based on the obtained regression models of the dynamics of the average heights (1) and diameters (2), as well as the growing stock per 1 ha (3) for each TFC in the age range from 5 to 160 years with a 5 year interval, for the basal area in the range 0.3-1.0 and the share of oak in the species composition from 10 to 1 units their values were calculated and the results entered into table 5.

Next, on the basis of the obtained values of heights \((H)\) and diameters \((D)\) according to the trunk volume model \((V_{st})\) of a growing tree (4), we calculated the average volume for the corresponding age, height and diameter of the trunk and also entered the results into table 5.

The obtained values of \(H, D, M_{1\text{ha}}\) (standing volume per 1 ha) and \(V_{st}\) formed the basis for calculating all the remaining forest inventory characteristics of the growing part of the stand, while in other classical methods [1, 2] those are \(H, D, M_{1\text{ha}}\) and \(G_{1\text{ha}}\) (the sum of the areas of the cross-sections of stands per 1 ha).

In our approach, the developed system of standards is based on the value of the volume of a growing tree trunk \((V_{st})\) found from the previously developed [10] model of the oak trunk volumes (4).

Additionally, according to the formula proposed by V K Khlyustov [5], the upper height \((H_{u})\) was determined and also entered into table 5:

\[
V_{st} = \exp(-9.00391 - 0.74478 \ln H + 0.098371 \ln^2 H - 0.00421 \ln^2 D + 1.014151 \ln HD^2)
\]

\[
R^2=0.999996, \; m_a=+0.003596, \; t_p> t_{0.05}=2.0; \; F = 31556907.8 \; \text{at} \; P<0.05
\]

The obtained forest inventory indicators of the growing part of tree stands (species number \(-F\), number of trunks \(-N\), sum of the areas of cross-section \(-G\), species height \(-H_{*}F\), average growing stock change \(-z_{avg}\), current stock change \(-z_{cur}\)) were determined using a formula which is well-known in forest inventory [1].

In order to build complete GRTs, in addition to the growing part of the stand, forest inventory indicators of mortality were calculated, the main characteristics of which are [1, 2]: \(N_{dec}\) (number of dead trees), \(V_{dec}\) (volume of an average dead tree), \(M_{dec}\) (dead timber stock during the period of growth), \(M_{dec}\) (the sum of the dead timber stocks).

At the same time, \(N_{dec}\) was calculated as the difference between the number of trees of the growing part at the age of \(A\) \((n = 10)\) and \(A\) years. \(V_{dec}\) of the resulting GRT (tables 5 and 6) for all ages and basal areas was determined on the basis of the regression equation (5):

\[
V_{dec} = \exp(0.8368539 - 0.5972225041lnH_{100} + 1.2060941lnV_{st} - 0.0097061ln^2V_{st})
\]

\[
R^2=0.9996; \; m_R=0.06127; \; t_p> t_{0.05}=2.0; \; F = 23432.5 \; \text{at} \; P<0.05
\]

The dead timber stock for a 10-year period \((M_{dec})\) was obtained by multiplying \(V_{dec}\) by \(N_{dec}\). The accumulated dead timber stock \((\sum M_{dec})\) was calculated by successive summation of \(M_{dec}\) for each 10 year period.

At the final stage of building growth tables for sprout-origin oak stands of the Voronezh region on a forest-typological basis (tables 5 and 6) for all age periods, the overall performance indicators were determined: total stock \((M_{tot})\), as the sum of stocks of the growing part of tree stands \((M)\) and the accumulated dead timber stock \((M_{dec})\); the overall average increase, by dividing the accumulated dead timber stock \((\sum M_{dec})\) by age \((A)\); the total current average periodic increase, by dividing the difference between the total stocks at the age \(A\) \((M_{tot,A})\) and \(A\)-n years \((M_{tot,A,n})\) by age \(A\) [1].

4. Conclusions

As a result of modeling, the regression models were built (1–3), and for the first time, the GRTs for oak stands of the Voronezh region with different basal areas and shares of oak in the forest
composition on a forest typology basis were built in electronic form, allowing investigation of the patterns of changes in their basic forest inventory indicators for TFC depending on the age and basal area.

The resulting GRTs for oak as the main forest forming species of the region, in the age range from 10 to 160 years, for the basal area of 0.3-1.0 and the share of oak in the forest composition from 1 to 10 units allow us to perform inventory of modal tree stands and can be used to make estimates during forest inventory.

**Table 5.** Growth trends of sprout-origin oak stands of the Voronezh region. TFC D3P (fragment).

| $A$, years | $H_s$, m | $H_t$, m | $D_t$, cm | $F$ | $HF$, m | $N_0$, unit*ha$^{-1}$ | $G_0$, m$^2$*ha$^{-1}$ | $V_0$, m$^3$ | $M_0$, m$^3$*ha$^{-1}$ | Growing stock change, m$^3$*ha$^{-1}$*year$^{-1}$ |
|-----------|--------|--------|----------|-----|--------|-----------------|-----------------|--------|----------------|----------------------------------|
| 1         | 2      | 3      | 4        | 5   | 6      | 7               | 8               | 9      | 10              | 11                               |
| 1         | 2      | 3      | 4        | 5   | 6      | 7               | 8               | 9      | 10              | 11                               |

**Oak =10 units, basal area =1.0**

20 11.2 7.7 8.0 0.552 4.3 3232 16.1 0.021 69 3.45 4.00
30 14.7 11.1 11.7 0.499 5.5 1903 20.6 0.060 114 3.79 4.47
40 17.5 13.9 15.3 0.473 6.6 1310 24.0 0.121 158 3.96 4.47
50 19.6 16.4 18.5 0.459 7.5 988 26.7 0.203 201 4.01 4.21
60 21.4 18.4 21.5 0.450 8.3 790 28.8 0.302 239 3.98 3.82
70 22.8 20.2 24.3 0.444 9.0 658 30.4 0.414 273 3.89 3.38
80 23.9 21.6 26.7 0.440 9.5 565 31.7 0.534 302 3.77 2.92
90 24.8 22.8 29.0 0.438 10.0 497 32.8 0.658 327 3.63 2.48
100 25.6 23.7 31.0 0.436 10.3 445 33.6 0.781 347 3.47 2.07
110 26.1 24.5 32.9 0.434 10.6 404 34.3 0.902 364 3.31 1.69
120 26.6 25.1 34.5 0.433 10.9 371 34.8 1.017 378 3.15 1.35
130 26.9 25.5 36.0 0.432 11.0 345 35.2 1.125 388 2.98 1.04
140 27.1 25.9 37.4 0.432 11.2 323 35.4 1.226 396 2.83 0.77
150 27.2 26.1 38.6 0.431 11.2 304 35.6 1.317 401 2.67 0.53
160 27.3 26.2 39.7 0.431 11.3 289 35.8 1.399 404 2.53 0.32

**Table 6.** Growth trends of sprout-origin oak stands of the Voronezh region. TFC D3P (cont.).

| $A$, years | $N_{dec}$, unit*ha$^{-1}$ | $V_{dec}$, m$^3$ | $M_{dec}$, m$^3$*ha$^{-1}$ | $\sum M_{dec}$, m$^3$*ha$^{-1}$ | $M_{tot}$, m$^3$*ha$^{-1}$ | Increment, m$^3$*ha$^{-1}$*year$^{-1}$ |
|-----------|----------------|--------|----------------|----------------|----------------|----------------------------------|
| 1         | 13            | 14     | 15             | 16            | 17            | 18                               |
| 20        | 4449          | 0.004  | 16             | 16            | 85            | 4.26                            |
| 30        | 1329          | 0.013  | 18             | 34            | 148           | 4.92                            |
| 40        | 593           | 0.033  | 19             | 53            | 212           | 5.29                            |
| 50        | 323           | 0.062  | 20             | 73            | 274           | 5.48                            |
| 60        | 198           | 0.101  | 20             | 93            | 332           | 5.53                            |
| 70        | 132           | 0.149  | 20             | 113           | 385           | 5.51                            |
| 80        | 93            | 0.203  | 19             | 132           | 434           | 5.42                            |
| 90        | 68            | 0.262  | 18             | 150           | 476           | 5.29                            |

**Oak =10 units, basal area =1.0**
A comparison of the obtained GRTs with those developed earlier for sprout-origin oak stands of the Central-Chernozem region on a yield class basis by I M Naumenko [3] showed their agreement with the main forest inventory indicators.

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