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Original Research

Dynamics of the Taxation Characteristics of Forest Stands in the North-West of Russia

Olga Grigoreva[1]*, Elena Runova[2], Evgeniy Tikhonov[3], Tamara Storodubtseva[4], Varvara Druzyanova[5], Edward Hertz[6], Ivan Garus[2], Igor Grigorev[7]

[1]Department of Forestry, Saint Petersburg State Forest Engineering University named after S. M. Kirov, Saint-Petersburg, Russian Federation
[2]Department Forest Crops, Breeding and Dendrology, Bratsk State University, Bratsk, Russian Federation
[3]Department of Transport and Technological Machinery and Equipment, Federal State Budget Educational Institution of Higher Education "Petrozavodsk State University", Petrozavodsk, Russian Federation
[4]Department of Industrial Transport, Construction and Geodesy, Voronezh State University of Forestry and Technologies named after G.F.Morozov, Voronezh, Russian Federation
[5]Department of Operation of Road Transport and Auto Repair, Northeastern Federal University named after M.K. Ammosov, Yakutsk, Russian Federation
[6]Department of Technologies and Equipment of Timber Industry, Ural State Forest Engineering University, Yekaterinburg, Russian Federation
[7]Department of Technology and Equipment of Forest Complex, Arctic State Agrotechnological University, Yakutsk, Russian Federation

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Abstract

Many researchers around the world show interest in forest ecosystems. Because the growth of forest stands depends on many environmental factors, forest stands can serve as study objects in research on climatic conditions and their role in forest architecture regulation. This study seeks to determine taxation indices of different tree stands to establish the possibility of forecasting the further course of forest development. The study sample includes forest stands with trees of different bonitet classes in the Leningrad region. The results show that climatic and other factors affect trees in different ways, depending on their species, age and location. The estimated height of pine in bonitet class II-IV is lower than the tabular one. The estimated diameter is higher than the tabular one in all cases except for one where stands consist of pine in bonitet class I. The biomass increment was smaller than expected in spruce trees of class III bonitet, pine trees of class II bonitet, and birch trees of class I bonitet.

Keywords: forest, growth phase duration, taxation, trend

*e-mail: ol_grigoreva@rambler.ru

Introduction

Climate change, greenhouse gases and other factors affect the growth dynamics of a forest ecosystem. This connection sparks huge interest among scientists, and the long-term observation of test plots enables them to investigate in those directions. Natural forest stands grow without human intervention that could change their natural composition [1]. Their growth dynamics depend on the ecological and biological properties of tree species in a stand. Therefore, knowing these properties, one can forecast the growth dynamics of a stand of trees and estimate the economic value it will have in the future [2].

Oddly enough, stand dynamics represent an area of knowledge where many conclusions and judgments stem from fragmentary and not systematized data, rather than longitudinal and detailed studies on vegetation dynamics and drivers controlling it. Intense human efforts to expand infrastructure and settlements entail changes in forest biocenosis. To assess the impact, scholars tend to track changes in the diameter and height of individual trees [3, 4].

The quantitative and qualitative dynamics of the forest ecosystem reflect the interaction between tree growth and tree mortality rates [5]. Its structure is influenced by many factors: wildfires, winds, zoocenosis, soil type, and more [6]. For example, the dynamics of forests with waterlogged soils are predominantly endogenous. Yet, water-saturated soils exacerbate the growth of the subterranean and aerial parts of the plant thanks to the slow gas exchange. Acceleration of the forest succession process is associated with, among other factors, the presence of peat in the soil, which encourages the growth of roots [7].

Compacted soils negatively affect the development of the root system of plants, which is associated with a limited supply of oxygen and water with nutrients [8]. This effect is mainly achieved by operating logging equipment (skidders, harvesters, etc.) of different capacities in the forest areas [9]. Another anthropogenic factor is tourism. In addition to direct compaction of soils by laying tourist routes, there is also an impact on the forest ecosystem during the construction of tourist recreation centers or other necessary structures [10]. Limiting organic carbon can be acting wind farms, which increase the erosion of the upper layers of the soil, especially in the proximity areas [11].

In other habitats, stand dynamics are associated largely with moderate-level and strong windfalls forming even-aged forest stands. The conventionally same-age stands of timber were seen to emerge simultaneously within relatively uneven-aged ones [7, 12]. Natural disturbances (such as root-rot and steam diseases, the influence of microbes, etc.) support a variable stand mosaic, including all stages of the regeneration cycle in which over-mature climax stands occupy the extensive area compared to other types of tree communities [13, 14].

The observations at natural park stations combined with data from silvicultural research lay ground for solving many theoretical, methodological and practical problems in natural resource management. The common challenges concern the drivers and directions of natural and artificial forest dynamics, the stages of dynamic forests, and the characteristics of the land allocated to preserve valuable ecosystems. Scholars seek, among other things, to redefine the methodology for forest dynamics accounting, to compare forests of different origins with respect to their values of sustainability and productivity, to establish ways of forest management for stands of varying origin, structure and dynamic state, and to develop a regional system for ecological regulation and rational resource management. The present study aims to estimate forest dynamics based on data from long-term observations and establish the possibility of forecasting the stand age dynamics.

A well-functioning forest ecosystem is characterized by a sufficient diversity of tree species. The composition of thereof depends on climatic, biotic and other conditions [15].

At the initial stages of stand establishment, trees encounter minimum competition and grow freely, forming larger niches. As the mixed stand reaches later stages, the competition increases strongly influencing its growth dynamics. The interspecific relations of tree species mediate the competition for resources among plants growing within restricted spaces. The growth architecture of woody plants defines the growth potential and size of adult species. This connection allows controlling the growth of the stand to obtain maximum financial return possible [16]. Changes in abiotic parameters affect the stand structure and distribution of woody plants, increasing competition between individual plants and expanding the area under large trees, making them more stress-tolerant. Such manipulation allows the population to survive even in unfavorable conditions [17].

Interpopulation relations indicate the dependence of plant species on the environment. Plant replacement during stand development results in more complex and stable forests. Competition is at the heart of the succession process [18]. The character of the coexistence at the level of cenosis leads to the emergence of other forest indicators (average taxation values and tree distribution by stem thickness) [16, 17].

Competition may be either interspecific or intraspecific. Both have similarities. For instance, they depend on the competitive vigor of the plants, which, in turn, is influenced by their growth strategy and environmental conditions. While some plants exhibit strong competitive ability, others are weak competitors that cannot withstand interspecific competition [19, 20]. There are also cases where species have a positive effect on each other. For example, a nurse plant increases the productivity of another species, resulting in a greater number of target species around it [19]. When growing together, some tree associations develop much better than in pure stands. In this case, the intraspecific competition is more intense than the interspecific one [21].

Korotkov et al. [22] examined the natural forest dynamics in the Moscow region. The authors show that reasoned judgments about the reasons, nature, mechanisms and directions of forest dynamics require re-inventory work on diverse permanent sample plots.

The growth dynamics of woody plants can serve as a marker of climatic changes in the area. An increase in the average air temperature entailed an increase in the number of closed forests and deciduous plants [23]. Chernogaeva and Kuhta [24] described the dynamics of boreal forests, where significant disturbances (wildfires, windfalls, and insect damage) destroy all or most of the trees at irregular intervals, resulting in plant community re-establishment. In the 1990s, the boreal forest dynamics was determined by a combination of natural and anthropogenic factors. Because natural factors play a more significant role in forest dynamics, it is vital to pay more attention to uneven-aged growth trends in this region.

Experimental

Methodology

Experiments were carried out on permanent sample plots (PSPs). The comparative analysis was to process data obtained from different experiments.

Estimation of the Current Increment in Growing-Stock Volume

The study duration was 5 years. The volume of the growing stock was determined using the complete enumeration procedure. Tree diameter measurements were taken using a metal pachymeter at a height of 1.3 m above root collar with an accuracy of 1 mm. The height of individual trees was measured using a pendulum altimeter (this procedure involved at least five trees in each diameter class). Data were arranged graphically to determine height classes of trees with different diameter. The stand inventory of the Arkhangelsk, Vologda and Leningrad regions was calculated using growth tables with an accuracy of about 3%. In cases of equal baseline stocks, the increment was calculated by the following formula:

$$\Delta V = V_{\text{p}} - V_c \tag{1}$$

where: V_{p} denotes the volume of the stand after natural thinning; V_{c} denotes the total volume of the control plots.

A formula for the total stand productivity is given below:

$$\sum V = V_{\text{p}} + V_{\text{o}} \tag{2}$$

where: V_{o} is the volume of the stand with respect to self-thinning mortality.

The volume of growing-stock trees that died due to competition (self-thinning process) was calculated similarly to that of the stand.

Study Objects

Experiments were carried out on pine stands comprising different bonitet classes (Table 1). Pine plantations are located within the territory of the Siversky Les forest agency (Leningrad region), established in 1929 by the Silviculture Laboratory staff working at the St. Petersburg Scientific Research Institute of Forestry at the time.

Results

According to Tretyakov's growth tables, stand volume and growth increments began to decline in the 60s. PSPs demonstrated a different trend: volume increments, decreasing in the 80 and 90s, began to grow again in the late 90s. Fig. 1 depicts changes in the diameter, height, and volume of growing-stock trees in pine plantations with class II of bonitet.

As can be seen, pine stand 1-1 exhibits the dynamics of height, diameter and volume growth similar to tabular estimates. The current increment curves, however, differ. When pine reaches an age of 53 years, its growth slows down substantially. The growth begins to gradually increase again at the age of 58. The only reason behind this effect can be climate change, cyclical or induced by the greenhouse effect.

The pine stand 2-1 represents a similar case (Fig. 2). The dynamics of height, diameter and volume growth is similar to tabular estimates, but the increment curves are different. The difference is a sharp increase of the growth curves for the study plot, followed by a decline.

The growth dynamics of the pine stand 11A (Fig. 3) are also consistent with the tabular estimates. The same is true for the plot 5-1 (Fig. 4). The increment curves for pine stands 3-1 and 11-A differ from the one based on tabular data and show a sharp decrease in growth, followed by an upward trend.

Due to the influence of climatic parameters, such as temperature and precipitation, pine trees grow by leaps and bounds.

Because some of the examined plantations were mixed, the change in taxation characteristics was also studied on spruce (Figs. 5-7) and birch stands (Fig. 8).

The dynamics of height and diameter growth within spruce stands 8A and 9A are consistent with the tabular values. The volume and current increment curves, on the other hand, differ. As can be seen, the volume growth of the stand 8A slowed gradually at the age

Table 1. Brief description of studied stands.

Taxation indices at the time of plantation						Year of plantation	Stand age at the time of plantation	Bonitet class at the time of plantation
H_{avg}, m	H_s, m	D_{avg}, cm	N, u/ha	G m²/ha	V, m³/ha			
Study plot 1-1; Pure stand: pine (10)								
12.5	16.8	11.3	2992	30.3	218	1966	48	II
Study plot 2-1; Pure stand: pine (10)								
9.0	14.1	7.0	5832	28.6	164	1973	50	IV
Study plot 3-1; Pure stand: pine (10)								
8.0	11.8	6.4	6805	22.0	122	1969	30	III
Study plot 4-1; Pure stand: spruce (10); Forest type: blueberry spruce forest								
4.1	9.1	3.6	55063	13.7	48	1971	22	II
Study plot 5-1; Pure stand: pine (10); Forest type: blueberry spruce forest								
15.5	17.1	13.9	1555	23.8	190	1971	43	I
Study plot 6A; Mixed stand: spruce (7) + birch (3) + pine + aspen								
10.2	16.0	8.6	3260	19.6	123	1930	43	III
Study plot 7A; Mixed stand: spruce (7) + birch (3) + pine + aspen								
9	14.5	7.9	32456	16.9	91	1930	43	IV
Study plot 8A; Mixed stand: spruce (8.7) + birch (1) + pine (0.3)								
14.6	20.2	11.0	3714	35.6	306	1930	48	II
Study plot 9A; Mixed stand: spruce (10); Forest type: sorrel spruce forest								
10.6	17.3	8	6236	31.7	213	1929	44	III
Study plot 11A; Pure stand: spruce (10)								
14.9	23.3	12.2	2984	35.2	322	1931	65	IV
Study plot 12A; Mixed stand: spruce (10) + pine; Forest type: blueberry spruce forest								
12.9	22.6	10.7	2620	23.8	201	1931	45	III
Study plot 24A; Pure stand: spruce (10); Forest type: blueberry spruce forest								
4.1		3.9	16663	13.2	48	1937	18	IV

Note: H_{avg} − the average height of the individual trees; H_s − stand height; D_{avg} − the average diameter of the individual trees; N − number of standing trees; G − total basal area; V − stand volume.

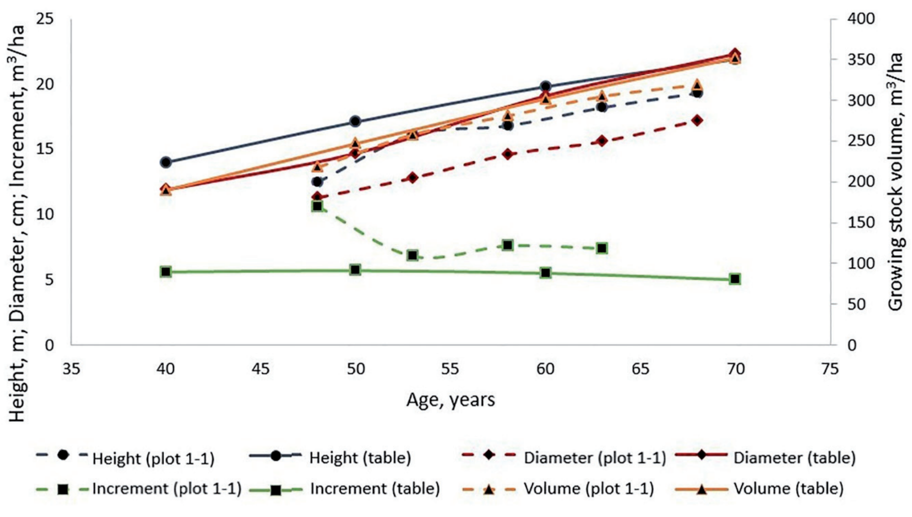

Fig. 1. Changes over time in taxation characteristics of standing pine (II class bonitet).

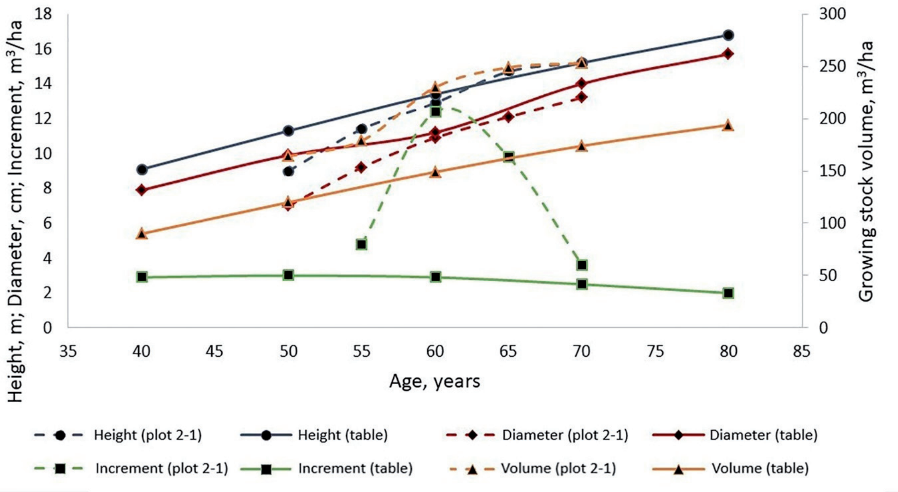

Fig. 2. Changes over time in taxation characteristics of standing pine (IV class bonitet).

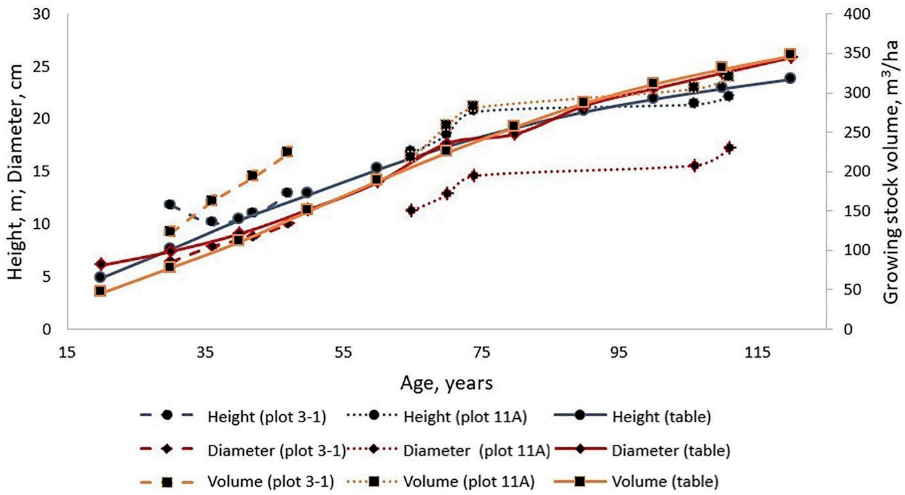

Fig. 3. Changes over time in taxation characteristics of standing pine (III class bonitet).

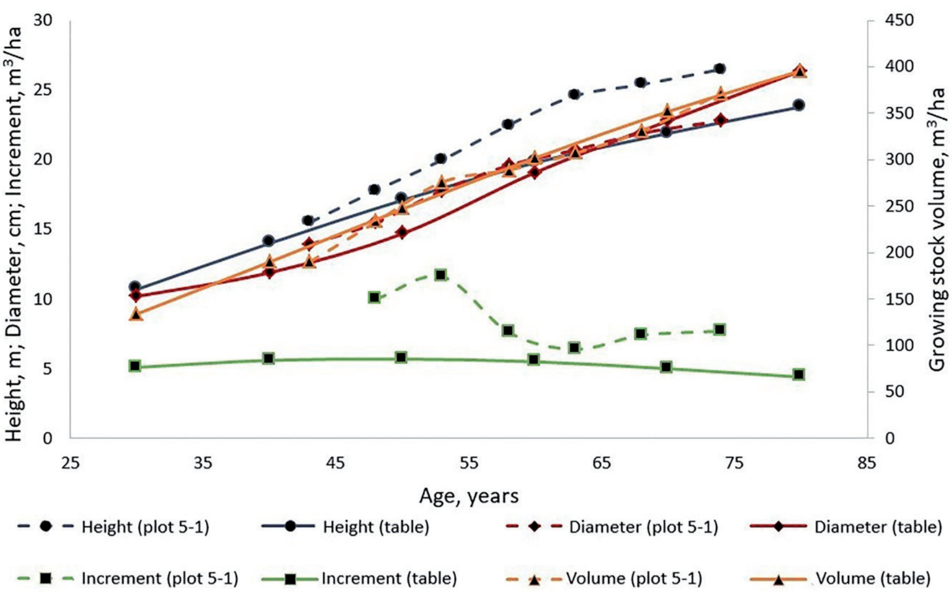

Fig. 4. Changes over time in taxation characteristics of standing pine (I class bonitet).

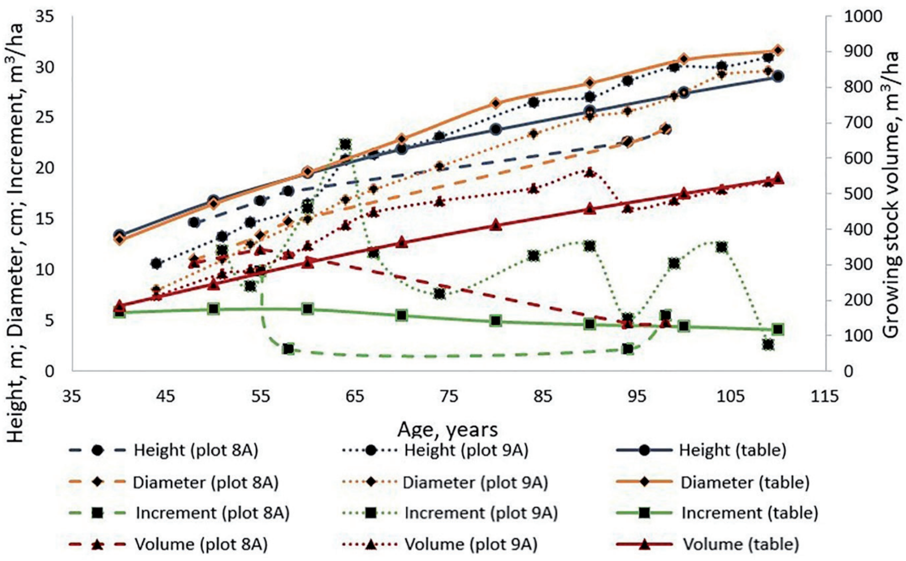

Fig. 5. Changes over time in taxation characteristics of standing spruce (I class bonitet).

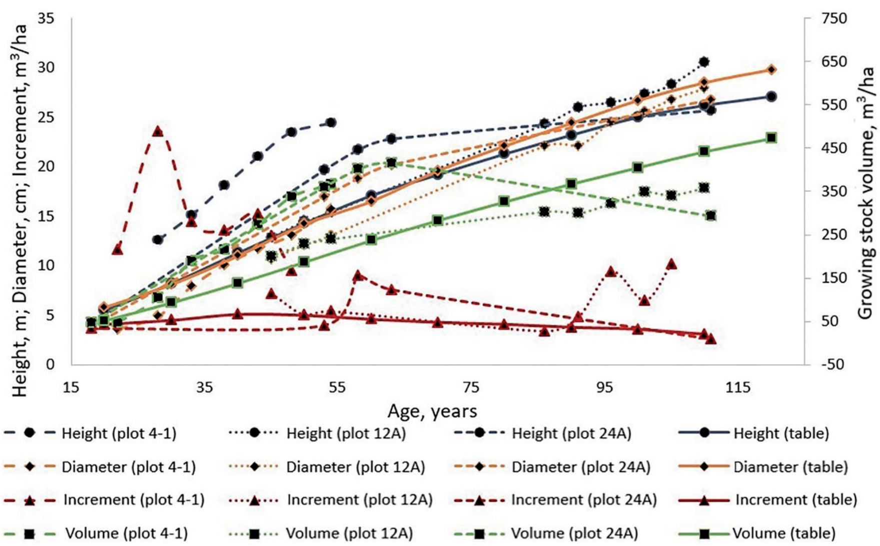

Fig. 6. Changes over time in taxation characteristics of standing spruce (II class bonitet).

of 55 years. The likely reason for this is windfalls. As regards growth increments, they became much smaller with time but then became slightly larger again. At the age of 98 years, trees grew in much larger increments. According to the volume growth curve for the study plot 9A, the first 60 years, growth was very similar to that after the age of 95 years. Volume growth between the ages of 60 and 95 exceeds the tabular values. The spruce stand 9A grew with leaps and bounds, while the growth table suggests a gradual and insignificant slowdown in growth. This difference is likely the result of weather impacts.

The dynamics of volume growth within spruce stands of II class bonitet (Fig. 6) are similar to tabular estimates. The stand 24A is the only exception displaying a gradual slowdown in volume growth after 64 years. Spruce stands 4-1 and 12A grew with varying increments that did not coincide with the tabular values. The spruce stand 24A, on the other hand, exhibited increments similar to those in the table. The current increment of the standing volume of the spruce stand 1-1 also differs from the tabular one. Spruce growth on the study plot 1-1 slowed gradually after 53 years and slowly sped up after 63 years.

The dynamics of height and diameter growth within the stand 6A (III class bonitet) are similar to tabular values. Yet, the height, diameter and volume values were lower. The likely reason behind this is windfalls and, accordingly, increased tree mortality (Fig. 7). As can be seen, the volume curve for the study plot 6A stopped growing once the spruce stand reached the age of 63 years, while the increment curve showed a dramatic decline and continued to grow afterwards.

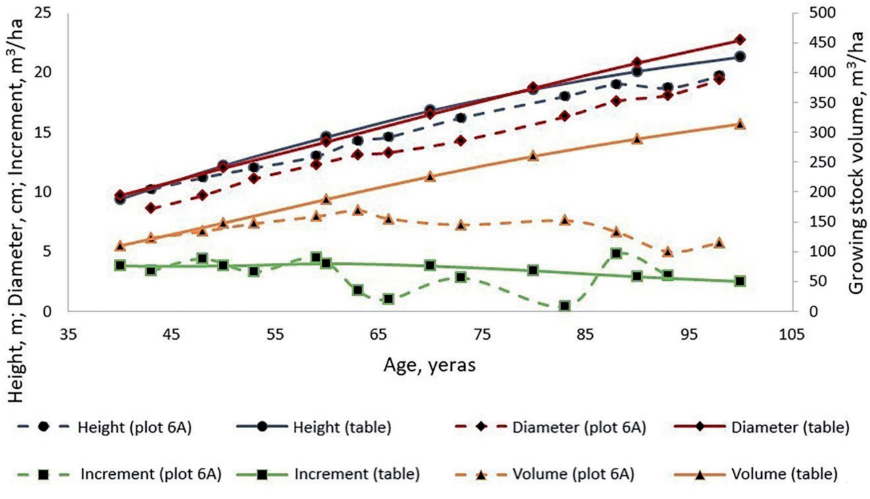

Fig. 7. Changes over time in taxation characteristics of standing spruce (III class bonitet).

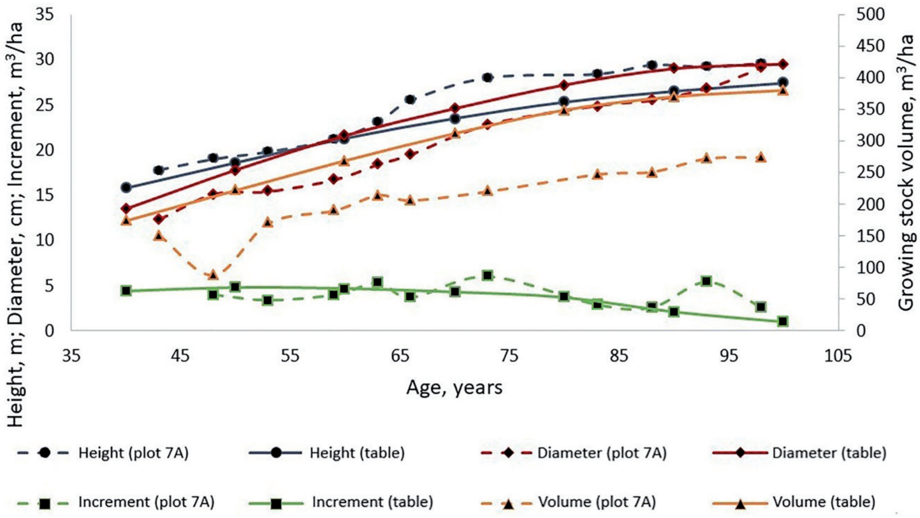

Fig. 8. Changes over time in taxation characteristics of standing birch (I class bonitet).

Birch stand 7A exhibits the dynamics of height, diameter and volume growth similar to tabular estimates for standing birch and spruce of I class bonitet. Birch grew in varying increments. A sharp decrease in growth proceeded a dramatic increase. Meantime, the growth table shows a gradual slowdown of birch growth with age (Fig. 8).

Discussion

Estimating the height and diameter of young trees (pine, birch, beech, etc.), Van de Peer et al. found that birch trees were substantially taller than pine trees, although their trunk diameter was slightly smaller. This trend is true for adult plants as well, but there are age-related variations in the size of differences. For instance, the difference in height between tree species ranges between 5% for young trees and 50% for old trees, while the difference in diameter is 15 to 35%, respectively [16]. The present study shows that birch and spruce have similar height and diameter regardless of their age.

Tudoran et al. [6] found that the proportion of trees (i.e., beech and fir) has a tendency to change when the trees grow older. Their diameter approximately doubles within more than 50 years of growth. The present work show that the trunk diameter of spruce and birch trees increases by 2-3 times depending on the bonitet class and location. For pine, the diameter increment ranges between 50 and 60%. Tudoran et al. [6] also show that the growth of biomass decreases with age. In this study, the growth occurred unevenly, sometimes by leaps and bounds.

Russian scholars [25] examined the growth of tree height and found that birch were the tallest of the examined species and spruce were the shortest ones. The results of this study obtained for birch are consistent with those findings, but pine trees were appeared to be shorter than the spruce trees.

Shevelina et al. [26] report that the crown diameter of spruce increases 7-fold in 50 years of growth. They suggest that this is achieved due to favorable growth conditions, namely the distance between trees. Regarding the diameter of the trunk, the situation is similar in the case of young and mature stands. Dancheva [27] analyzed the effect of felling on the value of taxation indicators of pine stands. As shown, at the age of 60 years in natural stands the average height is 12.5-14.0 m, and trunk diameter 14.0-17.0 cm and all plantings belong to class IV bonitet. In the case of artificial stands with thinning, the height of stands reached 14.2 m, and the diameter up to 17.2 for trees 45 years old, so these stands belong to the III class of bonitet. That is, thinning has a positive effect on the growth dynamics. It is possible that natural disasters, which mainly fell old dry trees of even large diameters and heights, may affect the average values, as indicated in the current work. Therefore, this indicator requires a more extensive study, taking into account the historical records of the region.

Conclusions

The authors studied the taxation indicators of forest stands, such as: plant height, trunk diameter, age of stands, timber stock, stand density, appraisal class, etc. The present study found a certain degree of similarity between taxation data collected from pine, spruce and birch plantations and data from the growth table. The growing stock volume of spruce in the pure spruce stands was the exception. It decreased, probably due to windfalls. The increment varied in all plantations. If the increment curves created based on tabular data depict steady dynamics, those based on experimental measurements display abrupt changes in growth, which can only be the result of climate change.

The dynamics of natural forest stands is subject to the following laws. In the initial stages of growth, there is a significant increase in diameter. With mature plants, the situation is the opposite. If the forest system does not regenerate, then the number of trees within the stand will decrease. Tree decline may also be due to adverse weather conditions or thinning. This process is more intense in young plantations. The peak growth occurs between the ages of 30 and 50 and gradually decreases after. Older trees (about 100 years old) are characterized by higher growth of indicators. Changes of indicators for plants under the age of 60 years were observed similar to older ones. For higher accuracy of conclusions, further research should investigate the growth dynamics of other types of trees growing in other areas.

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Conflict of Interest

The authors declare no conflict of interest.

References

1. KULAKOWSKI D., SEIDL R., HOLEKSA J., KUULUVAINEN T., NAGEL T.A., PANAYOTOV M., SVOBODA M., THORN S., VACCHIANO G., WHITLOCK C., WOHLGEMUTH T., BEBI P. A walk on the wild side: disturbance dynamics and the conservation and management of European mountain forest ecosystems. For. Ecol. Manag., **388**, 120, **2017**.
2. CHAZDON R.L., BRANCALION P.H., LAESTADIUS L., BENNETT-CURRY A., BUCKINGHAM K., KUMAR C., MOLL-ROCEK J., VIEIRA I.C.G., WILSON S.J. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. Ambio., **45** (5), 538, **2016**.
3. DALLA CORTE A.P., REX F.E., ALMEIDA D.R.A.D., SANQUETTA C.R., SILVA C.A., MOURA M.M., WILKINSON B., ZAMBRANO A.M.A., DA CUNHA NETO E.M., VERAS H.F.P., DE MORAES A., KLAUBERG C., MOHAN M., CARDIL A., BROADBENT, E.N. Measuring individual tree diameter and height using GatorEye High-Density UAV-Lidar in an integrated crop-livestock-forest system. Remote Sens., **12** (5), 863, **2020**.
4. POTAPOV P., SIDDIQUI B.N., IQBAL Z., AZIZ T., ZZAMAN B., ISLAM A., PICKENS A., TALERO Y., TYUKAVINA A., TURUBANOVA S., HANSEN M.C. Comprehensive monitoring of Bangladesh tree cover inside and outside of forests, 2000-2014. Environ. Res. Lett., **12** (10), 104015, **2017**.
5. MCDOWELL N.G., ALLEN C.D., ANDERSON-TEIXEIRA K., AUKEMA B.H., BOND-LAMBERTY B., CHINI L., CLARK J.S., DIETZE M., GROSSIORD C., HANBURY-BROWN A., HURTT G.C., JACKSON R.B., JOHNSON D.J., KUEPPERS L., LICHSTEIN J.W., OGLE K., POULTER B., PUGH T.A.M., SEIDL R., TURNER M.G., URIARTE M., WALKER A.P., XU C. Pervasive shifts in forest dynamics in a changing world. Science., **368** (6494), eaaz9463, **2020**.
6. TUDORAN G.M., CICȘA A., BOROEANU M., DOBRE A.C., PASCU I.S. Forest dynamics after five decades of management in the Romanian Carpathians. Forests., **12** (6), 783, **2021**. https://doi.org/10.3390/f12060783
7. SIKSTRÖM U., HÖKKÄ H. Interactions between soil water conditions and forest stands in boreal forests with implications for ditch network maintenance. Silva Fenn., **50** (1), 29, **2016**.

8. VAROL T., ERTUĞRUL M., ÖZEL H.B., EMIR T., ÇETIN M. The effects of rill erosion on unpaved forest road. Appl. Ecol. Environ. Res. **17** (1), 825, 2019.
9. VAROL T., EMIR T., AKGUL M., OZEL H.B., ACAR H.H., CETIN M. Impacts of small-scale mechanized logging equipment on soil compaction in forests. J. Soil Sci. Plant Nutr., **20** (3), 953, **2020**.
10. CETIN M., ZEREN I., SEVIK H., CAKIR C., AKPINAR H. A study on the determination of the natural park's sustainable tourism potential. Environ. Monit. Assess., **190** (3), 8, **2018**.
11. PEKKAN O.I., SENYEL KURKCUOGLU M.A., CABUK S.N., AKSOY T., YILMAZEL B., KUCUKPEHLIVAN T., DABANLI A., CABUK A., CETIN M. Assessing the effects of wind farms on soil organic carbon. Environ. Sci. Pollut. Res., **28** (14), 18216, **2021**.
12. IMBERT D. Hurricane disturbance and forest dynamics in east Caribbean mangroves. Ecosphere., **9** (7), e02231, **2018**.
13. HILMERS T., FRIESS N., BÄSSLER C., HEURICH M., BRANDL R., PRETZSCH H., SEIDL R., MÜLLER J. Biodiversity along temperate forest succession. J. Appl. Ecol., **55** (6), 2756, **2018**.
14. QU Z.L., LIU B., MA Y., XU J., SUN H. The response of the soil bacterial community and function to forest succession caused by forest disease. Funct. Ecol., **34** (12), 2548, **2020**.
15. TIKHONOVA E, TIKHONOV G., SHEVCHENKO N., KNYAZEVA S., PLOTNIKOVA A., LUKINA N., SHASHKOV M. Tree diversity patterns along the latitudinal gradient in the northwestern Russia. For. Ecosyst., **4** (1), 27, 2017.
16. VAN DE PEER T. Effects of tree species diversity on early-stage forest dynamics. Doctoral dissertation. Ghent University: Ghent, 2018.
17. ZHANG Z., PAPAIK M.J., WANG X., HAO Z., YE J., LIN F., YUAN Z. The effect of tree size, neighborhood competition and environment on tree growth in an old-growth temperate forest. J. Plant. Ecol., **10** (6), 970, **2017**.
18. GU L., O'HARA K.L., LI W.Z., GONG Z.W. Spatial patterns and interspecific associations among trees at different stand development stages in the natural secondary forests on the Loess Plateau, China. Ecol. Evol., **9** (11), 6410, **2019**.
19. DAS A.J., LARSON A.J., LUTZ J.A. Individual species-area relationships in temperate coniferous forests. J. Veg. Sci., **29** (2), 317, **2018**.
20. VAN DE PEER T., VERHEYEN K., KINT V., VAN CLEEMPUT E., MUYS B. Plasticity of tree architecture through interspecific and intraspecific competition in a young experimental plantation. Forest. Ecol. Manag., **385,** 1, **2017**.
21. THURM E.A., PRETZSCH, H. Improved productivity and modified tree morphology of mixed versus pure stands of European beech (Fagus sylvatica) and Douglas-fir (Pseudotsuga menziesii) with increasing precipitation and age. Ann. For. Sci., **73** (4), 1047, **2016**.
22. KOROTKOV S.A., MAKUEV V.A., LOPATNIKOV M.V., NIKITIN V.V., SIROTOV A.V., STONOZHENKO L.V. Forest-use issues in Moscow Region at the beginning of the 21st century. Bull. Transilv. Univ. Bras. II: For. Wood Ind. Agric. Food Eng., **9** (2), 17, **2016**.
23. GRIGOR'EV A.A., DEVI N.M., KUKARSKIKH V.V., V'YUKHIN S.O., GALIMOVA A.A., MOISEEV P.A., FOMIN V.V. Structure and dynamics of tree stands at the upper timberline in the western part of the Putorana Plateau. Russ. J. Ecol., **50** (4), 311, **2019**.
24. CHERNOGAEVA G.M., KUHTA A.E. The response of boreal forest stands to recent climate change in the north of the European part of Russia. Russ. Meteorol. Hydrol., **43** (6), 418, **2018**.
25. SANNIKOV S.N., PETROVA I.V., SANNIKOVA N.S., KOCHYBEI A.A., SANNIKOV D.S. Divergence of biogeocenoses within pine forest types. Russ. J. Ecol., **48** (4), 340, **2017**.
26. SHEVELINA I.V., SHARAFIEVA G.I., NAGIMOV Z.Y. Siberian Spruce stand structures peculiarities in urban plantations. In IOP Conference Series: Earth and Environmental Science (Vol. 226, No. 1). IOP Publishing, 012056, **2019**.
27. DANCHEVA A.V. Influence of thinning of different intensity on the taxation parameters of pine stands. Russia's Forests and Management in Them, **4** (55), 22, **2015**.