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Growth and Carbon Sequestration Potential of Tbilisi City Forest Under Climate Change Conditions (South Caucasus)

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Abstract

Climate change is one of the pressing issues in today's world. Greenhouse gases play a major role in maintaining the global energy balance, but a small change in their concentration in the atmosphere can affect the Earth's climatic conditions. Carbon dioxide (CO_2) is one of the main greenhouse gases, the concentration growth of which in the atmosphere is the main cause of global warming. Urban forests have great potential to sequester carbon dioxide from the atmosphere and mitigate the impacts of climate change in urban areas, however, at the same time, they are vulnerable to climate change and anthropogenic pressure. Our study object Tbilisi city (the capital) forest is located in the area of negative impact of dangerous natural events caused by climate change, which is enhanced by the anthropogenic factor caused by growing urbanization. Rapid urbanization is considered a major driver of global change in the atmosphere, climate change, driving land use change, habitat loss, biodiversity decline, and pollution both within and outside the city. This research examined the potential of growing wood stock, living biomass, and carbon sequestration in the different forest formations of Tbilisi city forests under climate change conditions for the following years: 1964, 1874, 1984, and 2018. The study data show that the growth rate of Tbilisi city forest, respectively, accumulation ability of wood stock, biomass, and carbon stock is low, both in comparison with the corresponding data of the forests of eastern Georgia and with the corresponding data of the forests of Central-Eastern Europe. However, some forest formations, namely, Beech - is good. The mentioned data show that the forest in the surroundings of Tbilisi cannot properly fulfill its protective function including climate change mitigating function, and it is clear that effective management measures are needed to maintain and enhance the sustainability of the study forest. To improve the conditions of Tbilisi city forest, it is necessary, on the one hand, to reduce the negative impact factors associated with rapid urbanization, and on the other hand, to activate measures to promote the natural regeneration of local woody plant species that are more adaptable to climate change.

Keywords

Urban forest, Biomass, Carbon Sequestration,

Climate change.

Introduction

Climate change is one of the pressing issues in today's world (Ugle et al., 2010). Climate change can be defined as the long-term fluctuations of the Earth's climate, usually appearing as increasing temperatures, rising sea levels and more frequent extreme weather events (Kraeuchi, 1993; Zhang & Brack, 2021).

According to the data of the Intergovernmental Panel on Climate Change (IPCC) the average temperature on Earth has increased by 0,7 ^{0}C since the beginning of the industrial revolution (from the second half of the 18th century). It is clear that since preindustrial times, temperatures have risen faster than before and it is extremely likely that human influence is the dominant factor of this change (IPCC, 2006) and the role of human activities in influencing the Earth's climate is becoming more and more obvious (Lindner *et al.*, 2010). Climate is changing rapidly globally and is expected to change at an even faster rate in the coming decades (IPCC, 2006).

The greenhouse effect is one of the most important factors determining the Earth's climate (Kraeuchi, 1993). Greenhouse gases play a major role in maintaining the global energy balance, but a small change in their concentration in the atmosphere can affect the Earth's climatic conditions. Carbon dioxide (CO_2) is one of the main greenhouse gases and a primary cause of global warming (Ugle *et al.*, 2010; Lal & Singh, 2000).
According to IPCC and Earth System Research Laboratories (ESRL) data, the level of CO_2 is continuously rising in the atmosphere since preindustrial times (IPCC, 2006; Heil & Selden, 2001; ESRL, 2023). The observed increase in levels of atmospheric CO_2 (from 280 ppm in 1800 to 315 ppm in 1957 to 358 ppm in 1996 to 395 ppm in 2010) has forced nations in recent years to assess their contributions to sources and sinks of CO_2 and to evaluate the processes that control CO_2 accumulation in the atmosphere (Ugle *et al.*, 2010; Lal & Singh, 2000). If the emission of CO_2 increases at the current rate, it will reach a dangerous level of 495 ppm by the end of the 21st century (ESRL, 2023).

Accelerating climate change is a problem that affects all ecosystems on Earth [9]. Climate change can also affect tree physiological processes and influence plant growth, phenology, and morphology (Zhang & Brack, 2021).

Forest ecosystem plays a very important role in the global carbon cycle (Ugle *et al.*, 2010) as one of the most important "carbon reservoirs" of the terrestrial ecosystem (Suryawanshi *et al.*, 2014). Woody plants absorb the carbon dioxide through the process of photosynthesis, convert it to organic compounds, and sequester the carbon in tissue above and below ground until it burns or dies and decays (Lal & Singh, 2000; Suryawanshi *et al.*, 2014; IPCC, 2003; Vashum & Jayakumar, 2012).

There is strong evidence that climate change threatens urban areas and populations (Ordóñez & Duinker, 2014), where the adverse impacts are amplified by the urban heat island (UHI) effect (Zhang & Brack, 2021; Gago *et al.*, 2013). Respectively, urban forests can play an important role in mitigating the impacts of climate change by reducing CO_2 (Liu & Li, 2012; Sharma *et al.*, 2020; McPherson, 1999).

Despite their mitigation effects, urban trees and forests by themselves are vulnerable to climate change (Lindner *et al.*, 2010; Brandt *et al.*, 2016). Thus, their ability to adapt to climate change and their size, structure and species composition determine the scale and effectiveness of mitigation and provision of ecosystem services (Zhang & Brack, 2021; McPherson, 1999).

Climate change is already occurring in the South Caucasus. The evidence indicates that the South Caucasus will continue to become drier and warmer this century (Westphal *et al.*, 2011).

The process of climate change in Georgia has been observed since the middle of the last century (Ministry of Environmental Protection and Agriculture of Georgia, 2021; Elizbarashvili *et al.*, 2017). According to the Fourth National Communication of Georgia to UNFCCC (2021), in 1986-2015, compared to 1956-1985, the mean annual ground air temperature in the country increased almost everywhere, depending on the regions – in the range of 0.25–0.58 ^{0}C. The average increase in air temperature in the territory of Georgia is 0.47 ^{0}C. During the same period, the annual precipitation in western Georgia has mainly increased, while it decreased in some eastern regions of the country (Ministry of Environmental Protection and Agriculture of Georgia, 2021). The largest decrease in precipitation is observed in Kvemo Kartli, south of Tbilisi, and is more than 5% (Elizbarashvili *et al.*, 2017).

Our study object Tbilisi city (The capital) forest is located in the area of negative impact of dangerous natural events caused by climate change, which is enhanced by the anthropogenic factor caused by growing urbanization. Rapid urbanization is considered a major driver of global change in the atmosphere, climate change, driving land use change, habitat loss, biodiversity decline, and pollution both within and outside the city (Satterthwaite et al., 2010).

This study focuses on assessing the growth, biomass, and carbon sequestration potential of the Tbilisi city forest, taking into consideration the climate change over the past half a century. Quantifying carbon (C) storage by urban forests is important to assess its actual and potential role in reducing atmospheric CO_2 [15]. Estimating the growth, biomass, and carbon sequestration potential of forests is also important to the assessment of their productivity, protective and recreational, and other ecosystem functions (Terakunpisut *et al.*, 2007).

Materials and methods

2.1 *Study area*

We focused on the urban forest of the surroundings of Tbilisi, which is located between Longitude 44°35'12.425" to 45°1'0.59"E and Latitude 41°50'15.263" to 41°37'38.7"N. The elevation ranges from 307 m to 1,490 m above sea level.

Climate – climate is transitional from steppe to moderately humid subtropical. The mean annual precipitation is 501.6 mm. the mean annual temperature is 13.2°C. The absolute minimum temperature is -16.3°C and the absolute maximum temperature is 40°C. The average relative humidity is 68.2% (Kartvelishvili *et al.*, 2009).

Soil - loamy soil is developed in the study forest; in particular, up to 500 m above sea level Cinnamonic calcareous-Calcaric Kastanozems soil type is developed, and from 500 to 1,500 m above sea level Brown forest weakly unsaturated-Eutric Cambisols and Brown forest acid-Dystric Cambisols are developed (Urushadze *et al.*, 2019).

Tbilisi forest is located in the central floristic region of Transcaucasia, which is distinguished by species diversity, that is most clearly expressed in the surroundings of Tbilisi. According to the latest forest inventory data (2018), the total area of forest is 11,900 ha, where 9,203 ha is covered with forest including natural forest cover of 7,101.2 ha (77.2 %), and artificial forest cover 2,101.7 ha (22.8 %). The total forest area is divided into 8 forest districts (World Agroforestry (ICRAF), 2023), (Fig. 1).

2.2 *Studied subject*

Tbilisi city forest is mainly represented by deciduous forest. A large part of the forest area is covered with natural secondary forest. Artificial forests are mainly coniferous.

Study forests were further classified into nine study forest formations based on the main forest-forming tree species listed in Table 1.

The ratio of the volume of the target woody species to the total volume of the city forest is 94.35%, and the area is 82.8% to the total area of the city forest. These data revealed that the study forest covers most of the city forest area and includes all the main forest-forming tree species, which makes it possible to generalize the study results to the entire forest with high accuracy.

2.3 *Methods*

The biomass and carbon sequestration were assessed using a non-destructive method. We mainly used the methodological recommendations of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2006; IPCC, 2003).

2.3.1 *Biomass and carbon stock calculations*

Estimating the biomass in trees is the first step in carbon accounting (Ugle *et al.*, 2010). The following allometric equation (Eq. 1) was used to calculate total biomass:

$$B = V \times WD \times BEF_2 \times (1 + R)$$

$$(Eq.1)$$

where:

B – is total biomass, t/ha^{-1} (the sum of the above and below-ground biomass);

V – is stem volume (including bark), m^3/ha^{-1};

WD - is basic wood density, is a conversion factor that transforms the green volume of wood into dry weight, g/cm^3;

BEF_2 – is biomass expansion factor, is a conversion factor that transforms volume into biomass;

R – is the ratio of below-ground biomass to above-ground biomass, ton d.m. below-ground biomass (ton d.m. above-ground biomass)$^{-1}$.

The average annual increment in aboveground biomass was calculated using the following equation (Eq. 2):

$$G_w = I_V \times WD \times BEF_1$$
(*Eq.2*)

where:
G_W – is an above-ground biomass growth, tons d.m. ha^{-1}/yr^{-1};
I_V – is the average annual increment of tree (including bark), m^3/ha^{-1};
WD - is basic wood density, is a conversion factor that transforms the green volume of wood into dry weight, kg/m^3;
BEF_1 – is biomass expansion factor, is a conversion factor that transforms the average annual increment of trees into the average annual increment in aboveground biomass.

Wood density (WD) values for target woody species were obtained from various authentic sources listed in Table 2. We used the values of the conversion factors: BEF_1, BEF_2 and *R*, recommended by IPCC for forests of the temperate climate zone (IPCC, 2003), because corresponding local values are not available (BEF_1=1.20 (overbark); BEF_2=1.35 (overbark); *R*=0.23).

Carbon stocks (tC/ha^{-1}) were calculated from total biomass using the following equation (Eq. 3):

$$C = B \times CF$$
(*Eq.3*)

where:
C – is a total carbon stock, tC/ha^{-1};
B - total biomass, t/ha^{-1};
CF - conversion factor that transforms the total biomass into the carbon stocks (Carbon fraction).

Generally, for any plant species 50% of its biomass is considered as carbon [4, 29], however, it differs slightly for deciduous and coniferous species. According to IPCC Guidelines for deciduous trees CF=0.48 and for coniferous trees CF=0.51 (IPCC, 2006).

CO_2 equivalent is calculated using the below-given equation *(Eq. 4)*:

$$CO_2\ (eq.) = (Carbon\ content * 44)/12$$
(Eq.4)

Factors such as natural decay of wood and carbon release from soil are not considered in this study.

2.3.2 *Data collection*

Field data, collected within the study, as well as data obtained from scientific and grey literature (e.g., forest management plans and inventory materials; climatic data) are used for this research.

Forest management plans (with inventory materials) of the study forest for the years 1964, 1974, and 1984 were obtained from the archives of the National Forestry Agency and current inventory materials (2018) from Tbilisi City Hall.

Historical climatic data of the relevant periods were obtained from the National Environment Agency.

The analysis of climatic elements is given by the data of Kojori and Tbilisi weather stations. Climatic data of the Tbilisi weather station were generalized for the forests up to 1,000 m above sea level, and those of the Kojori weather station - for the forests above 1,000 m above sea level (Table 3).

3. Results and discussion

3.1 *Climate data analyses*

In the territory of the study forest, the indicators of climatic elements are characterized by variability, which had an intense character in certain years.

The distribution of the annual precipitation in the study period (from 1960 to 2018) is characterized by the following trend: according to the data of the Tbilisi weather station, in the period from 1965 to 2008, the annual precipitation ranged from 400 mm to 600 mm. The period from 2009 to 2012 was relatively rich in precipitation and ranged from 630 mm to 715 mm, while the precipitation since 2013 has been characterized by a decreasing trend. According to the data of the Kojori weather station, the range of annual precipitation distribution in the period from 1965 to 1984 is wide compared to the data of Tbilisi station, which ranged from 638 mm to 946 mm, and the precipitation fallen since 1985 is characterized by decreasing trend (Fig. 2).

According to the data of both weather stations, the smallest amount of precipitation was recorded in 1962, which was 240.4 mm in the case of Tbilisi, and 488.5 mm in the case of Kojori. The most abundant precipitation was in the year 1963, when the amount of precipitation reached 765.7 mm according to the data of the Tbilisi station, and 1,286 mm according to the data of the Kojori station. The year 1972 was also rainy (Tbilisi 812.9 mm; Kojori 1,074.6 mm). It can be seen that there was a significant uneven distribution of precipitation in the mentioned years (Fig. 2).

According to the data of the Tbilisi weather station, the annual partial pressure of air water vapor varies from 10 hPa to 12 hPa from 1961 to 2003. Since 2004, this indicator has exceeded 12 hPa and is characterized by an increasing trend. According to the data of the Kojori station, the annual partial pressure of air water vapor is lower than the data of the Tbilisi station, which does not exceed 10 hPa and has a narrow range of variation (Fig. 3).

The average annual air temperature in the study period (from 1960 to 2018) is characterized by the following trend: according to the data of the Tbilisi weather station, the average annual temperature in the period from 1965 to 1998 fluctuated within 10-11^{0}C. Since 1999, the temperature has been characterized by an increasing trend, ranging from 12^{0}C to 13.5^{0}C. By the data of Kojori station, the average annual temperature is lower than the data of Tbilisi station and is not characterized by an increasing trend, which varies between 8-9^{0}C (Fig. 4). However, it should be noted that the data of Kojori station are available only for the period up to 1994, which does not provide the opportunity to create a complete picture.

From the analysis of the indicators of climatic elements, it can be seen that the climate change is expressed in the surroundings of Tbilisi. In particular, the average air temperature is characterized by an increase, while the amount of precipitation, on the contrary, decreases. This trend can be seen especially from the data of Tbilisi station, which refers to forests up to 1,000 m above sea level.

3.2 *Wood stocks, biomass and carbon stocks*

The general characteristics of the study forest, given in Table 4, differ according to the study woody plant species.

Pine (*Pinus hamata*) is represented in the form of artificial plantings, the area of which has been increasing since 1964 due to the addition of artificially planted areas. The area is the largest according to the data of the 1984 inventory, which is 2,423 ha. According to the latest inventory data of 2018, it has decreased to 1,512 ha, which is mainly due to the dying of existing artificial plantings (it was significant in 2010-2018). The frequency is characterized by decreasing, respectively.

Ash (*Fraxinus excelsior*) is represented as both artificial and natural mixed forest. According to the latest inventory data of 2018, the area of natural forest is 241.5 ha, and the area of artificial is 121.4 ha. It should be noted that by the data of the 2018 inventory, the area of natural ash trees has increased compared to the data of 1974 and 1984, but it has decreased compared to the data of 1964. Until 1964, ash was represented only in the form of natural stands, the area of which was 234 ha.

Oak (*Quercus iberica*) is represented by both seed-grown and coppice-grown natural forests. It creates both pure and mixed stands mainly with hornbeam and ash. The area of seed-grown oak stands in the study period is characterized by a significant increase, which according to the inventory data of 1974 was 983 ha, and according to the data of 2018, it is 2,562 ha. There is also a trend of rejuvenating seed-grown stands. On the contrary, the area of the coppice-grown stands decreases significantly, and their frequency also decreases.

Hornbeam (*Carpinus caucasica*) is represented by both seed-grown and coppice-grown natural forests. It forms both pure and mixed stands mainly with oak, beech and maple. The area of seed-grown hornbeam stands in the study period is characterized by a significant increase, which according to the data of the 1974 inventory was 218 ha, and according to the data of 2018, it is 972 ha. There is also a trend of rejuvenating the seed-grown stands and improving the site index class. On the contrary, the area of the coppice-grown stands decreases significantly, as well as their frequency.

Beech (*Fagus orientalis*) is represented by both seed-grown and coppice-grown natural stands. It creates both pure and mixed formations, mainly with hornbeam. During the study period, the area of beech forest, both seed-grown and coppice-grown, has been significantly reduced. According to the inventory data of 1974, the area of natural beech forest was 614 ha, and according to the data of 2018, it is 220 ha. The area of the coppice-grown forest in 1974 was 101 ha, and according to the data of 2018, it is 8 ha. Although a significant decrease in areas is recorded, the frequency does not decrease, and the site index class, on the contrary, improves.

Maple (*Acer ibericum*) and *elm* (*Ulmus glabra*) do not form pure stands and are represented by mixing with oak, hornbeam and beech. Their areas are small, which is characterized by a decreasing trend during the study period. The frequency and site index class of their stands also decrease.

Poplar (*Populus spp.*) is represented as artificial plantings, the area of which according to the data of 2018 has been decreased, compared to the data of previous inventory years. The site index class has also been reduced.

The rate of growth of the forest and accumulation of biomass is directly proportional to the rate of CO_2 absorption and carbon accumulation. Stem volume, biomass and carbon stocks per hectare are summarized in Table 5. It can be seen from the table that among the main formations of the natural, seed-grown forest, oak, hornbeam and beech stands have a high rate of growth in volume and biomass per unit of area (ha). A high rate of accumulation is also found in coppice-grown hornbeam and beech stands. According to the data of the 2018 inventory, stem volume of oak and beech stands is within 80-115 m^3/ha, and that of beech reaches 205 m^3/ha. The biomass of oak and hornbeam stands is within 87-122 t/ha, and that of beech – is 205 t/ha.
According to the data from the 2018 inventory, the volume and biomass of artificial forest stands is 98.6 m^3/ha in the case of pine stands, and 159.5 m^3/ha - for poplar stands. The biomass in the case of pine is 76.1 t/ha, and that of poplar is 111.2 t/ha.
According to the mentioned indicators of biomass, the rate of carbon stocks and its equivalent carbon dioxide is high in the seed-grown and coppice-grown hornbeam and beech stands and in the seed-grown oak stands.

Based on the inventory data of 2018, the calculated carbon stocks in the case of the hornbeam stands are in the range of 51-59 t/ha, and the CO_2 equivalent is in the range of 190-215 gg/ha. In the case of beech stands, the mentioned indicators is in the range of 94-98 t/ha, and the CO_2 equivalent is in the range of 344-360 gg/ha. The carbon stock of oak seed-grown stands is 42 t/ha, and that of coppice-grown stands is 24 t/ha. The CO_2 equivalent in seed-grown oak stands is 153.8 gg/ha, and in coppice-grown stands, it is 88.1 gg/ha.

The indicators of carbon stocks and its equivalent carbon dioxide in the artificial pine forest are 38.8 t/ha and 142.2 gg/ha respectively, and those of poplar stands are 53.4 t/ha and 195.8 gg/ha, respectively.

The volume of ash stands and, accordingly, the biomass and carbon stocks per unit area (ha) are not high, although an increasing trend during the study period characterizes them. According to the data of the forest inventory of 1964, the volume was 17.5 m^3/ha, and according to the data of 2018, it is 33.9 m^3/ha. According to the data of 1964, the biomass was 18.3 t/ha, and according to the data of 2018, it is 35.5 t/ha. The carbon stocks in the mentioned years was 8.8 t/ha and 18.1 t/ha, respectively.

The mentioned indicators of maple and elm stands are also not high, although it is worth noting that they keep a stable development. Average annual increment in stem volume, biomass, carbon stocks and CO_2 equivalent per ha are summarized in Table 6. It can be seen from the table that from the main formations of the natural forest, both seed-grown and coppice-grown stands of hornbeam and beech are characterized by a good increment and growth trend during the study period. Oak seed-grown stands also have a good increment.

According to the data of the 2018 inventory, the average annual increment in volume of seed-growing hornbeam stands is 2.0 m^3/ha, in biomass - 1.6 t/ha, in carbon - 0.77 t/ha, while the CO_2 equivalent is 2.81 gg/ha. The average annual increment in volume of seed-growing beech stands is 2.7 m^3/ha, in biomass - 1.88 t/ha, in carbon - 0.90 t/ha, while the CO_2 equivalent is 3.31 gg/ha. The average annual increment in volume of seed-growing oak stands is 1.3 m^3/ha, in biomass - 0.99 t/ha, in carbon - 0.47 t/ha, while the CO_2 equivalent is 1.74 gg/ha. Artificial forest stands are also characterized by a good increment. The average annual increment in the volume of pine stands is 1.9 m^3/ha, in biomass - 0.92 t/ha, in carbon - 0.47 t/ha, while the CO_2 equivalent is 1.72 gg/ha. The average annual increment in volume of poplar stands is 3.1 m^3/ha, in biomass - 1.51 t/ha, in carbon - 0.72 t/ha, while the CO_2 equivalent is 2.65 gg/ha. The increment of ash stands are not high, although they are stable; the average annual increment in volume is 0.8 m^3/ha, in biomass - 0.58 t/ha, in carbon - 0.28 t/ha, while the CO_2 equivalent is 1.03 gg/ha.

The increment of maple and elm stands are also low, although they are characterized by stability.

The results of the total stem volume, biomass, carbon stocks and CO_2 equivalent in each study forest stand are presented in Table 7. It can be seen from the table, that a large share of stem volume, biomass, and carbon stocks from natural forest formations belongs to oak, hornbeam, and beech forests, and from artificial forests - to pine forests. According to the 2018 forest inventory data, the total volume of oak stands is 205,400 m^3, that of biomass is 223,891 tons, the carbon stock is 107,468 tons, and the CO_2 equivalent is 394.0 gg. The total volume of hornbeam stands is 102,990 m^3, biomass is 117,937 tons, carbon stock is 56,610 tons, and CO_2 equivalent is 207.6 gg. The total volume of beech stand is 45,090 m^3, the biomass is 45,034 tons, the carbon stock is 21,616 tons, and CO_2 equivalent is 79.3 gg.

The total volume of pine stands is 149,100 m^3, the biomass is 115,019 tons, the carbon stock is 58,660 tons, and CO_2 equivalent is 215.1 gg.

According to the study results, biomass and carbon accumulation of the main forest formations in the study period (1964-2018) were determined by the following indicators:

The average volume of seed-grown *oak stands* per unit of area (ha) is 80 m^3, and that of coppice-grown stands is 60 m^3. The biomass is 90 tons for seed-grown stands and 65 tons for coppice-grown ones. Accordingly, the carbon stock for seed-grown stands is 42 tons, and for coppice-grown stands - 30 tons. During the study period, the mentioned indicators of the seed-grown oak stands are stable, while those of coppice-grown is characterized by a decrease.

The average volume of seed-grown *hornbeam stands* per unit of area (ha) is 115 m^3, and that of coppice-grown stands is 98 m^3. The biomass is 130 tons for seed-grown stands and 112 tons for coppice-grown ones. Accordingly, the carbon stock for seed-grown stands is 63 tons, and for coppice-grown stands - 54 tons. In the study period, the mentioned indicators of the seed-grown hornbeam stands are characterized by a slight decrease, while the trend of growth for the coppice-grown stands was observed until 1984, and its decrease is evident according to the data of the last inventory of 2018.

During the study period of seed-grown *beech stands* (1964-2018), the average volume per unit of area (ha) is 172 m^3, and that of coppice-grown stands was 143 m^3. The biomass was 172 tons for seed-grown stands and 143 tons for coppice-grown stands. Accordingly, the carbon stock for seed-grown stands is 82 tons, and for coppice-grown stands - 68 tons. In the study period, the mentioned indicators of beech seed-grown stands were stable until 1984, and according to the 2018 inventory data, an increase is evident. The increase is also evident in the case of coppice-grown stands.

The mentioned indicators for artificial *pine stands* are characterized by an increasing trend and are significantly different for the study period. This is stipulated by the gradual increase in the area of artificial pine plantings. According to the last inventory data of 2018, the wood stock per unit of area (ha) is 98.6 m^3, and the average indicator during the study period is 40 m^3. According to the data of 2018, the biomass is 76.1 tons, and the average is 30.5 tons. Accordingly, according to the data of 2018, the carbon stock is 38.8 tons, and the average is 16 tons.

The mentioned indicators of the main formations of the study forest, except for the beech forest, are lower compared to the corresponding indicators of the forests of Georgia and Central-Eastern Europe. A comparison is given in Table 8.

Conclusions

The study data show that the growth rate of the Tbilisi city forest, respectively the average indicators of accumulation of wood stocks, biomass, and carbon stocks are low, compared to the corresponding data of the forests of eastern Georgia. These indicators are also significantly lower compared to the corresponding data of Central-Eastern European forests (Table 8), although the indicators of some forest formations, such as beech - are good, and the general characteristics of the forest are not characterized by a sharp deterioration trend.

The unsatisfactory state of the forest is influenced by the tendency to increase the areas of low-productivity forest, such as Oriental hornbeams (*Carpinus orientalis*) and coppice-grown forests. The area of beech trees, which is characterized by high productivity, is reduced.

The general trend of forest development is influenced by the negative anthropogenic factors of the territory, as well as the changed environmental conditions under climate change.

The above-mentioned data show that the forest in the surroundings of Tbilisi cannot properly fulfill its protective and mitigating functions to climate change and it is clear that effective management measures are needed to maintain and enhance the sustainability of the study forest.

To improve the conditions of Tbilisi city forest, it is necessary, on the one hand, to reduce the negative impact factors associated with rapid urbanization, and on the other hand, to activate measures to promote the natural regeneration of local woody plant species that are more adaptable to climate change.

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References

Ugle, P., Rao, S., & Ramachandra, T. V. (2010). Carbon sequestration potential of urban trees. *Proceedings of the Lake*, 1-12.

Kraeuchi, N. (1993). Potential impacts of climate change on forest ecosystems. *European Journal of Forest Pathology, 23*(1), 28-50.

Zhang, B., & Brack, C. L. (2021). Urban forest responses to climate change: A case study in Canberra. *Urban Forestry & Urban Greening, 57*, 126910.

IPCC. (2006). *2006 IPCC guidelines for national greenhouse gas inventories* (Prepared by Eggleston, H. S., Buendia, L., Miwa, K., Ngara, T., & Tanabe, K.). IGES.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbati, A., Garcia-Gonzalo, J., ... & Marchetti, M. (2010). Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management, 259*(4), 698-709.

Lal, M., & Singh, R. (2000). Carbon sequestration potential of Indian forests. *Environmental Monitoring and Assessment, 60*, 315-327.

Heil, M. T., & Selden, T. M. (2001). Carbon emissions and economic development: Future trajectories based on historical experience. *Environment and Development Economics, 6*(1), 63-83.

ESRL (Earth System Research Laboratories). (2023). Retrieved from https://gml.noaa.gov/outreach/faq_cat3.-html#45 (Accessed: November 27, 2023).

IPCC. (2013). *Climate change 2013: The physical science basis summary for policymakers*. In *Contributions of Working Group I to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press.

Suryawanshi, M. N., Patel, A. R., Kale, T. S., & Patil, P. R. (2014). Carbon sequestration potential of tree species in the environment of North Maharashtra University Campus, Jalgaon (MS) India. *Bioscience Discovery, 5*(2), 175-179.

IPCC. (2003). *2003 IPCC guidelines for national greenhouse gas inventories* (Prepared by IPCC National Greenhouse Gas Inventories Programme Technical Support Unit). IGES.

Vashum, K. T., & Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests—a review. *Journal of Ecosystem & Ecography, 2*(4), 1-7.

Ordóñez, C., & Duinker, P. N. (2014). Assessing the vulnerability of urban forests to climate change. *Environmental Reviews, 22*(3), 311-321.

Gago, E. J., Roldan, J., Pacheco-Torres, R., & Ordóñez, J. (2013). The city and urban heat islands: A review of strategies to mitigate adverse effects. *Renewable and Sustainable Energy Reviews, 25*, 749-758.

Liu, C., & Li, X. (2012). Carbon storage and sequestration by urban forests in Shenyang, China. *Urban Forestry & Urban Greening, 11*, 121–128.

Sharma, R., Pradhan, L., Kumari, M., & Bhattacharya, P. (2020). Assessment of carbon sequestration potential of tree species in Amity University Campus Noida. *Environmental Sciences Proceedings, 3*(1), 52.

McPherson, E. G. (1999). *Carbon dioxide reduction through urban forestry: Guidelines for professional and volunteer tree planters* (Vol. 171). U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station.

Brandt, L., Lewis, A. D., Fahey, R., Scott, L., Darling, L., & Swanston, C. (2016). A framework for adapting urban forests to climate change. *Environmental Science & Policy, 66*, 393-402.

Westphal, M. I., Mehtiyev, M., Shvangiradze, M., & Tonoyan, V. (2011). Regional climate change impacts study for the South Caucasus region. Report, United Nations Development Programme.

Ministry of Environmental Protection and Agriculture of Georgia. (2021). *Fourth national communication of Georgia under the United Nations Framework Convention on Climate Change*. Tbilisi.

Elizbarashvili, M., Elizbarashvili, E., Tatishvili, M., Elizbarashvili, S., Meskhia, R., Kutaladze, N., ... & Khardziani, T. (2017). Georgian climate change under global warming conditions. *Annals of Agrarian Science, 15*(1), 17-25.

Satterthwaite, D., McGranahan, G., & Tacoli, C. (2010). Urbanization and its implications for food and farming. *Philosophical Transactions of the Royal Society B: Biological Sciences, 365*(1554), 2809-2820.

Terakunpisut, J., Gajaseni, N., & Ruankawe, N. (2007). Carbon sequestration potential in aboveground biomass of Thong Pha Phum National Forest, Thailand. *Applied Ecology and Environmental Research, 5*(2), 93-102.

Kartvelishvili, L., Megrelidze, L., Melikidze, K., Kurdashvili, L., Dekanozishvili, N., Gudumidze, M., & Maridze, M. (2009). *Climatic reference book of Georgia*. National Environment Agency of the Ministry of Environmental Protection and Agriculture of Georgia.

Urushadze, T., Iashvili, N., Charkseliani, A., Gagnidze, O., Gugunava, T., Zarandia, K., ... & Kakhadze, R. (2019). *The soils of Georgia* [Map] (1:500,000). Agricultural University Press.

Tbilisi City Hall, Municipal Department of Environment Protection. (2018). *Green vegetation management plan* (Vol. I, II, III). Tbilisi.

World Agroforestry (ICRAF). (2023). Retrieved from www.worldagroforestry.org (Accessed: September 25, 2023).

Mirzashvili, V., & Kupharadze, G. (1955). *Forest taxation reference book*. Agricultural Institute Press.

Araujo, M. B., Pearson, R. G., Thuiller, W., & Erhard, M. (2005). Validation of species–climate impact models under climate change. *Global Change Biology, 11*(9), 1504-1513.

Vachnadze, G. S., Tiginashvili, Z. T., Tsereteli, G. V., Aptsiauri, B. N., & Nakaidze, E. E. (2023). *Carbon stocks deposited in the biomass of forest ecosystems of Georgia*. Free and Agricultural Universities Press.

Ministry of Environmental Protection and Agriculture of Georgia. (2023). *The first national forest inventory in Georgia: Report*.

Food and Agriculture Organization of the United Nations. (2020). *Global forest resources assessment 2020: Main report*. Food & Agriculture Organization of the UN.

FOREST EUROPE. (2020). *State of Europe's forests 2020: Report*.

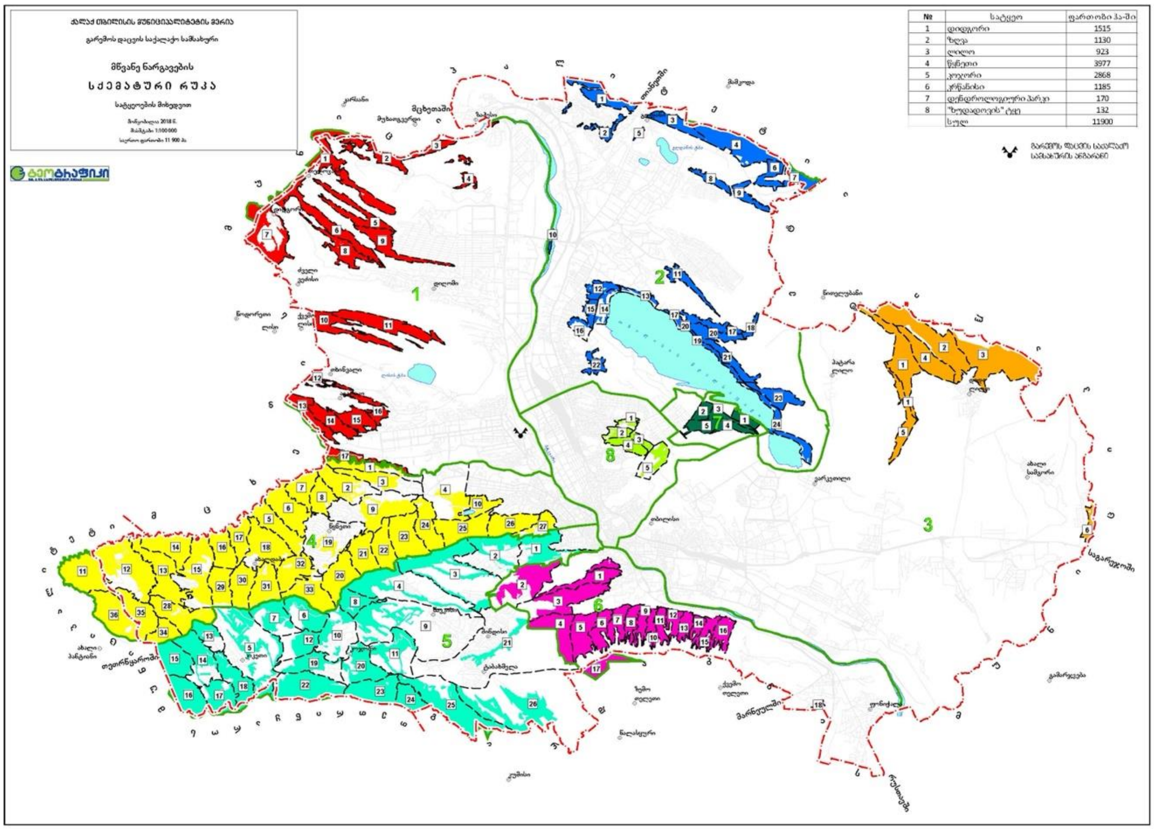

Fig. 1. Schematic map of Tbilisi city forest by forestries in 2018: *1-Didgori, 2-Sea, 3-Lilo, 4-Tskneti, 5-Kojori, 6-Krtsanisi, 7-Dendrological park, 8-Khudadovi* (Tbilisi City Hall, Municipal Department of Environment Protection, 2018).

Table 1. Actual characteristics of study forests (Tbilisi City Hall, Municipal Department of Environment Protection, 2018).

Forest formation	Origin	Average age, yr.$^{-1}$	Total area, ha^{-1}	Volume		Forest density
				Total, $10^3 m^3$	Average m^3/ha^{-1}	
Pine planted forest (*Pinus hamata*)	Artificial	52	1,512.4	149,075	98.6	0.50
Ash partly artificial forest (*Fraxinus excelsior*)	Partly Artificial	41	362.9	12,238	33.7	0.41
Oak natural (seed-grown) forest (*Quercus iberica*)	Natural	64	2,716.4	212,442	80.1	0.52
Hornbeam natural (seed-grown) forest 1 (*Carpinus caucasica*)	Natural	53	1,058.1	110,429	106.0	0.54

Hornbeam natural (seed-grown) forest 2 (*Carpinus orientalis*)	Natural	29	1,647.6	27,084	16.4	0.48
Beech natural (seed-grown) forest (*Fagus orientalis*)	Natural	76	228.1	46,622	204.7	0.60
Maple mixed natural (seed-grown) forest (*Acer campestre*)	Natural	50	16.0	0,557	34.8	0.36
Elm mixed natural (seed-grown) forest (*Ulmus glabra*)	Natural	31	30.9	0,787	25.5	0.46
Poplar planted forest (*Populus spp.*)	Natural	51	46.4	7,358	158.6	0.60
Total study forest			7,618.8	566,592		0.50
% of total			82.8	94.35		
Total Tbilisi city forest			9,202.9	600,462		

Table 2. Basic wood density for the study tree species.

Species	WD, g/cm^3	Source
Pine (*Pinus hamata*)	0.460	
Ash (*Fraxinus excelsior*)	0.608	
Oak (*Quercus iberica*)	0.633	[27]
Hornbeam 1 (*Carpinus caucasica*)	0.665	
Hornbeam 2 (*Carpinus orientalis*)	0.665	
Beech (*Fagus orientalis*)	0.580	[4] [Table 3A.1.9-1]
Maple (*Acer campestre*)	0.615	[27]
Elm (*Ulmus glabra*)	0.600	
Poplar (*Populus spp.*)	0.405	[27, 28]

Table 3. Locations of weather station.

Station	Municipality	Region	Altitude a.s.l.	Latitude	Longitude
Kojori	*Tbilisi*	Kvemo Kartli	1,381	41°40'	44°42'
Tbilisi	*Tbilisi*	Kvemo Kartli	432	41°45'	44°46'

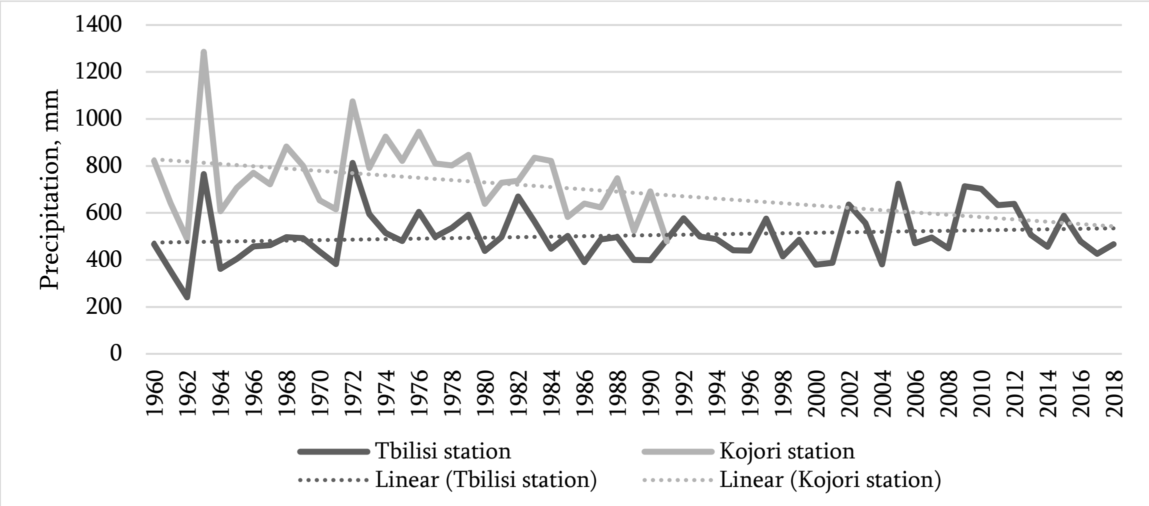

Fig. 2. Annual precipitation (mm) in 1960-2018.

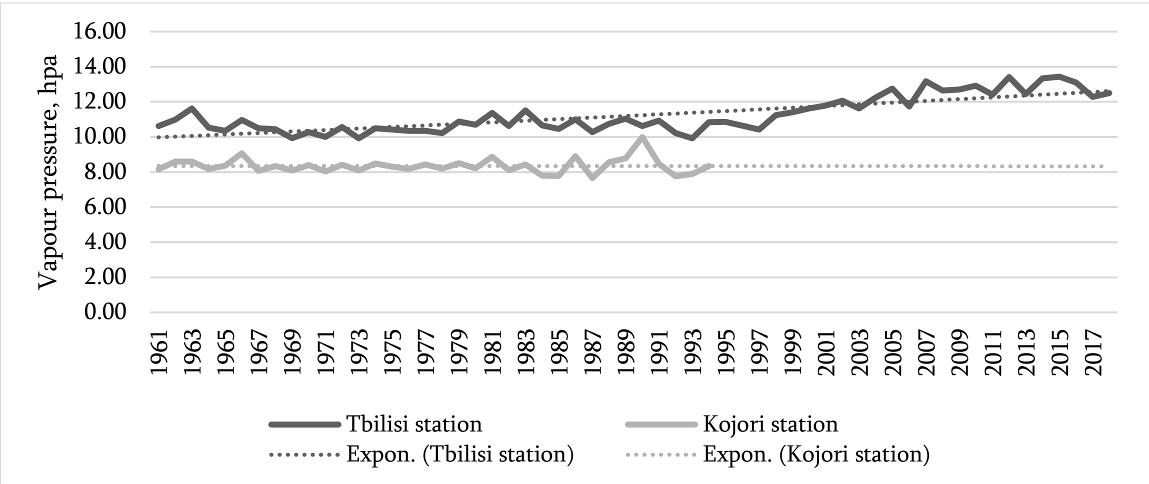

Fig. 3. Annual vapor partial pressure (hPa) in 1961-2017.

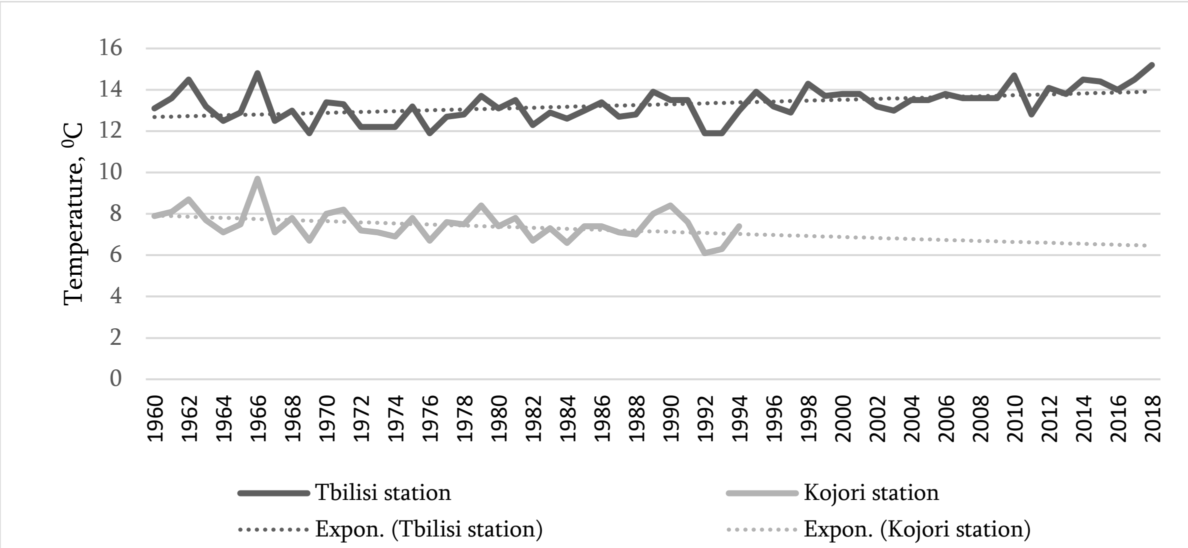

Fig. 4. Average annual temperature (⁰C) in 1960-2018.

Table 4. General characteristics of study forests ((Tbilisi City Hall, Municipal Department of Environment Protection, 2018).

Average age, yr.$^{-1}$				The total area covered with forest, ha^{-1}				Forest density				Site index "bonitate class"			
1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018
Pine planted forest (*Pinus hamata*)															
11	16	20	52	981	1,359	2,423	1,512	0.62	0.57	0.59	0.50	III.5	III.8	III.8	III.6
Poplar planted forest (*Populus spp.*)															
31	15	26	51	75	93	152	46	0.48	0.63	0.49	0.60	II.1	II.1	III.7	III.9
Ash partly artificial forest (*Fraxinus excelsior*)															
21	25	22	41	234	241	422	363	0.52	0.61	0.57	0.41	IV.6	IV.2	IV.2	III.0
Oak natural (seed-grown) forest (*Quercus iberica*)															
96	82	67	64	400	983	2,206	2,562	0.50	0.61	0.63	0.52	IV.5	IV.5	IV.6	IV.9
Oak natural (coppice-grown) forest (*Quercus iberica*)															
40	41	46	46	4942	3,050	2,069	155	0.68	0.62	0.66	0.57	IV.4	IV.5	IV.6	III.8
Hornbeam natural (seed-grown) forest 1 (*Carpinus caucasica*)															
72	69	67	53	92	218	186	972	0.65	0.68	0.61	0.54	IV.0	III.8	III.9	II.7

Hornbeam natural (coppice-grown) forest 1 (*Carpinus caucasica*)															
41	45	45	36	1,679	909	1,034	86	0.68	0.59	0.72	0.65	IV.4	III.9	III.7	III.5
Hornbeam natural (seed-grown) forest 2 (*Carpinus orientalis*)															
20	25	29	29	1,098	905	953	1,647	0.45	0.48	0.51	0.48	IV.9	IV.9	V.0	IV.1
Beech natural (seed-grown) forest (*Fagus orientalis*)															
94	78	84	76	3,253	614	707	220	0.68	0.66	0.67	0.60	III.7	III.7	III.8	II.6
Beech natural (coppice-grown) forest (*Fagus orientalis*)															
41	45	43	45	604	101	120	8	0.74	0.74	0.74	0.90	III.3	III.4	III.2	II.0
Maple mixed natural (seed-grown) forest (*Acer ibericum*)															
20	27	46	50	31	7	18	16	0.52	0.47	0.53	0.36	IV.2	III.7	III.4	IV.4
Elm mixed natural (seed-grown) forest (*Ulmus glabra*)															
14	15	27	31	89	76	48	31	0.54	0.51	0.48	0.46	IV.5	IV.4	IV.5	IV.2
Total study area															
28	30	34	49	14,634	9,846	11,925	9,202.9	0.57	0.51	0.52	0,49	IV.3	IV.3	IV.2	III.8

Table 5. Stem volume, biomass, carbon stock and CO_2 eq. gg/ha^{-1} in each study forest stand.

Volume, m^3/ha^{-1}				Biomass, t/ha^{-1}				Carbon, t/ha^{-1}				CO_2 eq., gg/ha^{-1}			
1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018
Pine planted forest (*Pinus hamata*)															
7.6	21.1	31.7	98.6	5.9	16.3	24.4	76.1	3.0	8.3	12.5	38.8	11.0	30.5	45.7	142.2
Poplar planted forest (*Populus spp.*)															
148.0	90.3	76.3	159.5	103.2	63.0	53.2	111.2	49.5	30.2	25.5	53.4	181.7	110.9	93.7	195.8
Ash partly artificial forest (*Fraxinus excelsior*)															
17.5	22.4	22.7	33.9	18.3	23.5	23.8	35.5	8.8	11.3	11.4	18.1	32.3	41.3	41.9	66.4
Oak natural (seed-grown) forest (*Quercus iberica*)															
82.0	90.9	78.8	80.2	89.4	99.1	85.9	87.4	42.9	47.6	41.2	42.0	157.3	174.5	151.1	153.8

Oak natural (coppice-grown) forest (*Quercus iberica*)															
66.8	53.7	70.0	45.9	72.9	58.6	76.3	50.1	35.0	28.1	36.6	24.0	128.2	103.1	134.3	88.1
Hornbeam natural (seed-grown) forest 1 (*Carpinus caucasica*)															
117.4	128.0	108.6	106.0	134.4	146.6	124.4	121.4	64.5	70.3	59.7	58.3	236.6	257.9	218.9	213.6
Hornbeam natural (coppice-grown) forest 1 (*Carpinus caucasica*)															
81.6	100.6	115.8	94.1	93.4	115.1	132.6	107.8	44.9	55.3	63.6	51.7	164.5	202.7	233.3	189.6
Hornbeam natural (seed-grown) forest 2 (*Carpinus orientalis*)															
14.7	16.7	23.0	16.4	16.8	19.1	26.3	18.8	8.1	9.2	12.6	9.0	29.6	33.6	46.3	33.0
Beech natural (seed-grown) forest (*Fagus orientalis*)															
164.2	154.2	163.2	204.7	164.0	154.0	163.0	204.4	78.7	73.9	78.3	98.1	288.6	271.1	286.9	359.8
Beech natural (coppice-grown) forest (*Fagus orientalis*)															
105.5	129.7	140.0	196.2	105.3	129.5	139.8	195.9	50.6	62.2	67.1	94.0	185.4	228.0	246.1	344.8
Maple mixed natural (seed-grown) forest (*Acer ibericum*)															
19.4	28.6	61.1	34.8	20.5	30.3	64.7	34.9	9.8	14.5	31.1	16.7	36.1	53.3	113.9	61.4
Elm mixed natural (seed-grown) forest (*Ulmus glabra*)															
15.7	9.2	25.0	25.9	16.3	9.5	25.8	26.7	7.8	4.6	12.4	12.8	28.6	16.7	45.5	47.1

Table 6. Average increment in stem volume, biomass, carbon stock and CO_2 eq. gg/ $ha^{-1}yr.^{-1}$ in each study forest stand.

Average increment in volume, $m^3/ha^{-1} yr^{-1}$				Average growth in above -ground biomass, $t/ha^{-1}yr^{-1}$				Average carbon accumulation in above -ground biomass, $t/ha^{-1}yr^{-1}$				CO_2 eq., $gg/ha^{-1}yr^{-1}$			
1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018
Pine planted forest (*Pinus hamata*)															
0.57	1.0	0.9	1.9	0.28	0.48	0.43	0.92	0.14	0.25	0.22	0.47	0.51	0.90	0.81	1.72
Poplar planted forest (*Populus spp.*)															
3.5	4.08	2.9	3.1	1.70	1.98	1.41	1.51	0.82	0.95	0.68	0.72	2.99	3.49	2.48	2.65
Ash partly artificial forest (*Fraxinus excelsior*)															
0.5	0.92	0.73	0.8	0.36	0.67	0.53	0.58	0.24	0.32	0.26	0.28	0.88	1.18	0.94	1.03

Oak natural (seed-grown) forest (*Quercus iberica*)															
0.87	1.14	1.22	1.3	0.66	0.87	0.93	0.99	0.32	0.42	0.44	0.47	1.16	1.52	1.63	1.74
Oak natural (coppice-grown) forest (*Quercus iberica*)															
1.65	1.31	1.56	1.0	1.25	1.0	1.18	0.76	0.79	0.48	0.57	0.36	2.90	1.75	2.09	1.34
Hornbeam natural (seed-grown) forest 1 (*Carpinus caucasica*)															
1.65	1.88	1.63	2.0	1.32	1.5	1.30	1.60	0.63	0.72	0.62	0.77	2.32	2.64	2.29	2.81
Hornbeam natural (coppice-grown) forest 1 (*Carpinus caucasica*)															
2.01	2.4	2.64	2.6	1.60	1.92	2.11	2.07	0.77	0.92	1.01	1.00	2.82	3.37	3.71	3.65
Hornbeam natural (seed-grown) forest 2 (*Carpinus orientalis*)															
0.67	0.61	0.8	0.6	0.53	0.49	0.64	0.48	0.26	0.23	0.31	0.23	0.94	0.86	1.12	0.84
Beech natural (seed-grown) forest (*Fagus orientalis*)															
2.07	1.83	2.04	2.7	1.44	1.27	1.42	1.88	0.69	0.61	0.68	0.90	2.54	2.24	2.50	3.31
Beech natural (coppice-grown) forest (*Fagus orientalis*)															
2.53	3.0	3.38	4.4	1.76	2.09	2.35	3.06	0.85	1.0	1.13	1.47	3.10	3.67	4.14	5.39
Maple mixed natural (seed-grown) forest (*Acer ibericum*)															
0.2	0.28	0.89	0.7	0.15	0.21	0.66	0.52	0.07	0.10	0.32	0.25	0.26	0.36	1.16	0.91
Elm mixed natural (seed-grown) forest (*Ulmus glabra*)															
0.6	0.69	0.83	0.8	0.43	0.50	0.60	0.58	0.21	0.24	0.29	0.28	0.76	0.87	1.05	1.01

Table 7. Total stem volume, biomass, carbon stock, and CO_2 equivalent in each study forest stand.

Total volume, m^3				Total biomass, tons				Total carbon, tons				Total CO_2 eq., gg			
1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018	1964	1974	1984	2018
Pine planted forest (*Pinus hamata*)															
7,500	28,700	76,700	149,100	5,786	22,140	59,168	115,019	2,951	11,291	30,176	58,660	10.8	41.4	110.6	215.1
Poplar planted forest (*Populus spp.*)															
11,100	8,400	11,600	7,400	7,741	5,858	8,090	5,161	3,716	2,812	3,883	2,477	13.6	10.3	14.2	9.1
Ash partly artificial forest (*Fraxinus excelsior*)															
4,100	5,400	9,600	12,300	4,293	5,654	10,051	12,878	2,060	2,714	4,824	6,568	7.6	10.0	17.7	24.1
Oak natural (seed-grown) forest (*Quercus iberica*)															

32,800	89,400	173,800	205,400	35,753	97,448	189,447	223,891	17,161	46,775	90,934	107,468	62.9	171.5	333.4	394.0
Oak natural (coppice-grown) forest (*Quercus iberica*)															
330,300	163,900	144,800	7,100	360,036	178,655	157,836	7,739	172,817	85,755	75,761	3,715	633.7	314.4	277.8	13.6
Hornbeam natural (seed-grown) forest 1 (*Carpinus caucasica*)															
10,800	27,900	20,200	102,990	12,367	31,949	23,132	117,937	5,936	15,336	11,103	56,610	21.8	56.2	40.7	207.6
Hornbeam natural (coppice-grown) forest 1 (*Carpinus caucasica*)															
137,000	91,400	119,700	8,130	156,883	104,665	137,072	9,310	75,304	50,239	65,795	4,469	276.1	184.2	241.2	16.4
Hornbeam natural (seed-grown) forest 2 (*Carpinus orientalis*)															
16,100	15,100	21,900	27,000	18,437	17,291	25,078	30,919	8,850	8,300	12,038	14,841	32.4	30.4	44.1	54.4
Beech natural (seed-grown) forest (*Fagus orientalis*)															
534,000	94,700	115,400	45,090	533,338	94,583	115,257	45,034	256,002	45,400	55,323	21,616	938.7	166.5	202.9	79.3
Beech natural (coppice-grown) forest (*Fagus orientalis*)															
63,700	13,100	16,800	1,530	63,621	13,084	16,779	1,528	30,538	6,280	8,054	733	112.0	23.0	29.5	2.7
Maple mixed natural (seed-grown) forest (*Acer ibericum*)															
600	200	1,100	557	635	212	1,165	558	305	102	559	268	1.1	0.4	2.1	1.0
Elm mixed natural (seed-grown) forest (*Ulmus glabra*)															
1,400	700	1,200	800	1,446	723	1,240	827	694	347	595	397	2.5	1.3	2.2	1.5
Total of study forest formations															
1149,400	538,900	712,800	567,397	1,200,335.5	572,262.1	744,314.0	570,800.1	1,130,410.7	512,766.9	660,189.9	472,431.9	4,144.8	1,880.1	2,420.7	1,732.3

Table 8. Comparison of actual stem volume, biomass, carbon stock and CO_2 eq. t/ha^{-1} of the study forest with relevant average characteristics of forests of Georgia and Central-Eastern Europe.

Stem volume, m^3/ha^{-1}	Living Biomass, t/ha^{-1}	Carbon in living biomass, t/ha^{-1}	References
Pine planted forest (*Pinus hamata*)			
98.6	76.1	38.8	This study
120	88.2	43.9	[30]
Oak natural (seed-grown) forest (*Quercus iberica*)			
80.2	87.4	42.0	This study
85.0	76.6	38.2	[30]
Hornbeam natural (seed-grown) forest (*Carpinus caucasica*)			
106.0	121.4	58.3	This study
100.0	101.6	50.7	[30]
Beech natural (seed-grown) forest (*Fagus orientalis*)			
204.7	204.4	94.0	This study
194.0	191.3	95.5	[30]
Average, ha			
65.2	60.6	29.1	This study
216.4	201.1	96.5	[31]; This study
173.9	140.2	68.4	[32] (Europe excl. Russian Federation)
254.6	184.0	92.0	[33] (Central-Eastern Europe)