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Comparison of tree species diversity, deadwood volume and regeneration of managed and old-growth Oriental beech (*Fagus orientalis* L.) forests in Eastern Georgia

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Abstract

Main stand characteristics and tree species composition were studied in managed and old-growth Oriental beech (*Fagus orientalis* L.) forests in eastern Georgia (Caucasus). Oriental beech dominates both the regeneration layer and the upper story in old-growth forest. In managed forests, Caucasian hornbeam (*Carpinus orientalis*) and Oriental beech co-dominate the tree layer as well as the regeneration layer. Tree species diversity and deadwood proportion are higher in managed forests than in old-growth forests. However, the absolute deadwood proportion is similar in both studied forest types. Hence, deadwood proportion is not a suitable indicator to assess the naturalness or management intensity of forests in the study area. The observed proportions of Caucasian hornbeam in managed forests raise concerns about the sustainable use of beechwood in the long term. Harvesting hornbeam and smaller removals of beech are recommended to maintain the uneven-aged forest ecosystem, with Oriental beech as the dominant tree species. The established long-term study plots are important to observe and improve future stand development and forest management.

Key words

Caucasus, coarse woody debris, forest characteristics, forest management, old-growth forest, regeneration density

Introduction

Oriental beech (*Fagus orientalis*) is the prevailing tree species in the forests of Georgia; about 50% of the forests are dominated by this species (Urushadze et al. 2010). In eastern Georgia, it occurs mostly at 1000 to 2000 m elevation above sea level (a.s.l.) (Nakhutsrishvili 2013). Optimum growth conditions are 1000 to 1500 m a.s.l. (Dolukhanov 2010), where most cuttings occur nowadays. While *Rhododendron* can form a dense understory in the western beech forests of the country, where precipitation is very high, eastern beech forests are characterized by *Rubus* and grass species (Nakhutsrishvili 2013) and up to 1000 mm of precipitation in the study area. Forest management can have strong effects on beech forests (Dolidze 2006). The research question of this case study is how tree species proportions can change after management compared to natural forest development.

The aim of the study is the comparison of stand structure (stem number, basal area, standing volume, deadwood proportions) and regeneration (density and tree species proportions) in unmanaged old-growth and managed beech forests. Based on western European literature (Meyer et al. 2021, Brüllhardt et al. 2021), we hypothesize that: i) deadwood proportion is higher in old-growth forests than in managed stands; ii) regeneration is more abundant and diverse in unmanaged old-growth forests.

Materials and methods

The plots are located in the east of Georgia, between 870 and 1182 m elevation a.s.l., at a northwestern slope where optimum growth conditions prevail for *Fagus orientalis* (Dolukhanov 2010). The old-growth forest is located in the core zone of the Lagodekhi Protected Area, near the border with Azerbaijan. The managed stands are located at the same exposition towards North-West and elevation 20 km east on the same soil type and similar site conditions. Two managed areas in Mtisdziri (Fig. 1) were unmanaged before logging, which took place 15 and 5 years ago.

There, 10 study plots with a 37.5 m x 37.5 m area (1406 m^2) were randomly distributed and established, with four plots in the cut area 15 years after cutting and six plots in the area that was cut 5 years ago. The cuttings were conducted during two subsequent years (hence 5-6 and 15-16 years ago). Ten other study plots of the same size were distributed in two unmanaged areas of the Lagodekhi Protected Areas. The size of the study plots is a result of nine smaller squares with a 12.5 m x 12.5 m area comparable to the size of crown cover by a canopy tree to analyze stand structure and natural forest dynamics, according to Tabaku (2000) and Drössler and Meyer (2006). On these small squares, forest developmental stages were determined according to the method by Tabaku (2000), with corrections according to Zenner et al. (2016). On the large plot, tree coordinates, tree species, and diameter at breast height (DBH ≥ 7 cm) were recorded. Standing and laying deadwood was recorded with a minimum diameter of 20 cm, following the method of Kucbel et al. (2012). The coordinates of the center of the 20 large plots can be found in Wolff (2021). There, measured trees were permanently marked with a tree number and a T sign where the tree was calipered. Trees larger than 30 cm DBH were cross-calipered.

To assess the tree species composition and diversity of both forest areas in Lagodekhi and Mtisdziri, the abundance of tree species per plot was calculated based on tree numbers. The R (R Core Team 2023) vegan package (Oksanen et al., 2020) was then used to calculate tree species richness.

In the center of each small square, natural regeneration was recorded on a circular subplot with a 1.78 cm radius (10 m^2 area). Wooden plants were measured from 10 cm to 200 cm in height. The regeneration survey follows the survey method by Staupendahl (1997), where all seedlings are counted, but only the nearest individual to the regeneration subplot center is measured and represents the tree species. In addition, the canopy density was estimated with a forest canopy densiometer (Lemmon 1956). The R packages stats and glmmTMB (Brooks et al. 2017) were used to compare regeneration density between managed and old-growth forests.

Results

Stand characteristics

The old-growth forest was characterized by a large proportion of *Fagus orientalis* (82%, std. dev. 11%). The two other most frequent species, *Carpinus caucasica* and *Tilia begoniifolia*, comprised 7% of the tree species each. In managed forest where mostly beech was harvested, the proportion of *F. orientalis* was only 41% (std. dev. 18%), while *C. caucasica* was 39% (std. dev. 17%), and *T. begoniifolia* was 8% (std. dev. 7%). *Castanea sativa* and *Acer* species were found in both managed and unmanaged stands, but the proportion was less than 5%, like for all the other following tree species (Fig. 2). Contrary to the old-growth forest, single *Populus tremula* and *Salix caprea* occurred in the managed forest, as well as *Prunus avium* and *Ulmus glabra* (see Supplementary Material S1 for full inventory data). Statistically, the tree species richness did not vary significantly between the two studied areas (p = 0.09).

In the unmanaged old-growth forests of Lagodekhi, the stand volume of living trees was 640 m^3 ha^{-1} (table 1). There, the deadwood proportion was only 5%. In managed forest, the relative proportion was 14% five and fifteen years after cutting. There, the stand volume was 271 m^3 ha^{-1}. Tree density was 197 trees per ha in the unmanaged forest and 274 trees per ha in the managed forest. Trees were considerably smaller in Mtisdziri (see stem diameter d_g in table 1). The basal area in Mtisdziri was also much lower than in Lagodekhi.

The diameter distributions of each plot were typical for uneven-aged forest, but with large differences between developmental stages. Tree harvest had a small effect on the distribution as large beech trees with valuable timber were selected. The diameter distributions of the old-growth forest were more similar to each other, and the number

Table 1. Main stand characteristics per study area for all tree species combined; statistically significant differences for the mean between Lagodekhi and Mtisdziri are indicated by bold text and the asterisk: *= p ≤ 0.05, **= p ≤ 0.01, ***= p ≤ 0.001, Wilcoxon rank-sum test/t-test. BA = Basal area of living trees DBH ≥ 7 cm, dg = DBH of the mean basal area stem, 95% CI = 95% confidence interval, SD = standard deviation, CV = Coefficient of variation; Tree number, BA, dg, stand volume was measured of living trees DBH ≥ 7 cm, deadwood diameter ≥ 20 cm.

Study area		Tree number (N ha^{-1})	BA (m^2 ha^{-1})	d_g (cm)	Stand volume (m^3 ha^{-1})	Deadwood volume (m^3 ha^{-1})
Lagodekhi	Mean	197	33.2***	47.5**	640***	34
	95% CI	[153, 241]	[29.3, 37.1]	[41.9, 53.1]	[521, 759]	[12, 56]
	SD	61.6	5.5	7.9	166.9	31.0
	CV	31.50%	16.5%	16.6%	26.1%	91.9%
Mtisdziri	Mean	274	19.0***	34.0**	271***	43
	95% CI	[145, 403]	[14.6, 23.4]	[25.2, 42.8]	[193, 349]	[20, 66]
	SD	180.3	6.2	12.3	109.4	31.5
	CV	65.70%	32.4%	36.0%	40.5%	72.8%

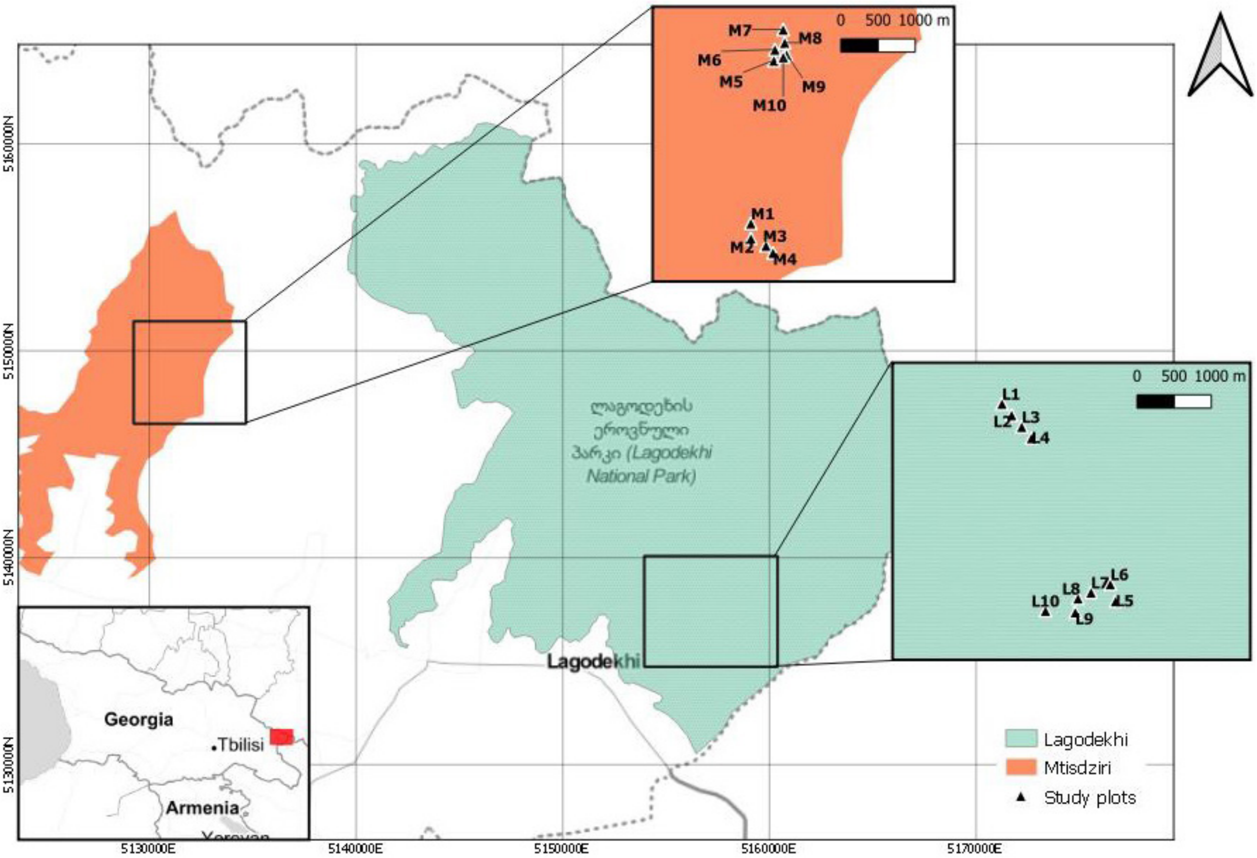

Figure 1. Map of the study areas Lagodekhi and Mtisdziri and location the of the study plots.

of trees decreased constantly with the tree size class (Fig. 3A). In managed forests, a large number of trees in the lowest tree size class are often found. On two plots, even a bell-shaped diameter distribution was found (e.g., plot M8 in Fig. 3B).

Regeneration

On average, 9588 seedlings per ha were counted in the old-growth forest Lagodekhi and 14200 seedlings per ha in the managed forest Mtisdziri. In both treatments (unmanaged and managed), the number of subplots decreased exponentially with an increasing number of seedlings per subplot. Using the Mann-Whitney U test, no statistically significant differences were found between the treatments (p = 0.12). In Lagodekhi, 50% was *Fagus orientalis*, 28% was *Tilia begoniifolia*, 12% was *Acer* species, and 9% was *Carpinus caucasica*. 40% of the subplots were without forest regeneration. In Mtisdziri, *C. caucasica* was much more frequent: 57% was *C. caucasica*, 42% was *Fagus orientalis*, and single seedlings of *T. begonifolia* and *Acer* species also occurred. 25% of the regeneration subplots were without regeneration.

In Lagodekhi, 86% of seedlings were 10-50 cm high, dominated by 47% *Fagus orientalis* and 34% *Tilia begonifolia*. Only *F. orientalis* seedlings occurred in the second height class, from 51-100 cm. 12% were 1-2 m high, mostly *Acer pseudoplatanus* trees growing in natural canopy gaps. In Mtisdziri, 55% of seedlings were 10-50 cm tall, 32% were 51-100 cm tall, and 13% were 1-2 m high. In the lowest height class, *Carpinus caucasica* was 54% and *F. orientalis* was 45% with a single individual of the *Acer* species. In the second lowest height class, from 51-100 cm, *F. orientalis* was 54% and *C. caucasica* was 45% again, with a single individual of *T. begonifolia* and *Acer* species. In the highest recorded height class from 1-2 m, 92 % (1800 individuals) were *C. caucasica* in the managed forest. Over all height classes, the number of *C. caucasica* seedlings was significantly higher in Mtisdziri compared to Lagodekhi ($p < 0.001$).

In Lagodekhi, 5000 seedlings were found where the canopy cover was 96-100% (45% *Fagus orientalis* and 33% *Tilia begonifolia*, as well as single individuals of *Carpinus caucasica* and *Acer* species). Similar species proportions were found in the canopy coverage class 91-95%. The lowest canopy coverage was 71% in the old-growth forest. From 71 to 90% canopy coverage, 1388 seedlings occurred with 81% *F. orientalis*. In the managed forest of Mtisdziri, *C. caucasica* dominated the lowest canopy class by 93% (2250 individuals). While *F. orientalis* prevailed with 58% (525 individuals) in the second lowest canopy class with 91-95% canopy coverage, *C. caucasica* dominated when canopy coverage was 81-90% (69%, equal to 4262 individuals). When the canopy was open (10-80%), then *F. orientalis* was most frequent with 74%, *C. caucasica* proportion was 25%, and single individuals of *T. begonifolia* and *Acer* species also occurred (Fig. 4). Figure 4A and B show no clear relationship between regeneration height and canopy. In subsequent regeneration surveys, if the annual top shoot length were measured, a closer relationship between canopy density and plant height might be found. In our study, the number of 160 regeneration sub-plots limited the analysis of regeneration.

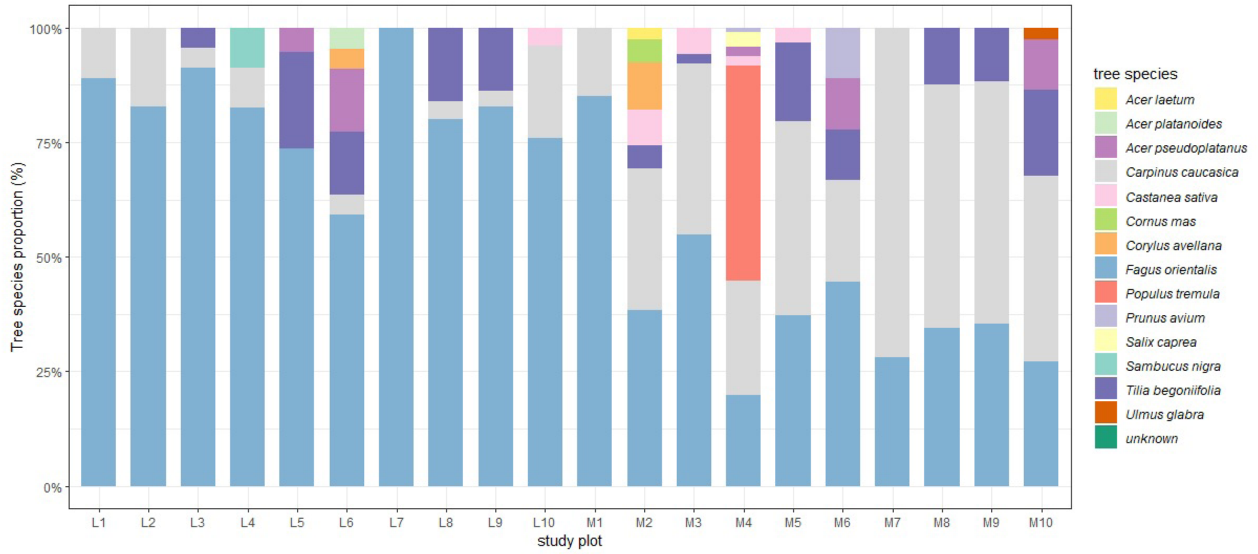

Figure 2. Tree species proportion of the number of trees for each study plot in Lagodekhi (L) and Mtisdziri (M). L1-10 = old-growth, M1-10 = managed.

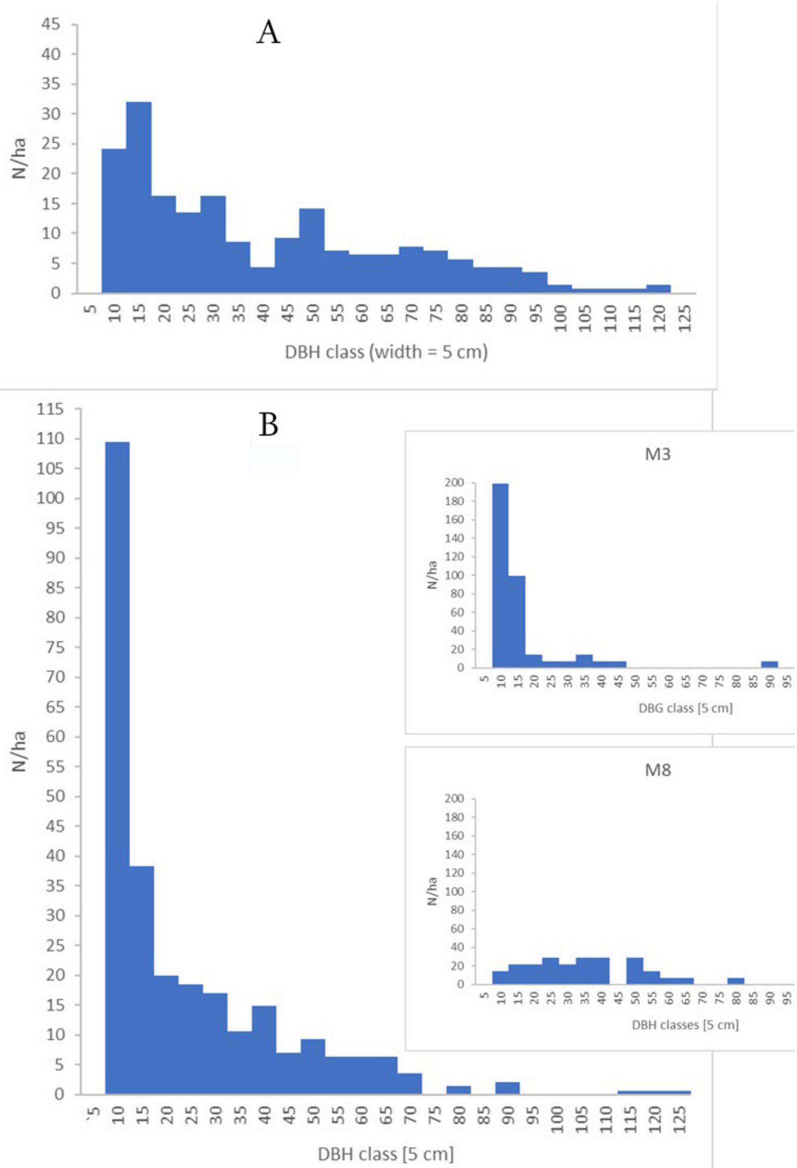

Figure 3. A: Diameter distribution of the old-growth forest Lagodekhi (10 plots covering 1.4 ha); **B**: Diameter distribution of the managed forest Mtisdziri (10 plots). To illustrate the large differences between the uneven-aged plots in Mtisdziri managed forests, 2 out of the 10 plots (M3 and M8) are shown.

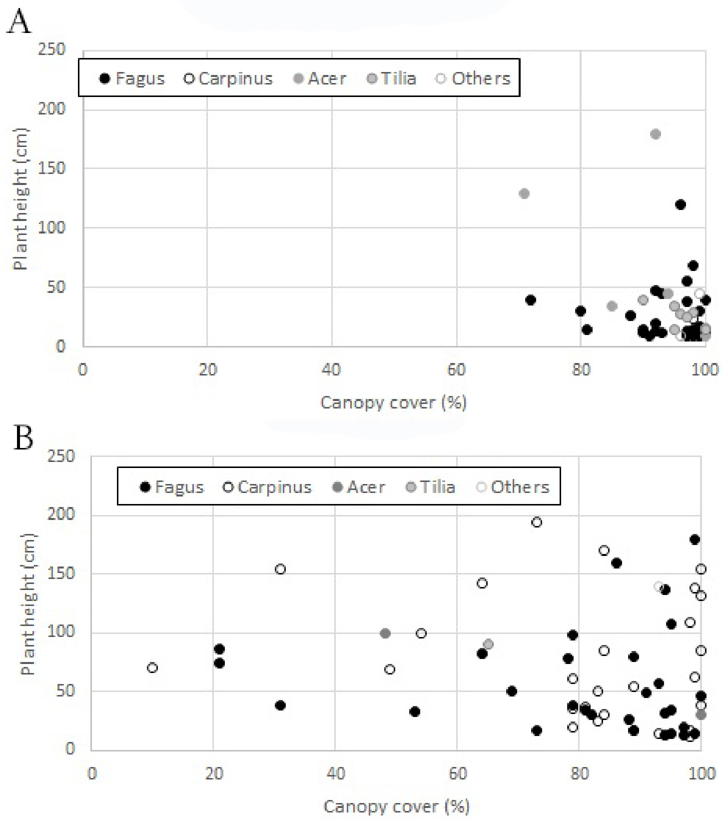

Figure 4. Relationship between the height of regeneration and canopy cover per tree species – **A**: the old-growth forests in Lagodekhi; **B**: the managed forests in Mtisdziri.

Discussion

Fagus orientalis is the prevailing tree species in old-growth forests (Nakhutsrishvili 2013), and the proportion of *Carpinus caucasica* is small. The latter is much more frequent in the managed forest with the same soil type, elevation, and exposition (Wolff 2021). Moreover, in unmanaged parts near the plots of Mtisdziri, *F. orientalis* also prevailed. Dolukhanov (2010) already mentioned that *C. caucasica* can replace *F. orientalis* in managed areas. Considering natural regeneration in both study areas, *F. orientalis* dominates in Lagodekhi, while *C.* caucasica and *F. orientalis* compete with each other in the managed forest of Mtisdziri. In some canopy openings of the old-growth forest, *Acer pseudoplatanus* can grow faster than *F. orientalis* (Schmidt 2021). In addition, *Rubus* species were more competitive in Mtisdziri when the canopy was open. However, the diversity of the ground-floor vegetation was also higher in Mtisdziri. To maintain the beech forest ecosystem, less intense cuttings can be recommended. Regarding the stability of the forest ecosystem, see also Dolidze (2006). Urushadze et al. (2010) describe the stand structure of virgin beech forests, with implications for conservation and restoration of managed beech forests.

Deadwood proportions are an important indicator to assess sustainable forest management in Central Europe today (Mamadashvili et al. 2023). However, in Georgia, with many old-growth forests and managed stands left with habitat trees and deadwood after cutting, this indicator can be misleading. The absolute amount of deadwood can be the same in both types of forest (unmanaged and managed), while only the standing volume of living trees is reduced by the logging. In many cases, there is no lack of habitat trees and coarse woody debris in native Georgian beech forests.

In our case study, both hypotheses were rejected. While the absolute deadwood proportion is similar, the relative deadwood proportion is higher in managed stands where valuable beech wood is harvested. Also, regeneration was denser and more diverse in managed forests. However, *Carpinus caucasica* can replace *Fagus orientalis* if the local harvest intensity is too high. After heavy removals, even competitive *Rubus* species can prevent forest regeneration for 1-2 decades. In conclusion, the local harvest intensity of *F. orientalis* should be reduced to maintain the same ecosystem. In addition, the logging area could be expanded by using wires and winches for logging on moderate slopes.

Maximum diameter or a special old growth indicator (Meyer et al. 2021) may be more suitable to assess the natural conditions of a forest than the proportion of deadwood. Hence, deadwood proportion is not suitable as an indicator for management intensity or sustainable forest management in our study area.

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Supplementary material 1

Authors: Lars Droessler, Tobias Wolff
Data type: .xlsx
Explanation note: List of trees with DBH ≥ 7 cm measured on the study plots in Lagodekhi and Mtisdziri.

Link: https://doi.org/10.3897/caucasiana.2.e106898.suppl1