Analysis of dendroflora of urbanized territories using the city of Vladikavkaz as an example

Z Okazova¹*, N Kusova¹, F Agaeva², I Bigaeva²

¹Faculty of Natural Science, Chechen State Pedagogical University, 33 Subra Kshieva street, Grozny 3336431, Chechen Republic, Russian Federation
²Faculty of Chemistry, Biology and Biotechnology, K L Khetagurov North Ossetian State University, 44Vatutina. street, Vladikavkaz 362000, Republic of North Ossetia-Alania, Russian Federation

*Corresponding email: okazarina73@mail.ru

Abstract. Urbanization is the main form of human adaptation to the environment. The increase in the area of urban areas and the level of development of urban areas is an objective reality at the present stage. Vladikavkaz in this regard is no exception. The purpose of the study is to analyse the dendroflora of urbanized areas using the city of Vladikavkaz as an example. The study was conducted in 2012-2018 in the city of Vladikavkaz. The study recorded about 60,000 trees belonging to 50 species. The studied trees were part of common and restricted use green areas: green ribbons along central streets including plots attached to shopping and administrative centres, as well as the largest parks, boulevards, and public gardens of the city of Vladikavkaz. We established that the species composition on the territory of Vladikavkaz is quite diverse; however, prerequisites exist for its expansion, which would improve the ecological situation in the city.

1. Introduction
Urbanization is the main form of human adaptation to the environment. Today, the increase in the area of highly developed urban areas is an objective reality. Vladikavkaz is not an exception, because it is one of the largest urban agglomerations of the North Caucasus, where ca 20% of the population of North Ossetia-Alania live. The main part of the city is intensively developed [1, 2].

At the present stage, the problems of the environmental pollution and the negative impact of pollutants on the city’s ecosystem are particularly important. We considered the possibility of using trees for bioindication, landscaping and reconstruction of the green zone of the city [3, 4].

The object of research was the phytocenoses of urbanized territories. The purpose of the study was to analyse the dendroflora of urbanized areas using the city of Vladikavkaz as an example. The field studies were conducted in Vladikavkaz in 2012-2018, in favourable climatic conditions.

2. Material and Methods
The soil of the study site is leached chernozem underlain by pebbles. The terrain is a sloping plain carved by rivers and ravines with a height difference of about 500 m, which is a characteristic feature of mountain areas.

In order to assess the condition of tree and shrub vegetation of the city, we carried out an inventory, in the course of which we recorded each available tree during 2012-2018.
The level of adaptation to the city environment of Vadikavkaz was determined by using the woody representatives of Sapindaceae as an example. We used the method of integral assessment developed by the Department of Dendrology of the State Botanical Garden. The following indicators were used: winter hardiness, habit maintenance, production of shoots, the regularity of shoot growth, generative development, the possibility of vegetative reproduction and decorative properties. For each indicator, we selected numerical values corresponding to a particular state of a plant. Based on the integral evaluation, the average total viability score was calculated.

3. Results and Discussion
The study recorded about 60,000 trees belonging to more than 50 species. The studied trees were part of common and restricted use green areas: green ribbons along central streets including plots attached to shopping and administrative centres, as well as the largest parks, boulevards, and public gardens of the city of Vladikavkaz (Figure 1).

![Figure 1. The family composition of the flora of Vladikavkaz(2012-2018).](image)

The observations demonstrated that, since the beginning of the twenty-first century, the species diversity of green areas in the city of Vladikavkaz has increased (Table 1).

| №   | Species                  | Count | % |
|-----|--------------------------|-------|---|
| 1   | Armeniaca vulgaris(Lam.) | 423   | 0.6 |
| 2   | Prunus cerasifera (Ehrh.) | 6132  | 10.4 |
| 3   | Cydonia (Mill.)          | 820   | 1.4 |
| 4   | Robinia pseudoacacia (L.) | 2992  | 5.0 |
| 5   | Acacia senegal (L. Mill.) | 800   | 1.3 |
| №  | Species                                      | Count | %    |
|----|---------------------------------------------|-------|------|
|    |                                             | Individuals |     |
| 6  | Betula pendula (Roth.)                      | 612   | 1.0  |
| 7  | Betula pubescens (Ehrh.)                    | 472   | 0.7  |
| 8  | Platanus orientalis (L. Franco)             | 364   | 0.5  |
| 9  | Pinus sylvestris var. hamata (Steven.)      | 472   | 0.7  |
| 10 | Ulmus laevis (Pall.)                        | 179   | 0.3  |
| 11 | Ulmus glabra (Huds.)                        | 471   | 0.8  |
| 12 | Gleditsia triacanthos (L.)                  | 538   | 1.0  |
| 13 | Carpinus betulus (L.)                       | 147   | 0.3  |
| 14 | Pyrus communis (L.)                         | 159   | 0.3  |
| 15 | Quercus rubra (L.)                          | 659   | 1.1  |
| 16 | Picea pungens (Engelm.)                     | 1274  | 2.2  |
| 17 | Picea abies (L. Hkarst)                     | 296   | 0.5  |
| 18 | Salix spp. (L.)                             | 79    | 0.1  |
| 19 | Salix babylonica (L.)                       | 204   | 0.3  |
| 20 | Salix caprea(L.)                            | 106   | 0.1  |
| 21 | Catalpa speciosa(Ward.)                     | 359   | 0.6  |
| 22 | Catalpa crenata(Ward.)                      | 130   | 0.2  |
| 23 | Catalpa ovate (Ward.)                       | 105   | 0.1  |
| 24 | Chamaecyparis lawsoniana(A.Murray bis Parl.)| 71    | 0.1  |
| 25 | Acer platanoides (L.)                       | 2392  | 4.1  |
| 26 | Acer palmatum (L.)                          | 601   | 1.0  |
| 27 | Acer saccharum (Marshall.)                  | 364   | 0.5  |
| 28 | Acer pseudoplatanus (L.)                    | 3278  | 5.4  |
| 29 | Acer negundo(L.)                            | 859   | 1.4  |
| 30 | Aesculus hippocastanum(L.)                  | 3677  | 6.1  |
| 31 | Tilia caucasia(L.)                          | 123   | 0.2  |
| 32 | Tilia platyphyllos (Scop.)                  | 1677  | 2.7  |
| 33 | Tilia cordata (Mill.)                       | 9694  | 16.3 |
| 34 | Juniperus spp.(L.)                          | 76    | 0.1  |
| 35 | Juglans regia (L.)                          | 2016  | 3.4  |
| 36 | Juglans nigra (L.)                          | 150   | 0.1  |
| 37 | Platanus orientalis (L.)                    | 153   | 0.3  |
| 38 | Prunus domestica(L.)                        | 3766  | 6.4  |
| 39 | Pinus banksiana (Lamb.)                     | 240   | 0.4  |
| 40 | Pinus sylvestris var. hamata (Steven.)      | 95    | 0.1  |
| 41 | Populus pyramidalis (L.)                    | 377   | 0.6  |
| 42 | Populus canadensis (Moench.)                | 3123  | 2.1  |
| 43 | Populus nigra (L.)                          | 764   | 1.3  |
| 44 | Populus tremula (L.)                        | 454   | 0.7  |
| 45 | Thuja occidentalis(L.)                      | 2012  | 3.3  |
| 46 | Prunus avium (L.)                           | 467   | 0.7  |
| 47 | Morus alba(L.)                              | 351   | 0.6  |
| 48 | Malus domestica (L.)                        | 365   | 0.6  |
| 49 | Fraxinus lanceolata(L.)                     | 2769  | 4.6  |
| 50 | Fraxinus excelsior(L.)                      | 3290  | 5.5  |
| Other species                         | 417   | 0.5  |
| Total                                 | 58669 | 100  |
It should be noted that, despite a rather large number of identified taxa, woody plants of the same species (no more than 30) have been planted more often. The following families are well represented: Rosaceae (25.3%), Tiliaceae (19.2%), Sapindaceae (18.5%) and Oleaceae (10.1%). The following woody species were in abundance: Prunus cerasifera (Ehrh.) – 10.4%, Robinia pseudoacacia (L.) – 5.0%, Acer pseudoplatanus (L.) – 5.4%, Aesculus hippocastanum (L.) – 6.1%, Tilia cordata (Mill.) – 16.3%, Juglans regia (L.) – 3.5%, Prunus domestica (L.) – 6.4%, Thuja occidentalis (L.) – 3.3%, Fraxinus excelsior (L.) – 5.5%, Fraxinus olaeceae (L.) – 4.6%.

The object of the research was conducted by using representatives of Sapindaceae as an example. According to the results of the survey, low vitality is observed in species growing along the main streets with heavy traffic. Plants of the following species were damaged to the highest degree: Populus canadenisis (Moench.) Acer pseudoplatanus L. and Tilia cordata (Mill.). The main causes of mass thinning, dieback and the dying of trees in the city are: lack of adequate agricultural technology, soil compaction and salinization, and mechanical damage. Vulnerability to pests and diseases increases. In the urban environment, woody plants are subject to stress; they are more often affected by various diseases and insects, which changes their appearance and leads to a decrease or complete loss of their ornamental value. The plants can be used for creating groups, edges, alleys, as single plants and along the roads.

The definition of winter hardiness, the possibility of preserving the habitus, ability to produce shoots, the regularity of growth of shoots, the possibility of artificial vegetative reproduction and ornamental value are the main parameters for assessing species. The above parameters determine the growth and development of plants at the place of introduction and are recorded in the course of long-term visual observations. For each specific parameter, quantitative indicators were developed according to the assessment of the state of a plant at a specific point in time. According to the integral evaluation, the integral vitality score was determined for each study period, and the total sum of points for the entire period was calculated. The total score is an integral value expressing the viability of the introduced plants (table 2).

The object of the research was Acer platanoides with a spherical crown. A. campestre. A. ginnala. A. saccharum and A. negundo. Winter hardiness in the studied species is different and is determined by the degree of lignification of shoots by the end of the vegetation period. The data obtained in the process of visual and laboratory studies allow us to draw the following conclusions [7, 8].

During the 2012–2018 observation period, no damage to A. platanoides with a spherical crown was caused by low temperatures; lignification of shoots was close to 100%; in severe winters, an insignificant dieback of annual shoots was observed. The frost damage of the ends of the one-year
shoots lignified by 85% in *A. campestre* and *A. ginnala* was observed during winters with a large amplitude of temperatures and thaws that occurred during the years of research. The same events led to frost damage of the current year's shoots in *A. saccharum* and *A. negundo*, the shoots of which were lignified only by 80%. But, despite the frost damage to a large number of one-year shoots, the above-ground parts of plants were easily restored, and annual flowering and fruiting occurred.

**Table 2.** Integral assessment of the potential of woody plants of the Sapindaceae family in the conditions of Vladikavkaz (2012 - 2018).

| Estimated indicators | Characteristics of indicators                              | Score | Species |
|----------------------|-----------------------------------------------------------|-------|---------|
|                      |                                                           | 1     | 2       | 3       | 4       | 5       |
| Hardiness            | Plants do not get frost damaged                           | 25    | 25      |         |         |         |         |
|                      | Parts of one-year old shoots can get frost damaged         | 20    | 20      | 20      |         |         |         |
|                      | The whole one-year shoots get frost damaged                | 15    | 15      | 15      |         |         |         |
|                      | Older shoots get frost damaged                             | 10    |         |         |         |         |         |
|                      | Whole plants get frost damaged to the level of the show cover | 5     |         |         |         |         |         |
|                      | Whole plants get frost damaged to the root neck            | 3     |         |         |         |         |         |
|                      | Plants get killed by frost                                | 1     |         |         |         |         |         |
| Habit                | Retained                                                   | 10    | 10      | 10      | 10      |         |         |
|                      | Recover                                                    | 5     | 5       | 5       | 5       |         |         |
|                      | Does not recover                                           | 1     |         |         |         |         |         |
| Formation of shoots  | Good                                                       | 5     |         |         |         |         |         |
|                      | Average                                                    | 3     | 3       | 3       | 3       | 3       |         |
|                      | Low                                                        | 1     |         |         |         |         |         |
| Increase in height   | Annual                                                     | 5     | 5       | 5       | 5       | 5       | 5       |
|                      | Not annual                                                 | 2     |         |         |         |         |         |
| Development          | Produces fruit, but seeds are not viable                   | 25    | 25      | 25      | 25      |         |         |
|                      | Produces fruit, but seeds do not ripen                     | 20    | 20      | 20      | 20      |         |         |
|                      | Flowering, but no fruiting                                 | 15    |         |         |         |         |         |
|                      | Does not flower                                            | 1     |         |         |         |         |         |
| Rooting success of cuttings | Average                                      | 15    | 15      | 15      |         |         |         |
|                      | Low                                                        | 10    | 10      |         |         |         |         |
|                      | Do not take root                                           | 1     |         |         |         |         |         |
| Decorative quality   | High                                                       | 10    | 10      | 10      | 10      |         |         |
|                      | Elevated                                                   | 5     |         |         |         |         |         |
|                      | Average                                                    | 3     |         |         |         |         |         |
|                      | Low                                                        | 1     |         |         |         |         |         |
| ∑                    |                                                           | 93    | 93      | 78      | 71      | 69      |         |

Group by score

1 - *Acer platanoides* with a spherical crown; 2 - *Acer campestre*; 3 - *Acer ginnala*; 4 - *Acer saccharum*; 5 - *Acer negundo*.

a - the most promising (91-100); b - promising (76-90); c - not promising (less than 76).

Thus, in the conditions of Vladikavkaz, *A. platanoides* with a spherical crown is a resistant species characterized by shoots lignified by the end of the growing season and resistant to frost damage; *A. campestre* and *A. ginnala* are medium-resistant species, their annual shoots can be damaged by frost up to 55% or less; *A. saccharum* and *A. negundo* are more frost sensitive species.
The ability of plants to produce shoots determines their ability to maintain or restore the crown habitus under the influence of negative environmental factors. All studied species differ in their average ability to produce new shoots. *A. saccharum* has a low ability to produce shoots.

Annual increment is a generalized indicator that combines parameters of plant growth and development accumulating in itself the effect of the natural environment on the plant. Growth and development are the main parameters of plant adaptability during introduction.

The annual increase in shoots of all studied species - about 10 cm in *A. saccharum*, *A. ginnala*, *A. platanoides* with a spherical crown. 15 cm in *A. negundo*. 30 cm in *A. campestre* - was observed, it was due to the high growth rate of these species.

The ability of plants to produce viable seeds indicates the degree of adaptation to environmental conditions. The formation of viable insures self-reproduction and dispersal in a new environment. In all studied species, we recorded the ability to produce fruits and viable seeds annually.

Diagnosis of seeds, that is, the determination of their sowing qualities (germination, germination energy) was carried out on the basis of GOST 13056.6 - 75 Methods for the determination of germination. The study found that the germination of seeds of *A. ginnala* and *A. negundo* was less than 70% and the germination energy, of about 28%. Germination of seeds of *A. platanoides* with a spherical crown was 89% and germination energy, 82%.

We evaluated the ability of the studied species to be propagated by cuttings. For this purpose, about 600 green cuttings were planted on June 30 and July 17; they were treated with an aqueous solution of physiologically active potassium humate-80.

Rooting in *A. negundo* cuttings was about 80%, and in all other species, up to 60%. The species studied were grouped according to their rooting ability: a) a high level of rooting - *A. negundo*; b) the average level of rooting - all other species. Thus, there is a possibility of reproduction of trees of the family Sapindaceae on the territory of Vladikavkaz by means of green cuttings.

Ornamental species were classified according to the scale developed by N. Kotelova and N. Grechko. The highest score (10 points) receive plants that remain ornamental throughout the year; 5 points, species that look attractive only during the growing season; 3 points, species that look attractive for a certain period of the growing season; and 1 point, species that are ornamental according to certain parameters.

*A. platanoides* with a spherical crown remains attractive during the entire growing season, especially due to its interesting leafy crown. In autumn, the leaves of this species become intensely yellow and orange in colour. Wintering buds are red. Its indisputable advantage is a spherical crown which over time becomes conical.

According to the results of the scoring, the species studied were split into three groups. The first group comprises the most promising species including those with a rating from 91 to 100. This group includes the *A. platanoides* with a spherical crown and *A. campestre* characterized by winter hardiness, high ornamental quality, and the ability to reproduce both by seed and vegetative parts. The second group comprises promising species with a rating from 76 to 90. This group includes the *A. ginnala*, a highly ornamental species, but less promising compared to species of the first group due to non-ripening seeds and poor rooting of cuttings. The third group comprises the least promising species with a total score of up to 76 points. It includes *A. saccharum* and *A. negundo*, species that have some fairly high scores, but inferior to other studied species.

Representatives of the pine family Pinaceae are common in Vladikavkaz. Pines are evergreen plants, rarely deciduous. Most often these are two to three meter high trees, and only few species can reach larger sizes.

Pines are long-lived; under favourable conditions, some species live up to three or four thousand years, the average age is 200-400 years. In most species, the leaves are shaped as needles, less often they are scale-like or linear. All pines have hibernating buds, often protected by resinous substances. The root system is characterized by abundant branching of the lateral suction roots; almost all species have mycorrhiza. Timber has well-defined annual rings and a system of horizontal and vertical resin canals. In addition, members of the family Pinaceae are not very demanding to the growing conditions.
All the above explains the choice of representatives of this family to determine their potential. The object of the study is the arboreal representatives of the pine family: *Pinus strobus*, *Pinus kochiana* and *Pinus nigra subsp. pallasianna*. The viability assessment was carried out during 2012-2018 (Table 3).

During the period of observations (2012–2018), all the species studied did not show signs of damage caused by low temperatures, lignification of the shoots was close to 100%.

Under the conditions of Vladikavkaz, representatives of the pine family are resistant species characterised by frost-tolerant shoots that become lignified by the end of the growing season. The life form of the species studied at the introduction point is similar to that within the native distribution range.

The studied species are characterised by low ability to produce shoots. *P. nigra subsp. pallasianna* has an average ability to produce shoots. The annual increase in shoots of all studied species was about 15 cm.

The seed germination rate of *P. strobus* was low, about 65%. The seeds of the remaining species studied did not ripen.

In the process of research, the ability of the studied species to reproduce by cuttings was studied. For this purpose, about 400 green cuttings were planted on June 30 and July 17; they were treated with an aqueous solution of physiologically active potassium humate-80.

The rooting rate of cuttings of *P. strobus* was about 80%; in all other species it did not exceed 50%. According to the rooting success, the species studied were divided as follows: a) a high level of rooting - *P. strobus*; b) low - all other species.

All studied species were attractive during the entire growing season, primarily due to the distinctive evergreen crown. According to the results of the scoring, the species studied were split into three groups. The first group includes *P. strobus*, the plants of which are characterized by winter hardiness, a high level of decorativeness and the ability to propagate by seed and vegetative parts. *P. kochiana* is a species with quite high scores; it belongs to the second group. *P. nigra subsp. pallasianna* (the third group) is a highly ornamental species, but it has a lower potential compared to *P. strobus* and *P. kochiana*.

### 4. Conclusions
We established that the species composition of the green areas of Vladikavkaz is quite diverse; however, prerequisites exist for its expansion which would improve the ecological situation in the city. *Acer platanoides* with a spherical crown, *Acer campestre* and *Pinus strobus* are the most promising species to be used in urban environment.

We consider it most appropriate to use in green areas of Vladikavkaz woody plants of the Sapindaceae and Pinaceae families, in particular *A. platanoides*, *A. campestre* and *P. strobus*.

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### Table 3. Integral assessment of the potential of woody plants of the Pinaceae family in the conditions of Vladikavkaz (2012 - 2018).

| Estimated indicators | Characteristics of indicators                                      | Score | 1  | 2  | 3  |
|----------------------|------------------------------------------------------------------|-------|----|----|----|
| Hardiness            | Plants do not get frost damaged                                  | 25    | 25 | 25 | 25 |
|                      | Parts of one-year old shoots can get frost damaged                | 20    |    |    |    |
|                      | The whole one-year shoots get frost damaged                      | 15    |    |    |    |
|                      | Older shoots get frost damaged                                   | 10    |    |    |    |
|                      | Whole plants get frost damaged                                   | 5     |    |    |    |
to the level of the show cover
Whole plants get frost damaged to the root neck
Plants get killed by frost
Habit
Retained
Recover
Does not recover
Formation of shoots
Good
Average
Low
Increase in height
Annual
Not annual
Development
Produces fruit, but seeds are not viable
Produces fruit, but seeds do not ripen
Flowering, but no fruiting
Does not flower
Rooting success of cuttings
High
Average
Low
Do not take root
Decorative quality
High
Elevated
Average
Low
|             | 1  | 2  | 3  | 4  |
|-------------|----|----|----|----|
| Habit       |    |    |    |    |
| Retained    | 10 | 10 | 10 | 10 |
| Recover     | 5  |    |    |    |
| Does not recover | 1  |    |    |    |
| Formation of shoots |    |    |    |    |
| Good        | 5  |    |    |    |
| Average     | 3  | 3  |    |    |
| Low         | 1  | 1  | 1  |    |
| Increase in height |    |    |    |    |
| Annual      | 5  | 5  | 5  | 5  |
| Not annual  | 2  |    |    |    |
| Development |    |    |    |    |
| Produces fruit, but seeds are not viable |    |    |    |    |
| Produces fruit, but seeds do not ripen |    |    |    |    |
| Flowering, but no fruiting |    |    |    |    |
| Does not flower |    |    |    |    |
| Rooting success of cuttings |    |    |    |    |
| High        | 20 |    |    |    |
| Average     | 15 | 15 |    |    |
| Low         | 10 |    | 10 |    |
| Do not take root |    | 1  |    |    |
| Decorative quality |    |    |    |    |
| High        | 10 | 10 | 10 | 10 |
| Elevated    | 5  |    |    |    |
| Average     | 3  |    |    |    |
| Low         | 1  |    |    |    |
| \(\sum\) Score | 91 | 72 | 83 |    |

1 – *Pinus strobus*; 2 – *Pinus skochiana*; 3 – *Pinus nigra* subsp. *pallasiana*.\(^a\) - the most promising (91-100); \(^b\) - promising (76-90); \(^c\) - not promising (less than 76).

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