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State of *in situ* forest genetic resources of broadleaved tree species in the Right-Bank Forest-Steppe of Ukraine

Ihor Neyko[1] ✉, *Veronika Monarkh*[2], *Svitlana Poznyakova*[3], *Mykhailo Matusyak*[2]

[1] State Enterprise 'Vinnytsia Forest Research Station', Maksymovycha 39, 21036 Vinnytsia, Ukraine,
e-mail: ihor_neyko@ukr.net

[2] Vinnytsia National Agrarian University, Sonyachna 3, 21036 Vinnytsia, Ukraine

[3] Kharkiv National Agrarian University named after V.V. Dokuchaev, Dokuchaevske-2, 62483 Kharkiv region, Ukraine

Abstract

Forest genetic resources (FGRs) are an important source of biodiversity conservation and forest restoration. Today, more than 600 genetic reserves (GRs) of more than 30 main forest tree species have been allocated in Ukraine. The main aim of the work is to reveal the features of the distribution, environmental condition and the trends of state of *in situ* gene sources of broadleaved tree species in the Right-Bank Forest-Steppe of Ukraine. Based on the research results, it has been established that the share of FGR *in situ* is only 0.3–0.5% of the total forest area of the region. The predominant species of forest stands of the region are English oak (*Quercus robur* L.) – 37.7%, European beach (*Fagus sylvatica* L.) – 26.8% and Common ash (*Fraxinus excelsior* L.) – 7.6%. The *in situ* locations of Black alder (*Alnus incana* L.), Sessile oak (*Quercus petraea* (Matt.) Liebl.), English oak and Common ash are characterized by the highest average annual temperature (8.1–8.2°C), the accumulated temperatures for the growing season (3111.9–3237.1°C). Stands with the European beech predominance are allocated in better moisture conditions by the precipitation-temperatures ratio (Selianinov Hydrothermal Index (HTI) – 1.769–1.802; climatic index by Vorobyov – 2.707–2.951). The *in situ* gene pool conservation units are defined by 12 soil types that are included in the 7 main groups according to the FAO international classification. The largest number of sites, 67 (56.8%), is concentrated on grey and dark-grey forest soils (Haplic Greyzems) (47%). According to the research results, GRs are not evenly distributed, they do not fully reflect the environmental diversity, and their area is negligible. We indicated the unsatisfactory condition of most genetic reserves. It was caused by reducing the share of main tree species, decrease in relative stocking density of stands and tree-breeding structure and deterioration of tree stands condition. This requires the development and implementation of an integration strategy based on the established concept of developing a national ecological network on both national and pan-European levels.

Key words

gene reserves, plus stands, plus trees, soil conditions, climatic parameters

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Introduction

Climatic and soil-hydrological factors are fundamental for the formation of the stand composition and productivity of forest ecosystems. The human impact increase during the last century has led to the necessity of developing measures to preserve and enhance the reproduction of forest resources (Hensiruk 2002, Prots et al. 2010, Tkach 2012). Implementation of programs for forest resources conservation and their effective use has been activated in most countries in Europe as well as on a worldwide scale (FAO 1997, FAO 2014). Along with that, a necessity of developing an international and world-class concept emerged. Such a strategy was adopted in Rio in 1992 (UNCED 1992). At the UN conference, a strategy for Sustainable Forest Management (SFM) was announced, which would, on top of everything else, ensure the practical implementation of the principles of conservation and not exhausting use of forest resources (UNCED 1992). The concept of SFM has been implemented in most countries all over the world. Currently, several regional strategies have been developed in accordance with the forest management features in the countries of Europe, North America, Africa, Asia as well as tropical countries (ITTO 1993, UNEP/FAO 1998, Wijewardena 1998, Prabhu 1999, Montréal Process 2015, Sustainable Forestry Initiative 2010–2014). Most doctrines are based on the optimal combination of environmental, economic and social factors that would ensure forestry activity. Each of them contains certain Criteria and Indicators (C&I). SFM concept was accepted by Ukraine (Kravets and Lakyda 2002; Furdychko and Lavrov 2009). Almost all concepts contain an indicator that reflects the conservation of biological diversity. Forestry genetic resources are reflected in the Pan-European Strategy of Sustainable Forest Management in indicator 4.6. One of their most important characteristics is the area of forest genetic resources *in situ* as well as their species diversity (MCPFE 1993, 1998, 2000).

Forest genetic reserves, plus stands and plus trees belong to objects of forest genetic resources conservation *in situ*. Over a period of 1970s to 1980s, a significant number of such sites were assigned in Ukraine (Volosyanchuk et al. 2003, Bilous 2004, Tkach et al. 2013, Neyko et al. 2019). Forest genetic reserves were selected in accordance with the Guidelines for Forest Seed Production and other guidelines (Molotkov et al. 1993, Volosyanchuk et al. 2001). According to the developed guidelines criteria, tree stands of genetic reserves represent the most valuable part of the species, population and ecotype in the genetic-selection context. The main criteria for the assignation of plus stands are quite high parameters of growth and productivity. The percent of plus trees in such stands should be 15–27%. The increase of the negative effect of environmental factors has led to a deterioration of forest health and its fertility decrease (Gudelines 1993). Currently, there are trends in reducing the share of major forest-forming species in the stand composition (Volosyanchuk et al. 2001, Hensiruk 2002, Yurkiv and Neyko 2017). That requires studies to investigate the state, tree species composition and conditions for the formation of forest genetic reserves that are on the gene-pool *in situ* conservation list and also the development of a long-term strategy for their conservation and successful functioning.

Material and methods

The research of forest genetic reserves, plus stands and plus trees in the conditions of the Right-Bank Forest-Steppe was conducted during 2004–2018. Field work was carried out in Khmelnytskyi, Vinnytsia, Kirovograd, Odesa, Kyiv and Cherkasy regions. Data on surveyed reserves are listed in the international forest genetic resources database EUFGIS (EUFGIS 2006–2011). Based on the database, we analysed the distribution of genetic reserves and plus stands by their location, area, tree species composition of the stands and environmental conditions (biome, climate condition and soil type). The location of the surveyed stands is shown on the map (Fig. 1).

For each object of gene pool conservation *in situ* geographic coordinates, contours of units were determined, and reconnaissance was conducted. The sample plots were created in typical parcels. At least 100 trees of the main tree species were surveyed within each sample plot. For each tree, the DBH, tree-breeding category (TBC) and health condition were assessed. The average height was evaluated from the results of the measurement of 25–30 trees of the main tree species. The data were processed using the statistical software package Excel. Information on climatic and soil conditions was

Figure 1. Forest genetic reserves and plus stands inventoried during 2004–2018 (map obtained using the EUFGIS portal)

obtained on the basis of EUFGIS analysis. Calculation of Seljaninov Hydrothermal Index was carried out according to the formula (1):

$$HTI = R \cdot 10/\Sigma t, \qquad (1)$$

where:

HTI – Selianinov Hydrothermal Index,
R – total precipitation for a period with temperatures above +10°C,
Σt – cumulative temperatures for a period with temperatures above +10°C.

Vorobyov Climatic Index was calculated according to the formula (2):

$$W = R/T° - 0.0286 \cdot T° \qquad (2)$$

where:

W – humidity index,
R – months total precipitation for a period with an average temperature above 0°C,
T – the sum of above-zero cumulative average monthly temperatures.

Indexes (Selianinov Hydrothermal Index and Vorobyov Climatic Index) make it possible to assess not only temperature conditions but also the level of humidity.

Soil characteristics are derived on the basis of spatial localization of forest genetic reserves. Information on soil types by international classification has been derived from the EUFGIS database.

Tree condition was assessed according to Sanitary rules in the forests of Ukraine and ICP-Forest Monitoring Program (Manual, 1998). We used a 5-point scale for the identification of trees condition (Sanitary rules in the forests of Ukraine 2016). The tree-breeding category (TBC) indicated for each tree at the sample plot (Veresin 1963).

Category 1 (plus trees) is the best trees for the whole set of features. In a one-year-old forest stands, they exceed the average DBH by at least 30% and 10% of average height. The trees are straight-stemmed, with good clearing from knots and branches, excellent quality of the trunk. They are in healthy, good or satisfactory condition, without mechanical damage, with normal fruiting.

Category 2 (best of normal) can have high-quality trunks that meet the requirements of plus trees of category 1, with a slight excess of average height and DBH, or have significant excesses in height and DBH, but have some defects in the trunks. They are in healthy, good or satisfactory condition, without significant mechanical damage, with normal fruiting.

Category 3 (normal trees) is trees that have a DBH and height at the level of average forest stands. They have defects in the quality of the trunks. They are in good or satisfactory condition, with mechanical and other damages.

Category 4 (minus trees) has trees poor in growth, quality and condition or one of these features. These include all undersized trees, as well as all trees of any size with pronounced defects.

Statistical analysis of the data included the collection, analysis and interpretation of data on forest genetic resources *in situ*. Statistical methods are used to calculate the average values, proportions and number of distributions. The package of statistical programs Excel was used to calculate these parameters.

Results

Forest genetic reserves and plus stands are the main source of conservation and extended recovery of the gene pool of major forest species populations (Molotkov et al. 1993, Los et al. 2017). The largest area of deciduous genetic reserves is located in Zhytomyr, Chernivtsi and Vinnytsia regions – 2909.7 ha, 1826.1 ha and 1286.0 ha, respectively. The area of forest genetic reserves in other regions is much lower and ranges from 172.8 ha to 584.3 ha (Table 1).

Table 1. Objects of *in situ* preservation of deciduous tree species gene pool under the conditions of the Right-Bank Forest-Steppe of Ukraine

No	Region	Objects of *in situ* preservation of gene pool		
		Forest genetic reserves area [ha]	Plus stands area [ha]	Number of plus trees, units
1	Vinnytsia	1286.0	530.3	123
2	Zhytomyr*	2909.7	110.2	290
3	Ivano-Frankivsk	584.3	612.7	189
4	Kyiv*	351.0	40.9	152
5	Kirovograd*	238.0	0.0	74
6	Odesa*	172.8	5.5	25
7	Ternopil	189.4	0.0	157
8	Khmelnytskyi	355.9	99.9	148
9	Cherkasy*	319.4	0.0	137
10	Chernivtsi*	1826.1	3.3	276
	Total	7053.5	872.5	1448

Note: * the region territory partly belongs to the Right-Bank Forest-Steppe of Ukraine.

The largest plus stands area of deciduous tree species were selected in Ivano-Frankivsk and Vinnytsia regions – 612.7 ha and 530.3 ha, respectively. In Zhytomyr and Khmelnytskyi regions, the plus stands area is about 100 ha. There are no plus stands in Kirovograd and Cherkasy regions.

According to the investigation, the largest proportion of genetic reserves and plus stands is located in Vinnytsia and Lviv regions. In these regions, the proportion of forest genetic reserves from the total area is 30–40%. The proportion of surveyed forest genetic reserves in Kyiv, Cherkasy, Kirovograd and Odesa regions is only 1–5%. The total number of forest genetic reserves and plus stands is 124 (Fig. 2).

The largest number of objects, namely 27 and 25 units, is located in Ternopil and Khmelnytskyi regions, respectively. The smallest number of seed orchards, which is 4 and 6, is located in Zhytomyr and Cherkasy regions.

The total area of forest genetic reserves and plus stands in the Right-Bank Forest-Steppe is 4053.3 ha. The largest areas of *in situ* units are concentrated in Vinnytsya and Lviv regions – 1472.2 ha and 1424.8 ha, respectively. The smallest total area of such objects is in the Cherkasy region – 60.0 ha. The distribution of the total area in the context of the regions belonging to the Right-Bank Forest-Steppe is naturally determined. In Vinnytsia and Lviv regions, the proportion of genetic reserves area is 35–36%, and in the Cherkasy region, it is 1.5%. The minor areas of these objects are concentrated in Kyiv – 196.0 ha (4.8%), Ternopil – 189.4 ha (4.7%), and Khmelnytskyi – 307.1 ha (7.6%) regions. The largest area of an individual genetic reserve is in Vinnytsia region and is over 200 ha. In Ternopil and Odesa regions, the area of largest objects is only 21.0–22.0 ha. The smallest area of genetic reserves in most regions is 1.0 ha. The smallest areas of such objects in the Kyiv and Cherkasy regions are 8.0–13.0 ha.

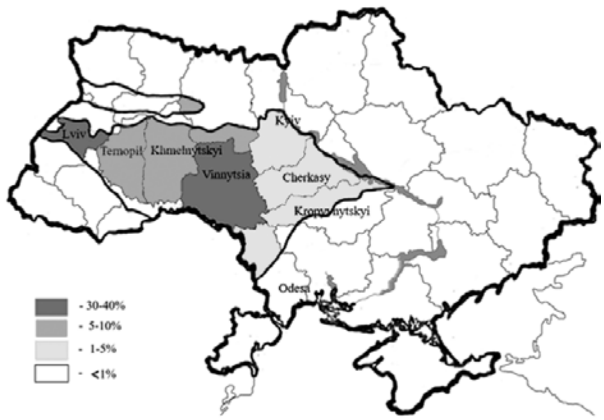

Figure 2. The share of forest genetic reserves and plus stands located within the limits of the Right-Bank Forest-Steppe of Ukraine

The predominant main forest-forming species of the forest genetic reserves of the Right-Bank Forest-Steppe are English oak, which stands take a share of 43.7%, and European beech – 31.5%. The stands with the predominance of Common ash cover 12.7% of forested area. The English oak and European beech have the largest number of genetic reserves – 53 and 43 units (44.9% and 36.3%, respectively; Tab. 2).

According to the international classification of natural zones based on climate classification (Köppen-Geiger), the territory of the Right-Bank Forest-Steppe belongs to the zone of cold and dry climate (HI). The climate of the sites with the predominance of European beech is characterized by a better humidification level according to the precipitation-temperatures ratio (Selianinov HTI is 1.769–1.802; Vorobyov Climatic

Index is 2.707–2.951). Lower precipitation for the year (589–598 mm) and the growing season are specific for the stands of Sessile oak, English oak and Common ash. The precipitation/accumulated temperatures ratio for associations with the predominance of these tree species is the lowest (Selianinov HTI is 1.245–1.290; Vorobyov Climatic Index is 0.830–0.946; Tab. 3).

Table 2. Number and area of forest genetic reserves for the main forest-forming tree species in the Right-Bank Forest-Steppe

Populations of main tree species	Number, units	Proportion of units [%]	Area [ha]	Proportion of [%]
Acer pseudoplatanus L.	1	0.8	1.8	0.0
Alnus glutinosa (L.) Gaerth.	1	0.8	3.3	0.1
Alnus incana (L.) Moench	1	0.8	13.0	0.3
Fagus sylvatica L.	43	36.3	1275.9	31.5
Fraxinus excelsior L.	8	6.7	517.5	12.7
Quercus petraea (Matt.) Liebl.	9	7.5	449.4	11.1
Quercus robur L.	53	44.9	1773.3	43.7
Quercus rubra L.	1	0.8	13.0	0.3
Sorbus torminalis L.	1	0.8	6.1	0.2
Total	118	100.0	4053.3	100.0

The *in situ* gene pool preservation units are characterized by 12 soil types that are included in the 7 main groups according to the international FAO classification, specifically chernozems (Chernozems), grey forest soils (Greyzems), gleys (Gleysols), sod-calcareous soils (Leptosols), podzolic soils (Podzoluvisols) of varying podzolization degrees, meadow-chernozem soils (Phaeozems) and alluvial-meadow soils (Fluvisols). The largest number of plots, that is, 67 (56.8%), is characterized by the predominance of grey and dark-grey forest soils (Haplic Greyzems). The total area of such plantations is 1903.3 ha (47%; Tab. 4).

Meadow-chernozem soils (Luvic Phaeozems) make up a significantly lower share – 16 units (13.6%) – and in terms of an area – 741.6 ha (18.6%). The number of genetic reserves on chernozems (Haplic Chernozems) is 11 (9.3%) with a total area of 334.7 ha (8.3%).

Associations with the English oak predominance are mainly distributed on grey forest soils (Haplic Greyzems). The total number of sites characterized by this soil type is 26 (49.1%) with a total area of 1091.4 ha (61.5%). The largest areas of oak-ash associations are located on meadow-chernozem soils (Gleyic Phaeozems) – 59.4 ha (3.3%). However, the largest number of these association sites, 3 (5.7%), is concentrated on grey forest soils (Haplic Greyzems). Oak-pine associations are limited to light-grey forest soils (Eutric Podzoluvisols) with a total area of 73.0 ha (4.1%). The English oak associations interspersed with Sessile oak are distinguished by prevailing meadow-chernozem soils (Luvic Phaeozems) with a total area of 28.0 ha (1.6%). Forest formations of European beech are main-

Table 3. Evaluation of precipitation and climatic parameters of genetic reserves by Vorobyov and Selyaninov indices

Genetic reserves (tree species)	$\sum P$ annual [mm]	$\sum P$ for the growing season [mm]	Selianinov HTI [$K = R \cdot 10/\Sigma t$]	Vorobyov Climatic Index [$W = R/T° - 0.0286\ T°$]
Acer pseudoplatanus L.	608	440	1.541	2.048
Alnus glutinosa (L.) Gaerth.	664	493	1.649	2.252
Alnus incana (L.) Moench	581	382	1.182	0.597
Fagus sylvatica L.	668	486	1.679	2.432
Fraxinus excelsior L.	633	466	1.610	2.220
Quercus petraea (Matt.) Liebl.	603	416	1.372	1.364
Quercus robur L.	632	444	1.473	1.691
Quercus rubra L.	646	463	1.565	2.022
Sorbus torminalis L.	654	485	1.584	1.982
Average	641	457	1.535	1.914

Table 4. Distribution of the total number of units and area of genetic reserves in the Right-Bank Forest-Steppe on the prevailing soil types according to the international classification (EUFGIS)

Soil types	Quantity [units]	Proportion from the total number [%]	Area [ha]	Proportion from the total area [%]
Dystric Fluvisols	1	0.8	18.0	0.4
Dystric Gleysols	1	0.8	2.4	0.1
Eutric Fluvisols	1	0.8	15.0	0.4
Eutric Podzoluvisols	8	6.8	175.2	4.3
Gleyic Phaeozems	5	4.2	368.1	9.1
Gleyic Podzoluvisols	1	0.8	58.0	1.4
Haplic Chernozems	11	9.3	334.7	8.3
Haplic Greyzems	67	56.8	1903.3	47.0
Haplic Phaeozems	2	1.7	194.4	4.8
Luvic Phaeozems	16	13.6	741.6	18.3
Rendzic Leptosols	2	1.7	20.3	0.5
Stagnic Podzoluvisols	3	2.5	222.3	5.5
Total	118	100.0	4053.3	100.0

ly represented by meadow-chernozem soils (Luvic Phaeozems) and grey forest soils (Haplic Greyzems). The largest association area is 390.5 ha with the meadow-chernozem soils predominance. The number of areas with grey forest soils is the largest and aggregates 29 units (67.4%) with a total area of 363.9 ha. A significant area of 264.6 ha (20.7%) is occupied by Gleyic Phaeozems, which is typical for 3 sites. For ash associations interspersed with English oak and Sessile oak, the predominance of grey forest soils (Haplic Greyzems) is typical (312 ha, 49.1%). There are 2 plots (16.7%) on these soils. The same soil types are typical for ash-oak associations – 83.0 ha (13.1%). Luvic Phaeozems and Haplic Chernozems are the prevailing soil types for the Sessile oak association with an admixture of English oak and ash, 186.1 ha (34.4%) and 182.4 ha (33.7), respectively.

According to the investigation of stands dynamic during last 20 years, we observed a decrease of the proportion of English oak in tree species composition, destruction of stands, deterioration of the tree-breeding structure of stands and deterioration of tree stands health condition (Tab. 5).

A significant part of the surveyed forest genetic reserves is characterized by deterioration of the health condition and selection structure. The decrease of the functional suitability of the gene pool *in situ* is primarily due to unsatisfactory tree species composition (26.2%), thinning of the forest canopy (24.6%) and weakening of trees (23.1%). Most forest stands have a fairly high selection rate. Only a small part of them (17.7%) needs to be replaced by this criterion. The most negative trends in reducing the proportion of the main forest species were observed in Vinnytsia and Kyiv regions (7.7%), reducing the relative density of stocking of stands in Odesa and Khmelnytskyi regions (9.2–10.8%), deterioration of the selection structure in Odesa region

Table 5. Distribution of surveyed forest genetic reserves and plus stands (%) according to the dynamics of the state during the last 20 years

Region	Reduction of the proportion of the main forest-forming species in the composition by more than 20%	Decrease in the relative density of stocking of stands below 0.7	Decrease of the tree-breeding category (below 3.0)	Weakening of trees (average category of health condition below 3.0)
Vinnytsia	7.7	3.1	1.5	15.4
Kyiv	7.7	1.5	1.5	1.5
Kirovograd	0.0	0.0	10.0	0.0
Odessa	4.6	9.2	4.6	4.6
Khmelnytskyi	4.6	10.8	0.0	0.0
Cherkasy	1.5	0.0	0.0	1.5
Total	26.2	24.6	17.7	23.1

(4.6%) and deterioration of the health condition in Vinnytsia region (15.4%).

Discussion and conclusions

Forest genetic resources are an important component of the biodiversity of forest stands conservation. Preservation of forest genetic resources *in situ* provides for the conservation of populations or individuals within their natural habitat. Conservation units *ex situ* are created artificially and involve the transfer of reproductive material. In most countries, the forest genetic resources conservation *in situ* is the main strategy for the conservation of forest genetic resources (FAO 1997, UNEP/FAO 1998, Eriksson et al. 2006). Such units include forest genetic reserves, natural reserves and national parks. Despite this, genetic reserves and natural reserves of all others are fully consistent with the Concept of Forest Genetic Resources Conservation (Los et al. 2014). The main disadvantage of natural reserves and national parks listing as *in situ* forest gene pools is the focus on fauna and other components of forest ecosystems. At the same time, the genetic structure of forest stands remains out of consideration. Initiation and location of certain national parks and forest reserves can be motivated by other considerations, in particular, such as political, social and economic constraints. In this regard, forest ecosystems can represent non-typical conditions (climatic and soil factors) that limit their value. On the other hand, rare objects for a particular region may not be represented.

Forest genetic reserves and plus stands selected in Ukraine are fully in line with the criteria for forest genetic resources conservation *in situ* (Hayda, Yatsyk 2013, Los et al. 2014). Forest genetic reserves adequately reflect the most typical environmental conditions. The gene pool conservation objects *in situ* are defined by 12 soil types that are included in the 7 main groups according to the international FAO classification. Despite the significant representation of the principal forest-forming species populations, their area remains catastrophically low (Hayda, Yu., et al. 2008, Yurkiv and Neyko 2017). Their total share in relation to the forest area of the Right-Bank Forest-Steppe is just about 0.3–0.5% (Neyko et al. 2019). Our research shows that a significant number of the gene pool preservation objects *in situ* have an area of no larger than 1.0 ha and are widely scattered.

Significant fragmentation of the forest gene pool conservation objects *in situ* requires the introduction of measures for their unification into a single structure. From this perspective, the development of an Ecological Network which includes forest genetic reserves is an important strategy (Neyko and Mudrak 2009). One of the main measures to improve the situation is to increase the forest genetic reserves area, to select the additional units and to associate them in the context of the development of the national and Pan-European Ecological Network.

The provision of natural seed regeneration of stands that are part of forest genetic reserves is another important aspect. Currently, the selection of the forest gene pool conservation *in situ* units in Ukraine is not a sufficient measure for their successful functioning. Our researches revealed the gradual aging of selected tree stands and the decrease of the main forest-forming species proportion in their composition. The most negative trends have been observed in the English oak forest stands. Over the last decades, we have been observing a significant decline in this tree-species composition because of their health condition worsening. The intensity of oak seed reproduction reduced according to changes in environmental conditions (Furdychko and Neyko 2019). In this case, sufficient natural seed reproduction of English oak is not provided. This requires the development of a further strategy not only for selection but also for ensuring the natural genesis of forest stands that are listed as the *in situ* conservation units in the Right-Bank Forest-Steppe of Ukraine.

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