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*ORIGINAL ARTICLE*

# State and dynamics of forest fund indicators in se "skrypaivske educational and research forestry" (Forest-Steppe, Ukraine)

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The peculiarities of forest fund indicators dynamics of Skrypaivsky educational and research forestry of Kharkiv National Agrarian University named after V.V. Dokuchaev (Kharkiv region, Ukraine) for the period of 70 years were studied on the base of forest accounting data and Forest Fund database. Recent dynamics of forest health condition was assessed on the base of forest monitoring data. Analysis of climate indices dynamics (from ClimateChart.net) for the region of study was performed.

Forest landscapes at the enterprise are typical for the left-bank Forest-Steppe of Ukraine. Over 90% of the area is occupied by English oak (*Quercus robur* L.) and Scots pine (*Pinus sylvestris* L.) stands, other species (black alder, aspen, willow, black locust, small-leaved lime and silver birch, poplar) are less represented. For the last two decades' trend to change of dominant tree species in forest stands was revealed. Areas of Scots pine, English oak, and aspen stands slightly decreased, while the area of other deciduous stands, especially black locust, small-leaved linden, common ash, and black alder, significantly increased. Also significand increase in areas of Scots pine damaged by the root rot, which in turn indicates the deterioration of the sanitary condition of these stands.

During last decade pine stands suffer from biotic damage-root rot and bark beetles, and increased trees mortality is observed. In young planted forest substitution of pine to black locust is observed, in oak young planted forest areas other deciduous became a dominant tree species. Monitoring data showed long-term trend to deterioration of health condition. The tend to stands aging as well as decreasing of density of stocking and site class was revealed.

Climate data for the region of study showed trend to warming and aridization.

**Keywords:** Monitoring, Forest area, Species composition, Health condition.

## Introduction

The forest is one of the main natural resources on which development of civilized humanity depends, especially in the conditions of climate change. A characteristic feature of forestry in Ukraine is variability of economic and natural-geographical conditions by regions. Unregulated exploitation of Ukraine's forests during certain periods has led to depletion of forest stands, impairment of their age structure and species composition, intensification of erosion processes and other natural phenomena. Therefore, the priority direction of forestry development in the context of modern issues is the expanded reproduction of forest resources, intensification of forestry and the analysis of the state forest fund dynamics (Makarenko, 2018).

The forest fund of forest enterprises is, on the one hand, a source of ecological stability of territories and an object of biodiversity conservation, and on the other hand, it is a resource for timber and other forest products. Consequently, the assessment of the current status and dynamics of the forest fund is extremely important. The main indicators that characterize the state of the forest fund are the area and its structure by distribution by forest site conditions and forest types, land categories, distribution of forest stands by species, age structure, quality, density of stocking and growing stock (Hrom, 2010; Zelensky, Goroshko, 2003).

The main sources of timely and objective information on forests are the state forest cadastre and forest accounting, as well forest monitoring. An important area of research is monitoring of forest condition, identifying factors of weakening of forest stands, development and implementation of measures to prevent these processes and mitigate their effects under anthropogenic pressure (Evstigneev, 2010; Pasternak et al. 2017).

In this regard, the aim of our study was to analyse the dynamics of forestry evaluation indicators of the forest fund of Skrypaivske educational and research forestry (Skrypaivske ERF) of Kharkiv National Agrarian University named after V.V. Dokuchaev, analysis of changes in the structure of the forest fund over the past 70 years, as well as the dynamics of forest stands condition on the basis of monitoring data.

## Materials and Methods

The territory of Skrypaivske ERF is located at the Left-Bank Forest-Steppe of Ukraine in Kharkivska oblast, Chuhuivskyi district. According to the forest typological zoning of Ukraine, the enterprise is located within the area of fresh temperate warm climate and belongs to Slobozhanskyi forest typological district-fresh mapleandlinden oakwood (Ostapenko and Tkach, 2002). Forest landscapes of the enterprise are typical for the Left-Bank Forest-Steppe of Ukraine, with a predominance of English oak (*Quercus robur* L.) and Scots pine (*Pinus sylvestris* L.) stands. Fresh relatively poor (pine) and rich (oak) forest site conditions are the most represented. About 82% of the enterprise area is covered by recreational and health forests, 18%-forests of environmental, scientific, historical and cultural purposes (Nazarenko, Babenko, 2015).

Forest inventory and management planning materials and the Forest Fund database were used to assess the dynamics of the forest fund indicators.

Forest monitoring is regularly carried out on the territory of Skrypaivske ERF at three I level monitoring plots (annually), and at two intensive monitoring plots (every 4 years) (Table 1). At the I level monitoring plots surveys were carried out according to standard methods, harmonized with the International Cooperative Programme methodology of forest monitoring in Europe (ICP-Forests) (Manual on methods, 2006) on sample plots with fixed amount of sample trees (24 trees) during 2003-2019. In 2020 the methodology was updated in order to harmonize with the recommendations of ICP Forest (2016); while the “old” sample trees were preserved to ensure long time series of monitoring data. According to new methodology circular plots with a fixed area (500 $m^2$) were laid, on them sample trees with a diameter over 14 cm (6 cm for sub-plots with a radius of 3.98 m) were mapped and assessed. Trees species, status (live/ dead), diameter, tree height (for model trees), crown base height, Kraft class were estimated. For each tree, crown defoliation, health condition index, and damage were assessed. Ground vegetation (vascular plants species) and their cover were assessed on the whole area of the I level monitoring plots.

The methodology of intensive monitoring was developed taking into account the approaches of the ICP Forests (2016) and US Forest Health Monitoring (Tallent-Halsell, 1994). On intensive monitoring plots forest stand description was carried out, including identification of forest type condition and the type of forest, tree species composition, stand origin, age, density of stocking, site index, ground vegetation, dead wood, litter and soils were assessed. In a pine stand the monitoring plot is circular, with a radius of 17.84 m (area 1000 $m^2$), in an oak stand plot it is rectangular (area 2500 $m^2$) (see Table 1). The tree species, tree status, diameter, Kraft class, health condition index and damage were estimated for the trees. For model trees representing all species growing on the site tree height and crown parameters were measured.

**Table 1**. Forestry characteristics of monitoring plots.

| S.No Plot | Forest Type | Composition* | Origin | Age, years | Density of Stocking | Site Index | Growing Stock, $m^3 \cdot ha$ |
|---|---|---|---|---|---|---|---|
| 312230-pine | $C_2$-limeandoakandPine | 10PinSyl | artificial | 50 | 0.88 | Ia | 402 |
| 312234-pine | $A_2$-Pine | 10PinSyl | artificial | 57 | 0.82 | II | 319 |
| 312235-oak | $D_2$-mapleandlimeandOak | 9QueRob1FraExc+AcePla,TilCor | coppice | 125 | 0.71 | II | 368 |
| 2263072-oak | $D_2$-ashandlimeandOak | 7QueRob2FraExc1AcePla +AceCam,TilCor, UlmSca | coppice | 126 | 0.68 | II | 271 |
| 2263079-pine | $B_2$-oakandPine | 10 PinSyl | artificial | 101 | 0.65 | I | 423 |

*PinSyl-*Pinus sylvestris* L., QueRob-*Quercus robur* L., FraExc-*Fraxinus excelsior* L., AcePla-*Acer platanoides* L., TilCor-*Tilia cordata* Mill., AceCam-*Acer campestre* L., UlmSca-*Ulmus scabra* L.

Climate data from the Climate Chart website (Zepner, 2020) for the Chuguivskyi district of Kharkivska oblast were used for assessment of climate change trends in the region of study. Changes in forestry characteristics and the health condition indices on monitoring plots were the criteria for evaluating the trends.

## Results and Dicussion

### Climate change trends

According to Climate charts (Fig. 1) (from Zepner at al., 2020) for recent 30 years at the region of study the climate class (according to Köppen, 1918) changed from Dfb-Warm-summer humid continental climate to Dfa-Hot-summer humid continental climate. However, the Vorobiev class remained 1e (dry relatively warm climate) (Vorobiev, 1961). The average annual temperature has increased by 1°C, while more intensive growth is observed in summer. Dry period occurred in August, which is typical for Steppe natural zone. Such changes are not favourable for forest vegetation in the region. Climate charts also show increasing of the vegetation period duration-from 8 months in the 1960-1989 to 9 months in 1990-2019.

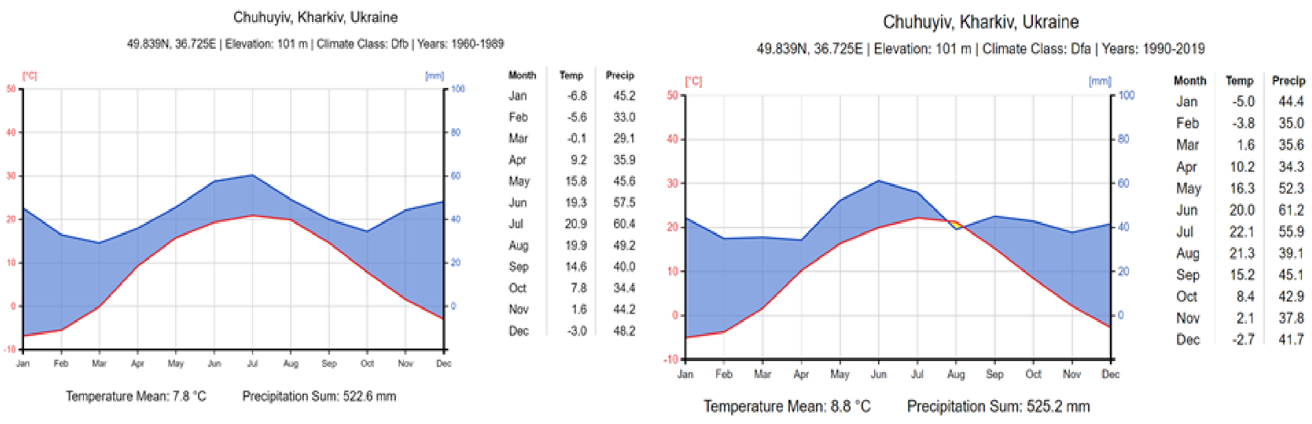


**Fig. 1.** Climate charts for the region of study (from Zepner at al., 2020) in 1960-1989 and in 1990-2019.

## Forest fund dynamics

The total land area of Skrypaivske ERF (Table 2) slightly increased since 1956, and during last 20 years it was almost constant. During last decade of the total forest area of the enterprise showed a relatively small increase (on 38 ha, or 0.9%). Area covered with forest vegetation is 7854,2 ha (93.8% of the forest area)) in 2020, of it 45% (3550.8 ha) are planted forests. Comparing to the 2011 the total forested area (item 2.1.) in 2020 slightly decreased (by 72.1 ha, or 0.9%).

Among the positive changes in the distribution of land the constant increase in the area of forest lands, and decrease of non-forest lands, cutting areas, sparse forests, burned areas and dead stands area is observed. At the same time, the sharp increase in the area of young planted forest, and decreasing the area of forest nurseries and plantations, increasing the share of areas of wastelands are observed, which in our opinion are shortcomings in the forest management.

Detailed description of the previous decade is given in the article (Nazarenko, Babenko, 2015).

**Table 2**. Dynamics of the forest fund area by forest land categories.

| Categories | Years of Accounting | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1959** | **1967** | **1979** | **1989** | **1999** | **2011** | **2020** |
| 1. Total land area | 8544.0 | 8549.0 | 8562.0 | 8565.0 | 8582.0 | 8582.0 | 8581.8 |
| 2. Forest areas-total | 8034.0 | 8019.0 | 8014.0 | 8103.0 | 8320.2 | 8310.4 | 8376.7 |
| 2.1. Forest areas covered with forest vegetation | 7401.0 | 7765.0 | 7867.0 | 7901.0 | 7889.0 | 7926.3 | 7854.2 |
| incl. Planted forest | 2073.0 | 2776.0 | 3083.0 | 3367.0 | 3415.0 | 3608.6 | 3550.8 |
| 2.2. Forest areas not covered with forest vegetation: | 633 | 255 | 158 | 202 | 431.2 | 384.1 | 522.5 |
| 2.2.1. Young planted forest | 382.0 | 210.0 | 95.0 | 86.0 | 105.0 | 83.3 | 243.5 |
| 2.2.2. Forest nurseries, plantations | - | - | 11.0 | 17.0 | 15.8 | 12.1 | 4.3 |
| 2.2.3. sparse forests | 2.0 | 2.0 | 6.0 | 10.0 | - | - | |
| 2.2.4. burned areas, dead stands | 3.0 | - | 4.0 | - | - | - | 3.4 |
| 2.2.5. cutting areas | 110.0 | 23.0 | 15.0 | 25.0 | 45.4 | 26.2 | 0 |
| 2.2.6. meadows, wastelands | 136.0 | 20.0 | 27.0 | 64.0 | 99.7 | 103.4 | 115.8 |
| 2.2.7 Forest paths, clearings, fire breaks | - | - | - | - | 165.3 | 159.1 | 155.5 |
| 3. Non-forest lands | 510.0 | 528.0 | 537.0 | 462.0 | 261.8 | 271.6 | 205.1 |

One of the important characteristics of the forest fund is the distribution of the area by the dominant trees species (Table 3). During the entire study period, more than 90% of the area was occupied by stands with the predominance of two forest-forming species, namely English oak (*Quercus robur* L.) and Scots pine (*Pinus sylvestris* L.). Other conifers are represented by Crimean pine (*Pinus nigra* subsp. *pallasiana* (Lamb.) Holmboe (1914)) and Norway spruce (*Picea abies* Karst.) (0.02%). Other deciduous stands are represented by common ash (*Fraxinus excelsior* L.)-1.5%, black alder (*Alnus glutinosa* L.)-1.2%, aspen (*Populus tremula* L.) and willows (*Salix* spp.)-each 0.3%, black locust (*Robinia pseudoacacia* L.)-0.2%, small-leaved lime (*Tilia cordata* Mill.) and silver birch (*Betula pendula* Roth.) 0.2% each, and black poplar (*Populus nigra* L.)-0.1%.

**Table 3**. Stands distribution by dominant tree species by years of accounting, ha /% (Forest fund DB) (for forest areas covered with forest vegetation)

| Dominant Species | Years of Accounting | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1959** | **1967** | **1979** | **1989** | **2000** | **2012** | **2020** |

| **Dominant Species** | **Years of Accounting** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **1959** | **1967** | **1979** | **1989** | **2000** | **2012** | **2020** |
| Scots pine | 2594.0<br>35.0 | 2949.0<br>38.0 | 3077.0<br>39.1 | 3099.5<br>39.2 | 3041.7<br>38.6 | 3066.9<br>38.7 | 3009.0<br>38.3 |
| Incl. damaged by root rot | n/a | n/a | n/a | n/a | n/a | 37.6 | 130.0 |
| Other conifers | 12.0<br>0.2 | 12.0<br>0.2 | 6.0<br>0.1 | 8.0<br>0.1 | 7.7<br>0.1 | 7.9<br>0.1 | 1.7<br>0.02 |
| English oak | 4539.0<br>61.3 | 4569.0<br>58.9 | 4590.0<br>58.4 | 4610.2<br>58.4 | 4646.5<br>58.9 | 4632.4<br>58.4 | 4508.9<br>57.4 |
| Common Ash | 19.0<br>0.3 | 18.0<br>0.1 | 11.0<br>0.1 | 10.9<br>0.1 | 12.6<br>0.1 | 35.9<br>0.4 | 119.3<br>1.5 |
| Black alder | 60.0<br>0.8 | 56.0<br>0.7 | 72.0<br>0.9 | 77.7<br>1.0 | 76.6<br>1.0 | 84.6<br>1.1 | 95.3<br>1.2 |
| Other deciduous | 177.0<br>2.4 | 161.0<br>2.1 | 111.0<br>1.4 | 94.4<br>1.2 | 103.9<br>1.3 | 98.6<br>1.3 | 120.0<br>1.5 |

During last decade significant increasing area of pine stands damaged by root rot (caused by *Heterobasidion annosum* (Fr.) Bref) was observed: for 2010 area of damaged pine stands was 37.6 ha (1.2% of total pine area), while in 2020 it made 130 ha (4.3% of total pine area), which indicates the deterioration of the health condition of these stands (Table 3).

For the last two decades' trend to change of dominant tree species in forest stands was revealed (Table 3).

During last decade pine stands suffer from biotic damage-root rot and bark beetles (outbreaks were in many regions of Ukraine in 2016-2018 (Meshkova, 2021)), which caused trees weakening and mortality. As a result, insignificant decrease of Scots pine area: by 57.9 ha (or 1.9% from 2011) was observed. Also for this period significant decrease in Crimean pine and Norway spruce areas (by 6.2 ha, or 78.5% comparing to 2011) caused by bark beetles was revealed. At the same time the significant increase in the area of black locust (*Robinia pseudoacacia* L.)-by 12 hectares (190.5%) comparing to the level of 2011, which occurs mainly in pine stands and young planted forest. So we can trace rather intensive distribution of non native tree species, which can negatively impact on forest biodiversity.

English oak areas for 1999-2011 decreased insignificantly (by 0.3%), and for the last decade 2011-2020 decrease is significant-by on 123.5 hectares (2.7%). At the same time, the area of stands with Common ash (*Fraxinus excelsior* L.) as the main species increased significantly (for the period 1999-2011 by 23.3 ha, and for the last decade by 83.4 ha (or by 232.3% on the level of 2011)), this mainly occurs in oak stands. Also significant increase in area of small-leaved lime (*Tilia cordata* Mill.) stands by 5.5 hectares (or 79.7%) over the last decade was observed. Such changes occurred due to substitution of oak in young planted forest areas by these deciduous species, which is associated both with shortcomings in care after forest crops and unfavourable climate conditions for oak seedlings. In older oak stands changes in the main species occurred due to oak trees mortality and their substitution by common ash, small-leaved lime.

In the floodplain parts of the enterprise gradual increase in the area of black alder (by 10.4 ha, 12.7%) last two decades is observed, mainly on abandoned hayfields.

Dynamics for the earlier period is described in the article (Nazarenko, Babenko, 2015).

The age structure of the forest fund is one of the relevant indicators in the assessment of forest resources. It provides information on the area of forests within age groups, which can form a prognostic assessment of forest use in the short and long term. Analysis of the existing and optimal distribution of stands by age groups showed the significant difference: in 2020 the share of young forests is the lowest for the studied period, the share of premature, mature and overmature stands tends to increase (Table 4). Such changes are associated with aging of forest stands due to the incomplete use of the logging fund (annual allowable cut) and the gradual natural growth of stands.

**Table 4**. Existing and optimal distribution of stands by age groups, %.

| **Age groups** | **1967** | **1979** | **1989** | **1999** | **2011** | **2020** | **Optimal*** |
|---|---|---|---|---|---|---|---|
| Young stands | 37.3 | 27.0 | 23.7 | 13.5 | 10.3 | 9.8 | 30.7 |
| Middle-aged | 37.1 | 47.9 | 63.7 | 70.7 | 66.9 | 59.0 | 45.0 |
| Premature | 14.1 | 13.2 | 6.6 | 10.0 | 12.2 | 21.0 | 15.3 |
| Mature and overmature | 11.5 | 11.9 | 6.0 | 5.8 | 10.6 | 10.2 | 9.0 |

* According to (Girs, 2011)

Site class is an integral indicator that reflects the productivity of forest stands in specific forest conditions and depends on many factors, such as: the soil fertility, species composition, origin, etc.

In the enterprise medium-productivity stands prevail. Scots pine stands are mostly characterized by high productivity: I (55%) and II (34%) site classes, oak stands have slightly lower productivity (stands of site class II occupy 83% of the area). In Scots pine, English oak, silver birch, small-leaved lime stands there are slight changes in productivity. Only fast-growing black locust and aspen tend to increase their productivity. At the same time, stands of common ash, black alder, poplar and willow have the opposite trend. Generally, for the analysed 70-yeared period, the average site class decreased by 0.1 unit.

The general trend to decreasing of density of stocking was revealed: the share of high-density stands decreased while medium-density stands increased. In some stands for the last 20-30 years there are no high-density stands at all, instead there are low-density stands. Tree species such as black locust, silver birch, black alder, aspen, poplar and willow in 2020 have the lowest density of stocking.

This can be explained primarily by the aging of stands and intense tree mortality damaged by pests and diseases, and consequently related management activities (clear and selected sanitary fellings) in them. The long-term effect of such sanitary measures can only exacerbates the current difficult situation.

Uneven distribution of stands by age groups, decrease in density of stocking, increase in average age affected the average forest evaluation indicators (Table 5).

**Table 5.** Dynamics of average forest evaluation indicators.

| | | | | | **Average Forest Evaluation Indicators** | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | **Growing stock, $m^3 \cdot ha^{-1}$** | | **Average stock change** | |
| **Dominant Tree Species** | **Year** | **age, Years** | **Site Class** | **Density of Stocking** | **Covered with Forest Vegetation Lands** | **Incl. Mature and Premature Stands** | **per 1 ha of Covered with Forest Vegetation Lands, $m^3$** | **Total, Thous. $m^3$** |
| Scots pine | 1959 | 35 | I.3 | 0.72 | 156 | 342 | 3.8 | 9.8 |
| | 1967 | 37 | I.3 | 0.78 | 159 | 312 | 4.4 | 13.0 |
| | 1979 | 44 | I.4 | 0.77 | 325 | 202 | 4.6 | 14.2 |
| | 1989 | 54 | I.4 | 0.74 | 369 | 263 | 4.8 | 15.03 |
| | 1999 | 60 | I.5 | 0.72 | 259 | 325 | 4.3 | 12.83 |
| | 2011 | 65 | I.4 | 0.74 | 293 | 367 | 4.5 | 13.66 |
| | 2020 | 69 | I.4 | 0.70 | 298 | 365 | 4.3 | 12.40 |
| English oak | 1959 | 54 | II.0 | 0.71 | 180 | 212 | 3.6 | 16.4 |
| | 1967 | 61 | II.0 | 0.75 | 207 | 274 | 3.6 | 16.2 |
| | 1979 | 67 | I.9 | 0.78 | 342 | 234 | 3.4 | 16.5 |
| | 1989 | 77 | I.9 | 0.76 | 305 | 256 | 3.3 | 14.86 |
| | 1999 | 82 | II.0 | 0.73 | 244 | 278 | 3.0 | 13.97 |
| | 2011 | 92 | II.0 | 0.72 | 262 | 272 | 2.9 | 13.24 |
| | 2020 | 99 | II.0 | 0.64 | 251 | 251 | 2.5 | 11.45 |
| Black alder | 1959 | 43 | I.2 | 0.73 | 208 | - | 5.2 | 0.3 |
| | 1967 | 37 | I.1 | 0.70 | 209 | 255 | 5.4 | 0.3 |
| | 1979 | 33 | I.2 | 0.75 | 267 | 153 | 5.1 | 0.3 |
| | 1989 | 40 | I.0 | 0.73 | 304 | 188 | 4.9 | 0.38 |
| | 1999 | 43 | I.2 | 0.73 | 184 | 273 | 4.3 | 0.33 |
| | 2011 | 48 | I.3 | 0.70 | 207 | 235 | 4.3 | 0.39 |
| | 2020 | 55 | I.6 | 0.65 | 216 | 250 | 3.9 | 0.38 |
| Total | 1959 | 46 | I.7 | 0.71 | 169 | 273 | 3.7 | 26.9 |
| | 1967 | 51 | I.7 | 0.76 | 187 | 270 | 3.8 | 29.9 |
| | 1979 | 57 | I.7 | 0.77 | 219 | 219 | 3.9 | 31.40 |
| | 1989 | 67 | I.8 | 0.75 | 255 | 255 | 3.9 | 30.68 |
| | 1999 | 72 | I.8 | 0.72 | 248 | 276 | 3.4 | 27.80 |
| | 2011 | 81 | I.8 | 0.73 | 272 | 293 | 3.4 | 27.92 |
| | 2020 | 86 | I.8 | 0.66 | 267 | 280 | 3.1 | 25.58 |

The decrease in density of stocking is caused by diseases, increased mortality, which is confirmed by monitoring data. Analysis of average forest evaluation indicators showed that most stands, especially target (pine, oak) are in old age. Only common ash and small-leaved linden are middle-aged. Fast-growing tree species, such as poplars, willows, black locust are generally in old age. All this indicates the aging of stands, which in turn affects in addition to the reduction of average forest evaluation indicators and the average change in growing stock.

Generally, for the enterprise, the maximum value of average stock change (3.9 $m^3$ $ha^{-1}$) was observed in the 1970s and 1980s, when the stands were about 60 years old. At the time of the last forest inventory (2020), this figure decreased by 0.8 $m^3$ $ha^{-1}$, and the average age is 86 years.

Analysis of individual, target, economically valuable tree species indicates the same trend. Thus, the general loss for pine is 0.5 $m^3$ $ha^{-1}$, for oak is 1.1 $m^3$ $ha^{-1}$, and alder in general 1.5 $m^3$ $ha^{-1}$ (comparing to the maximal values during studied period)

All these values indicate a decrease in the annual stock change, which in turn reduces the absorption of greenhouse gases and oxygen production.

## Forest monitoring data

Intensive monitoring plots represent mature Scots pine and overmature English oak stands of the Skrypaivske ERF. Considering relative long history of observations monitoring data gives valuable information on health condition and productivity dynamics.

**Table 6.** Dynamics of forestry indicators at intensive monitoring plot №2263079 (pine).

| Indexes | Years | | | | |
|---|---|---|---|---|---|
| | 2005 | 2009 | 2013 | 2017 | 2021 |
| Age, years | 85 | 89 | 93 | 97 | 101 |
| Mean diameter, cm | 31.2 | 31.7 | 32.8 | 33.1 | 34.1 |
| Mean height, m | 27.2 | 28.0 | 28.3 | 28.5 | 28.9 |
| Density of stocking | 0.68 | 0.66 | 0.70 | 0.70 | 0.65 |
| Canopy closure, % | 58 | 55 | 56 | 55 | 55 |
| Basal area, $m^2 \cdot ha^{-1}$ | 34.7 | 34.0 | 36.1 | 35.0 | 33.8 |
| Growing stock, $m^3 \cdot ha^{-1}$ | 414 | 410 | 442 | 426 | 423 |
| Dead wood, $m^3 \cdot ha^{-1}$ | 11.7 | 0.0 | 7.2 | 64.8 | 74.6 |
| Annual increment, $m^3 \cdot ha^{-1} \cdot year^{-1}$ | - | 8.2 | 9.1 | 6.7 | 5.6 |

At the intensive monitoring plot (No. 2263079), located in Scots pine stand, observations are carried out since 2005. The growing stock for the period 2005-2021 varied from 410 $m^3 \cdot ha^{-1}$ to 442 $m^3 \cdot ha^{-1}$. Sanitary felling in the stand was held in 2008. In 2017, there was a significant decrease in the total growing stock of the stand due to trees mortality, associated with natural aging and bark beetles caused by changes in the microclimate as consequence of the clear cut in 2013 in the neighbouring site (Table 6). At the same time accumulation of deadwood is observed on site. The general trend for last five years is decreasing of growing stock and annual increment and accumulation of deadwood.

**Table 7.** Dynamics of tree health condition indicators at intensive monitoring plot No. 2263079 (pine).

| Indicators | Years | | | | |
|---|---|---|---|---|---|
| | 2005 | 2009 | 2013 | 2017 | 2021 |
| Health condition index, (HCI) | 1.09 | 1.05 | 1.13 | 1.14 | 1.42 |
| The share of damaged trees, % | 2.7 | 2.9 | 9.5 | 8.6 | 5.8 |
| The average crown density, % | 74.1 | 74.4 | 70.2 | 70.0 | 70.0 |
| Average crown dieback, % | 0.6 | 0.3 | 0.8 | 2.5 | 3.0 |
| Average defoliation, % | 6.0 | 5.6 | 7.6 | 7.5 | 12.0 |

The health condition of the studied pine stand is satisfying according to all indicators, but it tends to deteriorate, especially during 2017-2021: the health condition index significantly increased from 1.14 to 1.42, the average defoliation from 7.5% (healthy) to 12.0% (weakened) (Table 7). Comparing to the 2005 and 2009 data the share of damaged trees during last decade significantly increased. The most frequent damage type is resin flow, which more often is the sign of stem bark beetles attack. Recent decrease in 2021 in the share of damaged trees from 8.6 to 5.8% is explained by mortality of some trees, which in 2017 were damaged.

Intensive monitoring plot № 2263072 is located in overmature oak stand (Table 8). In 2016 (Table 9) health condition of the oak stand (№ 2263072) was weakened (HCI was 2.3), deterioration of health condition was observed at oak trees, and most significant weakening was at Norway maple (*Acer platanoides* L.) and field maple (*Acer campestre* L.) (HCI 2.9 and 3.1 respectively), caused by Verticillium wilt (Pasternak, et. al., 2017). Such disease was registered in many forest stands of Kharkivska oblast (Meshkova and Davydenko, 2016). Damaged maple trees had significant crown dieback.

**Table 8**. Dynamics of forestry indicators at the intensive monitoring plot No. 2263072 (oak).

| Indicator | Years | | | | |
|---|---|---|---|---|---|
| | 2004 | 2008 | 2012 | 2016 | 2020 |
| Age, years | 110 | 114 | 118 | 122 | 126 |
| Mean diameter, cm | 37.8 | 38.4 | 38.8 | 39.6 | 41.5 |
| Mean height, m | 28.1 | 28.3 | 28.5 | 28.8 | 29.0 |
| Basal area, $m^2 \cdot ha^{-1}$ | 31.5 | 31.4 | 30.6 | 26.0 | 23.4 |
| Density of stocking | 0.85 | 0.84 | 0.82 | 0.75 | 0.68 |

| | | | | | |
|---|---|---|---|---|---|
| Growing stock, $m^3 \cdot ha^{-1}$ | 361 | 363 | 356 | 301 | 271 |
| Dead wood, $m^3 \cdot ha^{-1}$ | 4.4 | 17.6 | 14.5 | 18.6 | 30.6 |
| Annual increment, $m^3 \cdot ha^{-1} \cdot year^{-1}$ | - | 2.5 | 1.9 | 1.8 | 1.7 |

**Table 9.** Dynamics of the health condition index of living trees at intensive monitoring plot (oak) in 2012-2020.

| Tree species/ year | Health condition index | | |
|---|---|---|---|
| | 2012 | 2016 | 2020 |
| *Quercus robur* L. | 1.4 | 1.8 | 1.3 |
| *Fraxinus excelsior* L. | 1.6 | 1.4 | 1.2 |
| *Acer platanoides* L. | 1.2 | 3.1 | 2.4 |
| *Acer campestre* L. | 1.8 | 3.4 | 2.0 |
| *Tilia cordata* Mill. | 2.1 | 2.5 | 2.0 |
| *Ulmus scabra* L. | 3.0 | 1.0 | 2.0 |
| Total | 1.6 | 2.3 | 1.7 |

In 2020, the stand was characterized by a weakened health condition, although it slightly improved compared to 2016. HCI for English oak decreased from 1.8 to 1.3, for Common ash-from 1.4 to 1.2, Norway maple and field maple (from 3.1 and 3.4 to 2.4 and 2.0, respectively) due to partial restoration of the crowns, as well as mortality of severely damaged trees, but the dry branches and tops remained on trees. Part of dead trees was removed during sanitary felling, held between 2016-2020. As a result-the number of sample trees, density of stocking and growing stock on the plot decreased. Gradual decreasing of English oak participation in tree species composition is observed from 70% in 2008-2012 to 60% during last decade. As in the overmature stand there is the process of dead wood accumulation: the volume increased from 18.5 to 30.6 $m^3 \cdot ha^{-1}$ mainly due to trees mortality (see Table 8).

The analysis of the long-term dynamics of defoliation on I forest monitoring plots was performed comparing to the beginning of observations and to the average long-term defoliation. There is a general trend to increase the average defoliation over the history of observations. In 2021 at all plots average defoliation exceeded values of 2003-2005 (Table 10), and defoliation values in 2021 at two plots (312230 and 312235) were significantly higher than long-time average defoliation, which indicates a significant deterioration in the stands condition. In pine stand (plot 212234) a pathological high level of trees mortality was observed in 2016-2017 (25% of trees). This stand grows in the poor site conditions under constant anthropogenic influence: littering of the territory, frequent fires. In addition to the general trend during the observation period, in some years annual defoliation values exceeded long-term values: in pine stand at plot 312234-highest defoliation was registered in 2011, 2016 and 2017; at plot 312230-in 2007, 2020 and 2021. In oak stand (312235) highest values of average defoliation were observed in 2003-2004 (associated with foliage browsing insects) and 2021.

**Table 10.** Dynamics of average defoliation at I level monitoring plots.

| Plot | Period | | | | | Long-time average* for 2003-2021 |
|---|---|---|---|---|---|---|
| | 2003-2005 | 2006-2010 | 2011-2015 | 2016-2020 | 2021 | |
| 312230-pine | 12.5 | 12.5 | 10.2 | 11.7 | 13.9 | 11.8 ± 1.3 |
| 312234-pine | 8.4 | 10.2 | 10.3 | 13.8 | 9.4 | 11.4 ± 1.3 |
| 312235-oak | 8.4 | 9.1 | 10.0 | 9.9 | 11.8 | 10.1 ± 0.6 |

*average value ± confidence interval (95%)

Forest monitoring data also showed that recent years the percentage of damaged and drying trees has increased significantly. Trees damage were recorded in all plots, but in pine stands about 1-2 trees have damage signs (mainly resin flow), while in oak stand-58.3% of trees. The most widespread damage types of deciduous stands are: oak powdery mildew, crown dieback, and stem rots. In oak stand maximal damage (70% of sample trees) was registered in 2015-2016, then decreased slightly, at pine stands the trend to deterioration of health condition is observed since 2018.

Last years, pine decline in different regions of Ukraine caused by the outbreak of bark beetles *Ips acuminatus* (Gyllenhal, 1827) and *Ips sexdentatus* (Börner, 1776) was registered (Meshkova, 2021). It caused significant deterioration of heath condition of pines, increasing of their defoliation damage and mortality.

Main causes of forest decline in Ukraine are shortcomings of forest management in the past, global climate change, and increasing anthropogenic loading (Meshkova, 2021). According to the IPCC (2014) further climate change is expected. The study (Buksha, et al, 2017) predicted negative consequences for forests in Ukraine: shifting of nature climatic zones and natural ranges of forest forming species, especially for Scots pine. Our research showed that climate effect on forests is already observed: significant changes in species composition, decreasing of stands health condition and productivity. In current conditions it is necessary to improve forest management practice, by growing mixed forest, proper thinning and sanitary felling, to monitor pests and diseases foci.

## Conclusions

The analysis of the forest fund for the 70-year period indicates the deterioration of indicators in the enterprise, caused by various factors (climatic, anthropogenic, economical).

Aging of forest stands and deterioration of their health condition, as well as trend to change of dominant tree species was revealed for the last decade. Areas of Scots pine, English oak, and aspen stands decreased, while the areas of other deciduous stands, especially black locust, small-leaved linden, common ash, and black alder, significantly increased.

The biggest problem that need to be solved is the rejuvenation of stands, as there is an accumulation of mature and overmature stands that lose their productivity and ecological functions. In addition, it is necessary to grow mixed forest stands from native tree species and control non native black locust distribution, to provide forest biodiversity conservation, and other environment functions.

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