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SHORT COMMUNICATION

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The introduction of red oak (*Quercus rubra* L.) in Ukrainian forests: advantages of productivity versus disadvantages of invasiveness

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Abstract

The history and dynamics of the introduction of red oak into forest plantations in Ukraine are presented. The positive and negative consequences of this artificially introduced species are characterised. The anthropogenic factor of a broad representation of the species and the probability of low natural spread out outside the existing plantations are highlighted. The current data on the area of red oak plantations by administrative regions, forest categories, types of forest site conditions and age classes in Ukraine are indicated. The possibility of controlling and limiting the adverse invasive effects of red oak representation in forest stands is pointed out. It is recommended to conduct detailed and systematic interdisciplinary research on the degree of red oak invasiveness impact in Ukraine and effective forest care treatments for controlling its negative role.

Key words

forest ecology, eastern Europe, introduction, *Quercus borealis* Michx.

Red oak (*Quercus rubra* L. or *Quercus borealis* Michx.) is a North American forest tree species. The natural distribution range of red oak ranges from the provinces of Ontario and Quebec (Canada) in the north to the states of Minnesota and Nebraska in the west and the state of Georgia (USA) in the south (Hordiienko and Hordiienko 2005; Fig 1). In Europe, red oak was introduced for the first time as an ornamental tree species in Switzerland in 1691 y. (Nagel 2015) and later on in Belgium and Holland. The introduction of red oak into forest stands began in the late 19th century.

In Ukraine, *Quercus rubra* L. was firstly introduced in 1809 in Krasnokutskyi Park in Kharkiv administrative region (Kokhno and Kurdiuk 1994). In the

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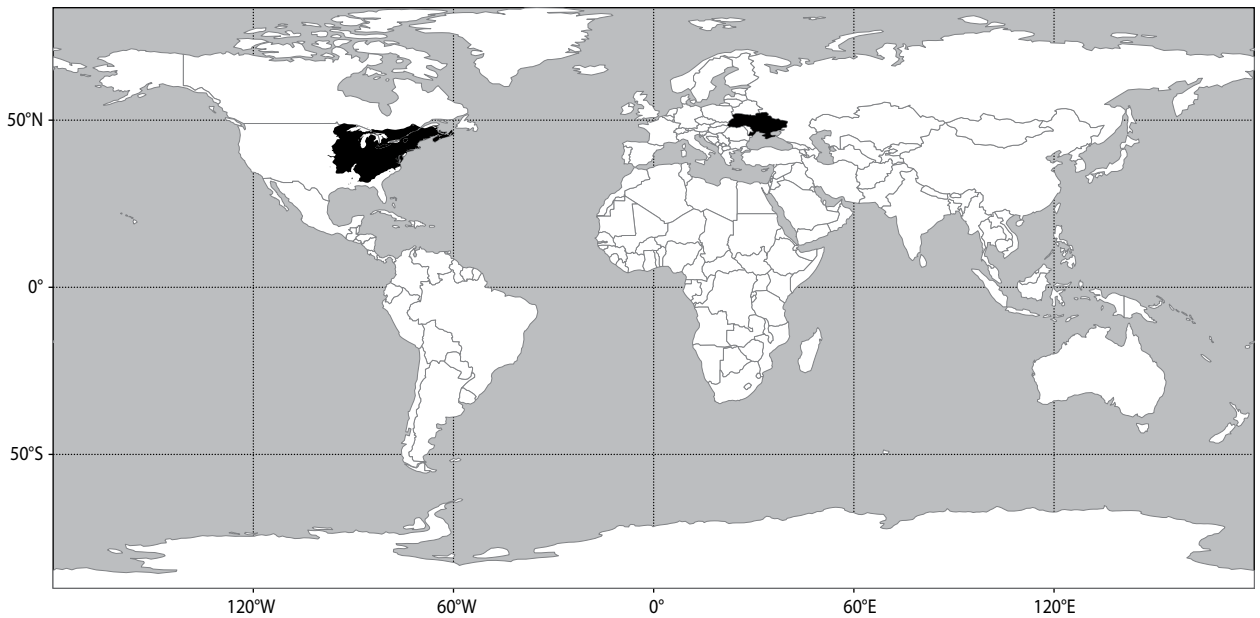

Figure 1. The natural distribution range of red oak (black fill area in North America) and Ukraine territorial map (black fill area in Europe)

middle of the 19th century, red oak was also planted in other parks and arboretums of Ukraine. Thus, there are a number of old red oaks in Ukraine. For example, in the Trostianets Arboretum of the Chernihiv administrative region, one of the largest red oaks is characterised by a height of 25 m and a trunk diameter of 73 cm at the age of 93 years (Mysnyk 1962). In one of the parks of the Zhytomyr administrative region, a 130-year-old red oak reached a height of 26 m and a trunk diameter of 76 cm (Lytvak and Komarov 1992).

In Ukraine, mass introduction of red oak into forest tree stands began in 1959, after the decision of the Main Directorate of Forestry and Logging of the Ukrainian SSR (Protsenko et al. 2019). At the beginning of the 21st century, red oak stands covered an area of more than 45,000 ha. As a result, this species became the most frequently introduced forest tree species in Ukraine. Most of the forest stands with red oak as the main tree species were established in the western part of the country, especially in Lviv, Ivano-Frankivsk and Ternopil administrative regions (Kahaniak 2002; Shvets et al. 2001). In terms of natural and climatic zones, 80% of the red oak stands were established in forest-steppe, 17% in Polissia and 3% in steppe. The red oak has been introduced, not only into forests with an economic function, but also into forests with a protective function (Husak 1989; Protsenko et al. 2019). In protective forests, red oak has been used to establish tree stands to protect against natural erosion, and to restore soil on artificially damaged areas. The species is also used to establish field protection strips or runoff control paths.

In its natural distribution range, red oak grows in almost all topographic positions. On the lower and middle parts of northern and eastern slopes, on the banks of rivers on soils without standing water the best growth of the species is observed. On the slopes of the southern Appalachians, it reaches up to an elevation of 1,680 m above sea level. On good quality sites, in natural growing conditions, the red oaks matured trees are characterised usually from 20 to 30 m tall and 61 to 91 cm, in diameter. (Eisenreich 1959; Sander 1990). In the natural distribution range of red oak, the average precipitation varies from 750 to 2000 mm per year (Kholyavko 1981). This may explain, the low level of introduction of this species in the eastern part of the European Plain.

In Ukraine, red oak grows in almost all natural and climatic zones of the country, except for the mountainous regions of the Carpathians and the Crimea. In Ukrainian growing conditions, the species is characterized by high winter hardiness, undemanding soil fertil-

ity and intensive growth in young stage. On moist sod-podsol soils, red oak grows 1.5 or even 2 times faster than the common oak, so the productivity of its plantations at the age of 40–45 years is 30%–40% higher than native species (Hordiienko and Hordiienko 2005).

An important factor in the biocenotic competitiveness of red oak is the intensive development of the root system in the upper, most nutrient-rich soil horizons. Thus, 50%–53% of fine roots (the most physiologically active roots) are concentrated in the upper part of the 25-cm-thick soil layer (Hordiienko and Hordiienko 2005). Sander (1990) reported the same structure of the root system of red oak in the natural distribution areas. The studies which were conducted in eastern Ukraine (Luhansk administrative region; Hrybachova 2014) suggest that red oak grows better than common oak on soils with lower moisture and humus content. Geochemical studies report that red oak takes up more nutrients from the soil compared to common oak, while it returns less nutrients to the soil during the organic precipitation process.

The large-scale introduction of red oak into the forest ecosystems in Ukraine and throughout Europe in the 20th century is explained by its fast characteristics of growth. Thus, monocultures of red oak can reach productivity of up to 600 m^3 per 1 ha at the age of 60 years (Debryniuk and Fuchylo 2020; Majboroda 2009). Red oak, which masts almost annually and is practically free of diseases and pest species, spreads rapidly throughout Europe and competes with native oaks and some other species (Ivchenko 2002).

The high intensity of fruiting is one of the main characteristics of this exotic tree species, which determines its high invasiveness. Red oak forms well-developed matured seeds from the age of 20 to 25 years and has mast years every 2–3 years. In addition, the germination capacity of its seeds is 2–3 times higher than that of common oak, and it is practically not infested by the acorn beetle (*Curculio glandium*; Kholyavko 1981). Fortunately, the weight of red oak seeds and their exclusively zoochoric distribution is a limiting factor in the distance of their spread out range from the mother trees.

In the forests of the Nature Conversation Fund, controlling the invasion of red oak is the most urgent problem. Currently, *Quercus rubra* L. is more often blacklisted by scientists as an invasive species that poses a threat to natural plant diversity, especially in the objects of the Nature Conversation Fund of Ukraine (Zavialova 2017).

It is observed that the displacement of common oak by red oak may significantly reduce the biodiversity of forest ecosystems. The comparative characteristics of the consortia composition of these two species clearly favour common oak (491 vs. 18; Leshchenko and Benhus 2017). Polish scientists and practitioners also note that species diversity in forest ecosystems decreased after the introduction of red oak (Woziwoda et al. 2014). Considering into account the role of this species in forest ecosystems, the authors also emphasise the possibility of finding a trade-off between the negative and positive effects of red oak introduction and the need for interdisciplinary research on this problem.

In Ukraine site conditions, the opinion about the invasiveness of red oak is valid, but it is confirmed mainly in certain forest site conditions, for example, in rich and wet forest sites, or in cases where timely and effective forest care treatments were not implemented. At the same time, it should be noted that planting the species in mixed coniferous forests (forests with soil fertility index B, i.e. relatively poor or sandy soils) on the left bank of Ukraine does not threaten local flora (Pozniakova and Shvydenko 2021). On the right bank soreststeppe, there are also recommendations to introduce red oak into forest plantations, but only under conditions that are less favourable for common oak, for example, in fresh and moist mixed coniferous forests (B2, B3) and fresh mixed deciduous forests (C2; Yurkiv 2015).

The results of experimental studies conducted in Poland have shown that it is possible to control the limiting factors of invasive spread out of red oak (Jagodziński et al. 2018). The treatments refer to: i) natural regeneration lighting, ii) soil moisture and richness and iii) acorn spread out. Chmura (2020) noted the negative effects of red oak on diversity in forests. However, the author also emphasises the important role of forest care treatments in the process of natural regeneration and spread out of this species.

One of the main characteristics of invasive species is their ability to spread out to new areas and occupy new ecological niches. The study conducted in Lithuania (Riepðas and Straigyte 2008) revealed an average degree of spread out of red oak. Thus, under conditions with rich soil fertility, 100 naturally regenerated seedlings per hectare were found at a distance of 100 m from

the red oak stand. Under conditions with average soil fertility, 350 naturally regenerated seedlings per hectare were found. Considering the photophilicity of the red oak understory, this level of natural regeneration is not sufficient to allow intensive spread out of the species beyond the cultivated areas.

It is believed that red oak in Spain, France and Great Britain does not completely fill the potential ecological niches, while in Central Europe, the filling is more complete. Climatic niches for the invasive spread out of red oak are reported to be wider in northern regions of Europe (Gentili et al. 2019).

Red oak is a zoochore species, its acorns are spread out exclusively by animals. The sowing distance depends on the animal species that disperses the acorns (birds are able to carry seeds over a much wider distance). Bieberich (2016) found that jays (*Garrulus glandarius* L.) do not actively disperse acorns of *Quercus rubra* L., while mice do disperse acorns, but usually only over short distances. This is evidence that the intensity of spatial invasion of red oak is not high under controlled conditions.

The degree of invasiveness of a species is also determined by the degree of natural regeneration. In general, the survival rate of naturally regenerated seedlings of red oak is low and similar to that of common oak. According to Dyderski and Jagodziński (2019), only 12.5% of naturally regenerated seedlings survive after 1 year of growth.

Nagel (2015) considers the red oak to be a non-invasive species. The author explains this by the inefficiency of the dispersal vectors, the inability to regenerate through root sprouts and the high risk of young seedlings being eaten by wild fauna. In addition, in the European Union based on Regulation (EU) 1143/2014, the Consolidated List of Invasive Alien Species is established. According to this list, the red oak is not recognised as an invasive alien species.

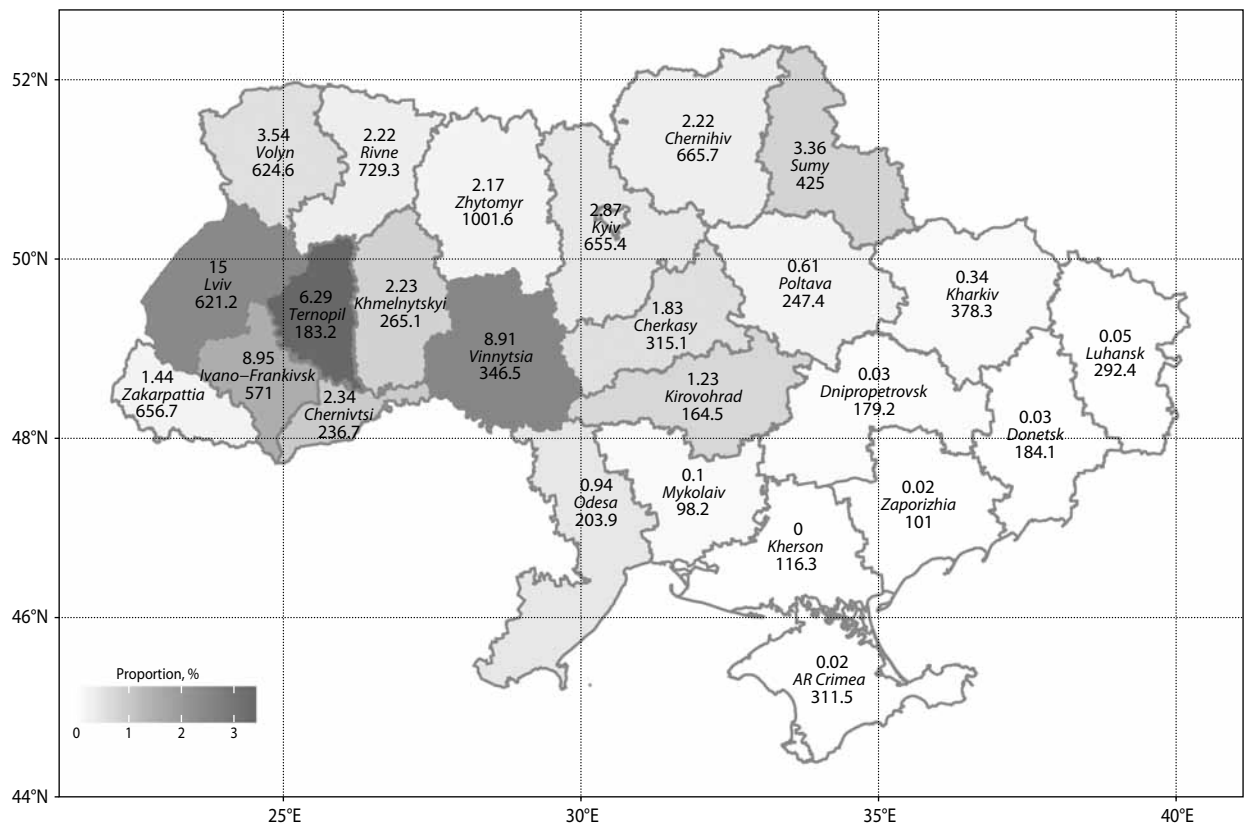

Figure 2. Distribution of red oak (*Quercus rubra* L.) tree stands in the administrative regions of Ukraine. Number in the numerator – the total area of red oak tree stands, thousand hectares; number in the denominator – the total area of forests, thousand hectares; grey fill intensity denotes the proportion of red oak tree stands to the total area of forests

According to the data of the last forest inventory in Ukraine (January 2020), the total area of the tree stands with red oak as the main tree species is 66.72 thousand hectares. The largest number of such stands are inventoried in the forest areas of Lviv (15 thousand hectares), Ivano-Frankivsk (8.95 thousand hectares), Vinnytsia (8.91 thousand hectares) and Ternopil (6.29 thousand hectares) administrative regions. For these regions, their share in the total area covered by forests is the largest (1.6%–3.4%; Fig. 2). While in two other western administrative regions, Rivne and Volyn, the share of forests with red oak is much lower, from 0.3% to 0.6%. Also, in the Sumy administrative region at the east of the country, many such tree stands with red oak participation are observed (3.36 thousand hectares). While in other eastern administrative regions, as well as in southern administrative regions, tree stands with the red oak as the main species are very rare. Furthermore, in the Kherson region, such tree stands are not inventoried.

The majority of red oak tree stands were established for commercial purposes (33.25 thousand hectares). Also, quite a lot of red oak tree stands are found in forests that possess recreational and social health functions (15.65 thousand hectares or one-fourth of the red oak tree stands in the country). Red oak tree stands are also found in forests that serve protective purposes (9.51 thousand hectares) and forests that serve nature protection, scientific, historical and cultural purposes (8.31 thousand hectares; Fig. 3A).

According to the distribution of red oak tree stands from the point of view of forest site condition, the dominant topology indexes are D2 and D3 (fresh and wet deciduous forests, respectively; Fig. 4). Unfortunately, these are also the forest site conditions of the very valuable and native species, which is common oak, so the red oak species is a serious competitor. In our opinion, it is necessary to exclude forest site conditions D2 and D3 from the potential site plantation of red oak cultivation. A possible solution for the limited introduction of red oak can be fresh and wet deciduous mixed forests (C2 and C3, respectively); however, mandatory application of measures to control the invasiveness of the species is needed. Currently, there are 18,000 ha of red oak tree

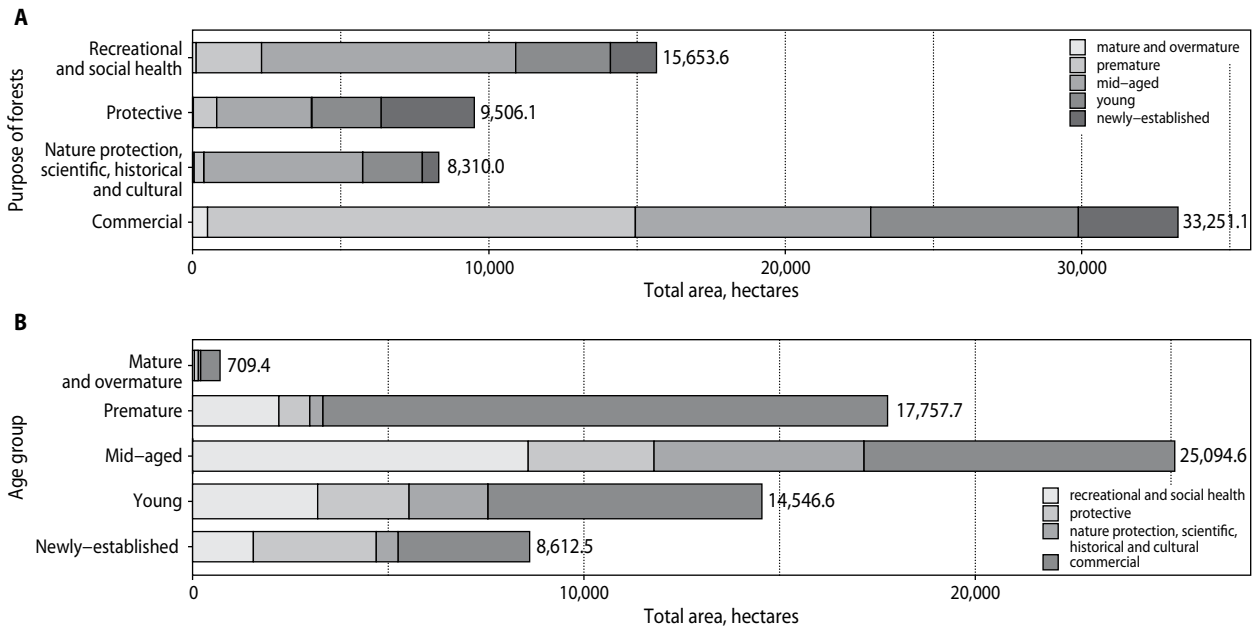

Figure 3. Distribution of the total area of red oak tree stands according to their purposes (A) and age groups (B). The age groups of red oak tree stands differ in age according to the serving functions: Newly established – 1–10 years old for all purposes; young – 11–20 years old for all purposes; mid-aged – 21–60 years old for forest stands with a commercial purpose, 21–70 years old for other purposes; premature – 61–70 years old for forest stands with a commercial purpose, 71–80 years old for other purposes; mature and overmature – older than 70 years for forest stands with a commercial purpose, older than 80 years for other purposes

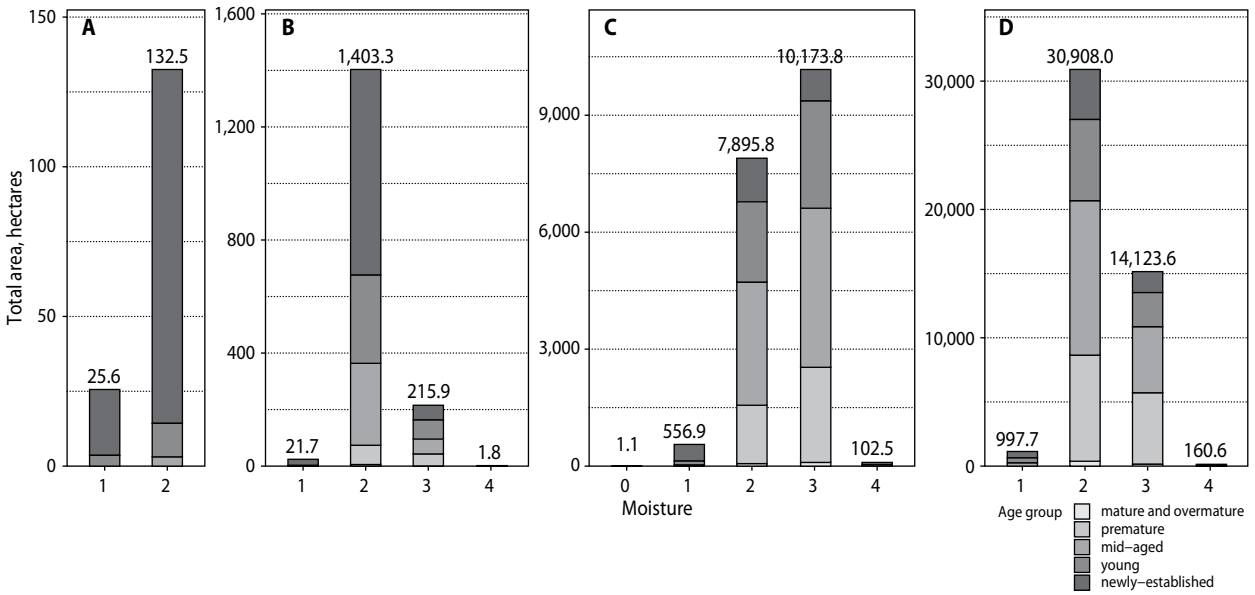

Figure 4. Distribution of the total area of red oak tree stands by forest site conditions. Forest site conditions adopted from Pohrebniak (1955). Soil fertility indexes: A – poor soils, B – relatively poor or sandy soils, C – relatively rich soils, D – rich soils. Moisture indexes: 0 – very dry, 1 – dry, 2 – fresh, 3 – moist, 4 – wet, 5 – boggy. Age groups are the same as in Figure 3

stands that grow in such conditions. In the poorer trophic site conditions of mixed coniferous and coniferous forests, the share of red oak tree stands is significantly lower (Fig. 4).

The age structure of red oak tree stands, which shows the history of the intensity of red oak introduction in the past, is presented in Figures 3 and 4. During the last 10 years, the intensity of the introduction of red oak into forest tree stands decreased. The ratio between the area of young tree stands (11–20 years old) and newly established tree stands (1–10 years old) is currently 14.55 versus 8.61 thousand hectares, respectively (Fig. 3B), while the intensity of special introduction has not decreased in forests which are defined for protective functions. In these forests, the area of newly established tree stands is more than 1.3 times higher in comparison to young tree stands (3.14 vs. 2.34 thousand hectares, respectively; Fig. 3); the reason is that red oaks are used for establishing tree stands with soil protection functions.

The majority of red oak forest tree stands (25.09 thousand hectares; Fig. 3B) are mid-aged, where the age of forests with a commercial purpose is 21–60 years old and for all another functions of forests is 21–70 years old. There are also 17.56 thousand hectares of premature red oak tree stands, where the age of forests with a commercial purpose is 61–70 years old and for all another purposes of forests is 71–80 years old. Thus, the second half of the 20th century was the period of large-scale artificial invasion of the species into Ukrainian forests, while the presence of a certain area of mature and overmature stands of red oak indicates that the relatively

Table 1. Measures to limit and control the invasive impact of red oak

1.	Prohibition of the introduction of red oak in the categories of forests with limited and special regimes of forest use
2.	Limited introduction of red oak in types of habitat conditions where this species is not a competitor for native main forest-forming species
3.	Creation of red oak forest plantation with a short rotation period
4.	Controlling the invasive spread out of red oak in neighbour tree stands by maintenance of felling
5.	Selection of red oak for the target trait – reduced reproductive capacity
6.	Application of species rotation after the felling of mature red oak stands and forest plantations with short rotation period

wide primary introduction of red oak into forest began even before the Second World War.

In the last decades, regarding introduced forest species including the red oak species, the forest policy of Ukraine has been redefined. Taking into account the ecological evidence of the disadvantages of the invasion of red oaks, an important role was fulfilled by requirements under the Forest Stewardship Council (FSC) law conditions for compliance with sustainable forestry management criteria. Thus, the scale of the introduction of this species has been decreased. Currently, the red oak species is introduced only in cases where it is possible to control its spread out to new areas. A set of measures and tools can be used to control this process (Tab. 1).

In summary, the need to develop large-scale research methods to assess the level of invasiveness of red oak in Ukraine and develop ways to prevent its uncontrolled wide spread out and other negative effects on ecology should be highlighted.

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