Distribution, productivity and natural regeneration of black alder (*Alnus glutinosa* (L.) Gaertn.) in Ukrainian Polissya

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Abstract

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The aim of the study was to assess the current state and productivity of black alder (*Alnus glutinosa* (L.) Gaertn.) stands and determine the optimal conditions for the emergence and further growth of its natural regeneration in Ukrainian Polissya. The area of black alder stands in Ukrainian Polissya (Ukrainian forest zone) is 162,348 ha, reaching 8.4% of the total forest area. Volyn Region has the largest area of alder stands within Ukrainian Polissya (61,271 ha covering 37.7% of the total area). In the forests of this region, a more detailed study of the current condition, productivity, growth and regeneration of alder stands was performed. The natural regeneration under the alder canopy was characterized as poor. The largest numbers of alder seedlings (1,600–1,800 stems per ha) were recorded under the canopy of 76–78-year-old stands with a relative density of stocking of 0.63–0.70 and 80–100% of alder in their composition. Naturally regenerating alder seedlings had mainly group distribution on the area (occurrence is up to 40%). These specificities should be taken into account to promote natural seed regeneration of alder stands.

Keywords

forest site type, growth class, relative density of stocking, stand composition, stand origin, Ukrainian Polissya

Introduction

The genus *Alnus* Mill. includes more than 30 species and belongs to the birch (Betulaceae) family (Shchepotiev, 1990). In the European forests, *A. glutinosa* (L.) Gaertn., *A. incana* (L.) Moench, *A. cordata* Desf., *A. orientalis* Decne. and A. viridis DC. are widespread (Gordiyenko and Gordiyenko, 2005; Claessens et al., 2010).

Black alder is naturally spread throughout Europe from Scandinavia to the Mediterranean countries (Fig. 1); it occurs in Western Siberia, Kazakhstan, Asia Minor, North Africa (Kajba and Gracan, 2003; Houston Durrant et al., 2016). In Ukraine, black alder stands are concentrated mainly in Polissya (forest zone in Ukraine) and Forest-Steppe zone; they are almost absent in the Steppe zone. Alder stands are located within the floodplains of large rivers such as the Dniester, Southern Bug, Dnieper, Siversky Donets, etc. (Minarchenko, 1996; Kotlyarevska, 2016).

The species prefers moist and wet lands, often forming pure and mixed forests. Alder trees grow along rivers, ponds, lakes on various soil types, including poor ones (Grigora, 1976; Kravchuk, 2009; Claessens et al., 2010; Sakalli, 2017; Slezák et al., 2017, 2020). In the mountainous regions of Central Europe, the species is found at an altitude of 1,500–1,800 m above sea level. The optimal precipitation amount for it is 800–860 mm per year. The trees can reach a height of up to 30 m and 40 m in very rare cases, having a diameter of 50 cm and more, and live up to 100–120 years (Kajba and Gracan, 2003; Jakubisová et al., 2013; Zayachuk, 2014).

Black alder is a light-demanding and frost-resistant tree species; however, it is very sensitive to early spring frosts at a young age (Davidov, 1979; Kharchuk, 1995). The root system

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Fig. 1. Native range of black alder (in blue) (Euforgen, 2009).

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is shallow; the trees do not have taproots (Jakubisová et al., 2013). In favorable site conditions, alder grows rapidly in the early stage of life (7–10 years), with the height growth rates up to 1 m per year (Davidov, 1979; Storozhenko, 2009; Claessens et al., 2010).

Alder is often affected by stem and root rots (Kharitonova, 2011; Arhiopova et al., 2012). At the end of the twentieth century, a new disease caused by *Phytophthora alni* was detected in alder trees, the symptoms of which are black spots on the leaves and small yellowish leaves (Brasier et al., 1995). The disease onset may be associated with fluctuations in groundwater levels, especially during the growing season (Tulik et al., 2020). Besides, alder forests are also characterized by a high fungal species diversity. For example, in black alder alluvial forests in Slovakia, 236 macromycetes species and 13 slime molds were found, in total 249 taxa belonging to Myxomycota, Zygomycota, Ascomycota, and Basidiomycota (Mihál and Blanár, 2014).

Alder, growing along rivers and water bodies, is essential for water and bank protection (Claessens et al., 2010; Jakubisová et al., 2013; Vacchiano et al., 2016; Slezák et al., 2020). It can also be recommended for planting in brackish coastal areas (Deptuła et al., 2020). It accelerates the restoration of soil structure on compacted forest soils, as its roots can grow under anaerobic soil conditions (Jakubisová et al., 2013; Warlo et al., 2019). Black alder plays an essential role as an air-purifying and environment-improving species. The trees release volatile compounds that can destroy harmful microorganisms (Kharchuk, 1995; Gordiyenko and Gordiyenko, 2005). Alder can increase the phosphorus availability in the soil (Giardina et al., 1995). The species has the highest carbon-absorbing capacity of 60–100 t ha^{-1} (Moroz et al., 2016). It is also valuable because of its availability to release nitrogen into soil through nodules on its roots (Davidov, 1976; Didur, 2008). Alder leaves contain about 3% of nitrogen being superior to any other species (Dawson and Funk, 1981; Pérez-Corona et al., 2006). According to Moiroud (1991), alder stands enrich the soil with nitrogen from 30 to 130 kg ha^{-1} per year after leaf fall. For this reason, alder is used for afforestation on reclamation sites (Cote and Camire, 1984; Roy et al., 2007; Euforgen, 2009; Kuznetsova et al., 2011; Brovko and Brovko, 2013; Jakubisová et al., 2013; Sroka et al., 2018).

Seed regeneration of black alder is complicated in many cases by the specific habitat conditions (Kravchuk, 2009; Storozhenko, 2009; Oborska, 2015). In recently felled areas, seed regeneration of alder is somewhat better for sites that felled in winter after the harvest year (Gordiyenko and Gordiyenko, 2005). Alder trees regenerate mainly via stump sprouts (Rytter et al., 2000). Alder retains the stump growth capacity until the age of 90, but the maximum shoot regeneration occurs at 60–70. The fact that only the shoots of the first generation produce high-yielding stands should be born in mind. The stumps of trees originated from seeds, without heart rot damage, produce the largest numbers of shoots (Stepanchik, 1982; Storozhenko et al., 2007; Shvachka, 2009; Storozhenko, 2009; Oborska, 2015).

Black alder wood is widely used in veneer and plywood production (Claessens et al., 2010). In Ukraine, 43.4% of plywood is produced from alder (Romanyuk, 2010). Alder wood is also used for furniture and cabinets as well as in underground and underwater constructions (Davidov, 1979; Claessens et al., 2010).

In medicine, alder is used as an astringent, anti-inflammatory and hemostatic agent (Muzyka and Hrytsiak, 2014; Karamatov and Aslanova, 2017).

Thus, black alder is a valuable forest-forming tree species in the Polissya and Forest-Steppe zones in Ukraine. It is practically the only species that can form highly productive stands under excessive moisture. Rapid growth, multiple

Fig. 2. Study region.

uses of wood, the significant ecological role of alder forests in air purification, and high intensity of carbon capture give grounds to consider black alder as a promising tree species. Therefore, the information about the current state of alder forests, including their occurrence, origin, forest site types, age, as well as averages of the main stand parameters, productivity, and features of natural regeneration, is of utmost importance.

The aim of the study was to assess the current state and productivity of black alder stands to determine the optimal conditions for the emergence and further growth of its natural regeneration to contribute to the reproduction of productive black alder stands.

Materials and methods

Black alder stands covering 162,348 hectares within six administrative regions in the Polissya zone in Ukraine, namely Volyn, Rivne, Zhytomyr, Kyiv, Chernihiv, and Sumy Regions (Fig. 2), were used for the study. The stands are managed by the State Forest Resources Agency of Ukraine. The study covered different in origin – coppice, naturally originated from seeds (self-sown) and artificially seeded – pure and mixed stands.

The study involved a combination of field observations and analysis of forest inventory materials (as of 2017). The subcompartment database from forest inventory materials served as a basis for the relevant calculations. The database contains the following information on each forest plot: location (state enterprise, forestry, compartment, and subcompartment), origin, age, composition, average height, average diameter, the relative density of stocking, quality class, forest site type, area, and stand volume. A total of 57,843 plots of alder stands within Ukrainian Polissya were analysed, including 18,596 plots of alder stands within Volyn Region. The data were processed using Microsoft Excel software.

The emergence and further growth of natural regeneration of black alder and other economically valuable species were studied under the stand canopy in 17 sample plots, in the stands aged from 33 to 78 (Table 1). The stands had different relative densities of stocking (from 0.58 to 0.86) and volumes. In our study, we estimated the stocking, i.e. the ratio between the actual and maximum stand basal area defined for the corresponding site quality and stand age (Barna et al., 2010). The data of the Ukrainian yield tables for black alder stands (Shvydenko et al., 1987) were taken as the reference for stocking of 1.0. The stand volume was defined as the volume of all living trees per unit area (m^3 ha^{-1}) (Hrom, 2007).

The sample plots were laid out in damp fairly fertile sites, which are the predominant forest site type for black alder within Volyn Region. The sizes of the sample plots were determined based on at least 200 trees of the main species on the plot. The rectangular sample plots were marked off instrumentally by measuring the angles with a Suunto compass and the sides with a measuring tape. The trees were recorded by species, determining their diameters. The tree diameters (dbh) were measured with a Codimex S-1 caliper at breast height (1.3 m above ground) with an accuracy of 0.1 cm. The average diameter of the trees was determined by dividing the total basal area of each species by the corresponding total number of stems. According to the calculated basal area of the average tree, the average diameters for all species were determined.

The tree heights were measured in field conditions using the Haglöf hypsometer. The average height of the species predominating in the stand composition was determined graphically by the average diameter of the trees of this species. To develop the height curve, we measured the heights of 25–30 trees. For the measurements, the trees were taken according to diameter classes and proportionally to the number of the trees belonging

Table 1. Mensuration characteristics of alder stands in wet fertile forest site type in Volyn Region

Sample plot number	Composition	Age (years)	Origin	Average height (m)	Average dbh (cm)	Relative density of stocking	Stand volume (m^3ha^{-1})
Stands aged from 31 to 50							
7	Alder 70%–Birch 20%–Hornbeam 10%	33	Vegetative	13.1	15.5	0.68	103
5	Alder 70%–Birch 30%+ Hornbeam	38	Vegetative	19.7	23.5	0.78	223
11	Alder 70%–Birch 20%–Ash 10%+Oak	38	Vegetative	19.2	23.6	0.74	205
10	Alder 100%	39	Vegetative	16.0	20.1	0.86	175
2	Alder 80%–Pine 10%–Birch10%	48	Natural seed	17.7	21.8	0.58	144
4	Alder 80%–Birch 20%	49	Vegetative	22.0	21.8	0.78	265
Stands aged from 51 to 70							
8	Alder 90%–Birch 10%+Pine	53	Vegetative	18.1	20.3	0.84	207
3	Alder 100%	56	Vegetative	20.4	22.1	0.69	215
1	Alder 70%–Pine 10%–Birch 10%–Aspen 10%	57	Natural seed	20.4	24.2	0.65	205
9	Alder 70%–Oak 10%–Birch 10%–Aspen 10%+Ash	58	Vegetative	23.2	26.1	0.68	250
6	Alder 80%–Birch 20%+Oak	63	Vegetative	21.2	26.1	0.63	206
12	Alder 70%–Oak 10%–Ash 10%–Birch 10%+Hornbeam, Aspen	63	Vegetative	20.9	23.8	0.82	267
Stands aged 71 and over							
13	Alder 100%	73	Vegetative	21.4	29.6	0.74	248
14	Alder 90%–Birch 10%+Oak	78	Vegetative	23.6	29.2	0.78	308
15	Alder 80%–Birch 20%+Oak, Ash	76	Vegetative	22.6	31.4	0.63	218
16	Alder 80%–Birch 20%	78	Vegetative	21.8	27.2	0.70	227
17	Alder 100%	78	Vegetative	23.2	28.4	0.66	256

Alder, black alder (*Alnus glutinosa* (L.) Gaertn.); Birch, silver birch (*Betula pendula* Roth.); Hornbeam, hornbeam (*Carpinus betulus* L.); Ash, common ash (*Fraxinus excelsior* L.); Oak, English oak (*Quercus robur* L.); Pine, Scots pine (*Pinus sylvestris* L.); Aspen, aspen (*Populus tremula* L.).

to them. For other species in the composition, the heights were measured for 10–15 trees close to a medium-sized tree.

Accounting sites of 10 m^2 (R = 178 cm), 20 per hectare (not less than 2% of the total stand area), were laid out to determine the quantities of naturally regenerating seedlings. We calculated the number of young seedlings (N, stems) per 1 ha using the formula (Equation 1):

$$N = \frac{n}{S} \times 10{,}000, \quad (1)$$

where n is the number of regenerated seedlings on the accounting sites (stems), and S is the area of the accounting sites (m^2).

Reliable young seedlings were distributed by species, age and height groups (up to 0.5 m, 0.6–1.5 m, 1.6 m and higher). Depending on the age of natural regeneration, 1-, 2-, …, and 6-year-old individuals were distinguished. Older regeneration was not included. The occurrence of each species in the natural regeneration was determined. The occurrence is a percentage of the number of accounting sites with the seedlings of the main and economically valuable species in the total number of accounting sites laid out on the sample plot. Three categories of regeneration occurrence were used: natural regeneration evenly distributed over the area (occurrence is more than 65%); natural regeneration unevenly distributed over the area (occurrence is 40–65%); natural regeneration located in groups on the area (occurrence is less than 40%).

The scale developed in the Ukrainian Research Institute of Forestry and Forest Melioration (Pasternak, 1990) was used to assess natural regeneration success. According to the scale, the available natural regeneration was doubly converted to the group of big 4-8-year-old regeneration using appropriate conversion factors for height and age. To convert the seedlings in height, a factor of 0.5 was used for small regenerating seedlings and 0.8 for medium ones. For age conversion, we used a factor of 0.7 to convert the regeneration younger than four years to the regeneration group of 4–8 years and a factor of 1.0 for the older regeneration (four years or older). After the calculations, we obtained the number of naturally regenerating seedlings in terms of big 4-8-year-old ones. Regeneration occurrence was considered for proper assessment of the natural regeneration success as well. The natural regeneration success rate was considered to be “good” if the number of reliable 4–8-year-old naturally regenerating seedlings was more than 6,000 stems ha^{-1} and their occurrence was more than 65%. It was considered to be “sufficient” for 3,000–6,000 stems ha^{-1} (40–65% occurrence) and “insufficient” for 1,500–2,900 stems ha^{-1} (20–39% occurrence). If the number of reliable 4–8-year-old naturally regenerating seedlings was less than 1,400 ha^{-1} (occurrence was less than 20%), the natural regeneration success rate was characterized as “poor”.

The results were processed and analysed according to the variation statistics methods (Hammer et al., 2001). The Mann–Whitney U test was applied to compare statistical populations.

Table 2. Distribution of alder forests within Ukrainian Polissya by administrative regions

Administrative region	Area (ha)	Area (%)	Stand volume (m^3)	Stand volume (%)	Stand volume (m^{3}ha^{-1})	Proportion in total forest area (%)	Average age (years)
Volyn	61,271	37.7	10,259,000	36.4	167	15.8	43
Rivne	45,203	27.8	7,374,000	26.2	163	10.3	44
Zhytomyr	24,977	15.4	4,546,000	16.1	182	5.0	47
Kyiv	12,833	8.0	2,441,800	8.8	190	5.7	47
Chernihiv	16,078	9.9	3,122,400	11.1	194	5.1	45
Sumy	1,986	1.2	407,400	1.4	205	3.3	49
Total in Polissya zone	162,348	100.0	28,150,500	100.0	173	8.4	45

Table 3. Average mensuration characteristics of alder stands in Volyn Region in terms of origin

Origin of alder stands	Area (ha)	Area (%)	Average stand parameters: Age (years)	dbh (cm)	Height (m)	Relative density of stocking	Stand volume (m^3 ha^{-1})
Coppice	53,426	87.2	44	19.0	16.0	0.71	170
Naturally seeded	3,310	5.4	45	18.3	15.2	0.72	170
Artificially seeded	4,535	7.4	35	15.8	13.6	0.76	140
Total	61,271	100.0	43	18.7	15.8	0.72	167

Results

The analysis of forest management materials shows that the total area of forests subordinated to the State Forest Resources Agency of Ukraine within Ukrainian Polissya is 1,925,746 ha. Among them, the most common are Scots pine (*P. sylvestris*) forests – 1,250,650 ha (64.9% of the total forest area), silver birch (*Betula pendula* Roth.) forests – 260,001 ha (13.5%), and English oak (*Quercus robur* L.) ones – 195,261 ha (10.1%). The black alder (*A. glutinosa*) forests, which are the object of the study, occupy 162,348 ha (8.4%). The other 55 species cover 57,488 ha (3.1%).

The largest area of alder forests within the Polissya zone is concentrated in Volyn Region (61,271 ha or 37.7% of the total area) and the smallest one in Sumy Region (1,986 ha or 1.2%). In these regions, their largest (10,259,000 m^3) and smallest (407,000 m^3) volumes were noted respectively. In general, the percentage of alder forests in the total forest area ranges from 3.3 to 15.8% in the administrative regions within the Polissya zone with an average of 8.4%.

The most productive alder forests grow in Chernihiv and Sumy Regions. Their average volumes there are 194 m^3 ha^{-1} and 205 m^3 ha^{-1}, respectively. The least productive alder forests are in Rivne and Volyn Regions, where their average volumes are

Table 4. Distribution of alder stands in Volyn Region by site types

Habitat type	Area (ha)	Area (%)	Stand volume (m^3)	Stand volume (%)	Stand volume (m^3 ha^{-1})
Fresh fairly infertile pine site Moist fairly infertile pine site	270	0.4	43,100	0.4	160
Damp fairly infertile pine site Swamp fairly infertile pine site	303	0.5	33,800	0.3	111
Fresh fairly fertile hardwood site Moist fairly fertile hardwood site	4,341	7.1	788,400	7.7	182
Damp fairly fertile hardwood site	51,788	84.5	8,671,700	84.5	167
Swamp fairly fertile hardwood site	3,805	6.2	559,700	5.5	147
Fresh fertile hardwood site Moist fertile hardwood site	38	0.1	10,700	0.1	283
Damp fertile hardwood site	727	1.2	151,600	1.5	209
Total	61,271	100.0	10,259,000	100.0	167

163 m^3 ha^{-1} and 167 m^3 ha^{-1}, respectively (Table 2).

It should also be noted that within such a large area where the studied forests grow, their productivity (volume) increases from west to east. The cause is that in Kyiv, Chernihiv and Sumy Regions the alder stands are mainly concentrated in richer forest site types. Within Rivne and Volyn Regions, the volumes of alder stands were the lowest, which can be explained by poorer forest site conditions in which the studied species grow there (Table 2).

More detailed information regarding the current state, productivity, growth and regeneration of alder forests was obtained for Volyn Region, where their largest areas are concentrated.

Notably, stands naturally originated from seeds or by coppice have higher mensuration values and therefore productivity than artificially seeded ones. This is due to the higher average age of the natural stands.

The distribution of alder forests by origin shows that natural stands predominate in Volyn Region covering 92.6%, including coppice ones – 87.2% and those originated from seeds –5.4%, while artificially seeded stands occupy only 7.4% of the area (Table 3).

The average characteristics of alder stands in Volyn Region according to their origin are presented in Table 3.

The vast majority of alder stands – 97.8% – grow in relatively rich and moist types of habitat, including 84.5% in damp fairly fertile forest sites (Table 4). The most productive alder forests grow in rich habitat types, namely fresh and moist fertile oak forest sites, where their volume reaches 283 m^3 ha^{-1} and exceeds the average value for the region by 69%.

The age structure of alder forests is unbalanced with a predominance of 41–50 and 51–60-year-old coppice stands (19.0% and 26.8% of the total area, respectively), 51–60 and 61–70-year-old stands of natural seed origin (18.5% and 17.2% of the total area, respectively), and 31–40 and 41–50-year-old artificially seeded stands (25.4% and 37.7% of the total area, respectively). Alder stands up to 20 years old as well as those over 70 years old have the lowest proportions, regardless of the origin (Fig. 3).

Stands of coppice origin have the lowest volumes compared with those that emerged from seeds, both artificially and naturally. The maximum volume of alder stands, regardless of the origin, was observed at the age of 81–90. This peculiarity should be taken into account when determining the age of the main felling for alder stands.

Specificities and priority of relevant forestry interventions, particularly tending felling (first felling age, thinning intensity, felling interval, number of interventions, etc.), depend primarily on the stand composition. In Volyn Region, mixed alder forests prevail, with 50 to 90% alder in the composition. The area of such forests is 68% of the total alder forest area (Fig. 4). Pure alder stands cover 15,820 ha (25.8%). The smallest area is occupied by alder forests with 30% of alder in their composition, making only 0.8% of the total alder forest area.

Under the canopy of alder stands of various ages, densities and origins, the number of naturally regenerating seedlings of black alder and other economically valuable species is insignificant. The total number of natural seedlings is in the range of 500–2,050 stems ha^{-1} for 31–50-year-old stands, 820–1,772 stems ha^{-1} for 51–70-year-old ones, and 333–3,562 stems ha^{-1} for 71 and older stands. The Mann–Whitney U test showed that the total number of small natural seedlings (height group up to 0.5 m) is significantly higher in younger stands (31–50 years) than in older ones (51–70 years and over 70 years) ($U = 1.5$, $p \leq 0.05$). The number of alder seedlings ranges within 218–643 stems ha^{-1} for 31–50-year-old stands, 178–792 stems ha^{-1} for 51–70-year-old stands, and 333–1,782 stems ha–1 for the stands aged 71 and older. The proportion of alder seedlings in natural regeneration is from 14.3% to 100% (Table 5). According to the Mann–Whitney *U* test, the numbers of alder seedlings do not differ significantly for various age groups (31–50 years, 51–70 years and 70 years and more) ($U = 16.935$, $p \geq 0.05$).

In addition to alder, the natural regeneration includes *B. pendula, C. betulus, F. excelsior, Q. robur, P. sylvestris and P. tremula. B. pendula* has the largest percentage among these species. In general, the proportion of other tree species in the total number of seedlings on the sample plots is 47.0–85.7%. Under the canopy of pure alder stands, only black alder advance growth was recorded.

The age of seedlings was 2–6 years for black alder, 3–6 years for silver birch, 3–5 years for hornbeam, 2–3 years for common ash and English oak, 2 years for Scots pine, and 3–4 years for aspen.

Alder regeneration has mainly group distribution throughout the area (occurrence was up to 40%), except plots 15, 16, and 17 (occurrence was 74, 70, and 67%, respectively), where it has a uniform distribution or uneven distribution, such as sample plots 2, 3, 6 (occurrence ranged within 40–65%). The occurrence of other tree species had much higher rates.

It was noted that the number of naturally regenerating individuals, including alder, increased with the increas-

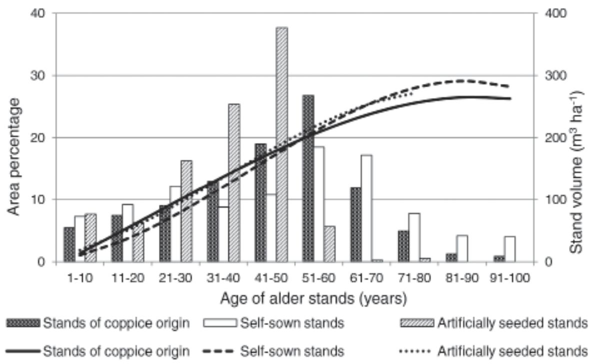

Fig. 3. Age distribution of alder stands in Volyn Region and dynamics of their productivity.

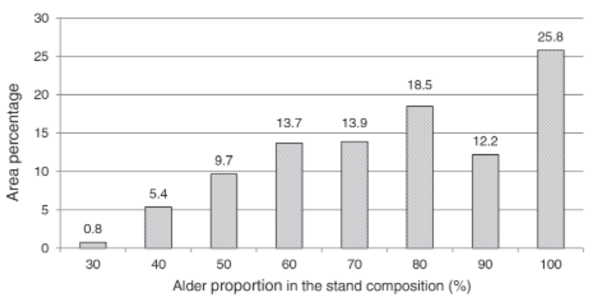

Fig. 4. Distribution of alder forest area in Volyn Region by the alder proportion in the composition.

Table 5. Characteristics of reliable advance growth (≤0.5 m, 0.6–1.5 m and >1.5 m) of economically valuable species under the canopy of alder stands and their natural regeneration success

Sample plot number	Species	Number of individuals (stems ha^{-1})				Age (years)	Species (%)	Occurrence (%)	Natural regeneration success
		(≤0.5 m)	(0,6–1.5 m)	(>1.5 m)	Total				
Stands aged 31–50									
7	Alder	–	156	62	218	3	19.4	16	Poor
	Others	–	500	406	906	4	80.6	28–38	
5	Alder	375	75	–	450	2	22.0	38	
	Others	–	1,375	225	1,600	3–4	78.0	63–70	
11	Alder	208	–	–	208	2	25.0	17	
	Others	83	458	83	624	2–4	75.0	8–25	
10	Alder	50	200	–	250	3	50.0	25	
	Others	250	–	–	250	2	50.0	10–15	
2	Alder	–	214	429	643	4	53.0	54	
	Others	–	250	321	571	3	47.0	50	
4	Alder	–	167	267	434	3	40.7	37	
	Others	133	–	500	633	2–3	59.3	13–40	
Average	Alder	106	135	126	367	3	38.0	31	Poor
	Others	78	431	256	764	3	65.0		
Stands aged 51–70									
8	Alder	–	178	–	178	3	21.7	14	Poor
	Others	71	393	178	642	2–5	78.3	4–29	
3	Alder	129	484	–	613	3	43.7	61	
	Others	–	355	436	791	4	56.3	34–42	
1	Alder	–	182	–	182	2	14.3	16	
	Others	204	477	409	1,090	2–5	85.7	18–55	
9	Alder	231	115	–	346	2	20.4	23	
	Others	385	769	192	1,346	3–4	79.6	12–42	
6	Alder		604	188	792	3	48.7	65	
	Others	–	250	583	833	5	51.3	71	
12	Alder	182	91	–	273	2	15.4	18	
	Others	636	863	–	1,499	3	84.6	14–41	
Average	Alder	90	276	31	397	3	46.2	32.8	Poor
	Others	216	518	300	1,034	4	72.6		
Stands aged 71 and older									
13	Alder	125	208	–	333	3	100.0	25	Poor
14	Alder	196	–	–	196	2	47.5	17	
	Others	–	217	–	217	3	52.5	17	
15	Alder	–	875	750	1,625	4	45.6	74	Insufficient
	Others	1,062	625	250	1,937	2–6	54.4	50–88	
16	Alder	200	875	475	1,550	4	53.9	70	
	Others	–	625	700	1,325	4	46.1	69	
17	Alder	–	956	826	1,782	6	100.0	67	
Average	Alder	104	583	410	1,097	4	69.0	51	Insufficient
	Others	354	489	317	1,160	4	51.0		

Alder, *A. glutinosa*; Others: *B. pendula*, *C. betulus, F. excelsior, Q. robur, P. sylvestris,* and *P. tremula.*

ing age of alder stands. The largest number of seedlings accounting for 1,800–3,600 stems ha^{-1} was recorded under the canopy of 76–78-year-old stands at sample plots 15–17, including 1,600–1,800 stems ha^{-1} of alder. In such stands, a relative density of stoking was 0.63–0.70 and alder comprised 80–100% of the stand composition. Such sites can be targeted to natural regeneration in the future.

Discussion

In most countries, the area of black alder stands is only about 1% of forest cover, as foresters have always preferred more valuable tree species such as English oak, common ash and others (Turok et al., 1996). However, in North-Central Europe (Netherlands, Northern Germany, Poland and the Baltic

States) and South-Central Europe (the plains of Slovenia and Croatia), black alder stands cover about 5% of the total forest area and form highly productive stands (Turok et al., 1996; Claessens et al., 2010).

In Poland, black alder stands occupy 522,000 ha, which is 5.7% of the total forest area. The volume of black alder wood is 137 million m^3 (263 m^3 ha^{-1}), which is 5.3% of the total volume of harvested timber (Pogoda et al., 2019). Socha and Ochał (2017) note that black alder, due to its tolerance to adverse climatic and edaphic conditions and fairly rapid growth, is considered one of the economically important tree species for the country. In addition, it is successfully used for afforestation on disturbed soils of dump areas (coal mining, etc.).

Black alder forests cover 694,500 ha in the forested area in Belarus, which is 8.6% (Rusalenko, 2014); they cover 161,200 ha in Latvia, accounting for 5.1% of the forests in the country (Arhipova et al., 2012).

In forests in Slovakia, a recent decline in the area of alder stands is observed, and anthropogenic activities are reported by Bugala and Pittner (2010) as the principal cause for it: in lowlands due to negative changes in water flows and in mountainous areas due to the land conversion to farmlands.

According to the Ukrainian state forest inventory (Ukrderzhlisproekt, 2012), black alder, being one of the most common tree species, occupied 275,800 ha, accounting for 4.4% of the total forest area of the country. During 2001–2011, the area of black alder forests increased by 0.2% (by 20,900 ha) (Romanyuk, 2010). The volume of alder stands is about 49 million m^3. Annually, forest enterprises harvest 1,000,000–1,200,000 m^3 of wood in these stands (Bugayov and Pasternak, 2020).

As of January 1, 2011, the area of alder stands within Ukrainian Polissya in forests managed by the State Forest Resources Agency of Ukraine was 162,100 ha, making 58.8% of the total area of alder stands in Ukraine. The alder stands represent 35.4% of the softwood broadleaved forests in Polissya. They make up more than half (58%) of all softwood broadleaved stands in Volyn Region and from 20.9 to 38.4% in other regions within the Polissya zone (Blyshchyk, 2014). According to forest management data (as of 2017), the area of alder stands within Ukrainian Polissya in the forests managed by the State Forest Resources Agency of Ukraine is 162,300 ha, which is 8.4% of the total forest area. Thus, there has been a slight increase of 200 ha in the area of alder stands during the last six years. Alder stands cover 90,700 ha in the Ukrainian Forest-Steppe zone (4.4% of the total forest area) and 7,300 ha in Ukrainian Steppe (1%). It should be noted, however, that the productivity of alder forests increases with the decrease in their area from west to east in the natural zones within Ukraine.

According to Blyshchyk (2014), as of January 1, 2011, the average volume of 46-year-old alder stands in Ukrainian Polissya was 173 m^3 ha^{-1}. In the present study, we obtained similar results: 173 m^3 ha^{-1} at the age of 45. At 71–80 years, the volumes were 256 m^3 ha^{-1} for coppice alder stands, 272 m^3 ha^{-1} for artificially seeded stands, and 280 m^3 ha^{-1} for those naturally originated from seeds. Thus, the stands of coppice origin were the least productive. The differences in stand volumes were 6% and 9% in comparison with artificially seeded and self-sown stands. The maximum volume of self-sown alder stands was observed for 81–90-year-old stands – 291 m^3 ha^{-1}.

According to Bugayov and Pasternak (2020), the productivity of alder stands growing within Ukrainian Left-Bank Forest-Steppe in damp fertile and fairly fertile black alder forest site types is 304 m^3 ha^{-1} and 320 m^3 ha^{-1}, respectively, at the age of 80.

In Ukrainian Steppe, a highly productive 60-year-old alder stand should have a volume of 400 m^3 ha^{-1} and an average increment of 6.7 m^3 ha^{-1} per year (Storozhenko, 2009). The maximum average annual increment for alder can reach 14 m^3 ha^{-1} per year (Claessens et al., 2010).

Under the stand canopy, the natural seed regeneration of black alder is mostly assessed as poor while coppice one as good (Frolov, 1993; Kravchuk, 2009; Storozhenko, 2009; Oborska, 2015; Kudin et al., 2017). The natural regeneration of alder is limited by a number of environmental factors such as insufficient light, fluctuations in groundwater levels due to climate change and the development of strong grass cover that prevents the emergence and survival of seedlings. Without the prior assistance to natural seed reproduction of black alder, its successful regeneration cannot be expected (Kravchuk, 2009; Oborska, 2015).

According to some studies (Frolov, 1993; Gordiyenko and Gordiyenko, 2005), the felling sites can regenerate successfully by combining seed and stump sprout regeneration if the mother stand is felled in winter after the crop year.

Conclusions

Alder stands cover 162,348 hectares in Ukrainian Polissya, which is 8.4% of the total forest area. Within the study region, the largest area of alder stands is accounted for the Volyn Region (61,271 ha or 37.7% of the total area of alder forests). Here, natural stands predominate, covering 92.6%, including 87.2% of coppice and 5.4% of self-sown stands. Artificially seeded stands occupy only 7.4% of the area. The self-sown stands are the most productive. Their volume at the age of 71–80 years is 280 m^3 ha^{-1}, while it is 272 m^3 ha^{-1} for artificially seeded stands and 256 m^3 ha^{-1} for stands of coppice origin.

Regeneration from seeds under the alder canopy is mainly assessed as poor or insufficient. The largest number of black alder seedlings (1,600–1,800 stems ha^{-1}) was recorded under the canopy of 76–78-year-old stands with a relative density of stocking of 0.63–0.70. Successful natural seed regeneration of black alder cannot be expected without a prior silvicultural assistance.

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