Characteristics of Afforestation in Azerbaijan: Oak Afforestation

Shahbaz Shiraliyev ✉ , **Ramiz Gulamov** ✉ , **and Elnara Gadirov** ✉

School of Advanced Technologies and Innovation Engineering, Department of Ecology and Environmental Sciences, Western Caspian University, Baku, AZ1072, Azerbaijan

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Abstract

This study examines the characteristics and prospects of artificial afforestation in Azerbaijan, with particular emphasis on the establishment and regeneration of oak plantations, especially chestnut-leaved oak (*Quercus castaneifolia*). The study provides an overview of the geographical distribution, forest resources, dominant tree species, and ecological significance of Azerbaijan's forests, while highlighting the importance of artificial afforestation and reforestation for sustainable forest management and biodiversity conservation. Particular attention is given to the distribution, ecological characteristics, and silvicultural potential of chestnut-leaved oak (*Quercus castaneifolia*) within the forest ecosystems of Azerbaijan. The study discusses the main methods of establishing oak plantations, including continuous and partial afforestation, seed sowing, planting, and combined approaches. Detailed recommendations are presented concerning acorn collection and storage, soil preparation, sowing techniques, planting density, species mixing patterns, protection of young plantations, and agronomic management. The findings suggest that appropriate sowing techniques, particularly the row-and-hole and square-cluster methods, combined with effective soil preparation and plantation protection, significantly improve the successful establishment and long-term sustainability of oak plantations. The study also highlights the potential for expanding chestnut-leaved oak plantations in suitable forest areas, including the Ismayilli Forest Fund, as an important measure for forest restoration, biodiversity conservation, and sustainable forest management in Azerbaijan.

Keywords: Afforestation; Oak plantations; Chestnut-leaved oak; *Quercus castaneifolia*; Forest restoration

1.Introduction

1.1. The geographical location and forest resources of Azerbaijan

The Republic of Azerbaijan is situated in the south-eastern part of the South Caucasus. Mountains cover almost half of the country's territory: the Greater Caucasus mountain range in the north-east, the Lesser Caucasus mountain range in the south-west, and the Talysh Mountains in the south. The Republic of Azerbaijan covers an area of 86.6 thousand km², of which: 11.8% is covered by forests, 1.6% by water reservoirs, and 50.0% by arable land. Azerbaijan is characterized by diverse natural landscapes, and its forests play a crucial role in maintaining ecological stability, biodiversity conservation, and the provision of ecosystem services. (Figure 1) (12). Its territory is home to vast plains lying below sea level and mountain peaks over 4,000 metres high, as well as hot deserts, cool alpine meadows and subtropical forests. Low-lying areas account for more than half of the territory.

Figure 1. *Geographical location and major forest regions of Azerbaijan*

Over the past 200 years, the world's forest cover has been reduced by more than half. In the 18th and 19th centuries, 35% of Azerbaijan's territory was covered by forests. The total area of forest in Azerbaijan currently stands at 1,021 thousand hectares. This also accounts for 11.8% of Azerbaijan's territory. In the Russian Federation, this figure stands at 44%, in Latvia at 41%, and in Georgia at 39%. The main role of forests in nature is to absorb 10-20 tonnes of carbon dioxide per hectare per year and, in return, to release oxygen. One hectare of forest absorbs 8 kg of carbon dioxide per hour, which is equivalent to the amount of carbon dioxide exhaled by 200 people in an hour.

Distribution of forests by natural zones and main tree species. 48% of our country's forest resources are located in the Greater Caucasus, 34% in the Lesser Caucasus, 16% in the Talysh region and 2% in the Aran region (including the Nakhchivan Autonomous Republic). In Azerbaijan, there are 0.11 hectares of forest per person (Aliev, 1984). Azerbaijan's vast forest areas stretch across the southern and south-eastern slopes of the Greater Caucasus mountain range. The forests cover an area in the south-west of the north-eastern part of Azerbaijan, mainly within the administrative districts of Qusar, Quba, Devechi, Siyazan and Khizi. From the Khizi district, the area of the forest gradually decreases towards the south-west and gives way entirely to treeless terrain. In the southern part of the Greater Caucasus mountain range, within the Shamakhi District, work is underway to restore a forest area that stretches right up to the border with the Republic of Georgia and forms a continuous canopy on the mountain slopes. The forests here mainly cover the mountainous areas of the administrative districts of Ismayilli, Gabala, Oguz, Sheki, Gakh, Zakatala and Balaken (Grossheim, 1939–1967; Khalilov, 2008).

A third of the forests are situated on the slopes of the Lesser Caucasus. Here, forests cover the northern, north-eastern and eastern slopes of the main mountain ranges in the form of separate massifs. It is only in the South Karabakh region that the forest belt breaks off and does not extend as far as the Iranian border. Furthermore, in the Shahbuz District of the Nakhchivan Autonomous Republic, on the slopes of Mount Kukudag, forests occur in the form of isolated patches. One of the extensive forest areas also covers the slopes of the Talysh Mountains. The forests here are situated within the administrative districts of Astara, Lankaran, Lerik, Masalli, Yardymly, Jalilabad and, in part, Bilesuvar. The Astar District accounts for the largest proportion of forest cover in the republic – 58% (Сафаров, 1979; Ibrahimov, 2012). A small proportion of the forests forms narrow, ribbon-like strips along the banks of the Kura and Aras rivers, forming riparian forests (Huseynov, 2022). Azerbaijan has gained worldwide renown for its enchanting beauty, rich natural resources, and diverse flora and fauna. There are 4,500 species of higher plants here, belonging to 125 families and 930 genera (Прилипко, 1970). Of these, 435 species of trees and shrubs, belonging to 48 genera and 135 families, grow in the Republic's forests. This accounts for 10% of the plant species that make up the Republic's flora. Azerbaijan's tree flora comprises 70 regionally endemic species. This also accounts for 16% of the total number of tree and shrub species. Despite the rich diversity of

Azerbaijan's tree species, there are few major forest-forming species here. Azerbaijan's forests consist mainly of broad-leaved species.

The forest area is divided between the dominant tree species roughly as follows. Pine – 0.3, juniper – 1.3, beech – 31.9, oak – 30.5, hornbeam – 22.4, ash – 0.9, maple – 0.3, shrubs – 2.2, birch – 0.14, poplar – 0.81, alder – 0.82, linden– 0.10, other species – 8.06% Although forests vary in structure, broadleaf forests mainly consist of tree species such as beech, oak and hornbeam. These three species account for 85% of the forest area.

The importance of artificial afforestation and reforestation. Forests are key to the planet's stability and the sustainable development of society, and are of ecological, economic and social importance. The main purpose of establishing forestry enterprises is to meet the demand for forest products from the public and the national economy. The main product of the forest is timber, and the forest remains its sole source. Timber is used either directly or as a raw material for the manufacture of 20,000 different types of products. The growing demand for firewood is leading to the rapid destruction of forests. According to FAO figures, 5.2 million hectares of forest were lost worldwide each year during the first five years of the 21st century.

Since 1990, the area of primary, undisturbed forests worldwide has fallen by more than 80 million hectares. More than 100 million hectares of forest are at risk of damage from forest fires, pest infestations, diseases, droughts and extreme weather events. Research also clearly demonstrates the impact of human activity on the Earth's forest cover. According to scientists' estimates, around 15 billion trees are felled each year, and around 5 billion are planted to compensate for this.

Net forest loss (taking into account reforestation) has fallen significantly since the 1990s; however, the world is still far from achieving the target set out in the UN Strategic Plan on Forests, which is to increase forest cover by three per cent by 2030. Whilst deforestation is taking place in some areas, in others forests are being restored through natural regrowth or targeted measures. Consequently, the net loss of forest area is lower than the rate of deforestation, and is also declining – from 8.3 million hectares per year in the 1990s to 5 million hectares per year in 2010–2020. In absolute terms, the world's forest area has decreased by 178 million hectares (Figure 2).

Sustainable forest management requires, first and foremost, an accurate assessment of forest resources. The FAO has taken on this task and has been carrying out this assessment every five years since 1990 (1990, 1995, 2005, 2010, 2015 and 2020). The Global Forest Resources Assessment (GFRA) has been carried out by the FAO every five years since 1990 (1990, 1995, 2005, 2010, 2015 and 2020). The results of the GFRA study are used to promote sustainable development and sound forest management. According to GFRA data, forests cover 30% of the Earth's land area, and their total area is almost 4 billion hectares, which equates to 0.51 hectares of forest cover per person. More than half of the world's forests are concentrated in five countries rich in forest resources (the Russian Federation, Brazil, Canada, the United States and the People's Republic of China). In 10 countries, there is no forest cover at all, whilst in 54 countries, the proportion of land covered by forest is less than 10%. Although there is a downward trend in the rate of deforestation, it remains at a level that gives cause for serious concern.

Figure 2. *Logged areas of woodland*

2. Results and Discussion

1. Key aspects of establishing afforestation sites. The main aim of establishing afforestation schemes is to meet the ever-increasing demand from the national economy and the population for various types of forest products, to enhance the positive impact of forests on agriculture, to improve public health, to improve the water regime of our rivers, and so on.

It is therefore important, when establishing man-made (artificial) forests, that all planting methods and operations are consistent with the objectives of the planting programme. This approach, which takes into account the potential impact of the forest stand, ensures compliance with the requirements for the cultivation of a specific stand, as well as for a specific dominant species and its quality.

Artificial forests, in the strictest sense of the word, are of an agricultural nature; they are also referred to as man-made forests. At the same time, afforestation is not merely a source of raw materials, but also constitutes an integral and highly significant part of the biosphere, as well as an element of the geographical landscape that forms part of a unified forest system. Broadly speaking, plantation forests are open biological systems managed by humans for a specific economic purpose. The term 'afforestation' is usually used to refer to artificially created forest areas. When establishing afforestation schemes, wild species or genera of wild-growing trees are generally used.

In international practice, the generally accepted classification system for afforestation can be presented as follows:

- *Systems – closed, open;*
- *Types – contiguous, partially;*
- *Breeds – purebred (single breed), mixed;*
- *Shapes – simple, complex*

A system of closed forest crops. In the near future, the closed-canopy system involves the establishment and cultivation of forest plantations on areas scheduled for planned clear-cutting; for this reason, such plantations are referred to as 'under-canopy' or 'primary' plantations. Primary afforestation reduces the time needed for forest regeneration.

The open-field system. The open-field system is regarded as the primary system in the field of artificial afforestation. Open woodland is defined as land that is planted with trees but not covered by forest. Open woodland is characterised by the fact that it is divided into areas devoid of tree cover, in the form of forest stands or copses. Such afforestation projects are also known as follow-up plantings. Forest stands are classified into two types: monocultures and mixed stands, depending on the presence of young trees of commercially valuable species and the even distribution of cultivated plants within the forest stand.

Contiguous forest plantations. Due to the relatively even distribution of areas for sowing or planting within these plantations, the dominant (cultivated) species is ensured to prevail in the future plantation. When establishing new forests, only monocultures are created, as there is no second source for the forest's further development.

Contiguous reforestation is carried out in areas where natural regeneration is observed or expected in the plantations. Therefore, the establishment of partial afforestation is regarded as a combined method of afforestation, combining natural and artificial forest regeneration. As a rule, partial reforestation is carried out on areas that have been clear-cut, where natural regeneration of the main tree species is taking place. They are widely used in forestry and park management.

In forests managed as continuous cover plantations, the forest stand is established without any natural regeneration taking place. The cultivation techniques, sowing patterns and variety mixtures, as well as the composition of this stand, are more diverse, and its potential is greater. Continuous-cover afforestation stands are characterised by a greater richness and diversity in terms of species composition, density, soil preparation methods, as well as planting patterns and species mixtures, compared with other types of stands.

Continuous and patchy forest stands may consist of monocultures, that is, single-species stands, or mixed stands comprising two or more species. As a generally accepted practice, monocultures are simple, whereas mixed stands represent a complex (two-component or multi-component) form of artificial cultivation.

Forest plantations can be established in three ways: by planting saplings, by sowing seeds, and by a combined method.

The planting method is almost universally regarded as a more reliable and cost-effective way of producing forest plants. At present, the majority of new forest plantations in the country's forestry sector (over 80% of them) are established through planting. The sowing method is considered to be more ancient and, in essence, closer to the natural process. The advantage of this method is that it does not require seedlings; the young plants have a naturally developed root system, and the planting technique is simpler. The combined method involves both planting and sowing on the same forest plot. It is used when creating mixed plantings with oak.

2. Characteristics of oak afforestation in Azerbaijan. Nine species of oak grow in Azerbaijan, the most common of which are the Iberian oak, the Chestnut-leaved oak, the Eastern oak, the Araxian oak and the Pedunculate oak.

Oak forests, found mainly in foothill and mountainous areas (up to 2,000 m), account for a significant proportion of the country's forest cover – up to 30%. It forms dense thickets on the southern slopes of the Talysh Mountains and the Greater Caucasus. These forests are also of significant ecological and economic importance (Figure 3).

Figure 3. *Chestnut-leaved oak (Quercus castaneifolia)*

One of the main species of oak is the chestnut-leaved oak (*Quercus castaneifolia*) – a relict tree species in Azerbaijan, belonging to the ancient Arctic Tertiary (Turkayan) Hircanian flora (Асадов & Асадов, 2001). It is mainly found in the Lenkoran biogeographical province (in the Talysh Mountains). It is listed in the 'Red Book of Azerbaijan'. The chestnut-leaved oak is a species of tree that thrives in warm, sunny conditions. This majestic tree can reach a height of 40-45 metres, and its trunk can measure 1,5-2 metres in diameter. Leaves: generally 10-15 cm long, lanceolate, lanceolate-elliptic or oblong-lanceolate, with a coarsely toothed margin. It flowers in April-May, and the seeds ripen in September-October. The weight of 1,000 seeds is 7 kg (Figure 4). It is a very long-lived plant; it can live for 400–500 years, and sometimes even longer. Due to its hardness and value, this timber is used in shipbuilding, woodworking, and the furniture industry, as well as in the manufacture of barrels. Range:

Figure 4*. Acorns of chestnut-leaved oak*

Ancient and giant specimens of this species can be found in Hirkan National Park. It grows in Iran (Gilan, Mazandaran), in the Caucasus, including the Talysh Mountains in Azerbaijan (from the plains up to 2,000 metres above sea level) (Асадов & Асадов, 2001). It grows faster than other species of oak and produces a bountiful crop of acorns every year. Natural regeneration from seed occurs successfully in moist forest ecosystems. It adapts quickly to local conditions and is therefore easy to plant and grow in a variety of climatic and soil conditions.

3. Key considerations for establishing plantations of chestnut-leaved oak. The ongoing decline in the range of the chestnut-leaved oak, combined with the ever-increasing demand for this species, has made it necessary to establish artificial plantations of this tree. The creation of artificial afforestation schemes, which are an important element of Azerbaijan's tree flora and a significant factor in ensuring the sustainable development of biodiversity, remains a matter of the utmost importance (FAO, 2020).

The artificial restoration of oak forests and the establishment of new plantations are therefore regarded as the most important forestry measures for protecting and improving the condition of the forest ecosystem (Stanturf et al., 2014). Although the establishment of oak plantations in our country became more widespread from the second half of the last century onwards, for a long time these plantations failed to yield the desired results. In the case of partial plantings, this was due to the difficulty of ensuring timely thinning, whereas in the case of full-row plantings, it was due to the lack of soil preparation, the difficulty of protecting the trees from adverse natural phenomena, and the unsuccessful acclimatisation of the oak (Figure 5).

Figure 5. *Artificial establishment of oak plantations*

Oak forests are currently being restored in Azerbaijan as part of government programmes (Forest Code of the Republic of Azerbaijan, 2020). For example, of the 45.7 tonnes of seeds collected for afforestation in 2021, 38.3 tonnes were acorns. Particular attention is paid to the artificial restoration of oak as one of the most valuable tree species, especially in the liberated territories and in the forests of Tugay (the Kura-Araz Plain), using methods designed to ensure the success of oak plantations.

Continuous oak plantations. These crops are grown using rain-fed farming methods on unirrigated soils in foothill, low-mountain and mid-mountain regions. These crops are grown on old logging sites, in clearings and fields, on land no longer used for agricultural crops, and on mountain slopes, using two methods based on a 2×2-metre grid: either by ploughing furrows with tractors, or by preparing 1×1-metre plots by hand. In continuous plantations, the stand develops without any natural regeneration taking place. The cultivation techniques, sowing patterns and species mixtures, as well as the composition of this stand, are more diverse, and its potential is greater. Compared with partial afforestation, continuous afforestation is characterised by greater diversity in terms of species composition, planting density, soil preparation methods, as well as planting patterns and species mixtures.

In the partial afforestation process, the land is prepared, and a monoculture is planted; in some cases, however, mixed woodland areas form as a result of natural forest regeneration. The advantage is that the plantation is established within a forest environment, which prevents the formation of natural grass cover and helps to reduce the need for planting material, labour and resources.

4. The method of sowing in oak plantations and its stages. In oak plantations, the sowing method should generally be used. This is because, in their first year, oak acorns develop strong vertical roots that penetrate the soil to a depth of up to one metre. When transplanted into the field, the seedling loses most of its root system, which has a very negative effect on its condition. The newly formed roots of cuttings penetrate the soil more slowly than those of fresh seedlings grown from seed.

a) Supply of seeds. The acorns of the chestnut-leaved oak ripen in mountain forests in late October – early November. Seeds must be fully ripe before they can be used in afforestation schemes and nurseries. This process may drag on until 15 November. The seed pods are harvested by hand once the seeds have ripened and been sown in the ground. To check the quality of the seeds, they are placed in water; empty husks that float to the surface are discarded, whilst those that sink to the bottom are considered suitable for sowing. The harvested seeds should be sorted, and any that are diseased or damaged should be removed.

In the mountainous and foothill regions of the Greater Caucasus and Talysh, it is more advisable to leave oak acorns in the forest until spring arrives. The area of woodland set aside for seed storage must first be cleared of shrubs. Nevertheless, whilst cleaning, you must not touch the dead layer or the leaves that have fallen to the ground. The seeds are sown to a depth of 5-6 cm and then covered with a layer of leaves 15-20 cm thick. If frosts are expected or likely, the depth of the layer of leaves covering the surface should be increased to 30 cm.

In the Aran regions, it is recommended to store acorns in cellars. Small batches of seeds for spring sowing can also be stored in running water. Oak acorns can be stored for up to two years in ice cellars, freezer cellars and deep trenches.

b) Soil preparation: Soil preparation is carried out taking into account the soil and climatic conditions of the area where sowing is to take place, its topography, altitude above sea level, the orientation and gradient of the slopes, as well as the availability of machinery.

When carrying out broadcast sowing on steep slopes in hilly terrain, on old felling sites, in clearings and forest aisles, on land cleared of crops, and on exposed hillsides:

- Where mechanical tillage is possible, ploughing to a depth of 60-80 cm promotes good root system development.
- Once the field has been harrowed, furrows are dug at 2 metre intervals for sowing the seeds.

Often on mountain slopes, in order to reduce costs, prevent the complete destruction of the site's soil cover and improve its resistance to erosion, the land is ploughed not across the slope but in furrows (50 per hectare) (Figure 6).

Figure 6*. Soil preparation for oak afforestation*

In areas where machinery cannot be used, the field is tilled in 1×1 metre squares measuring 2×2 metres, amounting to 2,500 squares per hectare. When planting forests, partial sowing is carried out in areas where

natural regeneration is occurring or is expected to occur. At present, between 1,200 and 1,500 plots of various layouts and sizes have been prepared in the open-air areas. On flat terrain, a combination of methods is used to establish protective oak shelterbelts, including the 'row-and-hole' and 'square-cluster' methods.

c) Sowing seeds: Sowing is carried out using the 'row-and-hole' and 'square-cluster' methods. In the **'**row-and-hole' sowing method, seeds are sown into holes made along the sowing rows, with 3-5 seeds planted in each hole; the resulting plants form a biogruppe.

When using the **'**square-cluster' method, sections of varying sizes are created in the sowing rows at distances corresponding to the planting pattern (in our example, a 2×2 m pattern, with sections measuring 1×1 m); these sections (forming a 'square') are created, in each of which 4 holes are made, with 3–5 seeds sown into each hole. Plants collected both in the nest and in the field form a single biogroup.

d) Protection: Artificially restored areas must be fenced off to protect the young saplings from damage caused by wild animals and livestock. A barrier, preferably in mountainous areas, 1.0 metres wide. This can be achieved by digging trenches 1.5 metres deep and 1.0 metre wide, with the excavated soil piled up on the inside to form berms, and local materials (branches and poles obtained from tree pruning, as well as shrubs, etc.) used on top of these berms. As this type of fencing is both cheaper and more effective, it is considered suitable for all afforestation projects in mountainous areas.

5. Sowing methods, mixing patterns and planting density in oak-based afforestation schemes (in mountainous areas)

When sowing in continuous rows using the 'row-and-hole' method (in a 2×1 m pattern), 50 furrows are dug per hectare at intervals of 2 metres.The holes are dug in furrows spaced 1 metre apart, and 3-5 acorns are sown in each hole. Given that the average weight of a single seed (of the chestnut-leaved oak) is 7 grams, the seed yield per hectare can range from 105 to 175 kg, and the number of one-year-old seedlings from 15,000 to 25,000.

When sowing continuously using plots (in a 2×2 m pattern) by the 'square-cluster' method, 2,500 plots measuring 1×1 metre are prepared per hectare (Figure 7).

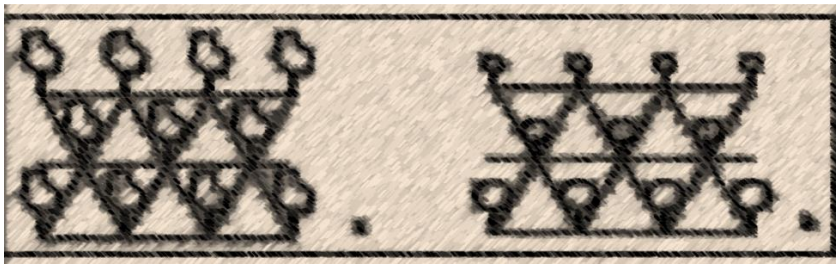

Figure 7. *Mixing pattern and planting density in oak plantations*

Four holes are prepared in each plot (square), one in each corner, and 3-5 seeds are sown in each hole. Consequently, there are 10,000 seed points per hectare. Given that the average weight of a seed (of the chestnut-leaved oak) is 7 grams, the seed yield per hectare can range from 210 to 350 kg, and the number of one-year-old seedlings from 30,000 to 50,000. When planting forests under natural regeneration conditions, sowing is carried out in partial plots (in a 2×2 metre grid) using the 'square-cluster' method, with between 1,200 and 1,500 plots, each measuring 1 square metre, allocated per hectare.

Four holes are made in each plot (square), and 3–5 seeds are sown into each hole. Consequently, approximately 4,800–6,000 sowing points are established per hectare. Under these sowing conditions, the number of seedlings may range from 14,400 to 30,000 per hectare, while the seed requirement varies between 100 and 240 kg per hectare.

From 1950–1951, work began in Azerbaijan on the creation of shelterbelts under the leadership of Ibrahim Safarov, the Republic's Honoured Forester. When establishing shelterbelts, preference was given to oak species (chestnut-leaved oak, pedunculate oak and Iberian oak). The oak seeds were sown using the 'square-cluster' method, with the holes arranged in blocks across the plots. This method was mainly used in arid conditions. The oak seeds were sown using Lisenko's 'hole' method, with some modifications. When sowing using Lisenko's 'hole' method on a 5×3 metre grid, the planting holes are arranged in groups (of 5 holes per plot) on 1×1 metre plots (667 plants per hectare), with 6-7 seeds sown in each hole. Oak seedlings are grown for 2–3 years, whilst agricultural crops are grown in the rows between them.

As soon as it becomes clear that the planting has been successful and the oak acorns have taken root, a row of companion species is planted between the rows of oak saplings, and rows of shrubs are planted between the companion species and the oaks. Growing oak in bio-groups on plantations will be more environmentally sustainable, whilst using the spaces between rows to grow crops will provide an additional yield and reduce operating costs (IPCC, 2022/In any case, it is important to clear the planting area of weeds, stones and shrubs.

6. Agronomic management of oak plantations. Agronomic management comprises a range of agronomic measures aimed at improving the growing conditions for tree and shrub species cultivated on oak plantations, creating more favourable conditions and ensuring optimal conditions.

In continuous oak plantations, the main aim of management is to ensure that the site remains free of weeds through systematic soil cultivation or inter-row cultivation, thereby reducing competition for light and water. In partial oak plantations, the main objective of this measure is, first and foremost, to remove excess oak stumps from the site through timely thinning, and to prevent them from hindering the successful growth of higher-quality trees; it is also aimed at preventing oak stands from being displaced by faster-growing species during their early years. In arid desert conditions, whether planting in pits or furrows, two 3–5-year-old oak saplings should be left in each planting hole, and the rest should be removed.

3.Conclusion

Based on the findings of the studies and investigations carried out, the following can be noted:

1. A brief general overview of the distribution patterns and ranges of oak trees in Azerbaijan is provided.

This section also examines the distribution patterns of the chestnut-leaved oak.

2. This paper presents the results of research and surveys concerning the distribution of the chestnut-leaved oak in the forest areas of Ismayilli, its ecological and silvicultural characteristics, its response to anthropogenic and climatic changes, and the general current status of this species.

3. This article examines the prospects for the spread of the chestnut-leaved oak across the lands of the Ismayilli Forest Fund, as well as the potential for establishing plantations of this species there.

4. The article also provides detailed information on the mixing and planting schemes that can be proposed for establishing chestnut-leaved oak plantations.

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