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Diploma Thesis

Gap regeneration of Sessile oak stands with respect to site heterogeneity

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Declaration

I declare that this Diploma thesis "Gap regeneration of Sessile oak stands with respect to site heterogeneity" has been composed solely by myself and that it has not been submitted, in whole or in part, in any previous application for a degree. Except where states otherwise by reference or acknowledgment, the work presented is entirely my own.

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Abstract

Sessile oak (*Quercus petraea (Matt.) Liebl.*) is native to Central Europe and Czech Republic, with an economic and ecological importance, it is possibly a key species in the battle against the effects of the climate change. Sessile oaks natural regeneration has been extensively studied and is still in the process of research, since sessile oak tends to fail to naturally regenerate in the Czech Republic and other countries around Europe.

The research and data collection for this project was made in the Kunratický forest, a green island surrounded by urban development. Kunratický forest is a multifunctional forest with an approach of an uneven age forest, the location is one of the most frequently visited parks in Prague. The chosen site presented open gaps with natural regeneration and visible differences of growth stages of sessile oak seedlings. The data collection was made in the autumn of 2019.

The study presents 3 research plots with different features. It was possible to obtain density of each research plot and the species composition inside the gap. Other measurements were taken, such as seedling height, diameter, quality of the stem, the effect of game damage, the forest floor coverage, increment gained in the periods of 2019 and 2018, and light characteristics under canopy.

In regard to natural regeneration the Small gap presents results of 24.31 indiv. /m², the Big gap shows samplings of larger height with an average 41.59 cm and a maximum of 310 cm. The light availability within the gaps has a beneficial effect on the regeneration, growth and quality of the seedlings of the gaps, average Direct light 11.67 in the Small gap and 11.61 in the Big gap.

Keywords: Sessile oak, gap regeneration, heterogeneity, light availability, silviculture, climate change, resilient forest.

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1. Introduction

The forests in Europe cover about 1.02 billion hectares, and although oak is not the dominant tree species in the forests of Europe, oaks are one of the most widespread tree species in the world. Oak is the second most important broadleaved tree species in the Czech Republic covering 2 668 392 hectares. These trees are rooted in the European history and culture. The natural regeneration of oak forests is an important topic for the forestry alongside the subject of resilience.

Sessile oak (*Quercus petraea (Matt.) Liebl.)* is a large deciduous tree up to 20–40 m tall native to Central Europe, is widely distributed across Europe, providing habitat to array of plants, animals, insects and fungi. (Primavera & Fiorentino, 2013). Also, Sessile oak plays an important role in the wood processing industry and has a great importance in the ecology of Europe. Currently Sessile oak has been study for its important to the climate change. However, in some places the natural regeneration tends to fail.

Natural regeneration of oak has become an important topic for the Forestry community in Europe. This project and it resolves will give us a better understanding of oak regeneration, opportunities for natural regeneration and oak resilience throughout climate change.

2. Literature review

2.1. Oak species in central Europe

Genus *Quercus* from the *Fagaceae* family, contain approximately 600 extant species of oak. The genus *Quercus* is a native of the Northern Hemisphere, it appeared in the early Holocene period, and it's spread into the forests happened in response to the warming of the climate. In the Atlantic period between circa 8000–4500 cal. yr. before present was the period of expansion of the Quercus species in Europe.

Central Europe present four native species: the thermophilus pubescent oak (*Quercus pubescens, Willd*), Turkish oak (*Quercus cerris*) and the more widespread pedunculate oak (*Quercus robur L.*) and sessile oak (*Quercus petraea (Matt.) Liebl.*) (Sayer, 2000).

Quercus cerris is also known as the Turkish oak or Austrian oak. The Turkish oak is an introduced species of Southern Europe, meanwhile pedunculate and sessile oaks are native. *Quercus pubescens* commonly known as pubescent oak, is part of the white oak genus. Native to southwest Asia and southern Europe.

2.1.1. Sessile oak and pedunculate oak

Sessile and pedunculate oaks are members of the white oak section (*Quercus section Quercus*), these two species are important for central and rest of Europe for their ecological and economic value. Both are large deciduous trees, native to central Europe, they are the most frequent tree species in Europe. Both oaks represent an economically important basis for the European forestry market

These species have an economic value for forest enterprises and forest wood processing of the countries in central Europe. However, both species are not just important for ecological-interest purposes, but also for their value as a food source for several animals, mammals, birds, fungi, etc. (Annighöfer et al., 2015).

The importance of the species in regards to climate change is visible in many studies. The impact of hotter droughts on the forests is starting to show the possible beneficial attributes of these two species (Perkins, 2018). Also, many forest enterprises have the objective to increase the proportion of deciduous species on managed forest land to increase the resilience of the forests (Lüpke, 2004).

These two species can naturally hybridize, and vary morphologically (Jensen et al., 2009). The central trunk of the pedunculate oak tends to disappear in the crown, developing irregular boughs with twisting branches, while sessile oaks usually develop a main stem with boughs gradually decreasing in size. The bark of both species is grey, sessile oak often tends to be exfoliated, meanwhile pedunculate oak tends to be fissured, forming rectangular elongated blocks (Jones, 1959). The leaves of the pedunculate oak are simple, obovate-oblong, deeply and irregularly lobed, with a short stalk (2-7 mm), unlike the long stalk (13-25 mm) of the sessile oak. Pedunculate oak represents the main commercial tree species of floodplain forests in the Czech Republic (Poleno, 2007).

These oak species are monoecious and wind-pollinated, with drooping male flowers in yellow catkins about 5 cm long and inconspicuous globular female flowers of 1mm at terminal shots, which appear just after the first leaves have flushed.

These specimens can live naturally over 1000 of years, attaining a diameter of 3 to 4 meters, and in some cases growing over 40 m tall.

2.1.2. Ecological characteristics and site requirements

Sessile and pedunculate oaks co-exist at many sites of the temperate deciduous mixed forests, both having adapted to a large range of environmental conditions. Their ecological niches largely overlap, and they often grow in mixture at the stand scale, however, they show and need different ecological characteristics (Chybicki & Burczyk ,2010).

Pedunculate oak occur widely across most of Europe (Appendix Fig.1), reaching northwards to southern Norway and Sweden, and southwards to the northern part of the Iberian Peninsula, south Italy, the Balkan Peninsula and Turkey. Pedunculate oak presents altitudinal range from sea level up to 1200 m in Europe, Russia, the Caucasus and the Near East. This oak can be found preferentially in sandy, loamy or alluvial sites in the lowlands, sessile oak on the other hand thrives well in dryer and warmer sites, especially in low mountain ranges, the later species is indifferent to the origin of the soil and tolerates profiles with pH between 3.5 and 9. Sessile oaks invaded the current distribution range of pedunculate oaks (Petit et al., 2004). The pedunculate oak has been recorded to grow up to 1300 meters above sea level in the Alps (Roloff et al., 2010). Pedunculate oak is more tolerant of different abiotic factors than the sessile oak.

Sessile oak shares the same occurrence site in Europe as pedunculate oak (Appendix Fig. 2), however it is restricted to central and western Europe, without extending eastward into Russia. Sessile oak is presented in the north where maritime conditions influence the climate. The oak occurs in upland areas over 300 m (984 ft) with higher rainfall and shallow, acidic, sandy soils, it prefers acidic pH, but is adaptable to neutral pH soils. Sessile oak is more accustomed to a montane environment, in southern Turkey where it can reach up to 2000 meters above sea level (Johnson & More, 2006).

The majority of oak forests in central Europe are classified as acidophilus oak forests (*Calamagrostio arundinaceae–Quercetum*). Oak trees have a wide capacity of growing in different types of soils, from siliceous substrates to lime stones soils. Sessile oak and pedunculate oak have different site requirements (Aas, 2002; Schmull & Thomas, 2000).

Sessile and pedunculate oaks, both are able to behave as climax trees species, the acorns possess large reserves of energy and are able to survive amongst grasses whilst developing sufficiently deep roots to allow rapid shoot growth. Both species rarely suffer from late frost due to their foliage not coming until relatively late in the year (late April or early May) unless the temperatures reach -3°C, killing the new foliage (Praciak, 2013). Pedunculate oak and sessile oak, these species have a good re-sprouting aptitude, they coppice and polar easily.

Sessile oak presents more development in taproots than pedunculate oak, this allows them to withstand moderate droughts by accessing deeper water.

Forests where each species is presented, under natural conditions are rarely pure oak stand forests. In these types of forests, the *Quercus spp*. encounter competitors such as beech (Fagus sylvatica) as well as other shade tolerant and half shade tolerant tree species. In damp to wet and nutrient-rich soils, is common the presence of hornbeam (*Carpinus betulus*), and other deciduous tree species such as ash (*Fraxinus excelsior* (*Fraxinus angustifolia*), maple (*Acer campestre, Acer Platanoides*) and the small leaved lime (*Tilia cordata*) (Bohn, 2000). In these oak-hornbeam forest communities, assigned to the *Carpinion betuli* alliance, beech is out of its range or replaced, as the soils are relatively dry and warm or too wet. On warmer dry sites in sub-Mediterranean regions, sessile oak tends to mix with pubescent oak and with other drought-tolerant tree species, forming communities belonging to the order of *Quercetalia pubescenti-petraeae*. In poor and acid soils, where beech is unable to regenerate, oaks form mixed forests belonging to *Quercetea robori-petraea* communities, which are relatively small and scattered inside the beech range (Ellenberg, 2009).

Pedunculate oak has a wider amplitude than sessile oak, as it is more sensitive to droughts when compared to the sessile oak (Dickson & Tomlinson, 1996). Pedunculate oak can grow on heavier soils, more continental climates, in wet lowlands and damp areas by streams and rivers, tolerating periodic flooding (Savil, 2013). It can also be found in more basic soils, rich in minerals and nutrients, however, both species tolerate an extremely wide range of soils (Jones, 1959).

Sessile oak is often found on well-drained shallows, stony and rocky dry soils, because the species is more sensitive to high groundwater levels and stagnating wetness, but is more tolerant to droughts (Aas, 2002; Schmull, 2000).

While both species are well adapted to an Atlantic, sub-Mediterranean climate with mild winters, only pedunculate oak grows well under oceanic and continental climate conditions. Therefore, pedunculate oak is found further to the east, north, and south compared to sessile oak.

2.1.3. Light requirements

Oaks can grow in a wide range of conditions. Sessile oak is an intermediate shade tolerance species, meanwhile pedunculate oak has a low tolerance of shade. Meaning the oak species are relatively intolerant to shade and grow slowly under heavy shading; however, survival rates are relatively high under moderate shading (Johnson, 1993). Light requirements of young deciduous woody plants usually increase with increasing plant size (Valladares & Niinemets, 2008).

Oak seedlings appear to be fairly shade tolerant throughout the first few years, which is attributable to the resources stored in the acorn (Ziegenhagen & Kausch, 1995). Light needs to be sufficiently high to assure the continued growth and survival of the seedling after the resources of the acorn are depleted. Oak regeneration is able to persist in shady forest understories at light levels of about 15% of open-field conditions over several years while levels over 20% are necessary for continuous height grow (Röhrig & Bartsch, 2006).

When considering natural oak regeneration from the acorn, seedling growth is initially largely independent of the light conditions. During the first two years of life, both growth and vitality of the seedlings appeared to be more strongly determined by the acorn weight than by the surrounding environmental conditions (Welander & Ottosson, 1998). The tolerance of young oaks towards canopy shading decreases significantly from an age of 7 to 10 years and, additionally, is largely determined by water and nutrient supply (Hauskeller-Bullerjahn, 1997; Ostrogović et al., 2010).

2.1.4. Stand competition

Resource competition among seedlings is considered as a major determinant of seedling survival (Nelson & Wagner, 2014). The competitive interaction from herbaceous and woody vegetation from above and below ground reduce the oak performance (Jensen et al., 2012).

Oak stands are propense to compete for soil space with shade tolerant species. According to other studies *Quercus spp.* often fail to capture growing space, due to their growth habit where more photosynthetic capacity is initially allocated to root production rather than to shoot growth. This physiological adaptation allows oaks to develop large root systems and consequently enables them to persist on droughty sites and reproof vigorously following fire, grazing, or other disturbances that kill or injure the shoot, such adaptation helps oak seedlings to prepare a root system to confront the disturbances as was explained above (Lorimer, 1993). This same physiological adaptation also causes oaks to have a slow juvenile shoot growth rate, which is a disadvantage on high quality sites (Helms, 1998). This lets fast-growing competitors to accumulate on the forest floor and capture space followed by the release of crown space. This strategy is effective on dry-mesic or xeric sites where moisture may be limiting and a moderate amount of light reaches the forest floor, but it is a poor strategy on mesic sites where light levels are much lower (Dickson, 1991).

The competition at the seedling stage may or can be critical for Sessile oaks. Invasion of competition is probable to appear on the resident dominant species, at any stage of their life cycle.

2.1.5. Climate change and oak species

The long-term accumulative impact of humans on the Earth's ecosystems to some extent is affecting climate change. The major impacts of humans on forest ecosystems include: loss of forest area, habitat fragmentation, soil degradation, depletion of biomass and associated carbon stocks, transformation of stand age and species composition, species loss, species introductions, and the ensuing cascading effects, such as increasing risk of fire (Uhl & Kauffman 1990; Gerwing, 2002).

The consternation regarding the climate changes and the effects it has on the forests are widespread. Tree species have experienced climate changes over a longer time period during many interglacial periods. However, the environmental changes were slower than those occurring now (Kremer, 2002).

During the Quaternary period, the earth's climate was dominated by the succession of more than 15 glacial and interglacial periods. Glacial periods lasted between 70 and 100,000 years, while interglacial periods were much shorter (from 10 to 20,000 years) (Hays et al., 1976). This drastic change resulted in the expansion of tree distribution in Europe, natural filters and evolutionary mechanisms that helped Quercus spp. to survive. There are 4 mechanisms: rapid distribution, extensive gene flow through pollen dispersal, interspecific hybridization, and rapid adaptation.

For oak forests in Europe and North America, climate change is not more than another disturbance amongst many that require consideration, when developing silvicultural prescriptions. Developing silvicultural prescriptions will help to resist the climate change, prescriptions can be modified as necessary to mitigate climate change by increasing carbon sequestration, increasing resilience to climate or transitioning to forest conditions well suited to the future climate (Johnson et al., 2019).

Pedunculate oak is declining in many regions of its native range. Many of the factors that are affecting the oaks are: tree age, competition, soil conditions, topography, acute drought, defoliators, pathogens and infections (Popa et al., 2013).

To what extent species will be able to colonize new areas after climate change, depends on the degree of the effects of the climate change, the availability of new and suitable areas in accessible distance, the capacity of migration etc.

As stated by Gil-Pelegrin in “Oaks Physiological Ecology” (2017): “Exploring the Functional Diversity of Genus, the following results from the niched-based model projections from holm oak, cork oak, pedunculate oak and sessile oak. Shows projected potential range shifts between the calibration period 1961-90 to the periods 19911- 2010 and 2051-2080 (Lorenz, 1995). The model projects the change in suitable habitats in geographic space for the four oak species in Europe. The general patterns of suitable habitats through time show a shift to the northeast for pedunculate oak. These four species are largely disappearing in Spain and in part of France and new habitats become in Northeast of Europe. A similar dynamic is projected for sessile oak, holm oak and cork oak is projected to disappear in the southwest of Spain and to gain new suitable habitats in western France.”

Further research must be done in order to find a way to use the correct treatment in order to propagate an oak species that will overcome the near future climate.

2.1.6. Resilient forest

The definition of resilience is - the capacity of an ecosystem to return to the pre-condition state following a perturbation, including maintaining its essential characteristics taxonomic composition, structures, ecosystem functions, and process rates (Holling, 1973).

The definition of a resilient forest - are those that can adapt to disturbance easily, such like climate change, pest and diseases.

The goal of various authorities is to maintain forest resilience as a mechanism to mitigate the climate changes. Forest ecosystems can respond in different ways to the disturbances and perturbations (Thompson, 2009). The capacity of the forest to cope with changes depends on the characteristic taxonomic composition, vegetation structure, and the rate of ecosystem processes.

The resistance of the ecosystems will be the key stones to combat the consequences of climate change. Ecological resilience is defined as the ability of a system to absorb impacts before a threshold is reached where the system changes into a different state altogether, for example, the case of increasing climatic drought (Thompson, 2009). Forests are biologically engineered for resilience, which means that the forest may recover, after time, from disturbance to the original, pre-disturbance state, expecting the original species- composition. Resilience is an emergent property of ecosystems that is conferred at multiple scales by genes, species, functional groups of species and processes within the system (Gunderson, 2000).

A resilient ecosystem can withstand shocks and rebuild itself if it is destroyed. The resilience of some oak species is important for central Europe and Mediterranean environments for the near future. The topic of resilient forests of Europe requires more research.

2.2. Regeneration of oaks

2.2.1. Introduction to oak regeneration

The regeneration of *Quercus spp*. has been studied in Europe and other countries, however the reasons for differing success of natural oak regeneration are still not well understood. Sessile oak does not occur naturally as far in the northeast as pedunculate oak. Sessile oak trees can have a long life of 800 years. Some of the features of sessile oaks are shared with pedunculate oaks. Sessile oaks reach fructification at the age of 40-50 years in open stands and 70-80 years in closed stands. The theoretical background for this assumption is that the regeneration performance of oak seems to be subject to a variety of variables. Before germination, acorn predation seems to be of large relevance for the failing oaks regeneration later competition, insects (e.g. *Tortrix viridana L.*), fungi (e.g. *Microsphaera alphitoides Griffon and Maubl*.), water supply, light availability, and browsing, are among the most important variables (Shawn, 1968; Nilsson et al., 1996). Natural regeneration in most of the oak forests depends on the accumulation of acorns beneath the parent stands.

Biotic and abiotic factors continually change the forest state, like in natural forests where gaps of various size occur, a managed forest with silvicultural intervention will show similar gap structures.

The size of gaps, distance from surrounding trees and location within gaps are very important for gap colonization by varied species (Whitmore, 1989). Regeneration of oaks in a small open canopy seems to be possible in principal. Regeneration in small gap openings, unregularly distributed in space and time has the same effect on the forest structure as stem by stem unevenness, but has a completely different effect in very large areas which leads to even aged and regular stand structure. The irregularity will come with time and space. Factors which conclusively affect fructification are site and stand conditions, crown size, tree position as well as climate history (Houšková & Jan, 2019).

The natural regeneration of oaks is relatively rare on the territory of the Czech Republic, justifying its difficulty on heavily embedded soils and because oaks are usually not kept in such quantity to ensure a natural restoration.

2.2.2. Germination period

The Pedunculate oaks begin to fructify at the age of 40–50 in the open and at the age of 70–80 years in dense canopies (Palátová 2008; Vyskot 1958). Maximum acorn production usually occurs between 80 and 140 years and seeding may continue beyond age 200 (Evans, 1988). Pedunculate oaks in nature fructify nearly every year while in stands, seed years repeat every 4–8 years (Svoboda, 1955). The mature stand production is 0.7-2.0 t acorns ha-1, a well-developed free-growing oak produces 40-100 kg acorns year-1, with most years production exceeding 50 acorns (Reif & Gartner, 2007). Sessile oak acorns start their germination in the beginning of autumn, the immature roots or radical develops rapidly. Epicotyls (immature stems) usually do not develop until the following spring (Shawn, 1968). In a small portion of germinant, shoots may begin to develop during autumn, but overwinter stay as short succulent stems that require additional chilling to develop further. Acorns must survive over the winter, desiccation and predation during this time, this requires protection. Acorns fall in the autumn during or somewhat before leaf fall, they are protected from desiccation and freezing by the current years leaf fall. Acorns maintain moisture of 40%, therefore freezing temperatures of -7°can be fatal for the acorns. Favorable conditions for acorn germination and seedling establishment in the field include a moist, friable soil that can be easily penetrated by the developing radical. A covering of leaf litter, enough to prevent surface soil drying and accord desiccation and freezing, also creates favorable conditions (Iqbal & Warkentin, 1972).

The viability of oak acorns is about 80%, according to Shaw, who recorded slightly lower figures in October (60-70%) but found that viability then rose quickly to 80-90% (Aldhous, 1972; Shaw, 1968). Acorns have evolved several physiological and morphological characteristics that confer drought tolerance, including large seeds that provide food reserves for a protected period during and after germination, the rapid development of a long taproot, ability to photosynthesize and conduct water through the xylem under high water stress. The amount of light provided, is an important factor on the photosynthesis of the seedlings, light levels under dense forest canopies often fall below 2% of that in the open.

2.2.3. Regeneration strategy

Regeneration strategy is the mechanism that promotes the continuation or regeneration of the species. Not all strategies function in all environments, to the extent where one's abilities of regeneration can be a disadvantage in certain locations.

Acorns of the sessile oak and pedunculate oak are important food sources for vertebrate in Europe. Some species of vertebrate continue to consume acorns during ripping period and seed fall. A high percentage of available seeds come from caught seeds that were not retrieved or predated. Jay and wood mice are the most important dispersers and collectors of acorns in Europe (Bosseman, 1979).

Seedlings from different species may spatially segregate and not interfere (Raventos at al., 2010). Seedlings and sprouts work as reproductive mechanisms. Regeneration tactics may differ between habitats and disturbance regimes. The continues dominance of oaks is depended on the seedling sprouts fighting for space after a disturbance in the under storey (Gotmark & Charliene, 2014).

An important strategy in the regeneration of oak is the pollen dispersal. Pollen dispersal kernels indicate localized dispersal (70–120 m). Seed dispersal is more restricted, but long-distance dispersal events have also been inferred. Vegetative propagation has an important part in the strategy regeneration of the *Quercus spp.*

2.2.4. Oak regeneration strategies used in central Europe

There are two regeneration strategies used in Europe. The main difference being human input in artificial regeneration and the economic advantages of natural regeneration.

Artificial regeneration: Direct seeding is when seeds from a desirable species of tree are planted in the area of interest. Another method of artificial regeneration is planting tree seedlings collected from a nursery directly to the chosen area of forest.

Natural regeneration: This strategy is the process by which woodlands are reforested by trees that develop from seeds that fall and germinate on site. Cultivation of oaks in central Europe and North America is often challenged by oak forests frequently failing to regenerate naturally. (Watt, 1919). Natural regeneration is used and put in to practice during a good seed year, using the shelter wood system (Hansen, 1995). A lot of tree species, particularly broadleaves, as well as light demanding species regenerate better in gaps rather than under regular shelter, as gaps provide better light environment, however not all spatial regeneration is comparable (Houškova & Jan, 2019). European oaks, as the lightest demanding tree species, require the minimal gap to ensure successful regeneration of 0.25 ha, which should be after enlarged at the thickest stage up to 0.5 ha. For a shade tolerant species like beech the minimal gap requirement is evidently smaller, about 0.1 ha (Schutz, 2016).

2.2.5. Spatial segregation strategy

The spatial segregation strategy hypothesis is based on the idea that intraspecific aggregation increases the importance of intraspecific competition relative to interspecific competition, thereby enhancing local coexistence in plant communities (Pacala & Levin, 1997).

Under scrambled competition, limited resources are partitioned equally among contestants so that no competitor obtains the amount it needs. Seedlings from different species may spatially segregate and not interfere between each other (Raventos et al., 2010). In such conditions, competition occurs only among conspecific seedlings and does not lead to any species loss. Spatial segregation between trees occurs at the stand scale (Wang et al., 2010). This may result from small-scale spatial heterogeneity in environmental factors (such as light availability), seed dispersal ability, or from interactions with other plant species (Grubb, 1977; Traissac & Pascal, 2014).

2.2.6. Intraspecific and interspecific strategy

Intraspecific competition is when organisms from the same species compete for resources and interspecific competition is when the competition for resources happens between different species. Natural regeneration of other tree species inside of the cluster, poses a strong competition for the oak seedlings, as these tree species grow faster. As the seedlings from different species regenerate together, seedlings compete strongly for below-ground or above-ground resources, but they may exist together if intraspecific competition is more intense than or equal to interspecific competition (Chesson, 2000; Wilson, 2011). Intra and inter specific competition happens on both sides of the cluster, usually the coexistence of the population is unstable, but if the intraspecific competition is higher in the cluster the coexistence will be stable on both sides, creating a balance. Strong intraspecific competition between oak seedlings that are closely planted within the clusters reduces the growth that results in more slender trees. Interspecific competition does not affect the DBH of successional group (Wilson, 2011).

The regeneration stages and the variety in seedling height and height growth rates have been previously studied. The substantial difference observed in seedling height growth occurs among mixed tree species regeneration, this will lead to a differentiation in stature among the species, excluding the slow-growing species (Vickers, 2014).

2.2.7. Advantages and disadvantages of natural regeneration

All the strategies that were mentioned above, secure the growth and survival of the oak seedlings. However, the natural regeneration presents advantages and disadvantages.

Advantages of natural regeneration:

- Usually natural regeneration is to be considered cheaper than artificial regeneration. This difference presents a significant economic advantage.
- Biological differences between planted seedlings and natural regeneration seedlings, can influence both early and late growth. During natural regeneration, transplanting shock is prevented, and root systems are better distributed than they are in planted seedlings.
- Relatively little labor and heavy equipment required.
- No issues with geographical origins of the seeds.
- Preventing soil disturbance.
- Fewer problems with pest and diseases for established stands.

Disadvantages of natural regeneration:

- Problems are commonly encountered on clear-cuts, on hot and dry south slopes, sites where frost hazard is common or on sites where seed sources are inadequate (Herman, 1978).
- Tree coverage does not guarantee survival of the seedlings.

- There is little control over spacing and initial stocking.
- The use of genetically improved planting stock is not possible.
- Loss of income due to leaving the mother trees for production. Precommercial thinning often required in the resulting stand.
- When natural regeneration fails and a site must be planted, the resulted delay is expensive (Horton, 1985).
- The use of a tractor for stratification in some cases, which requires additional costs.

2.2.8. Influential factors affecting oaks in Czech Republic

Influential factors for success of natural regeneration need to be conditioned by several abiotic and biotic factors, in particular the climatic conditions (Van Ginkel et al., 2013). These factors influencing the seed occurrence are stand structures inside the cluster, seed predation and the annual shoot browsing (Forcardi et al, 2000; Jesnse, 2012). Included in the factors are late frost and insect pests, the main pest affecting oaks are *Tortrix viridana* and *Thaumetopoea processionea*, this species affects the first blossoms. Other parts of the acorns are consumed by birds and squirrels or attacked by insect pests while still on the tree. Losses occurring after seed fall are even more substantial. Seeds on the ground are subjected to a complex of negative abiotic and biotic factors, mainly predation (insects, birds, mice, squirrels, and ungulates), water availability, late frost, fungal attack and diseases (Reif & Gärtner, 2007).

Autumn acorns represent a highly attractive food and ungulate predation can be a determining impact on the destruction of seed, sampling production and seedlings (Kollman & Schill, 1996). For pedunculate oak the main negative factors are fungal infections and diseases (*Microsphaera alphitoides*) (Dobrovolný et al., 2017). Successful natural regeneration of sessile oak stands in the Czech Republic is suppressed by ruminant ungulates, such as roe deer (*Capreolus capreolus Linnaeus*) and red deer (*Cervus elaphus Linnaeus*), that can cause significant damage to stand regeneration by retarding tree growth or preventing seed emergence. The population of wild boars (*Sus scrofa Linnaeus*) has been increasing, this will be significant for the regeneration of stands (Kuiters et al., 1996; Bokdam & Gleichman, 2000).

2.3. Oak silviculture in central Europe

2.3.1. Oak silviculture throughout time

Silviculture evolved from the 17th century silviculture, or the culture of stands and forests, it is traditionally regarded as the outcome of integrating site conditions with management objectives (Troup, 1928). Silviculture begins in Central Europe, and the silviculture systems for the management of oak species are extensive. The oak forests in central Europe and the rest of Europe have been changed by European inhabitants, and now close-to-nature forest management (CTNFM) is an important objective for the European forestry sector, in order to understand the necessary processes that occur naturally in forests (Butler-Manning, 2007). The main goal of silviculture is to produce high-quality timber (Attocchi, 2015). Silviculture methods can vary between countries, in Germany and the Czech Republic oak is commonly regenerated by natural regeneration methods and shelterwood. When the regeneration is established, the series of tending operations start.

2.3.2. Common silvicultural systems used in central Europe

Clear-cutting system: Clear-cutting can be a successful method in upland hard wood forests. The removing of all trees in one harvest treatment, providing full growing space for new trees to grow (Schweitzer et al., 2016). Prior to the clear-cutting, the site should be adequate for regeneration of the desired species. This type of system is most common in North America.

Shelterwood system: This system provides one or more cuts in the site that create an optimum condition for the establishment of seedlings. The preparation of the site requires multiple cuts, the first cut is made for the benefits of the strengthening of the bed seed. The second or third cut is to secure the reproduction. When managing oaks, the purpose of the first cut is different than managing conifer systems, first cuts may be a thinning from below and the removing of lower crown class trees. This allows only a small amount of light to stimulate the seedling (Schweitzer at al., 2016).

Group selection: This type of systems has less impact on a unit area than clear-cutting. Clearing a group of trees provides the necessary room for the new stand to grow into the overstory (Clark & Bryan, 1970). One disadvantage is the higher logging and administrative cost compared with the shelterwood or clear-cutting systems. Group selection is easier to use on small to medium ownerships, or on small areas.

Single tree selection: In which scattered individual trees of multiple age classes, whose canopies are not touching, are harvested. The single tree selection can be used to sustain uneven-aged oak forests. The selection system seems to be especially suitable for shade-tolerant species, there are some examples of implementation of this system in forests consisting of light-adapted species, such forests are usually characterized by smaller tree density, lower basal area, and relatively low growing stock (Guildin, 2011).

Coppice system: Coppice is a forest regenerated from vegetative shoots, these shoots may originate from a stump or from the roots. Exist different forms of coppice forests: simple coppice, coppice with standards, coppice selection, pollarding and short rotation coppice. Czech Republic has been subjecting forest owners and stakeholders to the new adaptive guidelines of the coppice system, to increase the resilience of abandoned sessile oak forests that are subjected to the potential climate-induced decline process (Stojanović et al., 2015).

2.3.3. Thinning methods in oak stands

Thinning is a silvicultural operation where the main objective is to reduce the density of trees in a stand, improving the quality and growth of the remaining trees and producing a saleable product (Kerr, 1996). This method is used between regeneration and the final harvest.

Thinning objectives include the enhancement of the growth of selected trees, as well as the enhancement of health. Also, the application of thinning can increase economic yields.

There are several thinning methods such as mechanical thinning, thinning from below, thinning from above, etc. Thinning practices are guided by the belief that the veneer market prefers oak to be slowly grown with an average ring width of 2 mm (Kerr, 1996). When applying thinning methods to the oak species, it was noted that the oaks responded rapidly to the first free growth thinning at age 21, with the visible results after 4 years from the method being applied. (Kerr, 1996). Also, the cleaning operation of the site is often used to removes unwanted species and wolf trees (Attocchi, 2015). Removing of the wolf trees promotes the potential crop trees in a passive way.

2.3.4. Pruning

One of the important intermediate treatments is pruning, it is generally recommended after the early and heavy thinning is conducted (Beinhofer, 2009). Pruning is the removal of a portion of a tree to maintain the structure or to correct the tree shape.

Pruning consists of three primary principals: structural development, biological health, aesthetical and functional values. When pruning young oak, it must be kept in mind that the procedure is to create the potential for them to become grand trees. Pruning in oak is used to remove green and dead branches, as well as the removal of epicormic shoots. If the oak stand produces acorns on the site, the regeneration will not be a problem, the issue will come in the development of those oak seedlings.

2.3.5. Silvicultural economics

Despite the biological fundamentals of silviculture, it is regarded as an economic activity. Silvicultural planning and program delivery are part of the business undertaking. Foresters must confront the question of whether the method planned is financially justifiable. The net present values are calculated using the standard discounting technique for comparing alternative scenarios of silviculture regimes that promise positive net present values. The economics of silviculture also involve a multitude of silvicultural activities, the risk and uncertainty associated with the pre-determining end products. Also, the environmental and social problems are part of the ecological and economic aims of silvicultural methods.

2.3.6. Oak shares in the forest and wood market

According to the information on forests and forestry in the Czech Republic in 2018, the shares of broadleaves have been increasing and the current oak share in Czech Republic is 189 842 ha., which is 7.3% of all broadleaved species. Pedunculate and sessile oaks are amongst the most economically important deciduous forest trees in Europe. Both species have a capacity to produce large volumes of valuable timber. Sessile oak wood is largely distinguishable from pedunculate oak and is particularly appreciated for its straight grain.

2.3.7. Principal uses of oak wood

The Sessile and pedunculate oaks are part of the white oaks of Europe, Asia and North America. The heartwood from white oaks is generally greyish brown, sapwood have a lighter color than the heartwood. In general oak wood is heavy, hard, stiff and strong and has a high ability to resist shock (Betts, 1959). All oak species are strong, hard, heavy and dense with very close grain and, due to their high tannin content, they are very resistant to insect and fungal infestation. Second- growth of oak is generally stronger, harder, and tougher than old growth, and takes a finer finish.

Oaks principal use is for lumber, veneer, railroad ties, fuelwood, cooperage, and mine timber. Lumber is the outstanding use in both amount and value. Much of the lumber is remanufactured into motor-vehicle parts, car construction, flooring, furniture, building, general millwork, boxes, crates, etc. Oak wood is one of the oldest furniture woods. Its hardness, strength, machining properties, and appearance, as well as its adaptability to various kind of finishes, qualify it well for all grades of furniture, oak wood has always been preferred for ship and boat construction (Betts, 1959).

2.4. Oak management systems and climate change

Climate change is affecting the altitudinal and longitudinal range of biomes, forest communities, and tree species. The influence in the productivity of the forest is visible, climate change is regarded as one of the most challenging issues that forest management needs to confront (Crow, 2008). The aim of some multi-agencies, private or public, are the initiatives to promote an understanding of potential climate change impacts on forests and how to address it with management. Forests are increasingly managed to meet multiple objectives designed to address a diverse set of ecological, social, and com-modifying goals (Gustafsson et al., 2012). Oaks are among the most important tree species in temperate deciduous forests, with ecological and economical perspectives for Europe and North America.

The development of silvicultural prescriptions to assist the continuation of the oak forests is essential, these silvicultural prescriptions are focused on sustaining the flow of traditional forest products and ecosystem services, however, some methods can be changes to mitigate climate change by increasing carbon sequestration, increasing resilience or transforming the forest conditions. However, this requires the choosing of species best suited for the future climate. The assistance of oak migration to suitable areas is one way to accelerate their movement across the land. This requires planning when and where new habitats will be available, the identification of suitable genotypes and thinking of scaling and timing the germination period, so that the new population of oak is ready to bear acorns at a time when future climate is suitable. Mixing genotypes within the range of oaks is another form of assisted species migration that can improve the ability of the population (Williams & Dumroese, 2013).

The aim of retaining tree groups is not to help the regeneration, but to ensure the continuity of the forest structure and composition and thus preserving the legacies of the forest’s biodiversity and functions.

2.5. Research locality and its’ characteristics

2.5.1. Kunratice Forest

The chosen locality was Kunratice Forest in the southern part of Prague, Czech Republic (284 ha, the highest point 310 m above sea level), surrounded by the development of Roztyl, Chodov, Kunratice, Krč and the Kačerov depot (or the Southern Junction). The western edge is bordered by the Kunratický brook, in the south by Kunratice creek, the forest crosses even to its left bank. The right bank of the creek is lined by steep rocky slopes opened by several former quarries covered with dwarf oak forests. The eastern part of the forest is predominantly flat, divided only by a few mostly anhydrous gorges, emerging from the valley of the Kunratický brook; the largest of them, intersecting virtually the entire Kunratice Forest (and the only one with a steady watercourse, not counting a short stream at Urešova studánka) is the gorge of the Roztylský brook.

2.5.2. Historical development of the locality

Kunratický forest has been managed by the local population for years. It is also popularly known as Kunraťák (the north-western part is called Michelský les and is also known as Krčský les or Krčák), a continuous wooded area that extends 300 hectares in the territory of the capital city of Prague, the largest forest in the city of Prague. Kunratický Forest is enclosed from other areas by urban development.

Kunratice forest is historically connected with the persona of Wenceslaus VI (Vaclav IV), it is Vaclav IV who bought the extensive Kunratice estate in 1407. The estate was bought from the debtor of the Olbramovice family to use this space to stay close to nature and hunt, in these lands was also built a hunting castle. The castle is called Wenzelstein, otherwise called Nový Hrad, built in between 1410 – 1412 (Prahy,2020). However, in 1419 Wenceslaus IV died in this very castle, from a heart attack. A year later the castle was conquered by the Hussites during the Hussite Wars, to this day only ruins of the castle Nový Hrad remain.

During the 20th century the territory of the Kunratický forest passed through interesting property developments. In 1923 Prague City Council bought the central part of the forest and in 1928 the Prague City Council was donated the territory around Nový Hrad. The northern part of the forest has been owned by the Charles University since 15th century. Interestingly, the part of the forest near Chodov was added after World War II; it was afforested after being originally agricultural land. Kunratický forest did not avoid the so-called "spruce mania" in the 20th century, where many European countries replanted the forests exclusively with spruces (Humlová, 2015).

2.6. Present status and functions of Kunratice Forest

2.6.1. Present day park management

The forest area is in a cluster, an island of greenery in the dense settlements that border the forest area. The forest is frequently visited by the neighbors that live in the margins, several marked hiking trails for pedestrians and cyclists have been made.

The high traffic of people in the forest brings a variety of challenges and issues, such as littering and vandalism. The annual anniversary of the Great Kunratický Running Tournament is part of the new issue added to the area. Each year the number of runners involved increases, this affects the nature of the forest. Waste bins, benches are constantly repaired, new ones added; picnic sites have public fireplaces and playgrounds, in addition arbors exist in the area (Humlová, 2015).

All forests that are inside the area of the city are owned by the Capital city of Prague and managed by the department of Municipal forests of Prague. The City of Prague has been the holder of the international, ecologically very strict forestry certificate FSC® (Forest Stewardship Council®) since May 2007 , which manages forest management aims to achieve nature-friendly forest stands, all taking into account the significantly non-productive mission of Prague forests (Prahy, 2020).

Forest certification means the process of inspecting a specific forest in order to determine whether it is managed in accordance with ecological, social and economic criteria and requirements defined by the Czech FSC standard (Grafique.cz, 2020).

During the FSC certification of forest property of the capital according to FSC standards, it was necessary to adjust some of the technologies and procedures used so far in the sense of "refining" the impacts on forest ecosystems and the entire environment. As part of the FSC certification, so-called reference areas were also defined, which are areas that are excluded from intensive forest use. Any interventions must always be aimed at achieving the natural state of forest ecosystems. Parts of the reference areas whose species composition and structure are similar to the presumed natural state are in a non-intervention regime (with the exception of measures against insect pests and forest fire safety). In these stands, it is therefore possible to meet, for example, dead trees (marked with blue color on the trunk), which are left for natural decay and are not removed from the forest (Prahy, 2020).

2.6.2. Natural conditions inside the park

The Kunratice forest sits on an acidic site, covered by forests of oak wood, with oak-hornbeam forest prevailing in the area. The socio-recreational potential of the forest is important, with the possibility of forest ecosystems maximum functional capacity for production under optimal conditions, with social effects to meet the physical and mental needs of the person (optimization of physiological processes of the organism) (Vyskot, 2003). One of the most prominent species in the Kunratice forest is the sessile oak (*Quercus Petraea (Matt.) Liebl*), 36% of the total area. Non-original monocultures of spruce (*Picea abies Lindl.*), which were artificially planted at the beginning of the 20th century, have 23% representation.

The area is largely covered by vegetation with extensive artificial plantings of Norway spruce and Scots pine (Prahy,2020). The spruces are now heavily affected by European spruce bark beetle (*Ips typographus*). Pine (*Pinus sylvestris L.*) is another coniferous tree that can be found in the forest area, with a 14% incidence. Near to the stream in the valley of the forest, it is possible to find *Stellario nemorum-Alnetum Glutinosae* and *Pruno padi-Fraxinetum excelsioris*, black alder (*Alnus glutinosa (L.) Gaertn.*), ash (*Fraxinus excelsor*), willow (*Salix spp.*) and poplar (*Populus spp.*). The surrounding 17 streams of the brook are commonly overgrown by hornbeam (*Carpinus betulus L.*) and other rare communities. Among the coniferous species from the area it is possible to find in small quantities European larch (*Larix decidua Mill.*) and douglas firs (*Pseudotsuga spp.*). Other species common in the forest are bird cherry (*Prunus padus*), common hazel (*Corylus avellana*), common hawthorn (*Crataegus leavigata*) and common dogwood (*Cornus sanguinea*), European spindle (*Euonymus europaeus*), common lilac (*Syringa vulgaris*), wild privet (*Ligustrum vulgare*), dog rose (*Rosa canina L.*). Also, in the area of the forest can be found some specimens of the giant sequoias (*Sequoia dendron giganteum*) growing in a former Kunratice forest nursery (Humlová, 2015).

2.6.3. Fauna of the Kunratice Forest

Due to the forest area being enclosed by urban areas, existing mammal groups in the forest of Kunratice are rather small, such animals can be encountered: mouflons, roe deer, rodents, forest badger. Common birds that dwell in the forest area are jays, straw balls and bricks. One of the major problems for the birds in the forest, are the free-running dogs that prevent the nesting of some bird species, which tend to nestle on the ground. This especially applies to the surroundings of the Kunratický brook, where most birds nest low above the ground or even directly on the ground.

Mouflons are not originally from the Czech Republic. The European mouflon is considered native in the Mediterranean islands of Corsica, Cyprus, and Sardinia. The absence of fossils in Corsica, Sardinia and the Italian peninsula points towards an origin of mouflon in the Mediterranean, European Mouflon prefers open or half-open areas, with a lot of sunshine and a small quantity of snow (Pedrotti et al., 2001). They poorly tolerate long periods of snow (due to limited length of legs) (Tosi & Lovari, 1997). Mouflons were placed in the region of Bohemia in the second half of the 19th century, the population that live in Kunratice was placed there in 1960s. Mouflons live in groups and enjoy extreme slopes with stunning rocks. Male mouflons or mouflon rams are horned, these horns are used in battles, some females or ewe are horned, while other are polled. In the Kunratice forest, however, the population of mouflons cause problems - they decimate all herbs and decaying trees, causing the most damage to young parts of plants and the degradation of subsoil.

However, the mouflons are not the only inhabitants of the Kunratice forest, it is common to find Carabus coriaceous, there are also 44 species of beetles for example *Magdalis barbicornis*, also it is possible to observe butterflies *Synanthedon conopiformis*, *Opostega salaciella*, etc. Spiders living in the forest include *Eresus kollar* and *Eresus moravicus*. Species of mollusks, several species of gastropods are observed here, such as the *Acanthinula aculeate* and in the zone of the creek is common to find *Clausilia pumila*.

3. Materials and methods

3.1. Site characteristics and locality

Forest stands presented in the area of Kunratice are specialized forests with a recreational function. The data was collected in the location of forest stand 149 A12 (Fig.1) with an age class VII, forest site soil composition is 2K5.

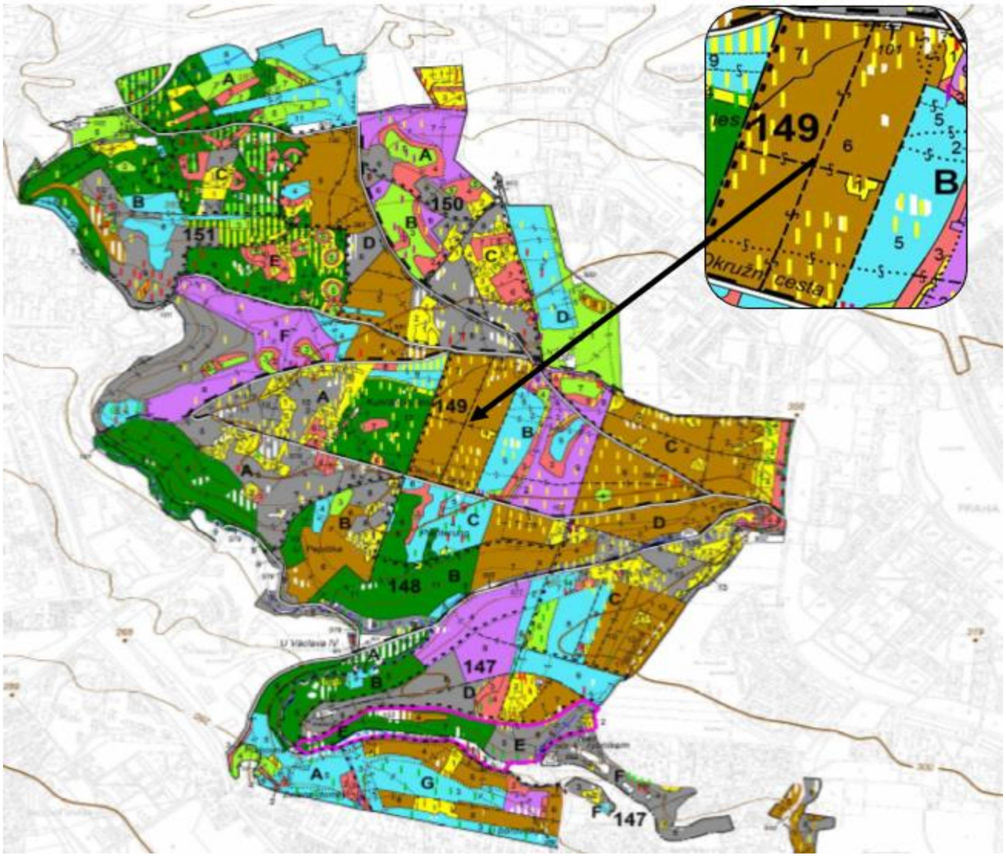


Figure 1. Kunratice forest (Kunratický les) and research stand composition.

Forest type: beech-oak zone (*Fagus sylvatica- Quercus petreae*), this zone covers 14.9% of the forested area in Czech Republic (Viewegh, 2005). Beech-oak forests are often found between 350 to 400 m over the sea level.

Climatic characteristics: mean annual temperature is 7.5 to 8°C, mean annual precipitation is between 600 to 650 mm per year; growing season is 160 to 165 days. Sessile oak is the dominant tree; however, European hornbeam and European beech are very abundant in the lower tree layers.

One of the prevailing soil types in the area is Cambisols. Due to the acidity on site of the Kunratice forest, the prevailing forest type are oak woods and oak-horn groves (Humlová, 2015). Edaphic series K series- Acidic (oligotrophic): forest vegetation zone *Fageto-Querceta acidophila* (acidic beech-oak forests) prevail at lower uplands and basins on nutrient-poorer soil parent materials (Fig.2).

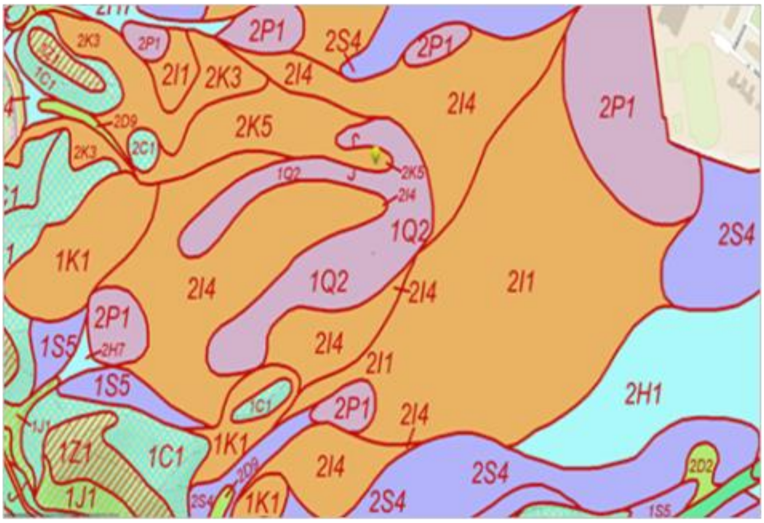


Figure 2. Soil composition of the site in Kunratický forest.

In nutrient richer localities, these types occur on shallow and desiccation-prone soils, which evoke transition to stunted growth types.

Occurrence: uplands on different base-poor soil parent materials; slopes and plateaus.

Soil: moderately deep, more or less gravelly, water deficient. Predominantly oligotrophic, Cambisols mostly podzolized; on sandy soils oligotrophic Cambic Arenosols. Soils are with predominant unification processes (browning). During oxidative weathering of primary minerals, which are iron oxide and aluminum oxide ($Fe2O3$, $Al2O3$), clay minerals are formed (Vokoun, 1993).

3.2. Data collection

The marking of the plots and collection of the data was executed during the months of October and November of 2019. The site consists of three research plots (RP) that are identified as: small gap (1), canopy (2), big gap (3) (Tab.1). Each RP is divided into 2 transections, each transection that crosses the RP is the length of 30 meters (m), which are measured from south to north and west to east.

Table 1. Classic characteristics of the research plot (RP).

Research plot (RP)	**ID**	**Size (m^2)**	**Number of subplots**
Small gap	1	310	13
Canopy	2	N/A	13
Big gap	3	615	13

The Small gap has an early stage of regeneration, the Canopy presents samplings under a shade environment and the Big gap presents old growth stands with a height ranging between 1 to 3 meters. A measuring tape was used to outline the 30 meters long transect; every 5 meters were measured, and a frame was placed to indicate a subplot of 1 m² (Fig.3).

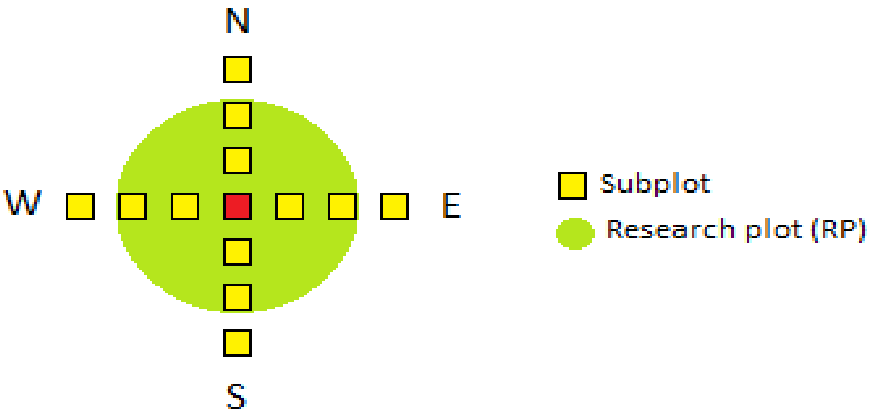


Figure 3. Research plot schematic.

Within the subplot the following measurements were taken: number of specimens with their respective species name; diameter (mm) of individual (diameter of the lower part of the stem or root collar near to the surface of the ground); height (cm) of each sampling; the quality of the stem (Q1: straight individual, Q2: some deformation of the stand, Q3: plagiotropic-full growth deformation); a brief description of the floor coverage; game damage effect (browsing) on the seedlings; as well as increments (cm) of 2018 or 2019 (if applicable).

In addition, photography of the canopy's openness gap was performed with a Canon EOS 1100D camera equipped with a fisheye lens. Light measurements were taken at breast height, the photographs were taken with the camera facing the canopy looking to the North (N).

3.3. Data evaluation

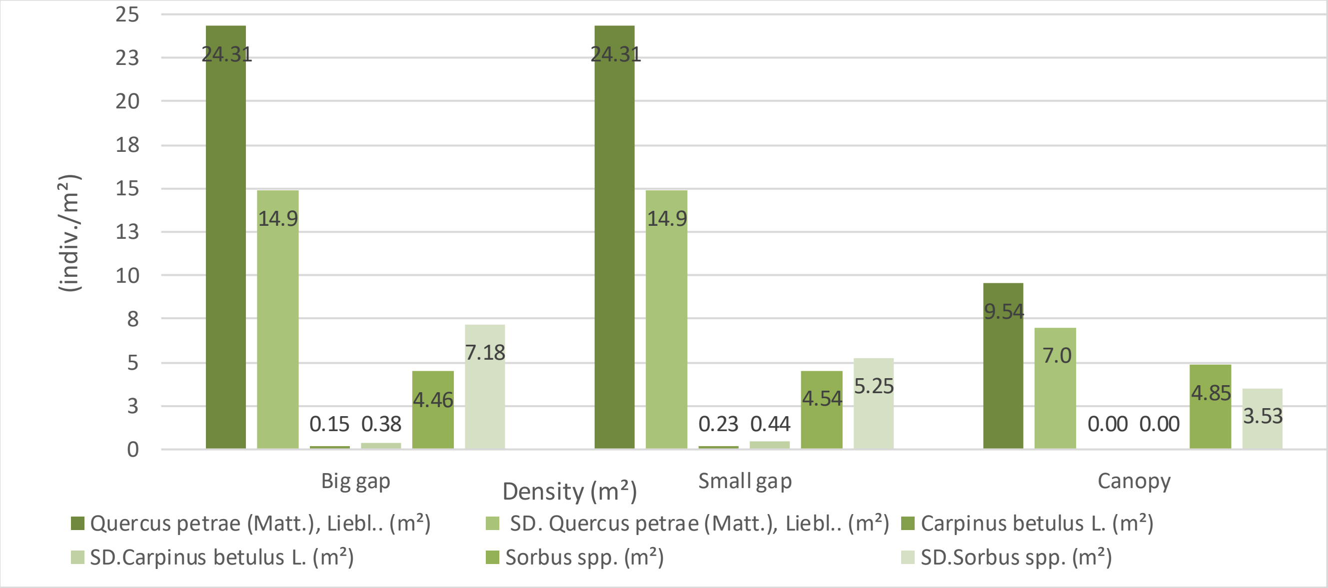
With the data collected from the site, characteristics for each Research Plot (RP) were gathered. The results are expected to represent aspects of gap regeneration and site heterogeneity. Images taken of the canopy's openness were processed on a computer with adobe Photoshop CS3 software to obtain binary photographs, later the images were processed and then analyzed by hemIMAGE software. For the statistical analysis regarding light characteristics (PPDF Direct, PPFD Diffuse, Canopy % and Canopy foliage) the Correlation Coefficient and Kruskal Wallis H Test or one-way ANOVA ($H=N(N+1)12(n1R12+n2R22$

+⋯+*nkRk*2)−3(*N*+1)) were used. Data analysis was possible with the use of RStudio and Microsoft Excel, all information collected has been set up to answer questions related to this work.

4. Results

4.1. Regeneration density and tree species composition

Analysing the regeneration density of each research plot (RP) allowed to identify the dominant tree species composition, which shows the majority is shared between the sessile oak (*Quercus petraea*) and *Sorbus spp*.

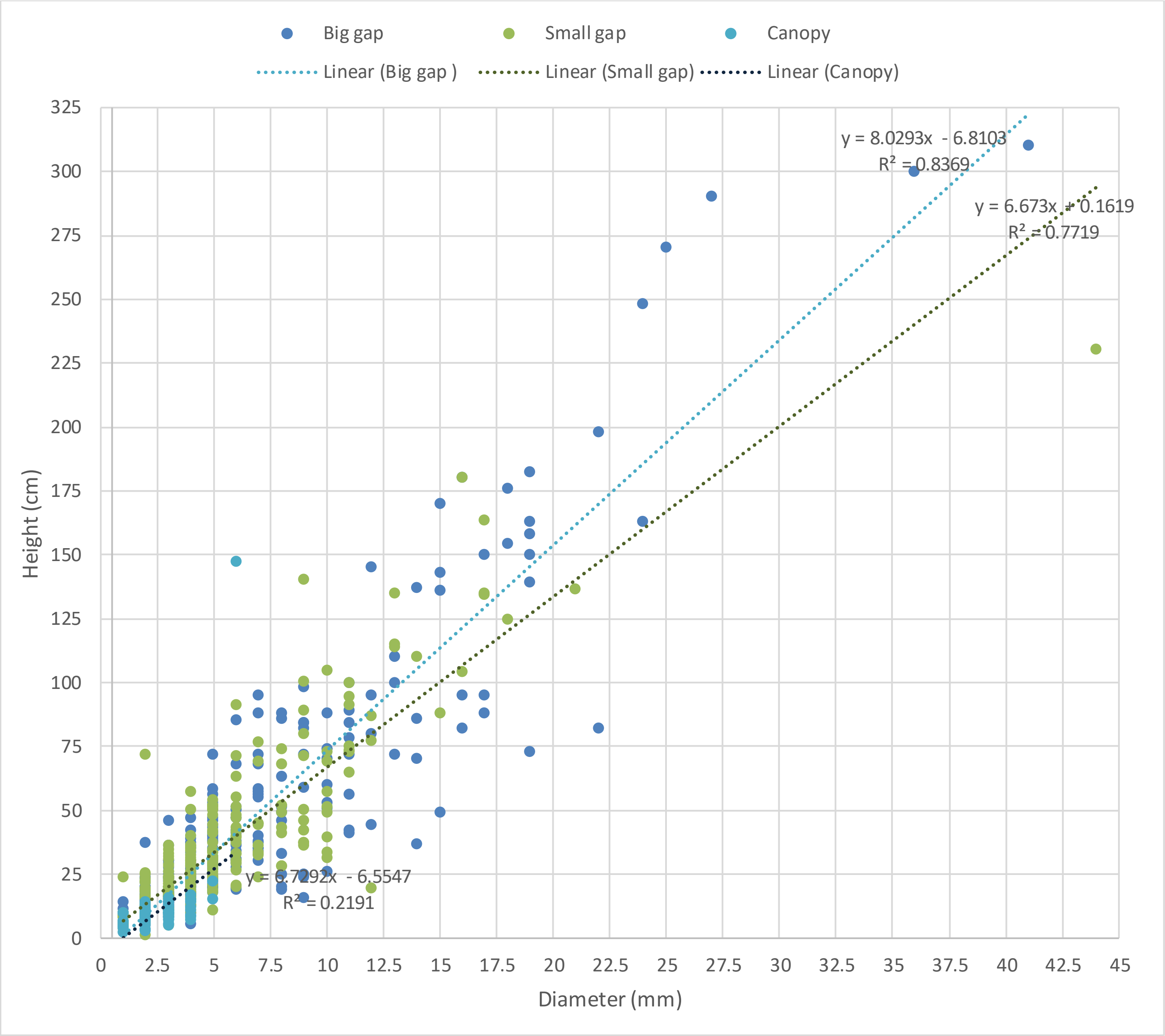


Graph 1. Number of individuals and regeneration density for each research plot (RP) and the standard deviation (SD).

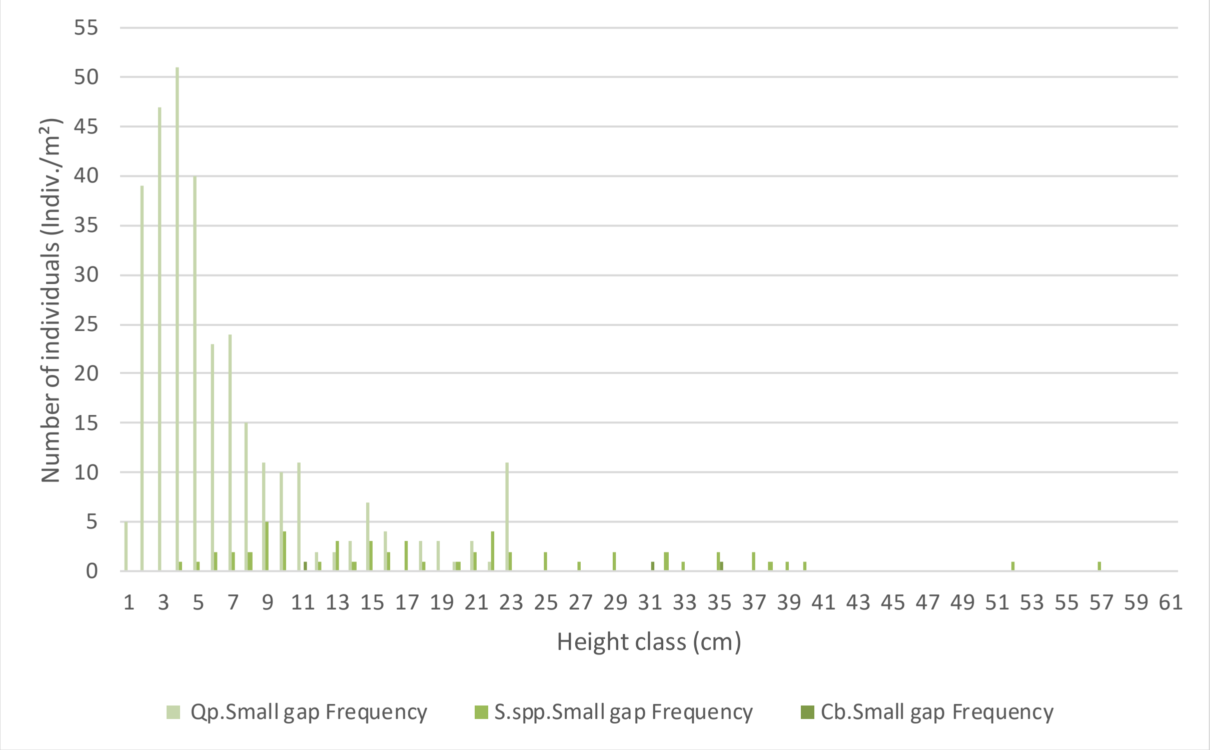
When researching the regeneration of oaks, it is important to compare regeneration density of sessile oak and the other species that can be found inside of the research plot (RP)

4.2. Height structure and diameter characteristics

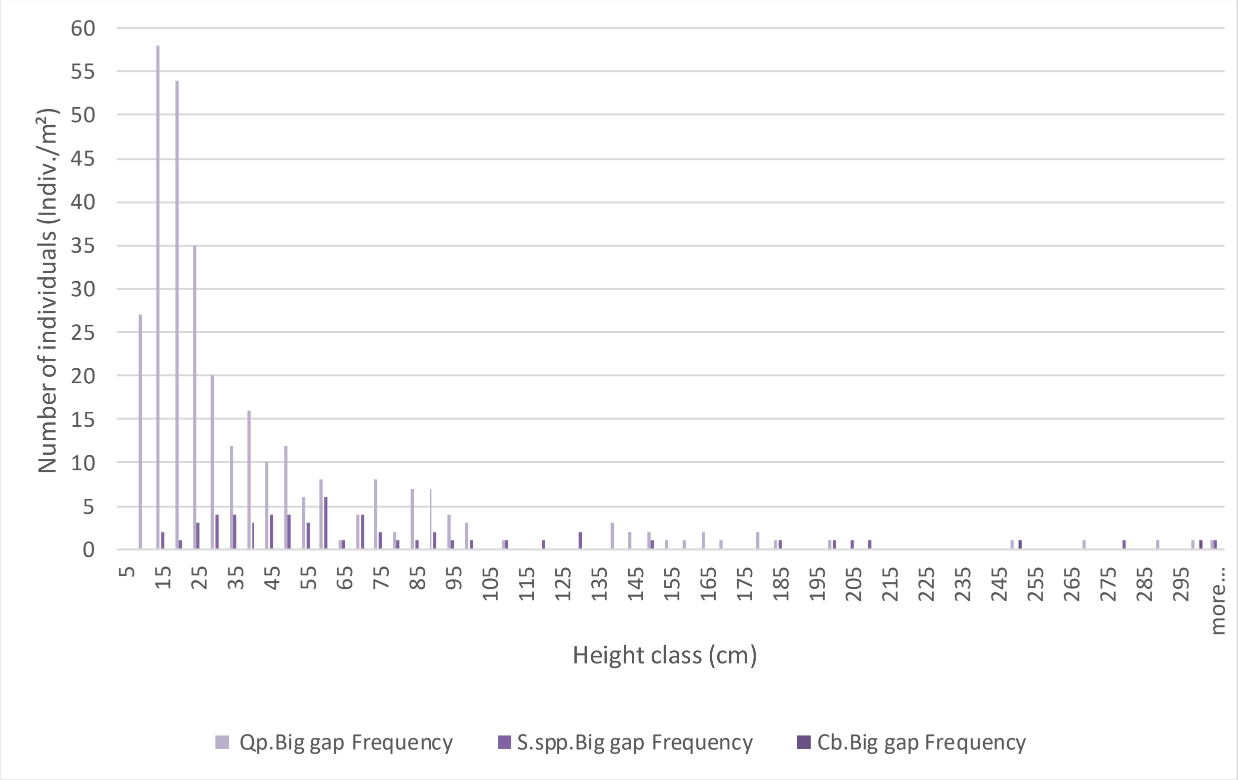
The height and diameter characteristics of the seedlings are the main visible attributes showing growth and the competitiveness of the space ground between the sessile oak individuals (Graph 2.). A visual representation of species composition and their height classes within the Research plots is found in Graph 3., Graph 4. & Graph 5.



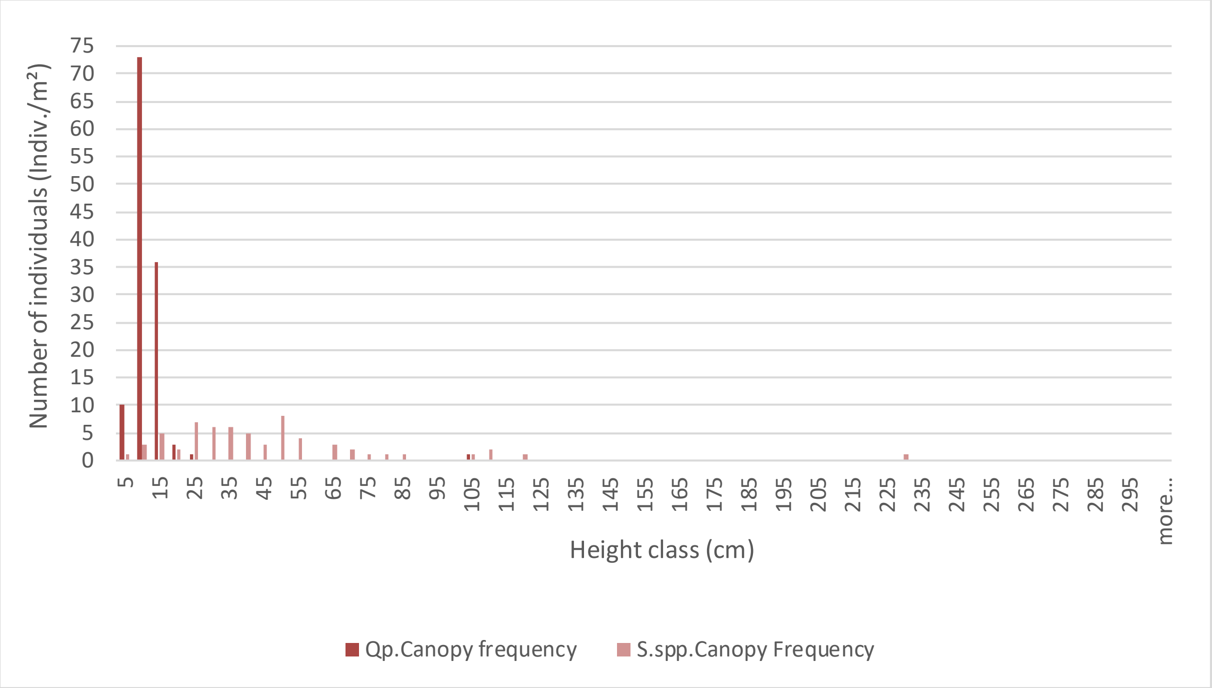
Graph 2. Height curve for sessile oak individuals on the research plot (RP).



Graph 3. Height class structure from Small gap, differences between species and spatial distribution. Qp-Quercus petraea (Matt.) L., S.spp- Sorbus spp. Cb-Carpinus betulus L.

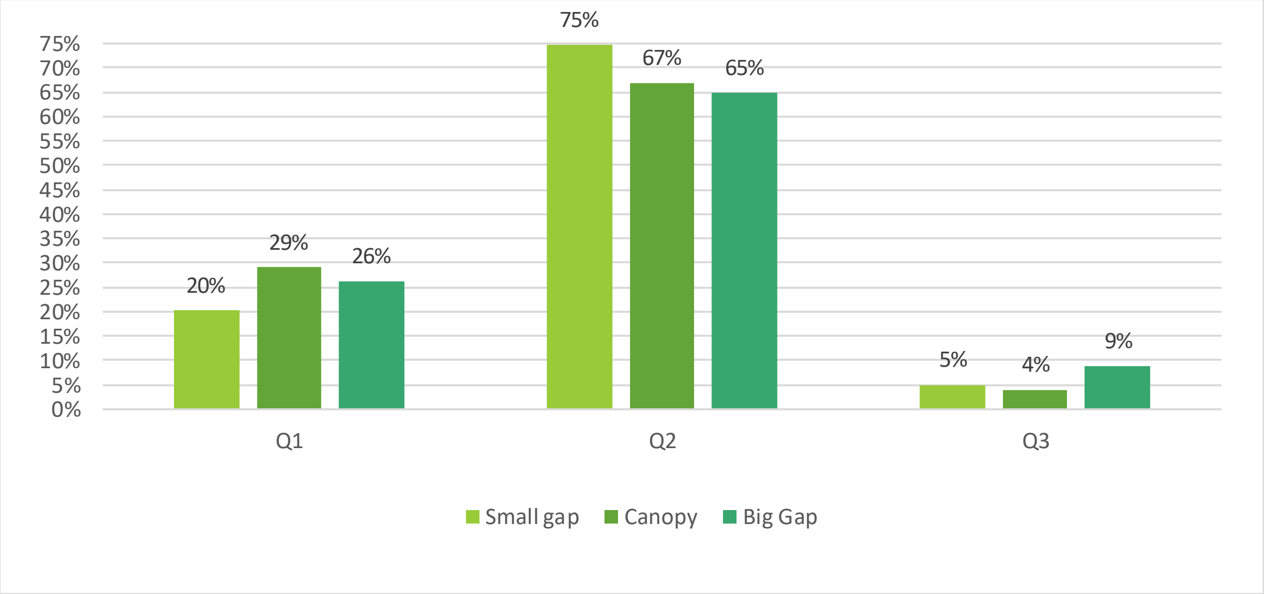


Graph 4.Height class structure from Big gap, differences between species and spatial distribution. Qp-Quercus petraea (Matt.) L., S.spp- Sorbus spp. Cb-Carpinus betulus L.



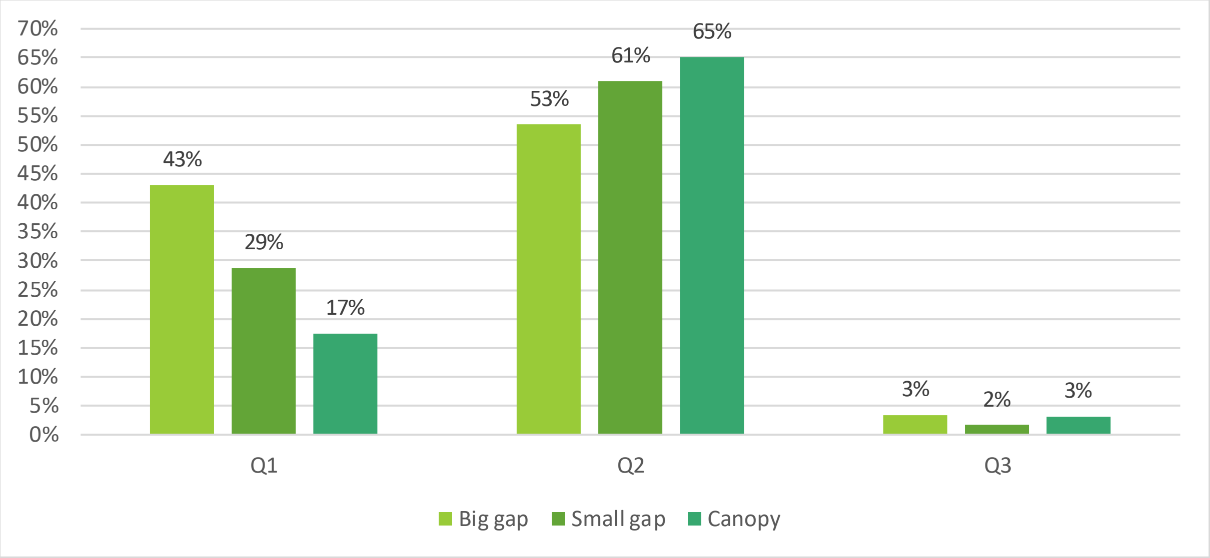
Graph 5. Height class structure from Canopy, differences between species and spatial distribution. Qp-Quercus petraea (Matt) L., S.spp- Sorbus spp. Cb-Carpinus betulus L.

The quality of the stems during the development of the seedlings, is presented as a percentage. Each RP presents a different growth stage of the seedlings, consequently each RP should have different values (Graph 6.).



Graph 6. Sessile oak stem quality (%). Q1: Perfect straight individual; Q2: Some deformation of the stem; Q3: Plagiotropic-full growth deformation.

For a clearer picture of the quality of the RP as a whole, the quality of the second most common species was taken into consideration (Graph 7.)



Graph 7. Sorbus spp. stem quality (%). Q1: Perfect straight individual; Q2: Some deformation of the stem; Q3: Plagiotropic-full growth deformation.

4.3. Differences within the research plots

Differences within the research plots can be observed. The research plots were divided into four directional margins: North, South, West and East, each margin presenting unique results (Table 2., Table 3. & Table 4.).

Table 2. Variations in measurements within the Small gap research plot (RP).

	Small gap				
	Center N 137	North Margin N67	South Margin N14	West Margin N39	East Margin N59
Av. Heigh (cm)	44.764	15.870	12.843	35.218	24.264
Av. Diameter (mm)	5.934	2.582	2.571	5.359	4.864
SD. Height (cm)	38.801	12.295	7.953	20.169	16.791
SD. Diameter (mm)	5.102	1.499	1.785	3.013	2.849
Me. Height (cm)	31.000	12.000	10.300	31.200	22.000
Me. Diameter (mm)	4.000	2.000	2.000	5.000	4.000
Var.Height (cm)	1505.518	151.162	63.243	406.786	281.940
Var.Diameter (mm)	26.032	2.247	3.187	9.078	8.119
Max.Height (cm)	230.000	72.000	28.000	80.000	87.700
Min.Height (cm)	4.000	1.360	4.800	7.000	4.700
Max.Diamter (mm)	44.000	11.000	8.000	12.000	15.000
Min.Diameter (mm)	1.000	1.000	1.000	1.000	1.000
	Increment				
Av. In. 2019 (cm)	5.606	1.418	1.636	3.405	2.727
Av. In. 2018 (cm)	3.050	1.012	0.929	0.921	1.212
SD. In. 2019 (cm)	7.189	1.487	1.981	3.195	2.985
SD. In. 2018 (cm)	6.338	2.095	2.500	2.370	3.027
Me.2019 (cm)	2.500	1.300	2.500	3.000	2.400
Me.2018 (cm)	6.000	3.200	6.500	3.400	5.100
Var.2019 (cm)	51.680	2.211	2.262	10.210	8.850
Var.2018 (cm)	71.311	4.389	8.820	5.616	9.165
Max.2019 (cm)	33.000	6.500	5.800	11.000	12.800
Min.2019 (cm)	2.000	1.000	2.000	1.000	1.000
Max.2018 (cm)	29.000	10.000	8.600	12.000	18.000
Min.2018 (cm)	2.300	0.000	4.400	2.000	0.000
	Forest coverage				
Forest floor (%)	0.71	0.5	0.5	0.85	0.58
Blueberry (%)	0.09	0.18	0	0	0
Grass (%)	0.13	0.32	0.4	0.1	0.37
Dead wood (%)	0.05	0	0.05	0.05	0.05
Moss (%)	0.02	0	0.05	0	0

Note: N- Number of individuals, Av- Average, SD – Standard deviation, Var- Variance, Me- Median, Max- Maximum value, Min- Minimum value, Height (cm), Diameter (mm). Forest cover is expressed as a percentage (%).

Table 3. Variations in measurements within the Canopy research plot (RP).

	Big gap				
	Center N95	North Margin N106	South Margin N28	West Margin N58	East Margin N28
Av. Height (cm)	66.557	32.723	40.623	29.631	20.218
Av. Diameter (mm)	8.402	4.462	6.688	5.552	4.393
SD. Height (cm)	70.736	33.123	30.918	19.479	14.628
SD. Diameter (mm)	7.786	3.492	4.468	3.424	3.392
Me. Height (cm)	39.000	18.900	31.000	22.700	16.600
Me Diameter (mm)	5.000	3.000	5.500	4.000	3.500
Var.Height (cm)	5003.611	1097.128	955.892	379.448	213.970
Var.Diameter (mm)	60.617	12.194	19.964	11.725	11.507
Max.Height (cm)	310.000	158.000	110.000	88.000	73.000
Min.Height (cm)	5.500	6.000	1.000	8.000	6.000
Max.Diamter (mm)	41.000	19.000	17.000	22.000	19.000
Min.Diameter (mm)	2.000	1.000	1.000	1.000	2.000
	Increment				
Av. In.2019 (cm)	5.331	3.254	3.269	3.321	2.485
Av. In.2018 (cm)	6.877	2.435	1.672	2.498	2.793
SD. In.2019 (cm)	7.767	3.378	3.779	3.110	1.835
SD. In. 2018 (cm)	10.533	3.505	2.967	3.517	3.828
Me.2019 (cm)	2.050	2.400	2.500	2.850	2.200
Me.2018 (cm)	2.000	4.100	5.000	4.150	2.250
Var.2019 (cm)	60.328	11.409	13.682	9.670	3.366
Var.2018 (cm)	125.071	12.283	7.242	12.372	14.411
Max.2019 (cm)	34.000	18.000	17.000	20.000	7.000
Min.2019 (cm)	1.000	1.000	2.000	1.500	0.000
Max.2018 (cm)	47.000	20.000	10.000	14.600	17.000
Min.2018 (cm)	1.600	1.300	4.000	1.000	0.000
	Forest coverage				
Forest floor (%)	0.50	0.88	0.55	0.65	0.25
Blueberry (%)	0.07	0.00	0.30	0.05	0.00
Grass (%)	0.29	0.00	0.28	0.25	0.70
Dead wood (%)	0.14	0.12	0.12	0.05	0.00
Moss (%)	0.01	0.00	0.20	0.00	0.05

Note: N- Number of individuals, Av- Average, SD – Standard deviation, Var- Variance, Me- Median, Max-Maximum value, Min- Minimum value, Height (cm), Diameter (mm). Forest cover is expressed as a percentage (%).

Table 4. Variations in measurements within the Big gap research plot (RP).

	Canopy				
	Center N39	North Margin N29	South Margin N35	West Margin N16	East Margin N10
Av. heigh (cm)	13.282	10.597	8.343	8.363	9.530
Av. Diameter (mm)	2.412	2.621	2.543	2.063	3.100
SD. Height (cm)	23.755	4.021	2.362	3.540	3.078
SD. Diameter (mm)	2.412	0.903	0.919	0.680	3.078
Me. Height (cm)	9.650	10.100	8.300	8.350	9.500
Me. Diameter (mm)	2.000	3.000	3.000	2.000	3.000
Var. Height (cm)	564.284	8.990	5.743	12.533	9.476
Var.Diameter (mm)	0.856	0.815	0.844	0.463	0.250
Max.height (cm)	147.000	22.000	15.200	13.400	14.600
Min.height (cm)	3.300	4.800	2.300	2.600	5.000
Max.diamter (mm)	6.000	5.000	5.000	3.000	4.000
Min.diameter (mm)	1.000	1.000	1.000	1.000	2.000
	Increment				
Av. In. 2019 (cm)	2.086	0.624	0.463	0.250	0.786
Av. In. 2018 (cm)	0.000	0.290	0.246	0.000	0.000
SD. In. 2019 (cm)	1.001	0.940	0.812	0.447	1.301
SD. In. 2018 (cm)	0.000	0.889	0.700	0.000	0.000
Me.2019 (cm)	2.000	1.900	1.550	0.000	0.000
Me.2018 (cm)	0.000	3.000	2.050	0.000	0.000
Var.2019 (cm)	0.698	0.883	0.406	0.200	1.692
Var.2018 (cm)	0.000	0.790	0.257	0.000	0.000
Max.2019 (cm)	3.500	2.900	2.600	1.000	4.000
Min.2019 (cm)	1.000	1.000	1.000	0.000	0.000
Max.2018 (cm)	0.000	3.400	2.800	0.000	0.000
Min.2018 (cm)	0.000	0.000	1.700	0.000	0.000
	Forest coverage				
Forest floor (%)	0.79	0.75	0.80	0.73	0.75
Blueberry (%)	0.00	0.00	0.02	0.03	0.00
Grass (%)	0.16	0.23	0.08	0.10	0.20
Dead wood (%)	0.05	0.02	0.10	0.10	0.03
Moss (%)	0.00	0.00	0.00	0.03	0.03

Note: N- Number of individuals, Av- Average, SD – Standard deviation, Var- Variance, Me- Median, Max-Maximum value, Min- Minimum value, Height (cm), Diameter (mm). Forest cover is expressed as a percentage (%).

Next table (Table 5.) presents a comparison of mean characteristics collected within the Research plots (RP).

Table 5. Comparison of mean characteristics of regeneration between both gaps and canopy.

		Small Gap	Big gap	Canopy
Density	Av.(Indiv./m²)	24.31	24.31	9.54
	SD.(Indiv./m²)	14.9	14.9	7.0
	Median (Indiv./m²)	30.0	20.0	7.0
	Variance (Indiv./m²)	220.76	337.06	48.94
	Min.(Indiv./m²)	5.00	5.00	2.00
	Max.(Indiv./m²)	49	61	28
Height	Av.(cm)	32.22	41.59	10.32
	SD.(cm)	30.66	47.62	12.77
	Median (cm)	22.35	23.55	9.20
	Variance	940.22	2268.12	162.99
	Min.(cm)	1.36	5.50	2.30
	Max.(cm)	230.00	310.00	147.00
Diameter	Av. (mm)	4.80	6.03	2.51
	SD.Diameter (mm)	4.04	5.43	0.89
	Median (mm)	4.00	4.00	2.00
	Variance	16.30	29.44	0.79
	Min.(mm)	1.00	1.00	1.00
	Max.(mm)	44.00	41.00	6.00
Increment of 2019	Av.Incr.2019 (cm)	3.80	3.80	0.47
	SD.Incr.2019 (cm)	5.37	5.07	0.88
	Median (cm)	2.20	2.40	0.00
	Variance	28.86	25.66	0.77
	Min.(cm)	0.00	0.00	0.00
	Max.(cm)	33.00	34.00	4.00
Increment of 2018	Av.Incr. 2018 (cm)	1.92	3.24	0.15
	SD.Incr. 2018 (cm)	4.68	6.51	0.59
	Median (cm)	4.00	0.00	0.00
	Variance	21.88	42.32	0.35
	Min.(cm)	0.00	0.00	0.00
	Max.(cm)	29.00	47.00	3.40

Note: Av-Average, SD- Standard Deviation, Incr- Increment, Min-Minimum, Max-Maximum.

4.4. Light characteristics inside the research plot.

Each subplot within the research plots (RP) was analysed for the difference of diffuse and direct light within the gap margins. Light of the above canopy distribution is presented in a percentage (%) (Table 6., Table 7. & Table 8).

Table 6. Percentage of direct and diffuse light in the research plot (RP).

RP	Quantity of subplot	Average	Median	Standard deviation	Minimal value	Maximum value
			Direct Solar Radiation %			
Small gap	13	11.67	12.25	5.14	3.85	19.27
Canopy	13	5.71	5.34	1.79	3.56	8.91
Big gap	13	11.61	11.17	5.64	3.6	21.77
			Diffuse Solar Radiation %			
Small gap	13	1.80	1.96	0.56	0.85	2.46
Canopy	13	0.96	0.975	0.20	0.68	1.3
Big gap	13	2.20	2.39	0.58	1.42	2.97

Note: RP-Research plot, % - percentage.

Table 7. Comparison of light characteristics between gaps and canopy (all subplots).

Research Plots	Nr. Of Subplot	Nr.of individuals	PPFD over canopy	PPFD Direct	PPFD Diffuse	PPFD Total	Canopy %	Canopy foliage %
Small gap	1	9	40.93	6.41	1.06	7.48	14.97	85.03
	2	5	40.93	3.85	1.5	5.35	18.54	81.46
	3	13	40.93	9.46	2.41	11.87	25.9	74.1
	4	30	40.93	17.29	2.46	19.75	26.95	73.05
	5	32	40.93	19.27	2.07	21.34	23.83	76.17
	6	49	40.93	13.11	1.05	14.16	15.22	84.78
	7	18	40.93	5.84	0.85	6.69	12.5	87.5
	9	34	40.93	13.05	1.91	14.96	22.57	77.43
	10	24	40.93	17.85	2.3	20.14	26.53	73.47
	11	38	40.93	15.15	2.15	17.3	26.85	73.15
	12	40	40.93	11.44	2.01	13.45	26.07	73.93
	13	19	40.93	7.34	1.84	9.18	24.42	75.58
Canopy	14	28	40.93	8.91	0.96	9.87	14.77	85.23
	15	7	40.93	4.51	0.99	5.51	14.09	85.91
	16	12	40.93	5.77	1.3	7.06	18.48	81.52
	17	4	40.93	6.17	1.02	7.19	14.33	85.67
	18	5	40.93	5.48	0.89	6.37	11.35	88.65
	19	17	40.93	5.23	0.68	5.91	9.77	90.23
	20	12	40.93	8.19	1.11	9.31	14.26	85.74
	21	6	40.93	4.87	0.88	5.75	10.93	89.07
	22	10	40.93	3.93	0.96	4.89	10.65	89.35
	23	11	40.93	3.56	0.71	4.27	9.1	90.9
	24	2	40.93	8.51	1.27	9.78	16.94	83.06
	25	3	40.93	5.34	1.02	6.36	13.37	86.63
	26	7	40.93	3.77	0.63	4.4	10.2	89.8
Big gap	27	24	40.93	11.36	1.58	12.94	18.38	81.62
	28	8	40.93	17.45	2.54	19.99	29.08	70.92
	29	9	40.93	12.4	2.66	15.05	29.4	70.6
	30	12	40.93	10.14	2.77	12.9	32.02	67.98
	31	5	40.93	11.17	2.73	13.9	32.61	67.39
	32	61	40.93	12.3	2.69	14.99	32.79	67.21
	33	45	40.93	8.87	2.39	11.27	30.08	69.92
	34	42	40.93	3.6	1.5	5.1	20.99	79.01
	35	16	40.93	6.17	1.42	7.6	18.96	81.04
	36	20	40.93	6.61	1.63	8.24	22.52	77.48
	37	46	40.93	21.5	2.97	24.47	33.63	66.37
	38	23	40.93	21.77	2.24	24.01	27.57	72.43
	39	5	40.93	7.55	1.51	9.06	17.43	82.57

Note: PPDF- Photosynthetic Photon Flux Density, %- percentage

Table 8. Direct and diffuse light percentage of each margin of the research plots (RP).

Research plot	Aver.Center ± SD	Aver.NM ± SD	Aver.SM ± SD	Aver.WM ± SD	Aver.EM ± SD	Center Min ± Max.	NM Min. ± Max.	SM Min. ± Max.	WM Min. ± Max.	EM Min. ± Max.
Direct Solar radiation %										
Small plot	15.80 ± 1.29	9.48 ± 5.14	5.13 ± 1.81	13.05 ± 3.39	9.39 ± 2.90	9.46 ± 19.27	5.84 ± 13.11	3.85 ± 6.41	13.05 ± 17.85	7.34 ± 11.44
Canopy	5.90 ± 3.87	6.71 ± 2.09	6.710 ± 3.11	4.40 ± 0.66	4.56 ± 1.11	3.56 ± 8.51	5.23 ± 8.19	4.51 ± 8.91	3.93 ± 4.87	3.77 ± 5.34
Big gap	12.36 ± 5.54	10.59 ± 2.43	14.41 ± 4.31	4.89 ± 1.82	14.66 ± 10.06	6.61 ± 21.50	8.87 ± 12.30	11.36 ± 17.45	3.60 ± 6.17	7.55 ± 21.77
Diffuse Solar Radiation %										
Small plot	2.28 ± 0.17	0.95 ± 0.14	1.28 ± 0.31	2.11 ± 0.28	1.93 ± 0.12	2.07 ± 2.46	0.85 ± 1.05	1.06 ± 1.50	1.91 ± 2.30	1.84 ± 2.01
Canopy	1.04 ± 0.25	0.90 ± 0.30	0.98 ± 0.02	0.92 ± 0.06	0.83 ± 0.28	0.71 ± 1.30	0.68 ± 1.11	0.96 ± 0.99	0.88 ± 0.96	0.63 ± 1.02
Big gap	2.55 ± 0.53	2.54 ± 0.21	2.06 ± 0.68	1.46 ± 0.06	1.88 ± 0.52	1.63 ± 2.97	2.39 ± 2.69	1.58 ± 2.54	1.42 ± 1.50	1.51 ± 2.24

Note: Center- The center of the research plot, NM- Margin North, SM-Margin South, WM-Margin West, EM-Margin East, Aver. - Average, SD-Standard Deviation, Min- Minimum, Max-Maximum, %-Percentage.

4.5. Correlation between light characteristics under canopy and measurments.

Below tables show light characteristics (PPFD Direct, Diffuse, Canopy % and Canopy foliage %) and how they relate to the Height, increments and forest surface coverage found in the Research plots (RP) (Table 9., Table10., Table 11., Table 12. & Table 13.).

Table 9. Results of correlation of PPDF Direct and height, annual increment and characteristics of the forest surface.

		Small gap	Big gap	Canopy
PPFD Direct	Height	0.56	-0.07	0.06
	Increment 2019	0.34	-0.02	-0.17
	Increment 2018	0.54	0.03	0.64
	Forest Floor	0.61	0.10	0.01
	Grass	-0.76	-0.03	0.02
	Blueberry	0.53	-0.16	0.29
	Dead wood	-0.18	-0.03	0.03
	Moss	-0.46	-0.03	-0.46

Note: PPFD - photosynthetic photon flux density.

Table 10. Results of correlation of PPDF Diffuse and height, annual increment and characteristics of the forest surface.

		Small gap	Big gap	Canopy
PPFD Diffuse	Height	0.79	0.36	0.03
	Increment 2019	0.77	0.37	-0.59
	Increment 2018	0.75	0.29	0.13
	Forest Floor	0.54	0.32	0.28
	Grass	-0.60	-0.41	-0.26
	Blueberry	-0.14	0.13	-0.08
	Dead wood	0.27	0.41	0.15
	Moss	0.13	-0.13	-0.35

Note: PPFD - photosynthetic photon flux density.

Table 11. Results of correlation of PPDF Total and height, annual increment and characteristics of the forest surface.

		Small gap	Big gap	Canopy
PPFD Total	Height	0.60	-0.03	0.06
	Increment 2019	0.40	0.02	-0.22
	Increment 2018	0.58	0.05	0.61
	Forest Floor	0.63	0.13	0.04
	Grass	-0.77	-0.07	-0.01
	Blueberry	0.48	-0.14	0.26
	Dead wood	-0.15	0.01	0.05
	Moss	-0.41	-0.05	-0.47

Note: PPFD - photosynthetic photon flux density.

Table 12. Results of correlation of Canopy % and height, annual increment and characteristics of the forest surface.

		Small gap	Big gap	Canopy
Canopy %	Height	0.71	0.39	0.08
	Increment 2019	0.69	0.41	-0.50
	Increment 2018	0.67	0.34	0.16
	Forest Floor	0.56	0.36	0.35
	Grass	-0.56	-0.46	-0.27
	Blueberry	-0.19	0.16	-0.01
	Dead wood	0.25	0.42	0.04
	Moss	0.02	-0.28	-0.39

Note: PPFD - photosynthetic photon flux density.

Table 13. Results of correlation of Canopy Foliage % and height, annual increment and characteristics of the forest surface.

		Small gap	Big gap	Canopy
Canopy foliage %	Height	-0.71	-0.39	-0.08
	Increment 2019	-0.69	-0.41	0.50
	Increment 2018	-0.67	-0.34	-0.16
	Forest Floor	-0.56	-0.36	-0.35
	Grass	0.56	0.46	0.27
	Blueberry	0.19	-0.16	0.01
	Dead wood	-0.25	-0.42	-0.04
	Moss	-0.02	0.28	0.39

Note: PPFD - photosynthetic photon flux density.

The next table presents the results of the Kruskal-Wallis test, with a breakdown for each individual light characteristic and their relation with the following measurements Height (cm), Increment 2019 (cm), Increment 2018 (cm), Forest floor (%), Grass (%), Blueberry (%), Deadwood (%) and Moss (%).

Table 14.Kruskal-Wallis test: light characteristics in relation to height, annual increments and forest surface.

		H	X^2	P	R/NR
PPDF Direct	Height	22.74	3.84	0.00	R
	Increment 19	38.21	3.84	0.00	R
	Increment 18	48.16	3.84	0.00	R
	Forest floor	56.26	3.84	0.00	R
	Grass	56.26	3.84	0.00	R
	Blueberry	56.26	3.84	0.00	R
	Deadwood	56.26	3.84	0.00	R
	Moss	56.26	3.84	0.00	R
PPFD Diffuse	Height	56.26	3.84	0.00	R
	Increment 19	0.74	3.84	0.39	NR
	Increment 18	1.82	3.84	0.18	NR
	Forest floor	43.45	3.84	0.00	R
	Grass	55.33	3.84	0.00	R
	Blueberry	56.26	3.84	0.00	R
	Deadwood	56.26	3.84	0.00	R
	Moss	56.26	3.84	0.00	R
PPFD Total	Height	16.75	3.84	0.00	R
	Increment 19	42.29	3.84	0.00	R
	Increment 18	49.61	3.84	0.00	R
	Forest floor	56.26	3.84	0.00	R
	Grass	56.26	3.84	0.00	R
	Blueberry	56.26	3.84	0.00	R
	Deadwood	56.26	3.84	0.00	R
	Moss	56.26	3.84	0.00	R
Canopy %	Height	0.05	3.84	0.83	NR
	Increment 19	54.10	3.84	0.00	R
	Increment 18	51.98	3.84	0.00	R
	Forest floor	56.26	3.84	0.00	R
	Grass	56.26	3.84	0.00	R
	Blueberry	56.26	3.84	0.00	R
	Deadwood	56.26	3.84	0.00	R
	Moss	56.26	3.84	0.00	R
Canopy foliage %	Height	43.52	3.84	0.00	R
	Increment 19	56.26	3.84	0.00	R
	Increment 18	56.26	3.84	0.00	R
	Forest floor	56.26	3.84	0.00	R
	Grass	56.26	3.84	0.00	R
	Blueberry	56.26	3.84	0.00	R
	Deadwood	56.26	3.84	0.00	R
	Moss	56.26	3.84	0.00	R

Note: H-hypothesis values, X^2-chi-square, P-P value, Alpha α-0.05, R-Rejected, NR-not rejected, PPFD-photosynthetic photon flux density

Table 15.Comparision by group Kruskal-Wallis Test, PPDF Direct and Measurements.

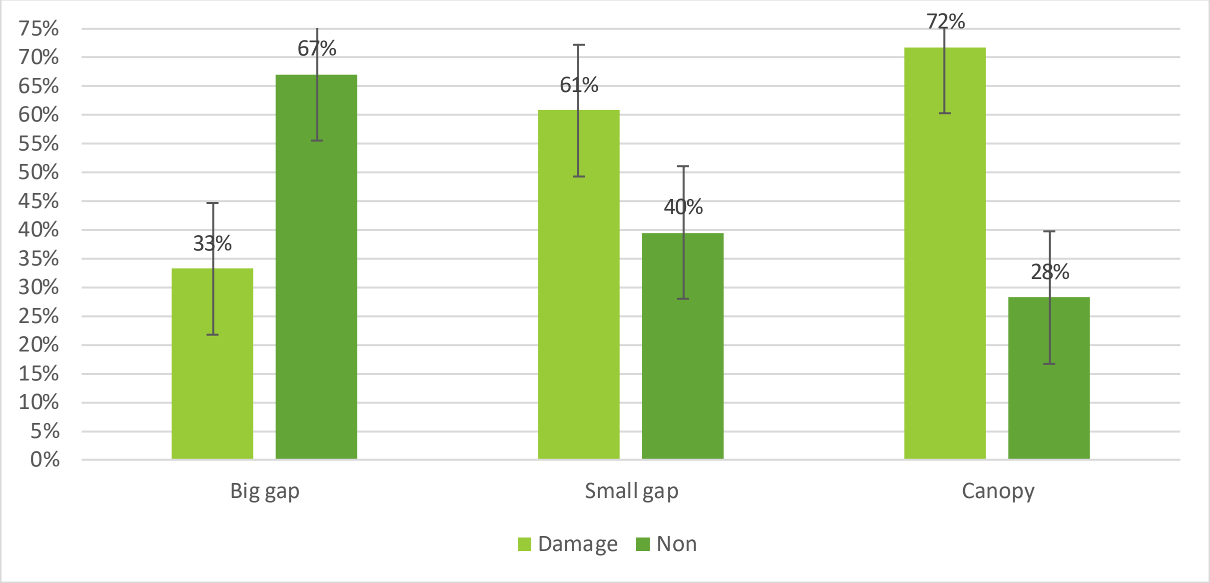
Col Mean-Row Mean	Ave.Height	Ave.Inc.19	Ave.Inc.18	Blueberry	Dead wood	Forest Floor
Ave.Inc.19	2.95					
	0.00					
Ave.Inc.18	1.91	-1.04				
	0.03	0.15				
Blueberry	6.09	3.14	4.18			
	0.00	0.00	0.00			
Dead wood	6.27	3.32	4.37	0.18		
	0.00	0.00	0.00	0.43		
Forest Floor	3.54	0.58	1.63	-2.55	-2.74	
	0.00	0.28	0.05	0.01	0.00	
Grass	4.87	1.91	2.96	-1.22	-1.41	1.33
	0.00	0.03	0.00	0.11	0.08	0.09
Moss	6.64	3.69	4.73	0.55	0.36	3.10
	0.00	0.00	0.00	0.29	0.36	0.00
PPFD Dir.	0.83	-2.12	-1.08	-5.26	-5.44	-2.70
	0.20	0.02	0.14	0.00	0.00	0.00

Col Mean-Row Mean	Grass	Moss
Moss	1.77	
	0.04	
PPFD.Dir	-4.03	-5.81
	0.00	0.00

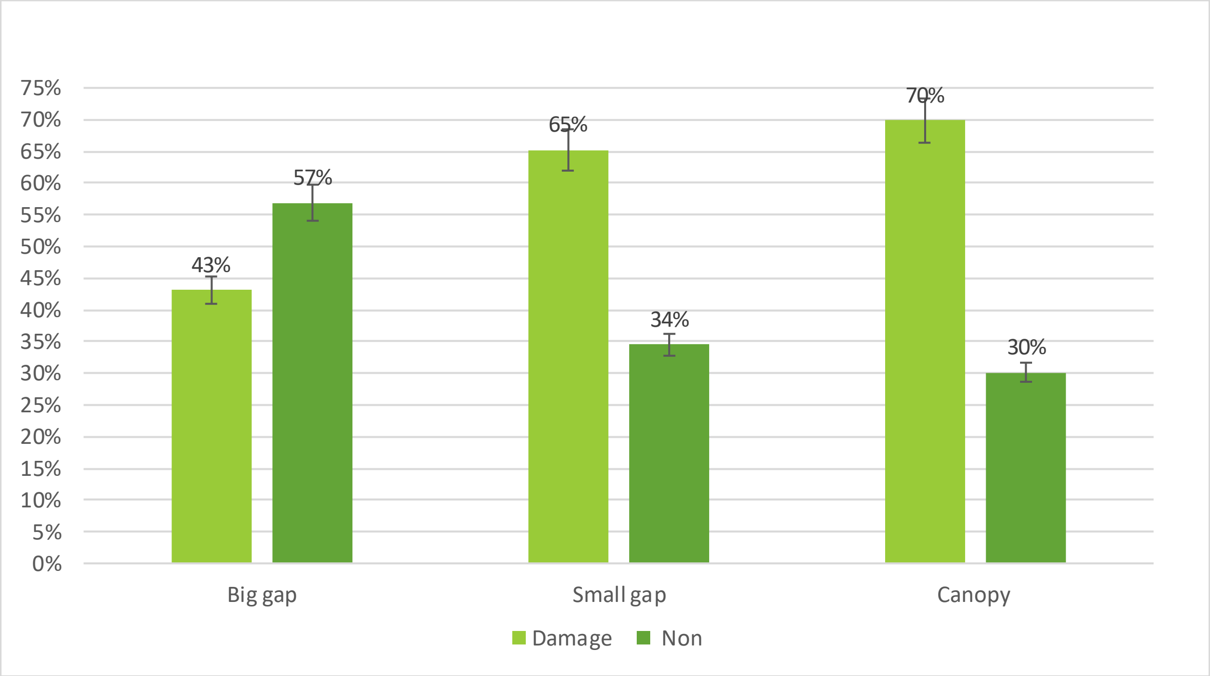
Note: Col-column, Ave-Average, Dir-Direct, Incr.-Increment, PPFD- photosynthetic photon flux density.

4.6. Game Damage

Other data collected was information of the browsing effects of local game on the seedlings and samplings (Graph 8. & Graph 9.). Since one of the most common problems for natural regeneration is game damage and its effect on the mortality and quality of the population in the gaps. Also, the Error bars are added into the graphic to showing the standard error.



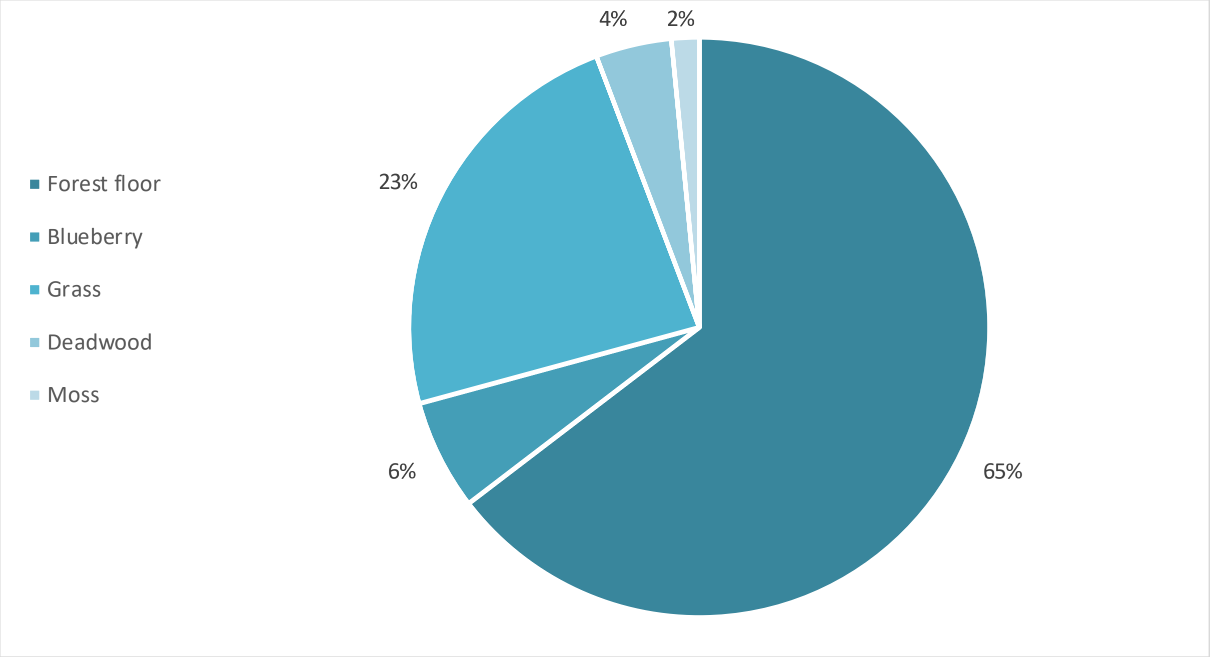
Graph 8. Effect of game damage on sessile oaks in each research plot (RP) as a percentage (%).



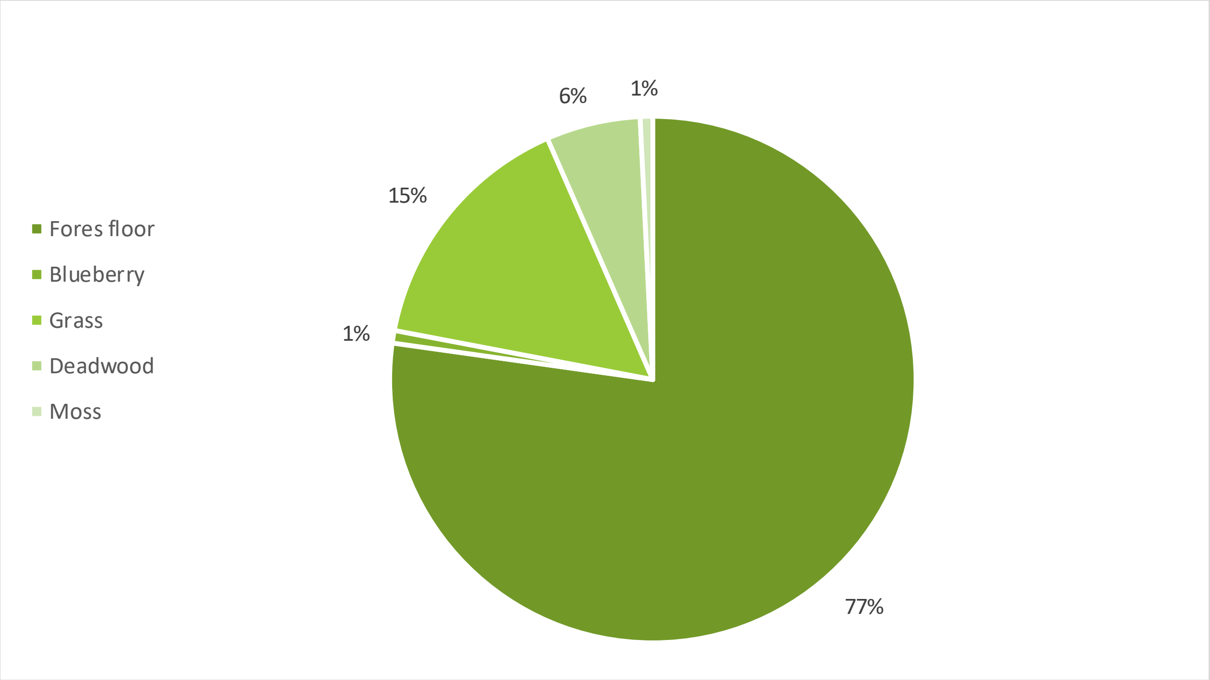
Graph 9. Effect of game damage on Sorbus spp. in each research plot (RP) as a percentage (%).

4.7. Floor coverage

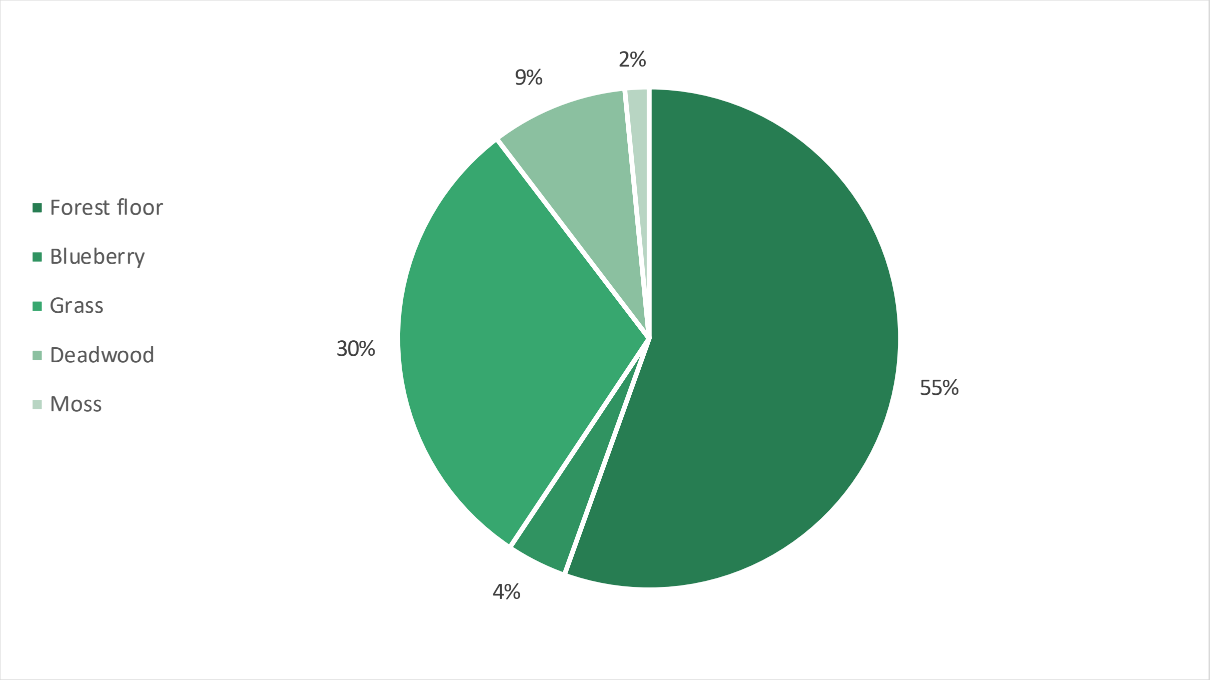
As part of the study, a basic evaluation of the floor coverage was made for each subplot from each research plot (RP). The data shows the effects on the seedlings in their growth stage. The categories included in the data evaluation: forest floor, blueberry, grass, dead wood and moss (Graph 10., Graph 11. & Graph 12.).



Graph 10. Floor coverage distribution of the Small gap research plot (RP) as a percentage (%).



Graph 11. Floor coverage distribution of the Canopy research plot (RP) as a percentage (%).



Graph 12. Floor coverage distribution of the Big gap research plot (RP) as a percentage (%).

5. Discussion

Sessile oak is the dominant species in the research area. The minimum number of individuals required in the Czech Republic is 13 000 individuals per hectare (Příloha č. 7, 2004). The Research plots (RP) present a greater density value than the minimum accepted by the Czech authorities. The density differences between gaps show that the Small gap and the Big gap share the same regeneration density 24.31 (indiv./m2) for the sessile oak, even though the Small gap presents the early stages of seedling growth, meanwhile the Big gap presents more developed specimens. The Canopy Research plot shows a regeneration density of 9.54 (indiv./m^2). The whitebeam (*Sorbus spp*.) presented smaller differences in the regeneration density in each Research plot, the results showing: the Small gap 4.54 (indiv./m2), Big gap 4.46 (indiv./m2) and Canopy 4.85 (indiv./m2). The size of the gaps is an important aspect in the results of the regeneration density. The highest density and frequency of small oak seedlings was found in gaps of 100 – 150 (9094 ha − 1) and 51 – 300 m2 (13 392 ha − 1) (Dobrowolska, 2006).

The height class difference between the gaps is evident, the Canopy shows predominantly sprouts and seedlings of lower height, the Small gap presents more saplings, meanwhile the Big gap shows taller saplings and more mature individuals.

The measurement differences within the gaps are certainly visible. The Small gaps center margin shows the greatest Av. height of 44.76 cm and Av. diameter 5.93 mm. In the case of the increments the center margin of the Small gap presents an Av. 5.61 cm with a SD. of 7.19 cm for increments in 2019 and an Av. of 3.05 cm with SD. of 6.34 cm in the increments of 2018. The center of the Big gap shows an Av. height 66.56 cm and Av. diameter 8.40 mm with an increment Av. 5.33 cm and SD. 7.77 cm in 2019 and Av. 6.88 cm and SD. 10.53 cm for 2018.

Within the Small gap the west margin contains the next largest measurements, showing Av. height 35.22 cm with a SD. 20.17 cm, Av. diameter 5.36 mm and SD. 3.01 mm, as for the increments of 2019 the Av. 3.41 cm and SD.3.20 cm, 2018 shows less increment with an Av. 0.92 cm and SD. 2.70 cm. The south margin in the Big gap shows an Av. height of 40.62 cm, but with an Av. diameter 6.69 mm, regarding the increments in 2019 data shows Av.3.27 cm with SD. 3.78 cm and in 2018 an Av.1.67 cm with SD. 2.97 cm. The Big gaps south and north margins show the greatest values compared to the Small gap, where the west and east margins show the greatest values within the gap.

From the processed images of the canopy's openness, information about Direct Solar Radiation and Diffuse Solar Radiation was obtained. The Small gap presented an Av. of 11.67% with a standard deviation (SD). of 5.14% and a maximum (Max.) of 19.27 % of direct light; the Big gap shows an Av.11.61%, a SD. 5.64, a Max. 21.77%; the Canopy presents an Av. 5.71%, SD. 1.79%, Max. 8.91%. As to the Diffuse Solar Radiation results, the Big gap shows the highest percentage with an Av. 2.20%, SD. 0.58% and a Max. 2.97%. Sessile oak seedlings have been shown to prefer light levels higher than 15–20% of full sunlight, meaning that gaps of at least 17–20 m diameter or smaller, an open canopy are suitable regeneration sites (Lüpke, 1998). The light differences within the gaps are clear, height increments increase with radiation roughly up to 40% (Březina & Dobrovolný, 2011).

The correlation between light characteristics, height increments and floor coverage, show that there is a strong, moderate positive relation between PPFD Direct and Height, increment 19, increment 18, forest floor within the Small gap, for the PPFD Diffuse correlation with the above characteristics there is a strong positive relationship. In the Big gap a weak correlation between Height, Increment 19 and Increment 18 can be observed. In reference to the Canopy % the correlation with Height, presents a strong positive. For the Floor surface coverage of the Small gap Research plot a moderate positive relation with PPFD Direct is visible, meanwhile in the Big gap it shows a strong, moderate negative relation. The Canopy Research plot presents a moderate positive relationship with the PPFD Direct with Increment 18, also showing a weak relation between Light characteristics and Height, Increment 19 and Increment 18. From the

Kruskal-Wallis test only PPFD Diffuse/Increment 2019 and Increment 2018 null hypothesis was not rejected. Also Canopy percentage (%)/Height show not rejected hypothesis

At last it should be mentioned the Game damage effects and Floor coverage on the research plots. Sessile oak in the Small gap show a 61% of damaged individuals, meanwhile in the Big gap the number is only 33%, the Canopy Research plot presents the most damage among the seedlings with 72% browsing. With regards to the whitebeam in the Small gap 65% of damage, within the Big gap 43% and Canopy 70%. The Small gap shows 65% of forest floor and 23% Grass coverage, the Big gap contains 55% forest floor and 30% grass, the Canopy has 77% forest floor and 15% grass. The Big gap shows the greatest value of dead wood between the other research plots with a 9%, with regards to blueberry coverage the greatest is the Small gap presenting 6%.

6. Conclusion.

Kunratický forest is a green forest territory in a cluster surrounded by developed areas. The forest has the intention to supply the needs of local communities, also with the aim to conserve the biodiversity of the park.

The silvicultural aspect of the park focuses on the creation of small gaps that favour the regeneration of the local community of sessile oaks, an important tree species for its values and potential resistance against the climate change effects.

After the obtained results and discussion, the analysed data provides a broader view of some aspect that affect the natural regeneration quality and quantity. It is possible to conclude that the Light characteristics in early stages of growth is important and the effects of the gap size take on a significant role in the regeneration density under the given conditions and dominance of the species. Regarding the quality of the stems of the seedlings, the effects of game is visible.

The study has shown that the natural regeneration efforts within the Research plots have been successful. However, the study has not yet been completed, with more aspects of the site to be seen, the topic is open for more research. The potential future studies may include sessile oak survival and mortality rates, temperature and climate change effects on the seedlings.

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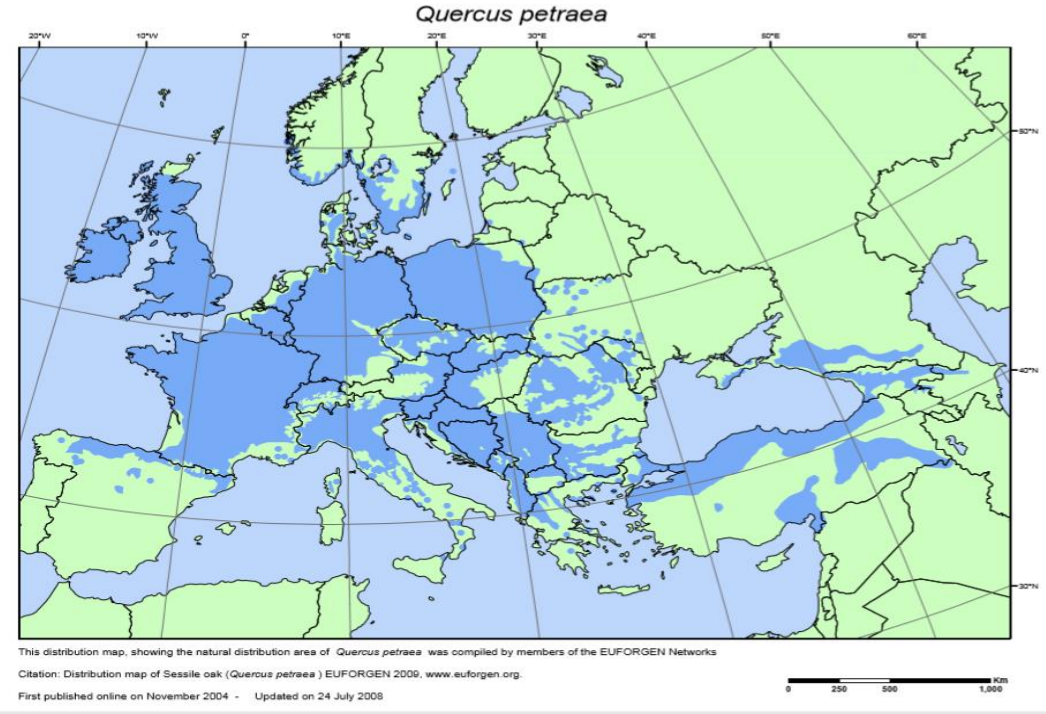
8. Appendix



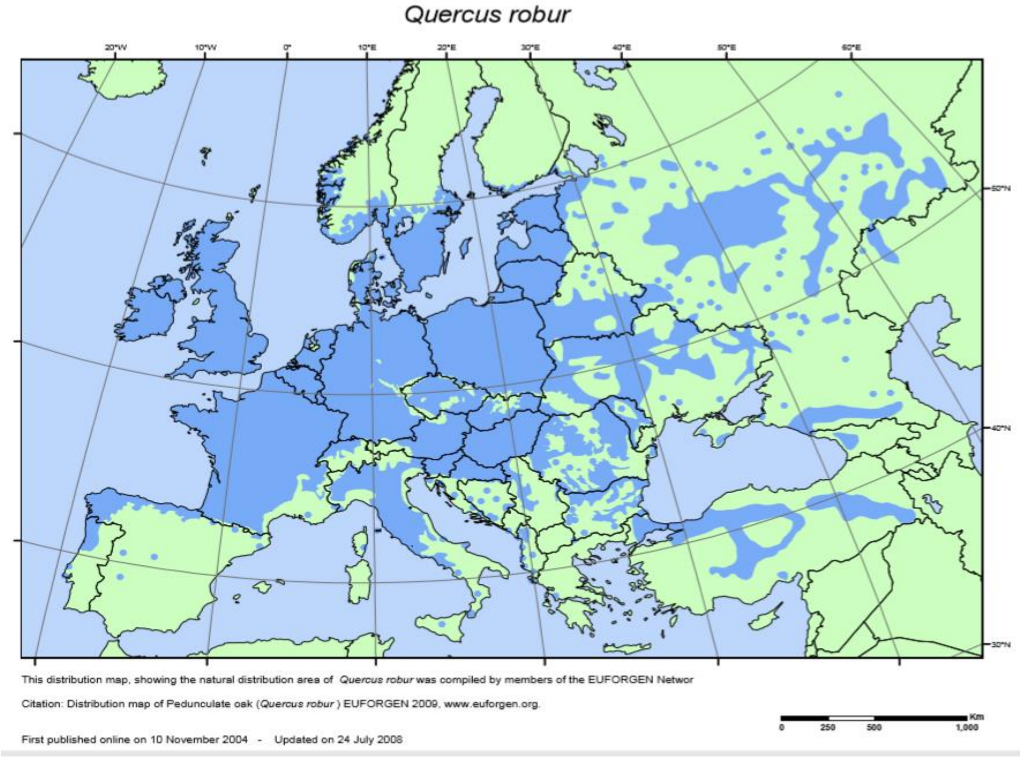
Quercus petraea

This distribution map, showing the natural distribution area of *Quercus petraea* was compiled by members of the EUFORGEN Networks

Citation: Distribution map of Sessile oak (*Quercus petraea*) EUFORGEN 2009, www.euforgen.org.

First published online on November 2004 - Updated on 24 July 2008

Appendix Figure 1. Natural distribution of sessile oak in Europe



Quercus robur

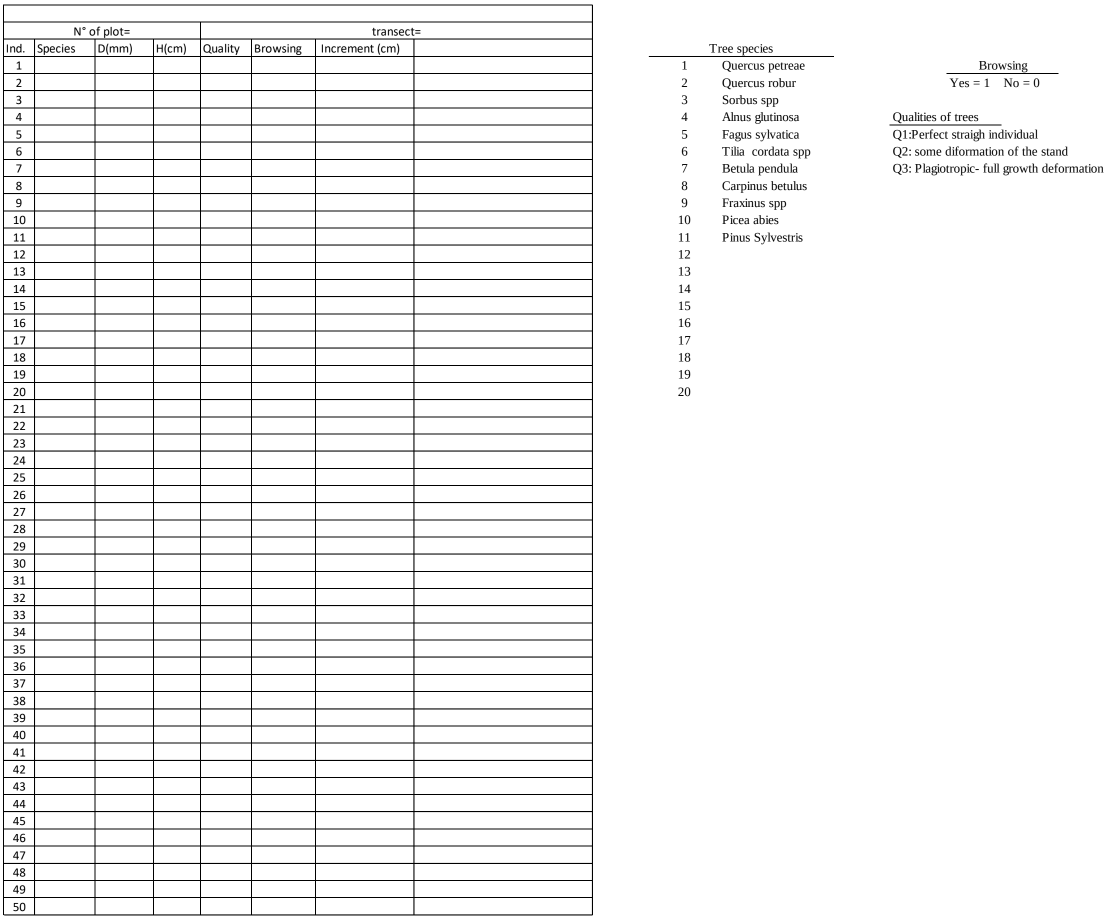
This distribution map, showing the natural distribution area of *Quercus robur* was compiled by members of the EUFORGEN Networ

Citation: Distribution map of Pedunculate oak (*Quercus robur*) EUFORGEN 2009, www.euforgen.org.

First published online on 10 November 2004 - Updated on 24 July 2008

Appendix Figure 2. Natural distribution of pedunculate oak in Europe

Table 16. Table used for research plot (RP) data collection



N° of plot=				transect=			
Ind.	Species	D(mm)	H(cm)	Quality	Browsing	Increment (cm)	
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47							
48							
49							
50							

Tree species	
1	Quercus petreae
2	Quercus robur
3	Sorbus spp
4	Alnus glutinosa
5	Fagus sylvatica
6	Tilia cordata spp
7	Betula pendula
8	Carpinus betulus
9	Fraxinus spp
10	Picea abies
11	Pinus Sylvestris
12	
13	
14	
15	
16	
17	
18	
19	
20	

Browsing

Yes = 1 No = 0

Qualities of trees

Q1:Perfect straigh individual

Q2: some diformation of the stand

Q3: Plagiotropic- full growth deformation

Figure 4.View of the Small gap and Big gap research plot (RP).

Figure 5.View of the Big gap Research plot.

Figure 6. Subplot marking and data collection in Canopy research plot (RP).

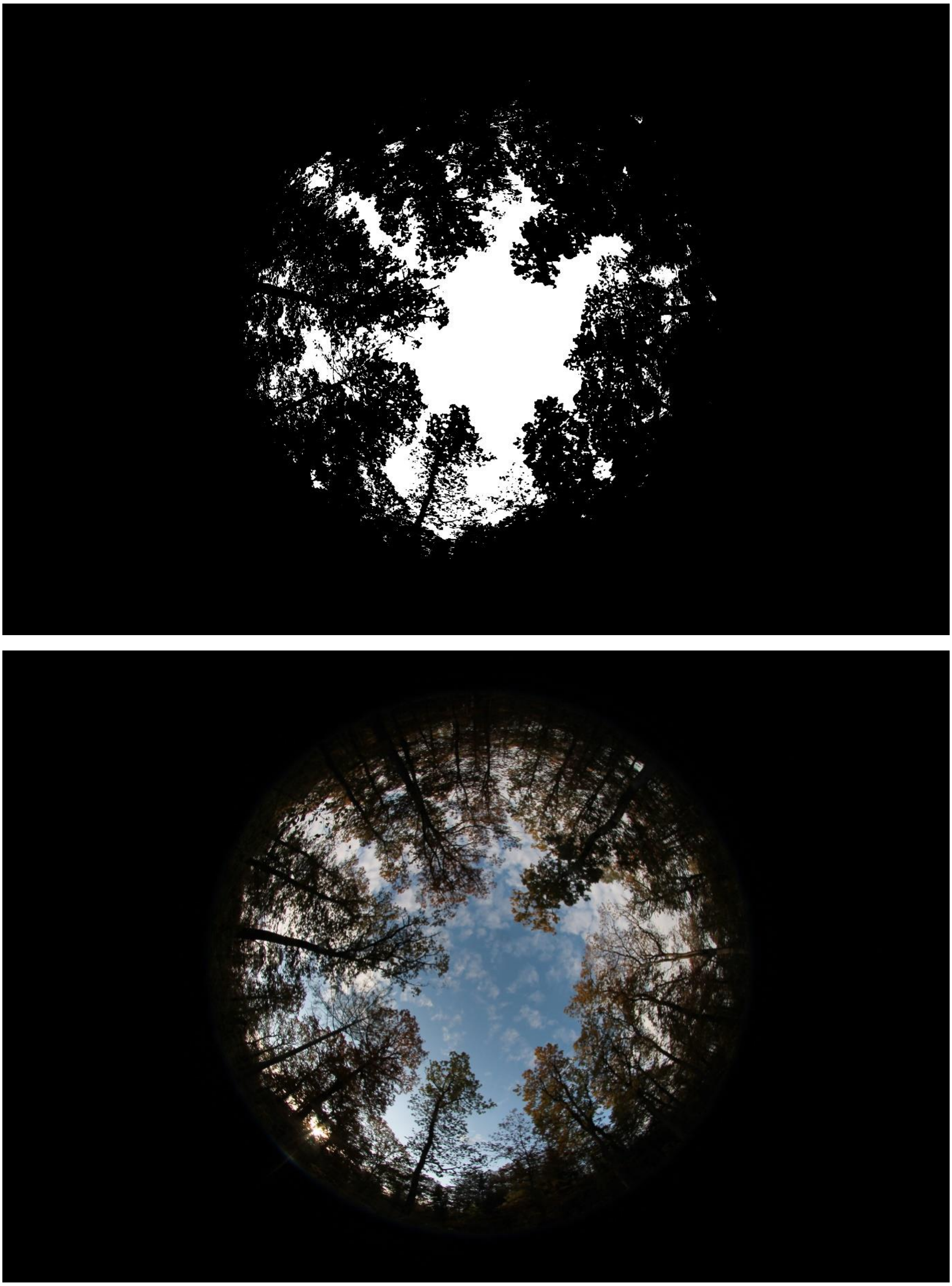

Figure 7. Above: the monochromatic processed image of the canopy, below: the picture of the canopy taken in the Small gap.